Norwegian University of
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Early decision making tools in selecting renewable energy solutions for Zero Emission Buildings (ZEB)

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MASTER THESIS

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Early decision making tools in selecting renewable energy solutions for Zero Emission Buildings (ZEB)

Beslutningsstøtteverktøy for tidligfasevalg av fornybar energi for bygninger uten klimagassutslipp

Background and objective

The energy supply of a building today is solved with a handful established solutions. In the future this will change and tomorrow's buildings will use many different renewable solutions and combinations to meet the energy needs. Different solution could emerge from combinations of different energy system. Viability of these solutions for ZEB would depend on many aspects ranging from climatic or building aspects to completely technical or economic feasibility.

This assignment is closely related to The Research Centre on Zero Emission Building at NTNU and SINTEF (FME ZEB) that has the vision to eliminate the greenhouse gas emissions caused by buildings. This national research centre will place Norway in the forefront with respect to research, innovation and implementation within the field of energy efficient zero-emission buildings.

The main objective of FME ZEB is to develop competitive products and solutions for existing and new buildings that will lead to market penetration of buildings that have zero emissions of greenhouse gases related to their production, operation and demolition. The Centre encompasses both residential and commercial buildings, as well as public buildings.

The student should perform the following tasks:

- Propose rational energy supply solution(s) for ZEB using combination(s) of different renewable / low carbon energy technologies
- Define design spaces (climates, building types etc) to sufficient details and investigate viability of proposed energy solution(s) within different design spaces
- Analyze applicability/potential of viable solution(s) in Norwegian building stock and identify associated challenges
- Prepare a draft for a scientific journal paper based on findings from this work as a part of the final report

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Within 14 days of receiving the written text on the master thesis, the candidate shall submit a research plan for his project to the department.

When the thesis is evaluated, emphasis is put on processing of the results, and that they are presented in tabular and/or graphic form in a clear manner, and that they are analyzed carefully.

The thesis should be formulated as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents etc. During the preparation of the text, the candidate should make an effort to produce a well-structured and easily readable reportreport. In order to ease the evaluation of the thesis, it is important that the cross-references are correct. In the making of the report, strong emphasis should be placed on both a thorough discussion of the results and an orderly presentation.

The candidate is requested to initiate and keep close contact with his/her academic supervisor(s) throughout the working period. The candidate must follow the rules and regulations of NTNU as well as passive directions given by the Department of Energy and Process Engineering.

Pursuant to "Regulations concerning the supplementary provisions to the technology study program/Master of Science" at NTNU §20, the Department reserves the permission to utilize all the results and data for teaching and research purposes as well as in future publications.

One – 1 complete original of the thesis shall be submitted to the authority that handed out the set subject. (A short summary including the author's name and the title of the thesis should also be submitted, for use as reference in journals (max. 1 page with double spacing)).
Two – 2 – copies of the thesis shall be submitted to the Department. Upon request, additional copies shall be submitted directly to research advisors/companies. A CD-ROM (Word format or corresponding) containing the thesis, and including the short summary, must also be submitted to the Department of Energy and Process Engineering

Department of Energy and Process Engineering, 14. January 2011

Olav Bolland
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PREFACE

This master thesis is written at the Department of Energy and Process Engineering, Faculty of Engineering Science and Technology, Norwegian University of Science and Technology (NTNU) in Trondheim as a final part of my master's degree in science (MSc). The work is closely related to The Research Centre on Zero Emission Buildings at NTNU and SINTEF (FME ZEB).

First of all, I would like to thank my academic supervisor, Professor Vojislav Novakovic at the Department of Energy and Process Engineering, for helpful and constructive advice during the work.

I would also like to thank my research advisors Usman Ijaz Dar, PhD student at the Department of Energy and Process Engineering, and Frode Frydenlund, SINTEF Energy Research, for their feedback and guidance during our meetings. A number of other people at the department have also kindly shared their knowledge, for which I am very grateful.

Special thanks as well to my father Arild Larsen, senior engineer at EM Teknikk AS, and my brother Fredrik Thorsås Larsen, energy consultant at AF Energi & Miljøteknikk AS, for their professional help with the work. The support from the rest of my family has also been very much appreciated.

Last, but not least, I would like to thank my girlfriend Anna for the support and encouragement she has shown during the work.

Håkon Thorsås Larsen

Håkon Thorsås Larsen
Trondheim, June 2011

ABSTRACT

The current *residential* building stock in Norway is organized in to groups, and sorted after number of building units. The criteria used for sorting, are criteria that affect the viability and rationality of various energy supply systems. The results from this survey forms a database where it is possible to go in and find the number of buildings sorted after region, building type, urbanity and year of construction.

Based on findings from the survey and other factors affecting the applicability, a set of four energy supply systems are introduced and studied closer as possible solutions in ZEBs; District heating (DH) + PV, Bio energy (BIO) + PV, Heat pump (HP) + PV, Combined heat and power (CHP) + PV. The *Zero Emission Building balance* is calculated for each solution and pre-defined energy level, to determine the required on-site electricity generation from the PV's.

A model is then developed to study the potential of the proposed solutions in the Norwegian residential building stock. The analysis is performed on future scenarios, which represent different development of the building stock with regards to new buildings, refurbishment and demolition. The number of buildings that can be converted to ZEBs with the investigated energy supply systems and [available roof area/floor area] are quantified.

Results show uptake potential for all of the technologies in buildings with energy demand lower than 94,5 kWh/m^{2}year, but limitations occur as soon as [available roof area/floor area] decreases from the upper limit investigated in the study (1:2). The greatest potential is shown by CHP + PV, where ZEB conversion is possible in approximately 30% of the total residential stock in year 2050. It is also observed a relative growth in the potential of DH + PV and HP + PV in small houses after year 2025 due to the estimated upgrade of energy-efficiency in the stock. In multi dwelling buildings, it is only CHP + PV and BIO + PV that show potential in both current and future stock.

SAMMENDRAG

Den eksisterende bygningsmassen av boliger i Norge er organisert i grupper, og sortert etter antall bygningsenheter. Kriteriene som er brukt for sortering, er kriterier som vil kunne påvirke levedyktigheten og rasjonaliteten til forskjellige energiforsyningssystemer. Resultatene fra denne kartleggingen utgjør en database der det er mulig å gå inn og finne antall bygninger sortert etter region, bygningstype, urbanitet og byggeår.

Basert på resultatene fra kartleggingen samt andre faktorer som påvirker anvendbarheten, er det introdusert fire energiforsyningssystemer som blir studert nærmere som en mulig løsning i ZEBs; Fjernvarme (DH) + solceller (PV), Bio energi (BIO) + solceller, Varmepumpe (HP) + solceller og Kraftvarmeanlegg (CHP) + solceller. *Zero Emission Building*-balansen blir beregnet for hver teknologi og definerte energinivåer, for å bestemme den nødvendige elektrisitetsgenereringen fra solcellepanelene.

En modell er deretter utviklet for å studere potensialet til de mulige løsningene i boligbygningsmassen. Analysen er utført på framtidige scenarioer, der det er antatt ulik utvikling med hensyn på renovering, nybygning og nedriving. Antallet bygninger som kan bygges som ZEBs med de gitte teknologiene og antatte tilgjengelige [tak areal/gulv areal]-forhold blir kvantifisert og sammenlignet opp mot den totale bygningsmassen.

Resultatene viser at det er potensial for alle teknologiene i bygninger med energibehov lavere enn 94,5 kWh/m^{2}year, men det oppstår begrensninger så fort [tak areal/gulv areal] avtar fra den øverste grensen som er undersøkt i denne studien (1:2). CHP + PV utviser størst potensial, og med denne teknologien finnes det at man kan bygge om 30 % av boligbygningsmassen i år 2050 til ZEBs. Det blir også observert en relativ vekst i potensialet for DH + PV og HP + PV i småhus etter år 2025 grunnet den estimerte oppgraderingen av bygningsmassen. I boligblokker er det kun CHP + PV og BIO + PV som utviser potensial i både den nåværende og framtidige bygningsmassen.

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1 INTRODUCTION

1.1 Background

1.1.1 Zero Emission Building

Definition

The Research Centre on Zero Emission Buildings' main goal is to eliminate the emission of greenhouse gases caused by buildings, related to their production, operation and demolition(ZEB 2009). In order to reach carbon-neutrality, the buildings need to be highly energy-efficient at all levels, including the choice of materials, energy supply systems and operating systems. The buildings shall also be competitive when it comes to indoor climate, economy, architecture and construction. It is set to apply for residential, commercial and public buildings, including both new and existing constructions within all these sectors.

ZEB Balance

As long as the building emits greenhouse gases, it has to be able to feed energy back in to the grid in order to reach the ZEB balance defined by Sartori et al(Sartori 2010). The energy fed back in to the grid can in principle come from any energy carrier as long as the balance is reached, but it is understood that this will primarily happen by generating electricity. Therefore, on-site and off-site *electricity generation* to reach ZEB balance is the main energy production concerned in this study.

1.1.2 Situation in current stock

Approximately 22%, or 50 TWh, of all energy use in Norway is being consumed by the residential building stock(Sartori 2009). Because of the level of energy-efficiency in the current stock, it is widely understood that there is a large potential for energy saving. At present (2011) the Norwegian residential building stock is highly dependent of electricity for heating purposes, and as much as 98% of all residents in Norway have installed electric heaters and/or heater cables. In total, approximately 80% of the energy demand in buildings in Norway is covered by electricity. This share is even higher when looking at residential buildings in specific. The second most utilized heating equipment in residents is wood-burning stove or open fireplace, which is represented in 69% of the households. Only a small share of the residential buildings has installed central-heating systems utilizing thermal energy carriers.

1.2 Structure and scope of report

The main objective of this study is to analyze the potential for market penetration of ZEBs in the *Norwegian residential building stock*, and to investigate the potential of different energy supply systems with the goal of reaching the ZEB balance. The analysis made can roughly be divided in to three main parts.

i) The first part is a survey on the Norwegian residential building stock, where the buildings are sorted after a set of pre-defined criteria. The main focus is on the physical appearance of each building, and to organize the buildings after measures that may affect the viability of different energy supply systems.

ii) In the second part, focus is shifted towards the energy supply systems. Based on their potential as a viable and rational solution in ZEBs, a set of four systems is introduced and studied closer. A tool is then made to calculate the ZEB balance for each system. The calculations are performed on buildings of different energy levels.

iii) The third part links the research done in part one and two. The chosen energy supply systems are applied to the building stock to analyze the potential for market penetration of ZEBs, and quantify the buildings that can be converted to ZEBs. The analysis is done on four scenarios, that all represent different development of the building stock when it comes to new buildings, refurbishment and demolition.

The outcome from the first part forms a database where it is possible to go in and find the number of dwellings and buildings in a preferred group, which is used in the further calculations. The main results from the second part are the values from the calculation of the ZEB balance and required electricity generation for all of the different building groups and energy supply systems. When it comes to the third part, the results display the potential for each energy supply solution in the residential building stock. The number of buildings that is able to reach the ZEB balance with the various solutions is compared up against the entire residential building mass. Together with the created scenarios, the results from this report will give preliminary indications on the potential of the chosen energy supply systems in ZEBs in the current and future building stock.

1.3 Method and tool

The work done in this report is closely related to The Research Centre on Zero Emission Buildings (FME ZEB), and is based on the work done in the report on *Upgrading of energy supply for existing building stock to reach Zero Emission Buildings (ZEB)*(Larsen 2010).

In the work on all three parts of this report, dynamic calculation tools were made in order to see the variation in the results when using different input data. The amount of output data is vast because of the range of variables tested and used in the calculations. Therefore, concrete points that need highlighting are discussed in the main report, while the complete range of results are collected in appendices.

Tools used in the work:

- Microsoft Word 2007 for text processing
- Microsoft Excel 2007 for calculations and handling of data
- Adobe Acrobat 9 Pro for completion

The main source used in the survey on the residential building stock is the bank of statistics provided by Statistics Norway(SSB 2010). Data on energy supply systems and specific energy demand is collected from standards, codes, statistics and previous papers on the subject.

2 SURVEY ON RESIDENTIAL BUILDING STOCK

2.1 Objective of survey

The main objective of the survey on the current Norwegian residential building stock is to organize the number of building units after certain criteria that can affect the viability and rationality of different energy supply systems. Focus in this part is directed towards the external physical appearance of each building, and not the technologies utilized in each case. This implies that variations in the construction and geographical positioning of the buildings will be discussed closer to enlighten their signification when choosing energy supply system. In addition, data from the survey can be used to identify the energy level of the current stock.

2.1.1 Method for sorting of buildings

The preferred sorting of buildings is shown on figure 1, where the number of buildings in Norway are sorted after four main criteria.

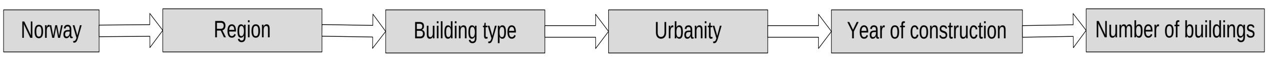


Figure 1 Preferred sorting of buildings.

Statistics Norway makes a clear distinction between *dwelling*[1] and *building*[2], and the available data on the two categories differ(SSB 2008). In this study, the number of buildings is most interesting because the appearance of each building unit is decisive when evaluating possible solutions for on-site energy production. Since the statistics on the dwellings are more complete than on buildings, assumptions are made to get an estimate for the number of buildings. The flowchart on figure 2 shows how the finite number of buildings within each category is found.

[1] Living unit built/rebuilt as a private residence for one or more people, with separate entrance.
[2] Construction that can be given by available area, calculated after method in NS-3940.

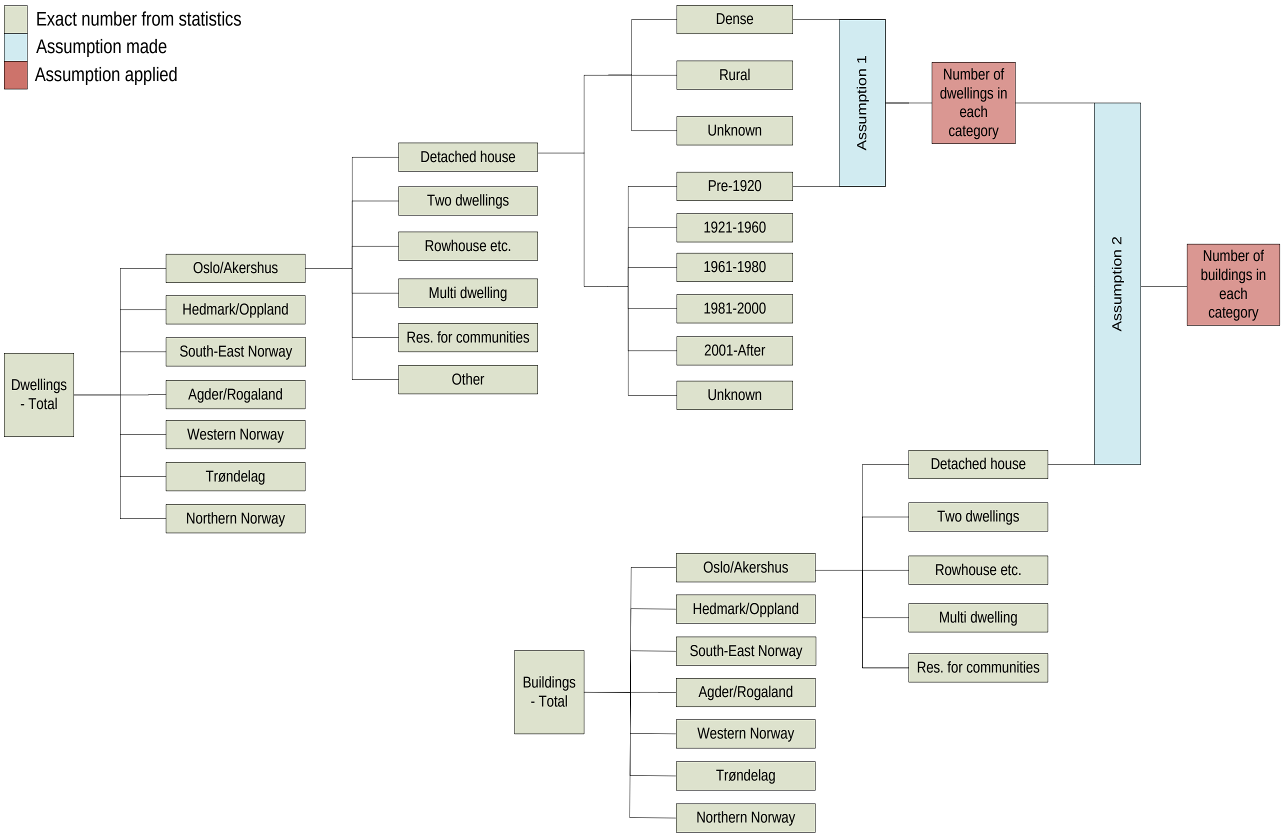


Figure 2 Flowchart for sorting of buildings.

Assumption 1

The percentage of the number of dwellings in dense/rural/unknown for each building type were calculated, and applied to the year of construction. This gives an assumption for the number of dwellings as preferred, and it is assured that the total number of dwellings is the same as in the exact statistics.

Assumption 2

The number of dwellings and number of buildings within each building type is known from the statistics, so the [dwellings/building] - ratio is calculated for each building type. This ratio is then applied to the number of dwellings in each category, to get an estimation of the number of buildings in each category. It is assured that the total number of buildings is the same as in the exact statistics.

2.2 Criteria for sorting of buildings

2.2.1 Region

Due to variations in climatic conditions as for instance solar irradiation, the buildings are sorted in to seven main regions of Norway. The regions coincide with those given in the statistics, and they are:

- Region 1 (R1): Oslo/Akershus
- Region 2 (R2): Hedmark/Oppland
- Region 3 (R3): South-East Norway
- Region 4 (R4): Agder/Rogaland
- Region 5 (R5): Western Norway
- Region 6 (R6): Trøndelag
- Region 7 (R7): Northern Norway

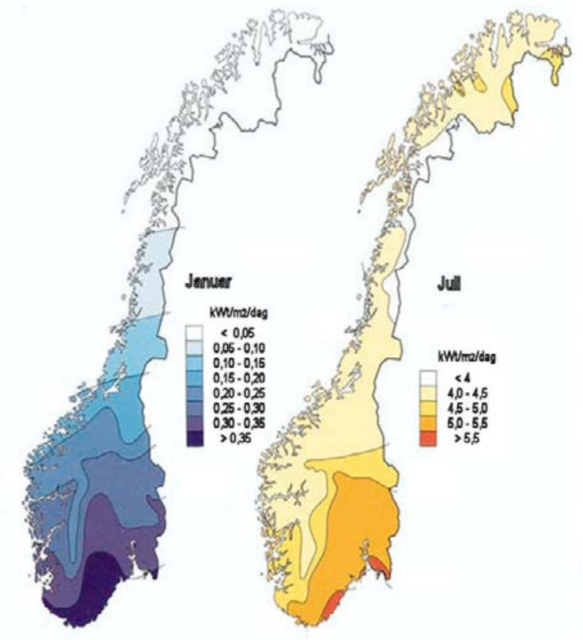


Figure 3 Seasonal variations for solar irradiation(NSF 2011).

Figure 3 shows the intensity of the solar irradiation [kWh/m^{2}day] during winter (January) and summer (July), respectively. Over the full course of a year, the total irradiation can vary from 700 kWh/m^2 in the north, to 1100 kWh/m^2 in the south(NSF 2011). Variations also occur between the inland and coastal areas.

A map with the regions and accompanying values for yearly average solar irradiation is shown in Appendix A.

2.2.2 Building type

The variation of building types in the residential sector and their construction gives indications for the available roof area, and accompanying potential for exploiting solar energy on-site. The statistics divide the number of buildings in to five main categories, and the building authorities have given the following description of the different building types(BE 2007);

Detached house

A detached building designed for one household. It may also contain an independent rentable unit, which fulfills the definition of a dwelling.

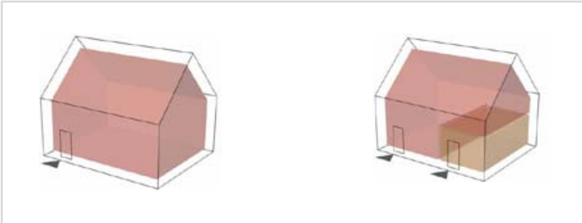


Figure 4 Detached houses.

Two dwellings (semi-detached house)

A detached building designed for two households, where the dwellings are approximately of the same size. Split either vertically or horizontally. Equal concept can be applied for three-/four-dwelling buildings as well.

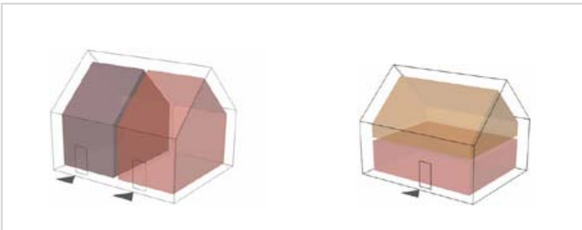


Figure 5 Two dwellings.

Row house, chain house and other small houses

Row houses are defined as three or more dwellings built together with only a vertical wall between them. Chain houses are split with a garage, shed or similar.

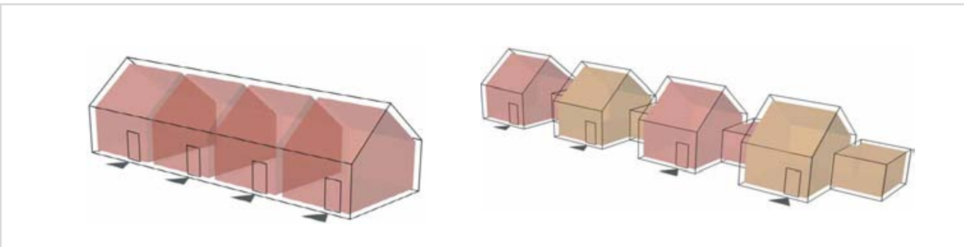


Figure 6 Row house and chain house.

Residence for communities

Buildings used for shared housing, typically inhabited by students or similar. Detached house used as related building type in this study.

Multi dwelling buildings

Block of flats containing multiple dwellings.
Low, ≥ 4 dwellings, ≤ 4 storey's
High, ≥ 4 dwellings, > 4 storey's

More detailed investigation is also made on multi dwelling buildings, to identify the variations in height and number of storeys.

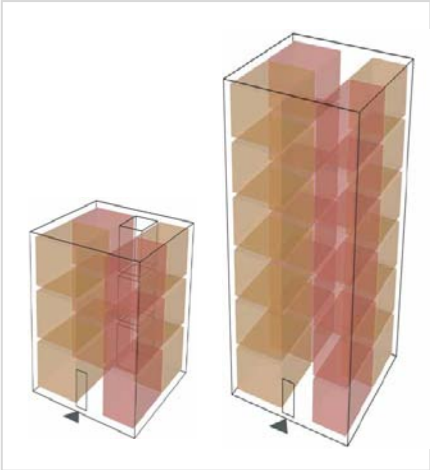


Figure 7 Multi dwelling buildings.

2.2.3 Urbanity

Statistics Norway has data on urbanity of dwellings, sorted after dense[3], rural[4] and unknown(SSB 2008). The surroundings of a building will affect the applicability of the energy supply systems in several ways. If the building is placed in a dense area, it can cause challenges with shadowing when it comes to exploiting solar energy. It can also be difficult to determine wind quality due to turbulence if wind turbines are considered. Local emissions when burning fuels must be considered because of the immediate distance to other buildings in urban areas.

On the other hand, it can be argued that the availability of certain heating systems is larger in a densely populated area, and it is for instance more likely that it is possible to connect to a district heating system in a city compared to the countryside. In the rural areas there is however a larger potential for space demanding systems as for instance wind turbines or photovoltaic's covering more than just the roof area of the building.

2.2.4 Year of construction

The purpose of organizing buildings after year of construction is to design a range of energy levels for the building stock. By studying historical building codes, building standards and

[3] Populated area with more than 200 persons, and maximum 50 meters between each building.
[4] Sparsely populated area, not fulfilling the criteria for "dense".

statistics on the subject, it is possible to make estimations for the energy demand on basis of the year the building is built.

The buildings are sorted in time intervals, and each interval can be defined as an energy level when performing calculations;

- Energy level 1 (L1): Built before 1920
- Energy level 2 (L2): Built between 1921 and 1960
- Energy level 3 (L3): Built between 1961 and 1980
- Energy level 4 (L4): Built between 1981 and 2000
- Energy level 5 (L5): Built after 2001
- Energy level 6 (L6): Unknown year of construction

Notice that not all of the intervals are of same size.

2.2.5 Criteria discussion

The criteria used when sorting buildings are chosen because of their influence on the applicability of the different energy supply systems and the desired level of detail in this study. This study is focused on the energy supply system to each individual building, therefore every unit is separated. Further analysis can include statistics on building clusters, where a range of building units can be supplied by one shared energy supply solution. This implies new challenges because of variation in building sizes and standards within the cluster.

When it comes to organizing after regions, the main concern in this study has been the solar irradiation. Other climatic measures as for instance outdoor temperatures and wind speeds could have been considered as well, and that could possibly have given a different division of regions. Further investigation on number of persons per household, amount of technological equipment and user preferences are also things that can be studied closer to better understand the energy use and suitable energy supply systems in each building.

The organizing after year of construction gives valuable information on the energy-efficiency of the stock. However, this does not take into account that a considerable share of the stock has gone through one or more renovations during the building’s lifetime. The assumed energy level of especially the oldest part of the stock should therefore be treated with this in mind.

2.3 Results

The outcome from the survey is used in part three of the study, but some important findings are presented in this paragraph. An overview of all of the residential buildings in Norway with respect to building type and urbanity is shown on chart 1. Out of the 1,459,727 registered residential buildings in Norway, as much as 1,131,782 buildings are detached houses. Regarding urbanity, almost 95% of the buildings in rural areas are detached houses. In general, every building type has more units in densely populated areas.

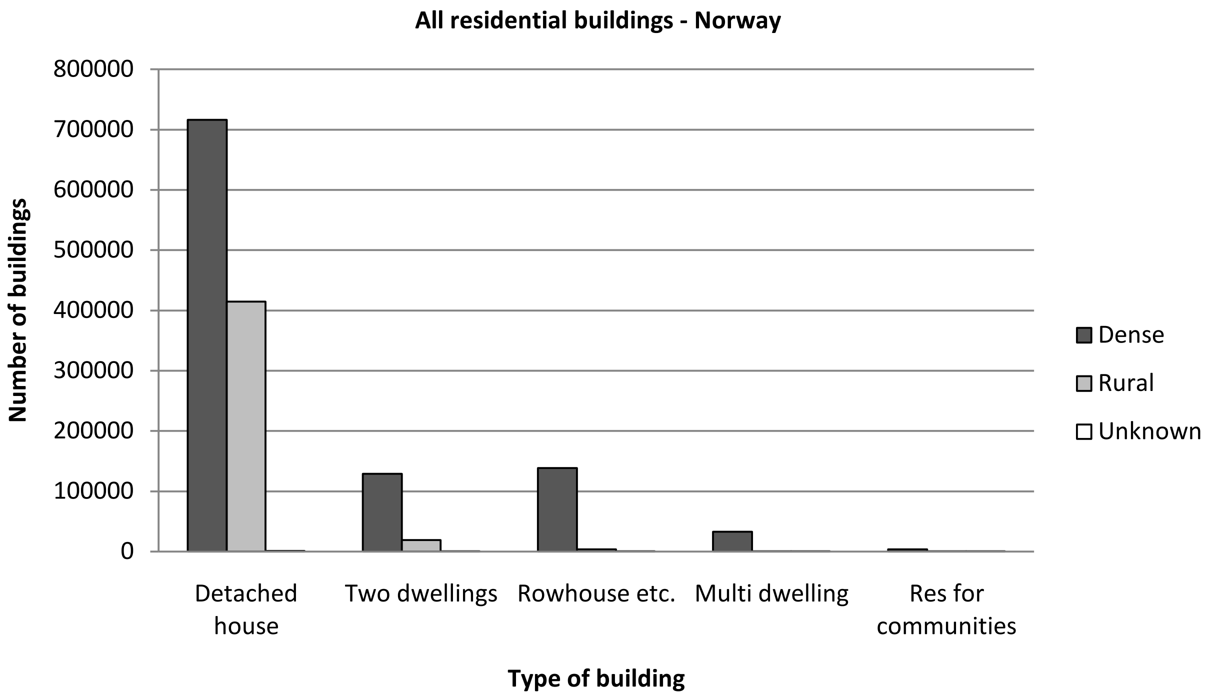


Chart 1 Residential buildings sorted after type and urbanity.

Even though, on a national scale, every building type is higher represented in the dense areas, there are still variations between the regions. Chart 2 shows the distribution of detached houses in R1: Oslo/Akershus and R2: Hedmark/Oppland, respectively. It highlights the possible variations between two regions and indicates that in many cases it is necessary to focus the study on a more detailed level than the national.

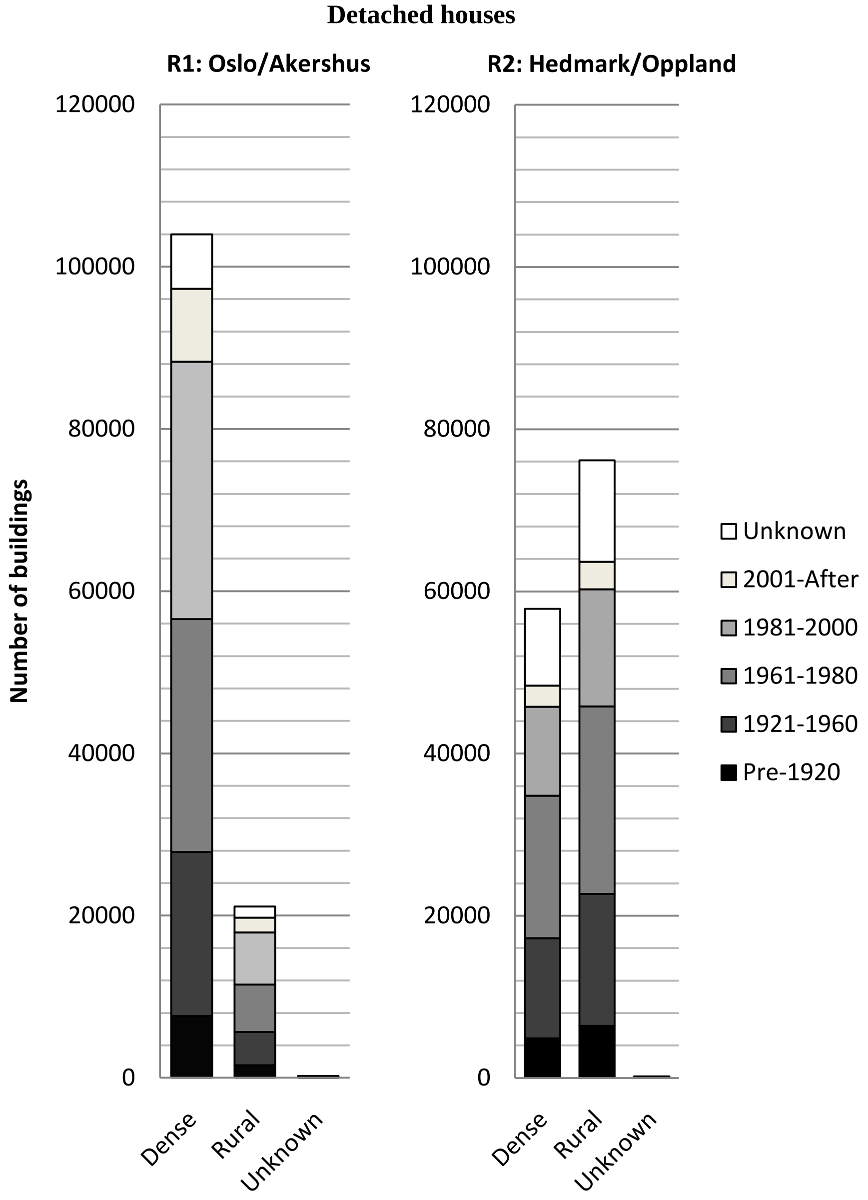


Chart 2 Detached houses in R1 and R2, sorted after urbanity and year of construction.

When it comes to year of construction, the buildings built between 1961 and 1980 (L3) constitute the largest share of the buildings in both rural and dense areas. It is also worth noticing that the Unknown-category is larger than the categories containing the oldest and newest buildings, which implies that there is a considerable share of dark figures. This is shown on chart 3.

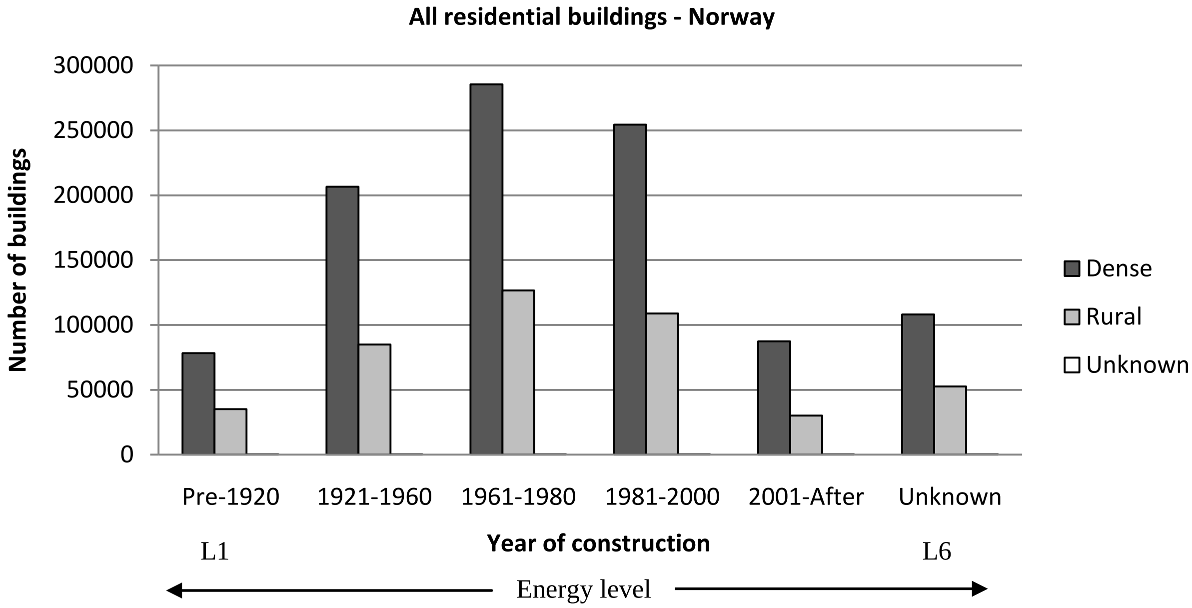


Chart 3 Residential buildings sorted after year of construction and urbanity.

As a specific example, it can be seen on chart 4 that multi dwelling buildings differ from the national average on several levels. First of all, less than 1% of the building units are located in rural areas, which is lowest for all of the building types. Another unique development for the multi dwelling buildings, is the growth of number of building units when comparing the time periods *1981-2000* and *2001-After*. This is worth noticing because;

i) The second of the two time periods is approximately 10 years shorter than the first.

ii) This tells something about the ongoing construction activity in the country, and that multi dwelling buildings have had an upturn the last decade.

iii) From an energy supply point of view, the development of multi dwelling buildings is important because of their different physical appearance, compared to the other building types.

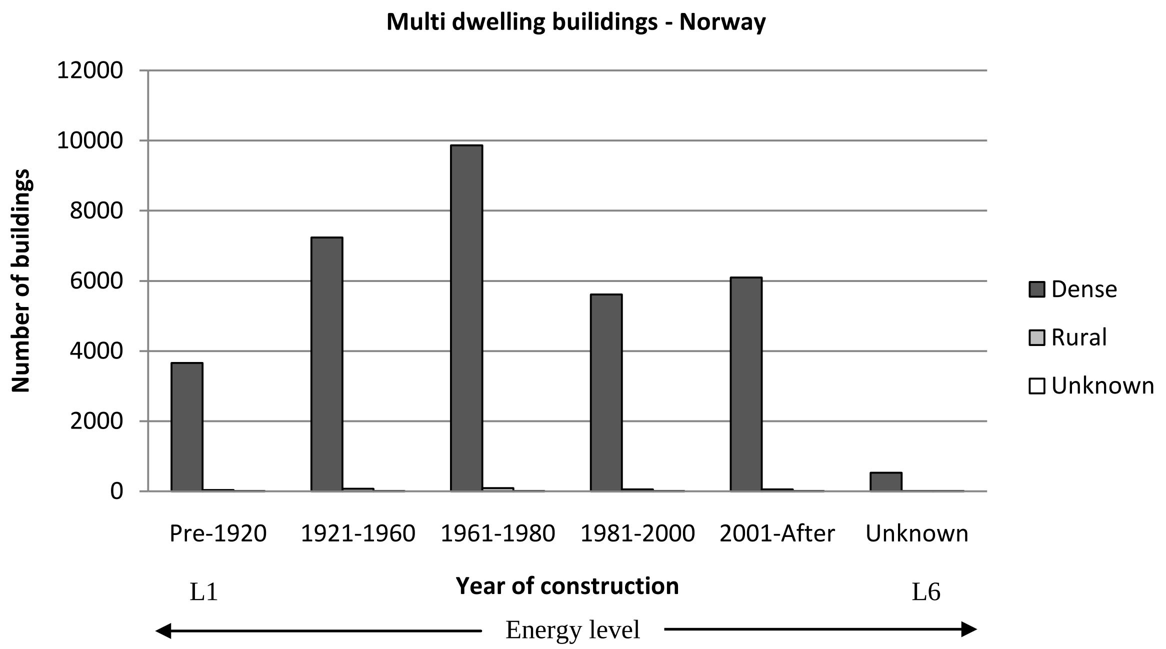


Chart 4 Multi dwelling buildings sorted after year of construction and urbanity.

The distribution of multi dwelling buildings in the different regions is shown on chart 5. Approximately 40% of the buildings are located in R1: Oslo/Akershus.

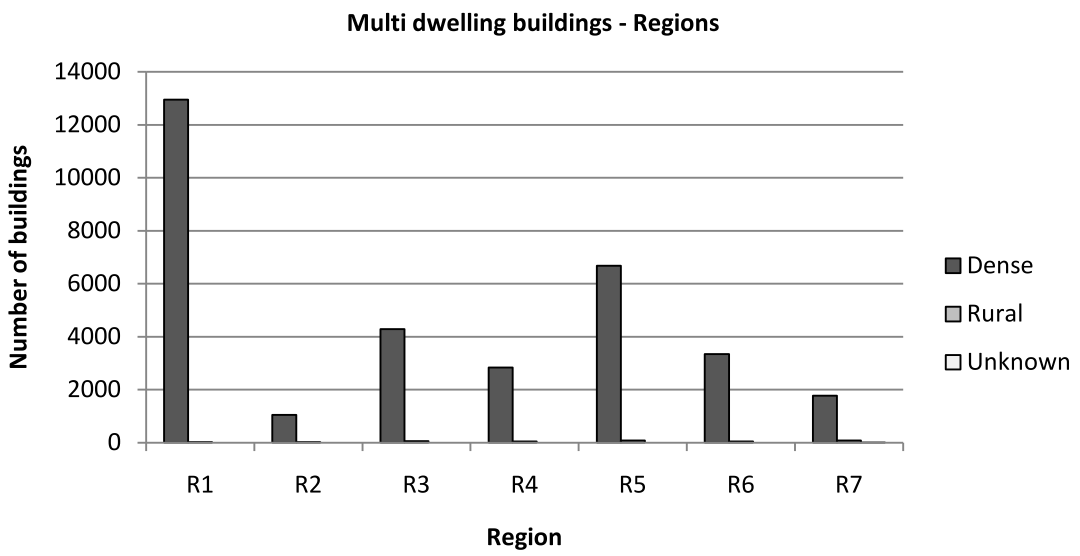


Chart 5 Multi dwelling buildings sorted after region and urbanity.

Further investigation in the statistics show that 35% of the dwellings in R1: Oslo/Akershus are in buildings with 5-9 storeys, which gives indications for the average size of a multi dwelling building in this region.

3 ENERGY SUPPLY SYSTEMS

3.1 Possible solutions in ZEBs

As discussed in the introduction, a Zero Emission Building has to be able to feed surplus energy back to the grid, to level out the possible emission of greenhouse gases caused by the production, operation and demolition of the building. On-site or off-site electricity production is therefore necessary and a minimum requirement when designing the energy supply system. There are also other important measures that must be considered when evaluating viable solutions, which are directly or indirectly connected to the emissions.

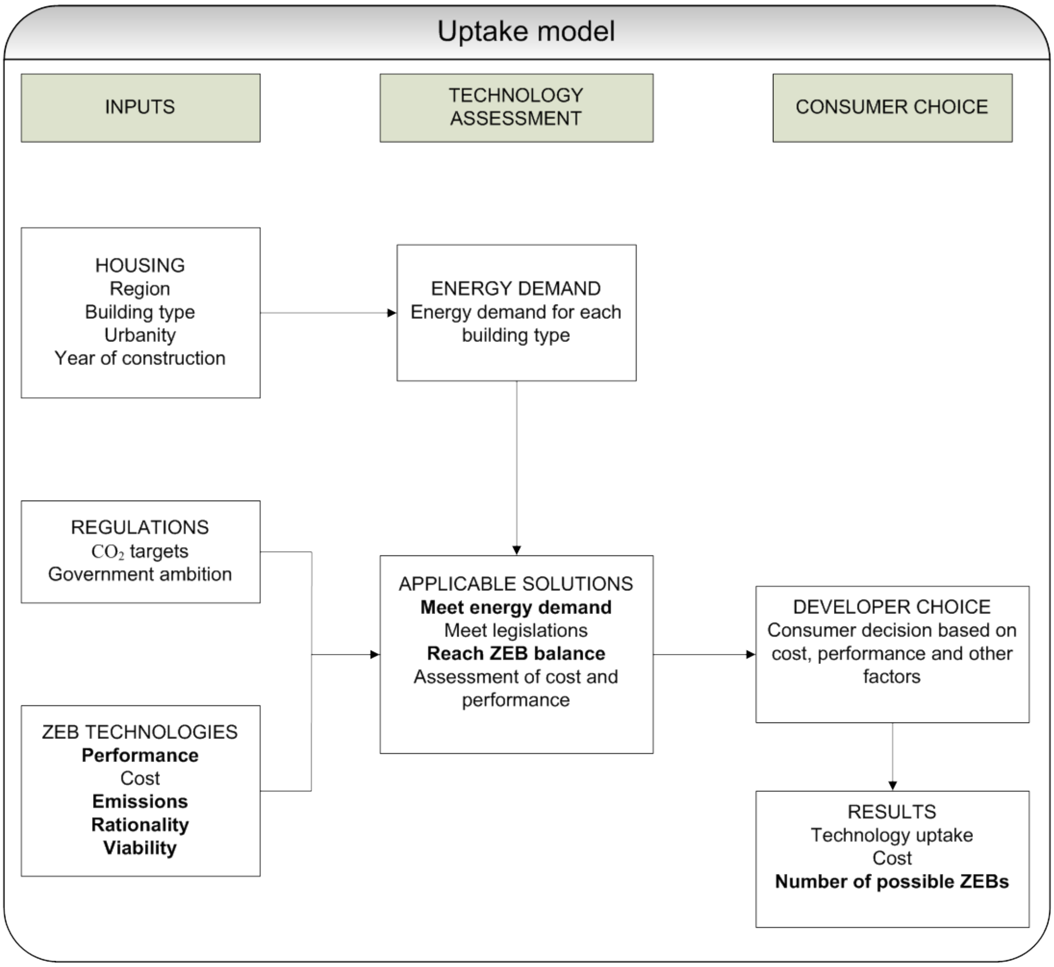


Figure 8 Uptake model for suitable energy supply solutions.

Figure 8 shows a range of factors that will affect the applicability of technologies in a building stock, and is based on the uptake model provided by *Renewables Advisory Board(RAB 2007)*. The inputs related to the appearance of the buildings and constructions are already discussed, and the focus in this part will be on assessment of technologies.

The CO_2 production and emissions from the heating system is vital when it comes to calculating the required electricity production and whether ZEBs are attainable or not. There are no “official” values for CO_2 production, so data from different sources has to be compared against each other to find realistic values to use in each specific case. The correct values will vary with different locations because of different resources used to provide energy. Primary energy factor is not directly used in the calculations done in this study, but it gives a good indication on how resource-demanding the various systems are, and is therefore considered in the selection.

In addition to thermal carriers and heat pumps, Sartori et al highlights the positive effect of adopting conservation measures on a large scale to reduce electricity and energy demand(Sartori 2009). This is used as a basis when choosing energy supply systems in this study, but a higher detailing level of each system is necessary to be able to perform wanted calculations. In his report on heating systems in low energy and passive houses, Stene shows applicable solutions in buildings with low energy demand(Stene 2008). It is difficult to quantify the maturity of these technologies, but based on current available solutions and ongoing research and development, it is possible to get an idea of what solutions that may have a significant market share in the future. Practical challenges as for instance space requirements and noise from the system must also be considered, and evaluated up against the appearance and urbanity of the building mass. Together with the probability of implementation in the Norwegian residential stock with the given Nordic climate and the technique of building, these criteria are assessed when choosing suitable solutions to study closer.

The costs of both investment and operation of technologies will always play a significant role for producer and consumer. Capital cost and energy cost of technologies will usually decrease rapidly with cumulative sales, until it reaches a lower boundary where it can compete with current technologies. This cost development is often seen because of economies of scale, increased production efficiency and improvements in technologies. However, in this study the cost has not been used as an absolute measure when choosing which energy supply systems to investigate closer.

3.2 Chosen solutions

Based on the criteria for a rational and viable energy supply system in ZEBs and highlighted points in the uptake model, a set of four domestic systems are chosen and studied closer;

- *District heating (DH) + PV*
- *Bio (BIO) + PV*
- *Heat Pump (HP) + PV*
- *Combined heat and power (CHP) + PV*

It is assumed that the heating system covers the entire demand for space heating and domestic hot water, while the PV covers the entire electricity specific demand and the required energy production to reach ZEB balance. Surplus electricity from CHP is fed in to the grid. The heat is distributed in a domestic water-borne system in every case. Further details used in the calculations are shown in table 1.

Energy supply	Technical specifications	CO_2 production [kg CO_2/kWh]	Efficiency/ performance
District heating	Domestic heat exchange with heat from non-domestic heating plant	0,231	η = 0,88
Bio	Pellet-fired boiler	0,05	η = 0,90
Heat pump	Integrated unit for space and DHW heating, ground/water - water	Electricity from PV	SPF = 2,22
Combined heat and power	Pellet-fired, stirling engine	0,05	η_{th} = 0,65, η_{el} = 0,25, η_{tot} = 0,90
		+	
Photovoltaic's	Mono crystalline silicon, complete module	-	15% conversion of solar energy to electricity

Table 1 Details on energy supply systems(NS-EN 2008; Frydenlund 2010; NS 2010b).

3.3 Energy levels

In order to perform energy related calculations on the residential building stock, the buildings are distributed in groups of different energy levels. The energy levels defined as the lowest are based on the year of construction (L1 – L6), as described in 2.2.4. Level 6 represent the buildings where the year of construction is unknown, so the related energy level here is estimated as a stock average. In addition, three energy levels which are based on codes and standards are introduced (L7 – L9). They are used as possible levels in the scenarios where it is expected upgrade of the building stock. The total range of energy levels is shown in table 2.

Energy level	Related year of construction	Related code or standard
L1 – Level 1	Pre-1920	
L2 – Level 2	1921-1960	
L3 – Level 3	1961-1980	
L4 – Level 4	1981-2000	
L5 – Level 5	2001-After	TEK1997
L6 – Level 6	Unknown	Stock average
L7 – Level 7	2010-After	TEK2010
L8 – Level 8	2010-After	Low Energy 1
L9 – Level 9	2010-After	Passive

Table 2 Defined energy levels(BE 1997; BE 2010; NS 2010a).

The estimated specific energy demand for each energy level, distributed after purpose within the building, can be found in Appendix A.

3.4 Results from ZEB balance

With the energy levels and emissions and efficiencies of the energy supply systems determined, the [required PV area/floor area] to reach ZEB balance is calculated. For balancing of the CO_2 emissions with on-site electricity production, equation 3.4.1 is applied;

$$\frac{PVarea_{required}}{Floor_{area,heated}} = \frac{(E_{el,specific} + E_{th,specific} \bullet \frac{Q_{th}}{Q_{el,grid}})}{PV_{conversion}} [\frac{m^2 PV}{m^2\ floor}] \text{ (Eq. 3.4.1)}$$

(See Appendix A for further description of equation.)

In the results shown in chart 6, it is used average value for solar irradiation in Norway, based on calculations made from data found in the *Photovoltaic Geographical Information System*(PVGIS 2011). For every energy level displayed on the horizontal axis, it is possible to go in and find the [required PV area/floor area] for the various technologies.

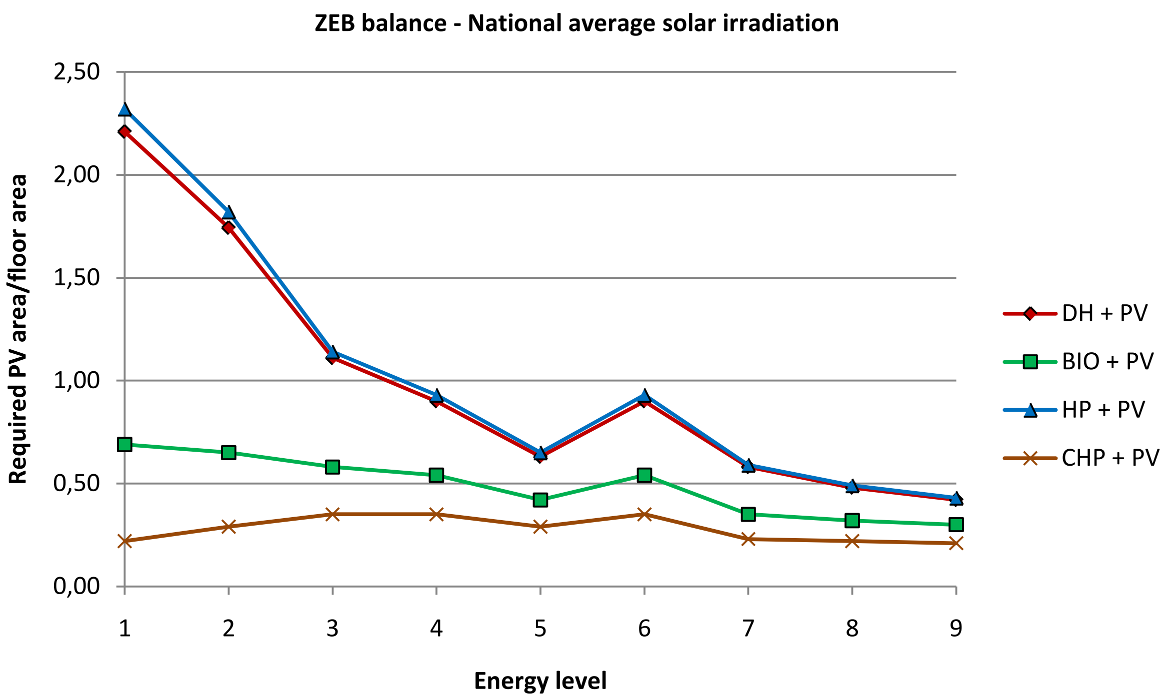


Chart 6 ZEB balance for average solar irradiation.

Both BIO and CHP are fired on pellets, which have low carbon emissions, and the required PV areas of those solutions are generally lowest. Because of CHP's increased electricity generation when the heating demand is high, it can also be seen that this solution gives good results even for buildings with poor energy-efficiency. It is however understood that the energy demand of a ZEB shall be reduced before the energy supply solution is chosen, so the main focus in this study is on energy-efficient building envelopes. The results converge as the energy level increases, and at L7 all of the technologies tend to show potential at [required PV area/floor area] = 1:2. In the following charts, the parameters are broken down to regions and specific energy levels for a more detailed analysis. Focus is directed towards L7, L8 and L9. Because of variations in yearly solar irradiation, the results vary for every single region.

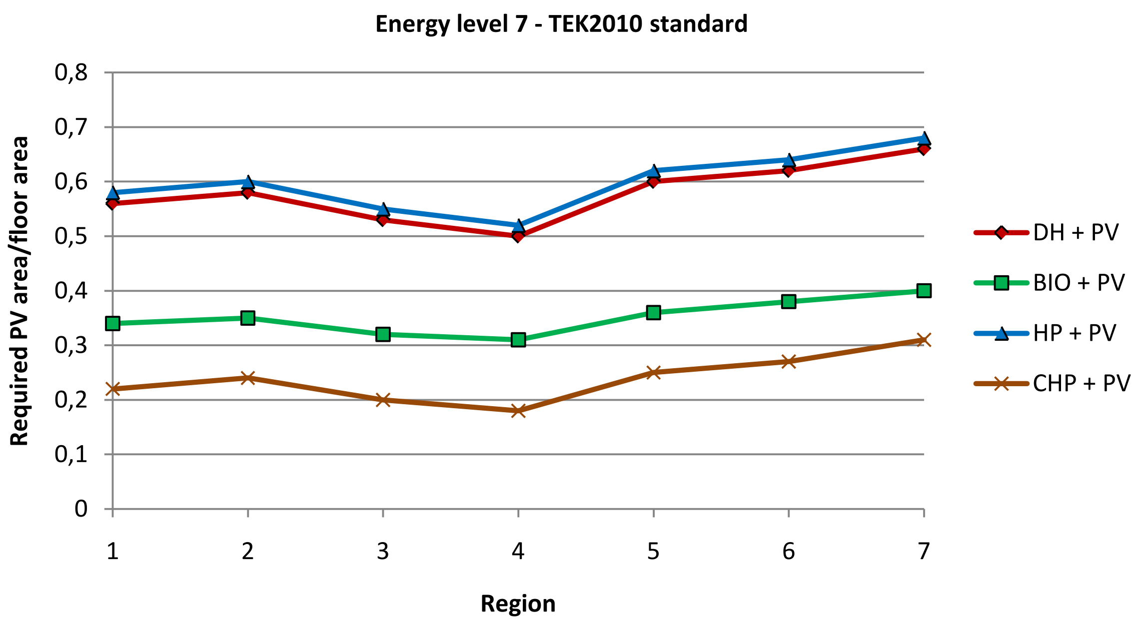


Chart 7 ZEB balance for energy level 7.

For L7, DH + PV touches ratio 1:2 in region 4, while HP + PV stays above in all regions. For the same energy level, the [required PV area/floor area] for BIO + PV fluctuates around ratio 1:3.

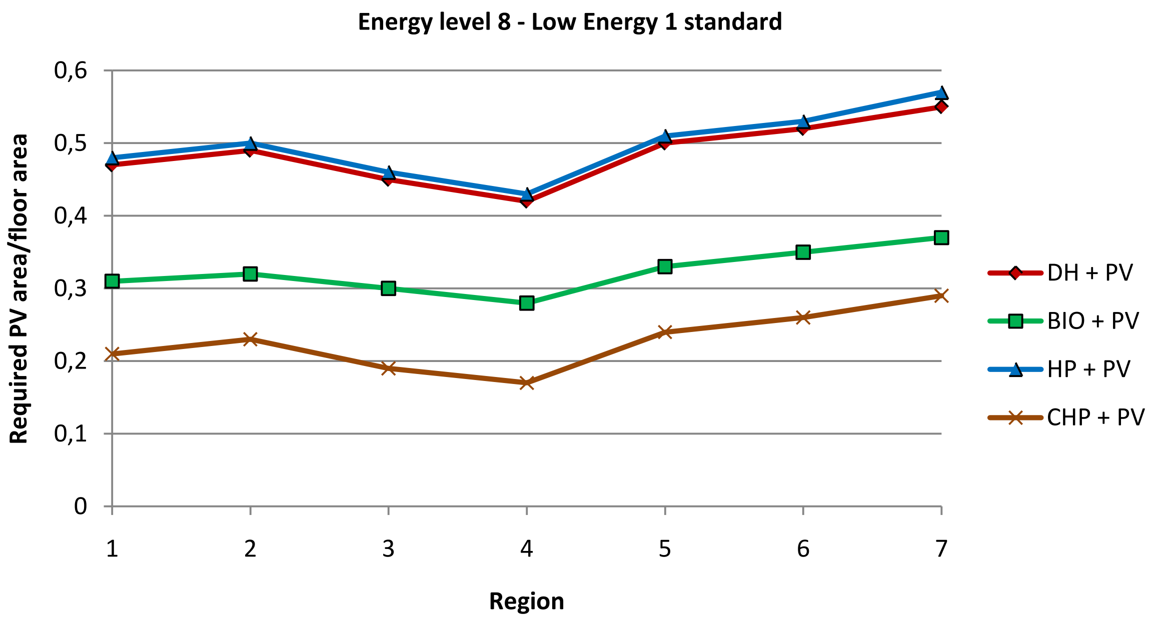


Chart 8 ZEB balance for energy level 8.

For L8 and L9 it is noticed that the [required PV area/floor area] for DH + PV and HP + PV decreases relatively more from L7, compared to the two remaining technologies.

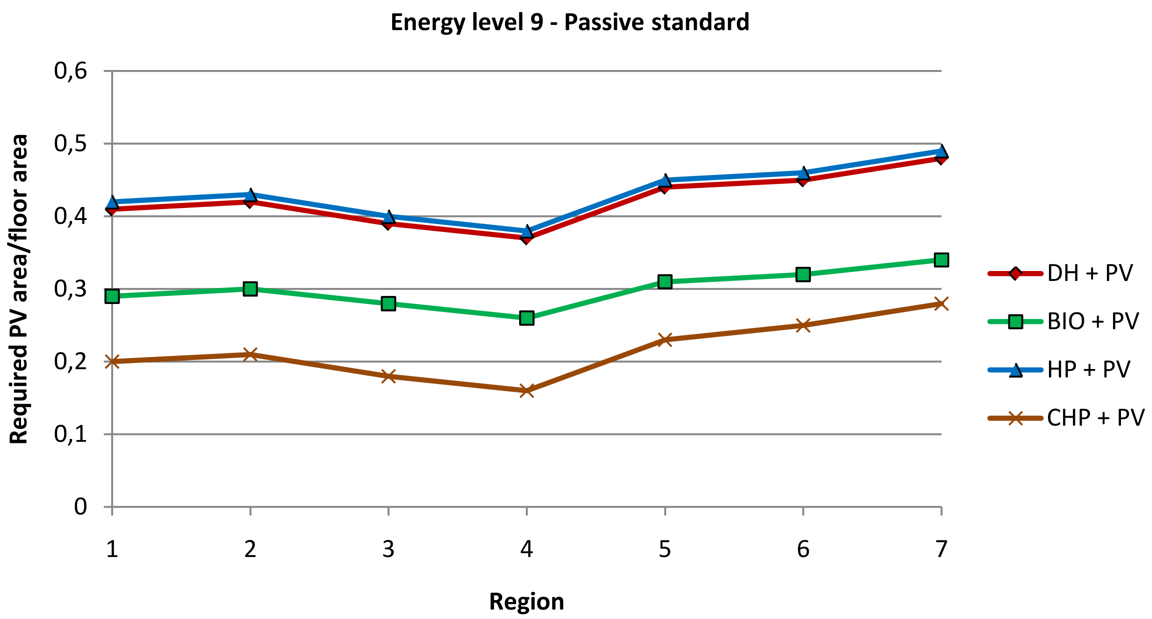


Chart 9 ZEB balance for energy level 9.

4 APPLICABILITY OF CHOSEN SOLUTIONS

4.1 Assumptions in analysis

With the four technologies and their performances determined, it is possible to analyze their uptake potential in ZEBs in the residential building stock. To "qualify" for uptake, the technology has to be able to reach the ZEB balance under the limitations determined from the survey on the stock. These limitations include energy demand, geographical positioning of the building and available roof area for PV-mounting. The analysis is performed on four different scenarios, with the following assumptions made;

- The on-site electricity generation is provided by PV in all the chosen energy supply solutions, and it is assumed roof-mounting of the PV's. This implies that the available roof area is the most important factor when it comes to how much electricity that can be produced on-site. When looking at the different building types, there are only minor variations for the [available roof area/floor area] for detached houses, two dwellings, row houses etc. and residence for communities. These four building types are therefore merged in to one category, and denoted *small houses*. The last category of buildings, *multi dwelling buildings*, is handled separately because of their different physical appearance with generally lower [available roof area/floor area].

- See Appendix A for the investigated ratios of [available roof area/floor area] for the two building categories used in the calculations.

- Because of the challenges discussed in the paragraph on *urbanity (2.2.3)*, it is not realistic that the chosen energy supply solutions can be installed in *all* buildings, even though they have enough available roof area. Assumptions are therefore made for system applicability in the stock satisfying the ZEB balance. See Appendix A.

- In Scenario 2 and Scenario 3, there are made estimates for how the residential building stock *can* look like in the future. The calculations are based on the probability distributions and methods described by Sartori et al in their paper on modeling Norway's dwelling stock(Sartori 2008). See Appendix A.

4.2 Scenario 1: Baseline

4.2.1 Method

The baseline scenario investigates the applicability of the chosen energy supply systems in the *current* residential building stock. The number of buildings in each category is taken straight from the survey on the stock, and in the results shown it is used average value for solar irradiation (832 kWh/m^{2}year) for every energy level.

4.2.2 Results

Small houses

The current population of buildings belonging to the small houses-category, with respect to energy level, is displayed on chart 10.

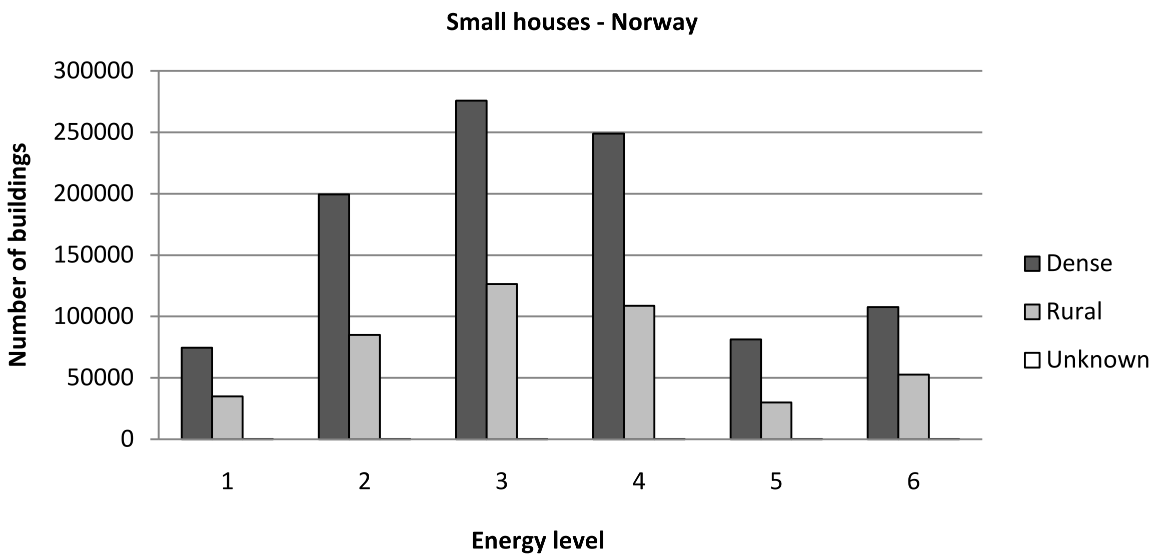


Chart 10 Small houses sorted after energy level and urbanity.

Chart 11 and 12 shows the potential technology uptake in the current stock (dense and rural areas) with the maximum investigated [available roof area/floor area] (1:2) for small houses. At every single energy level in the charts, it is possible to go in and see how many buildings that can be converted to ZEBs with the various technologies. The total number of buildings (solid line) in each investigated category is also included as a relative reference.

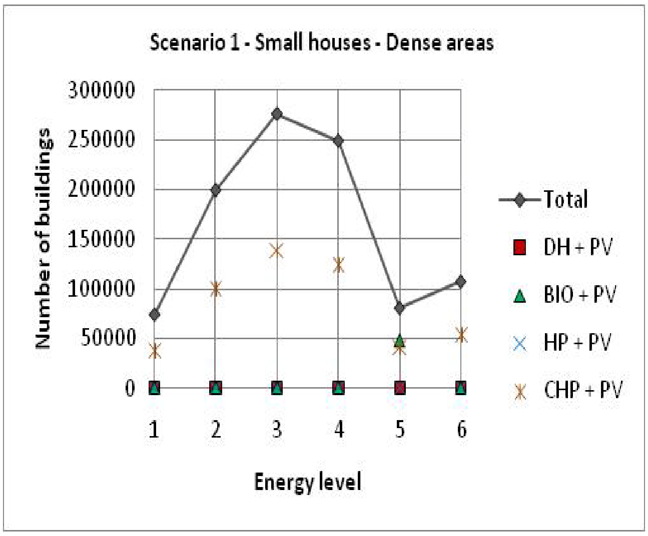


Chart 11 S1 – Uptake potential – Small houses (dense) – 1:2.

Because of low carbon emissions and surplus generation of electricity, CHP + PV has uptake potential at all energy levels. It can also be seen that ZEB balance is attainable with BIO + PV at energy level 5.

The remaining technologies show no potential in the current stock.

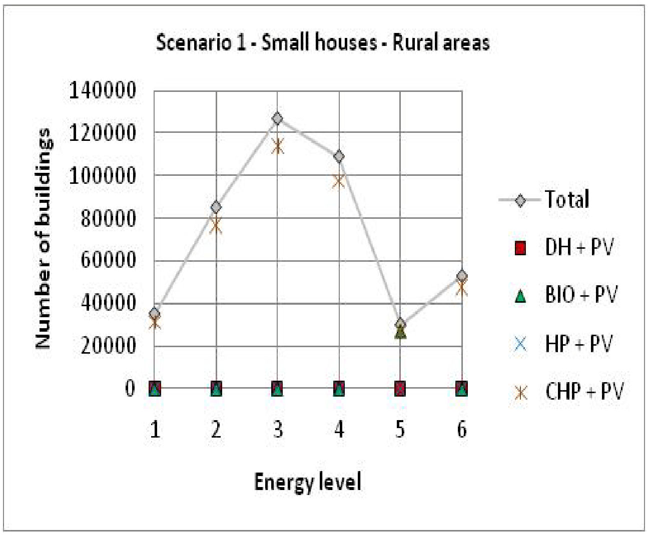


Chart 12 S1 – Uptake potential – Small houses (rural) – 1:2.

Reaching the ZEB balance is not dependent of the urbanity in this study, so the same technologies have potential in rural areas.

It is however expected that CHP + PV and BIO + PV can cover more of this stock because of better suitability in sparsely populated areas.

Multi dwelling buildings

Chart 13 shows the distribution of multi dwelling buildings in the current stock.

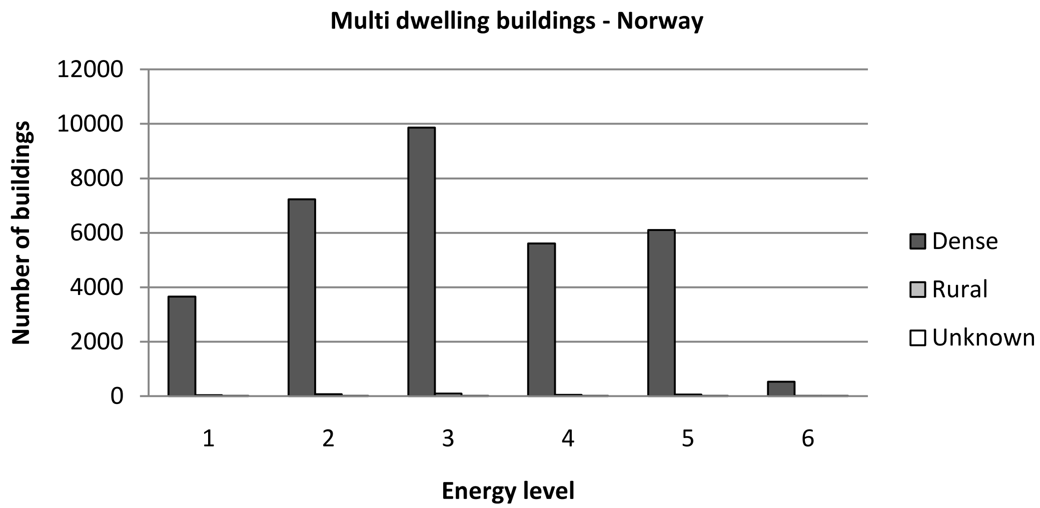


Chart 13 Multi dwelling buildings sorted after energy level and urbanity.

The results shown for this building type are also with the maximum investigated [available roof area/floor area], which is 1:3 for multi dwelling buildings.

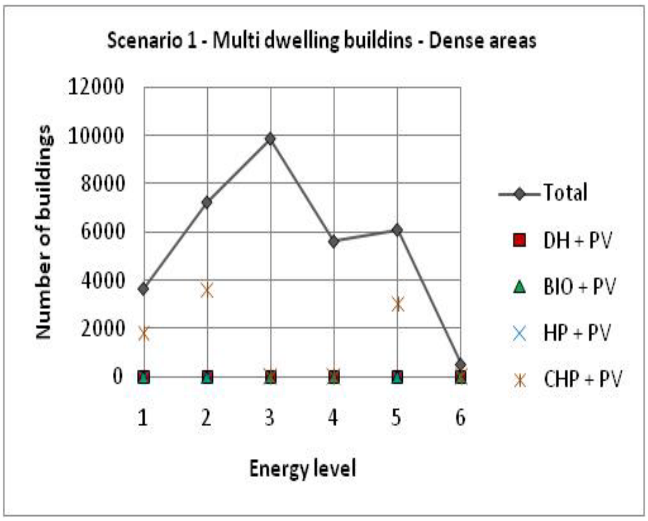
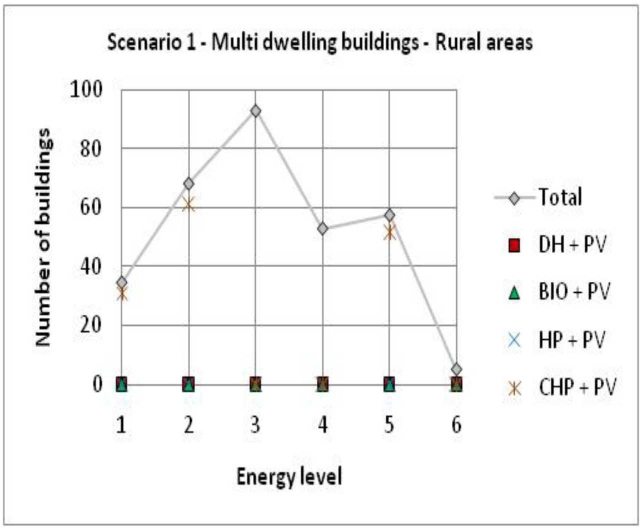


Chart 14 S1 – Uptake potential – Multi dwelling buildings (dense) – 1:3.

With the decreased ratio, CHP + PV is the only technology with uptake potential, limited to L1, L2 and L5.



There are very few multi dwelling buildings in rural areas, and even though CHP + PV has uptake potential at three energy levels, the number of buildings that can be converted to ZEBs are negligible compared up against the entire building mass.

Chart 15 S1 – Uptake potential – Multi dwelling buildings (rural) – 1:3.

The results from Scenario 1 show that the majority of the current residential building stock cannot be converted to ZEBs under the given conditions, and as long as no renovation is performed. If we look away from the solution with CHP + PV, the overall energy-efficiency of the building mass does not satisfy the severe requirements set to reach ZEB balance with the proposed energy supply solutions. Further focus is therefore directed towards renovation scenarios, new buildings and the highest energy levels (L7-L9).

4.3 Scenario 2: Year 2025

4.3.1 Method

In Scenario 2 it is made an estimate for how the building stock *can* look like in year 2025, with the assumptions described in 4.1 and the following development of the current building stock;

- L1-stock: 5% still standing, 3,2% renovated to L7.
- L2-stock: 30% still standing, 3,2% renovated to L7.
- L3-stock: 88% still standing, 3,2% renovated to L7.
- L4-stock: 98% still standing, 3,2% renovated to L7.
- L5-stock: 100% still standing, 0,0% renovated.
- L6-stock: 88% still standing, 3,2% renovated to L7.

Emphasis in this scenario will be on the buildings of energy level 7 and higher, based on the findings from the ZEB balance calculations and Scenario 1. All results are collected in Appendix B, but important findings are discussed in this chapter.

4.3.2 Results

Small houses

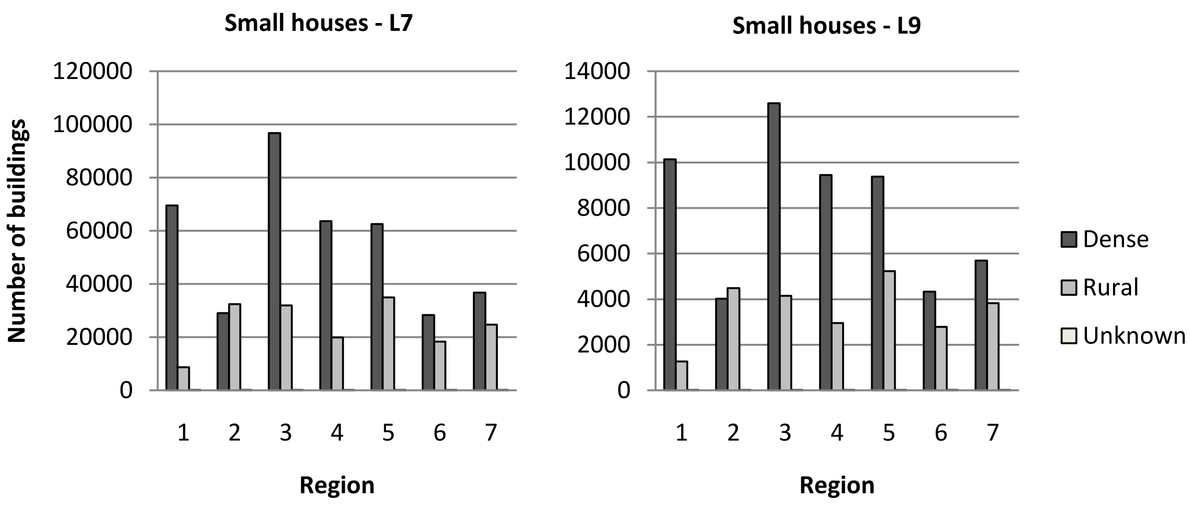


Chart 16 S2 – Small houses – L7 and L9.

The renovation of older buildings and rate of new buildings gives a shift in the stock, towards higher energy levels and a total increase of buildings in the stock. The majority of the small houses are now of TEK2010 (L7) standard and the share of passive houses (L9) are also significant.

At the following charts it is taken a closer look at the uptake potential for buildings of L7 and L9 standard in dense areas with ratio 1:2. For L7 it is CHP + PV and BIO + PV that are the most promising technologies. DH + PV does also have uptake potential in region 4, which is southernmost.

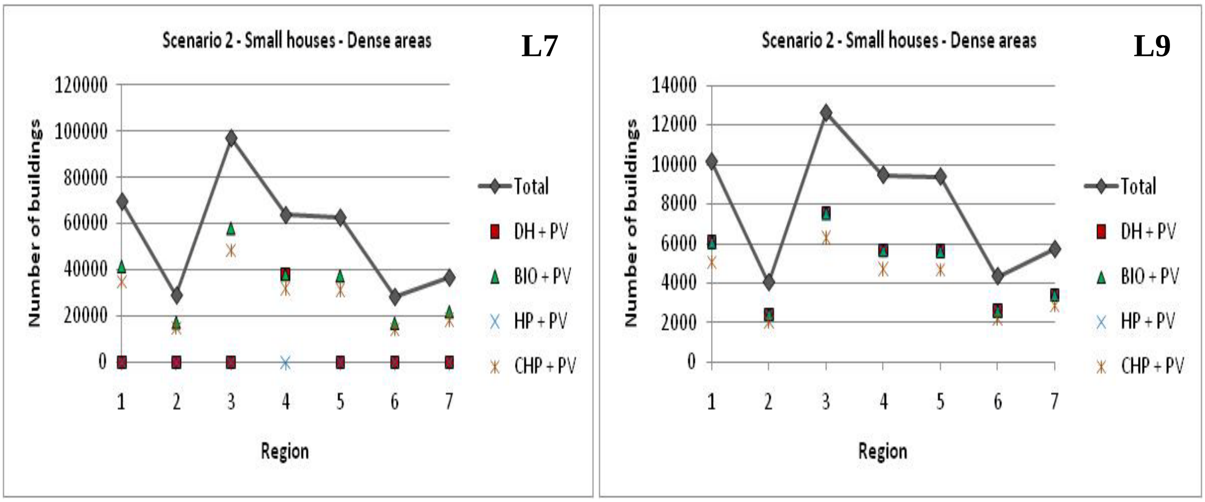


Chart 17 S2 – Uptake potential – Small houses (dense) – L7 and L9 – 1:2.

For energy level 9, all of the technologies show uptake potential, and can consequently be used to convert a considerable share of the stock to ZEBs.

Compared up against the entire small house-stock in year 2025 (ratio 1:2), it is for instance possible to convert approximately 17 % of the stock to ZEBs with BIO + PV, while HP + PV can be used in approximately 3 %. DH + PV show potential in almost 5 % of the stock, while the technology with highest uptake potential, CHP + PV, can be used in almost 24 % of all the small houses.

Multi dwelling buildings

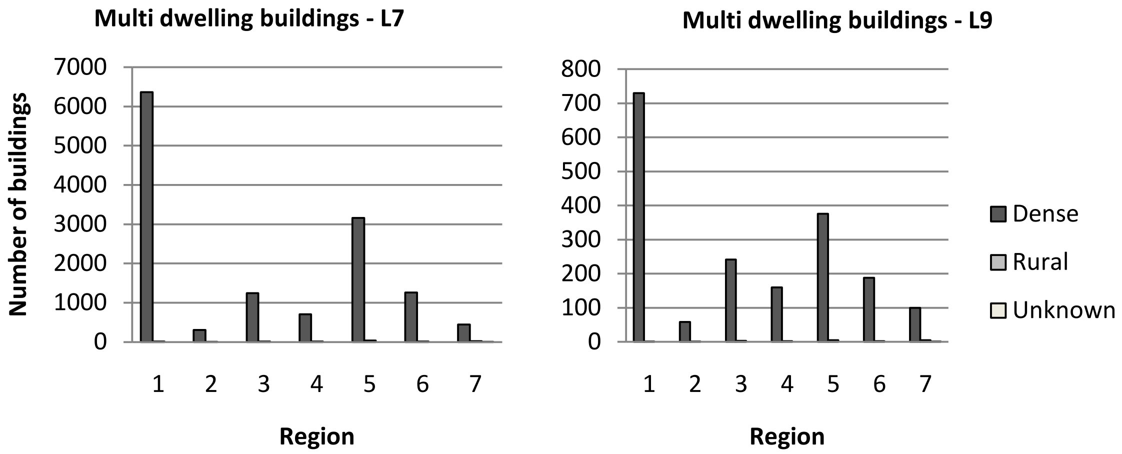


Chart 18 S2 – Multi dwelling buildings – L7 and L9.

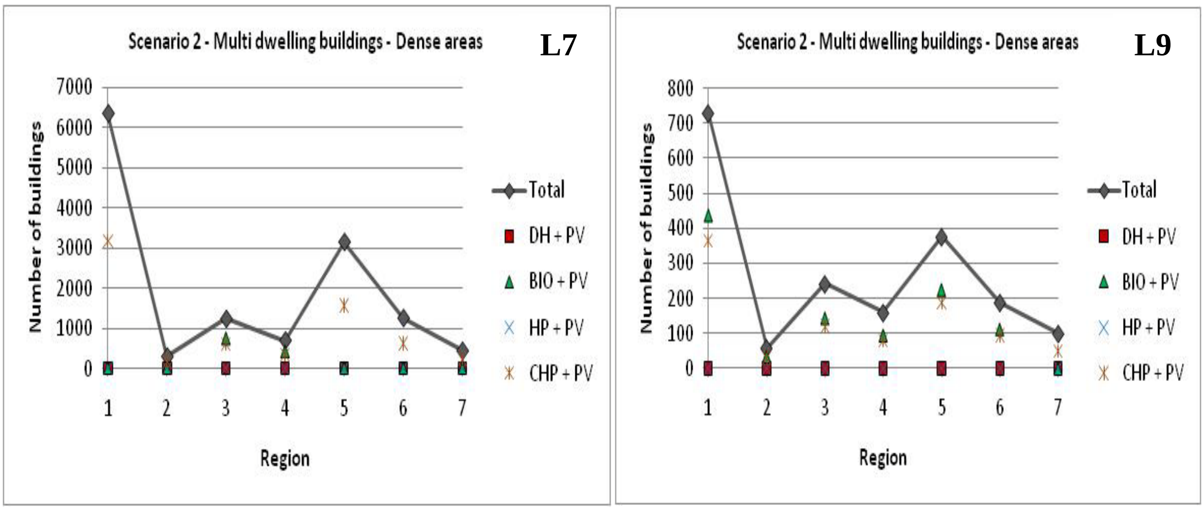


Chart 19 S2 – Uptake potential – Multi dwelling buildings (dense) – L7 and L9 – 1:3.

For multi dwelling buildings with ratio 1:3, it is only CHP + PV that show potential at L7 in the regions with the majority of the building units. At L9 it is also possible with BIO + PV in six regions, but it should be noticed that the number of buildings with that standard in 2025 is limited.

4.4 Scenario 3: Year 2050

4.4.1 Method

The same method and probability distributions as in *Scenario 2: Year 2025* is used, resulting in the following development of the residential building stock;

- L1-stock: All buildings demolished.
- L2-stock: 5% still standing, 3,2% renovated to L7.
- L3-stock: 40% still standing, 3,2% renovated to L7.
- L4-stock: 80% still standing, 3,2% renovated to L7.
- L5-stock: 90% still standing, 3,2% renovated to L9.
- L6-stock: 40% still standing, 3,2% renovated to L7.

4.4.2 Results

Small houses

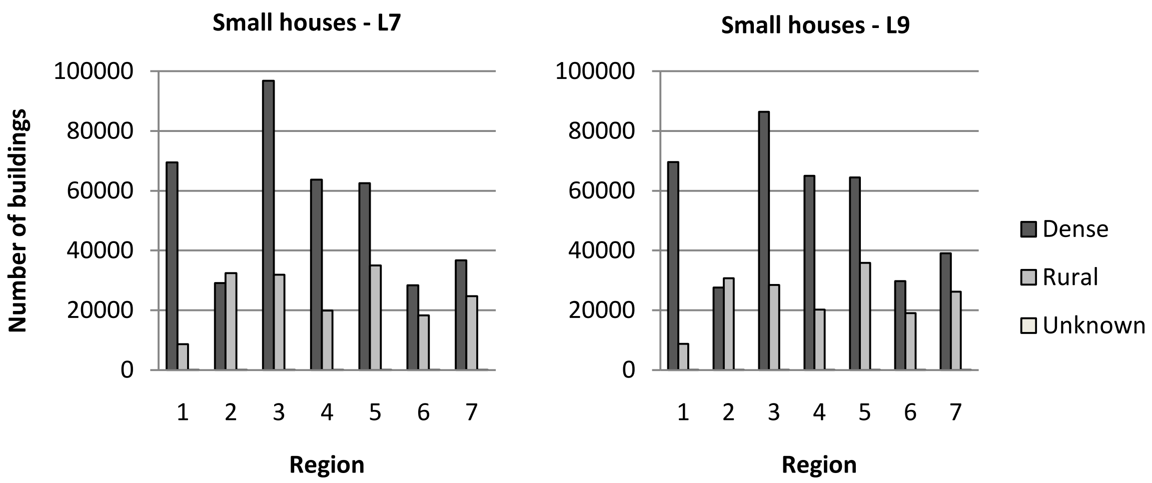


Chart 20 S3 – Small houses – L7 and L9.

Except the L1-buildings which are completely demolished, the stock is distributed in the same energy levels as in Scenario 2. However, the relative share of passive houses is now larger, and it constitutes almost 26% of the entire small houses-stock in 2050.

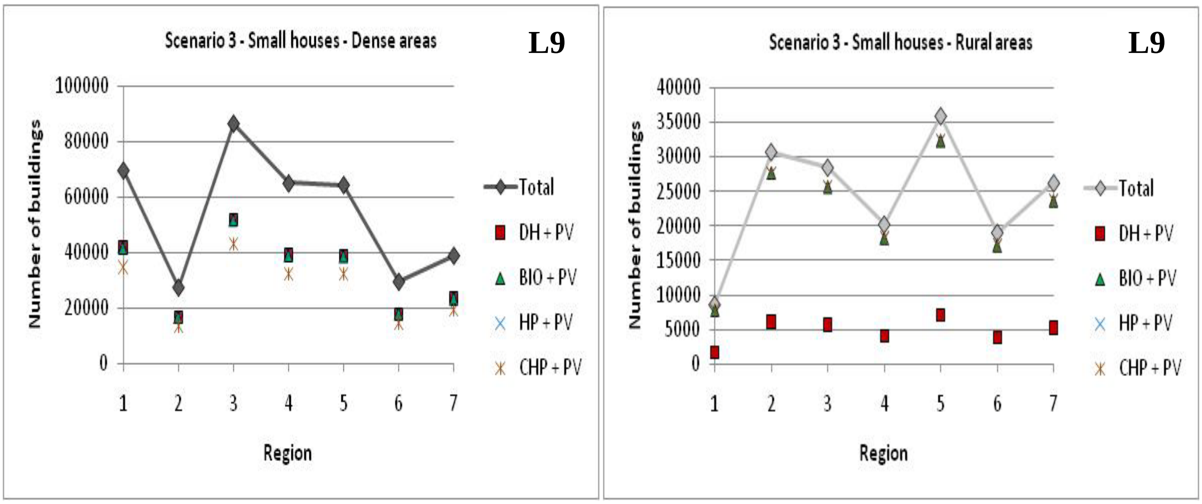


Chart 21 S3 – Uptake potential – Small houses (dense and rural) – L9 – 1:2.

The development of the stock opens up opportunities for especially DH + PV and HP + PV, which now shows a relative growth compared to the two remaining technologies. Many of the older buildings that could be converted to ZEBs with CHP + PV and BIO + PV are now demolished.

Multi dwelling buildings

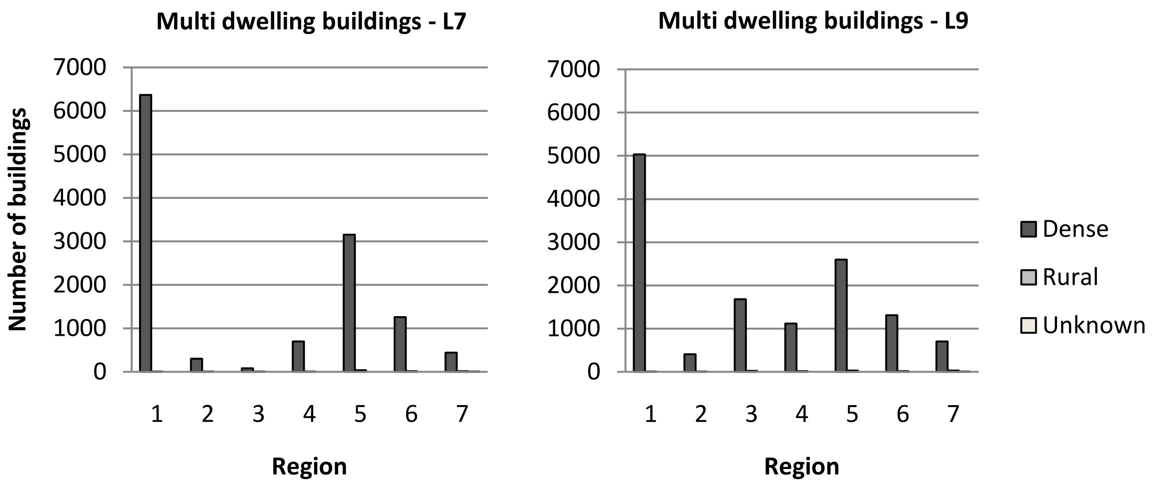


Chart 22 S3 – Multi dwelling buildings – L7 and L9.

Even though it is expected the same development of the multi dwelling buildings as in the small houses-stock, the technologies does not show the same uptake potential due to lower [available roof area/floor area].

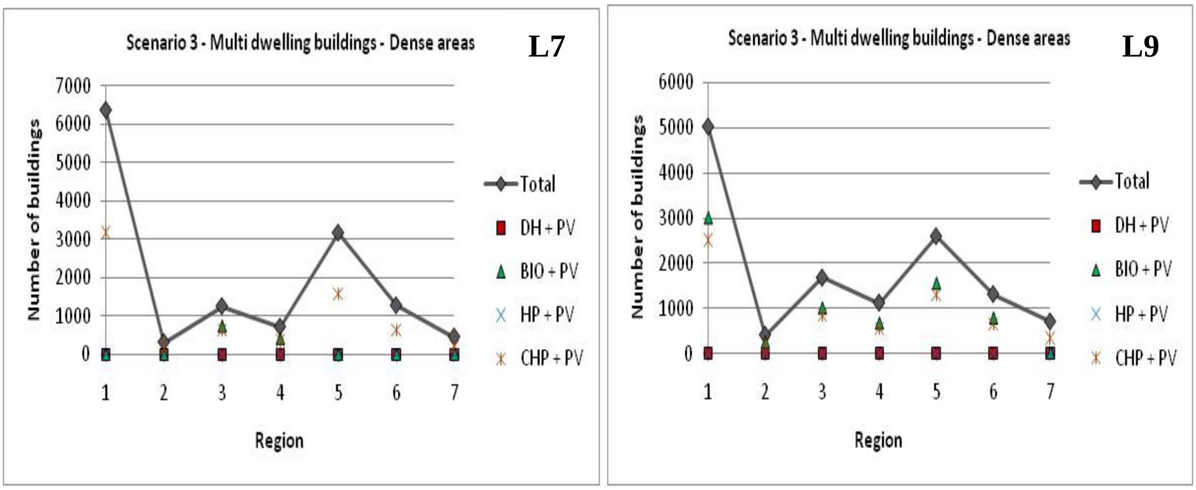


Chart 23 S3 – Uptake potential – Multi dwelling buildings (dense) – L7 and L9 – 1:3.

The absolute amount of potential ZEBs with CHP + PV and BIO + PV is increased for ratio 1:3, while DH + PV and HP + PV does not show potential.

4.5 Scenario 4: Flip

4.5.1 Method

This is an experimental scenario that investigates the possibilities when the current residential building stock is "flipped";

- L1-stock is upgraded to L7-standard
- L2-stock is upgraded to L8-standard
- L3-stock is upgraded to L9-standard

It is expected no additional demolition or renovation of the remaining stock, or any new buildings.

4.5.2 Results

Small houses

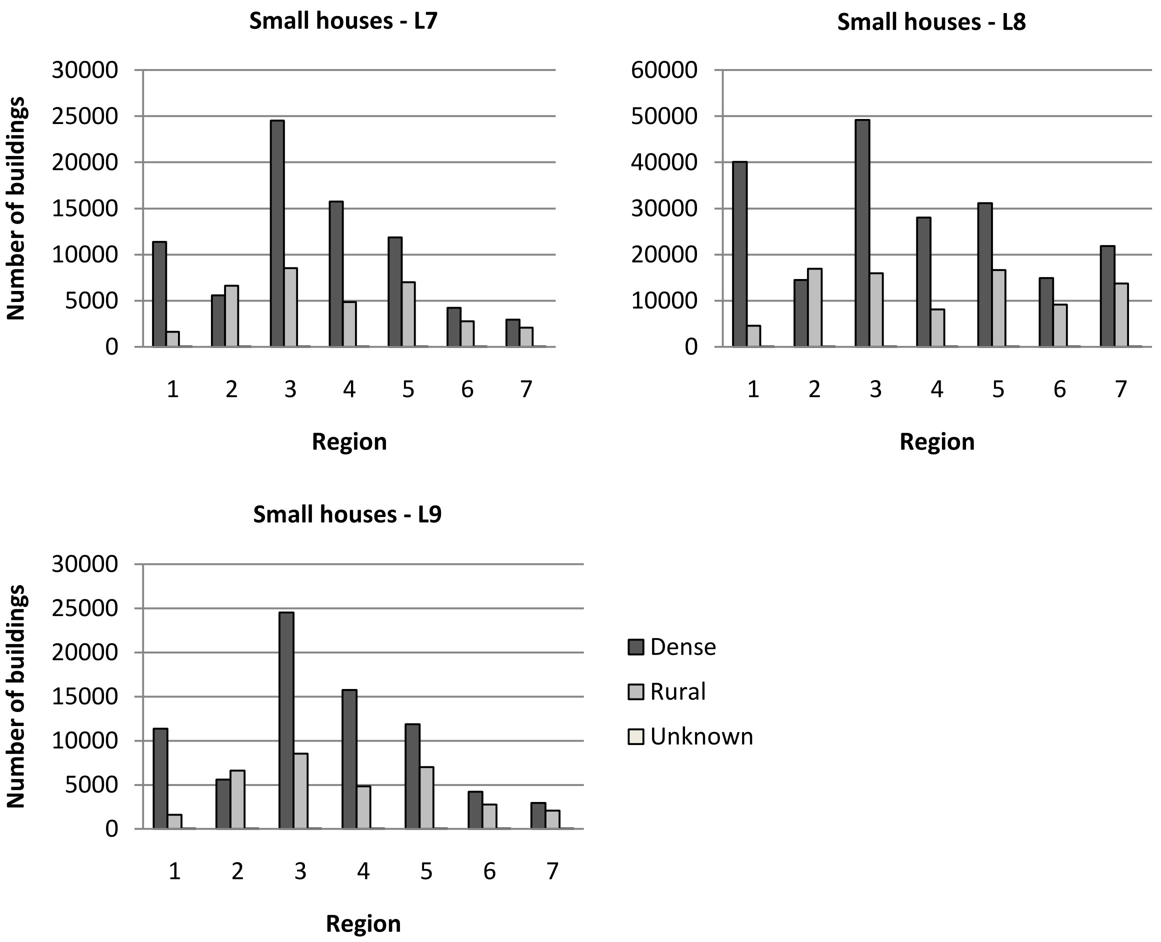
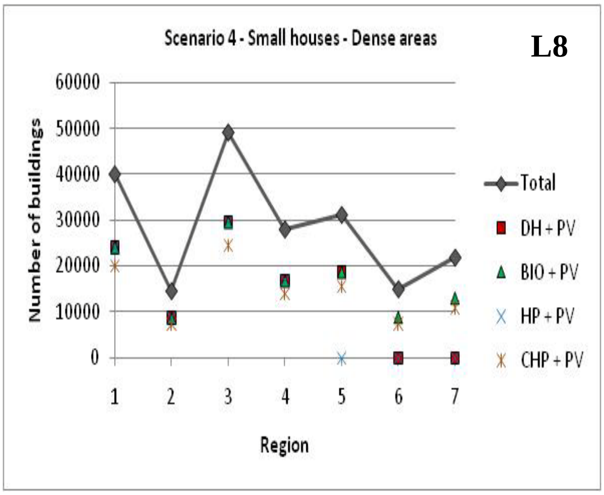


Chart 24 S4 – Small houses – L7, L8 and L9.

It can be argued that this is not a realistic development of the stock, and it is also emphasized that this is a rather experimental scenario. However, a new energy level is introduced in this scenario that will be taken a closer look at.



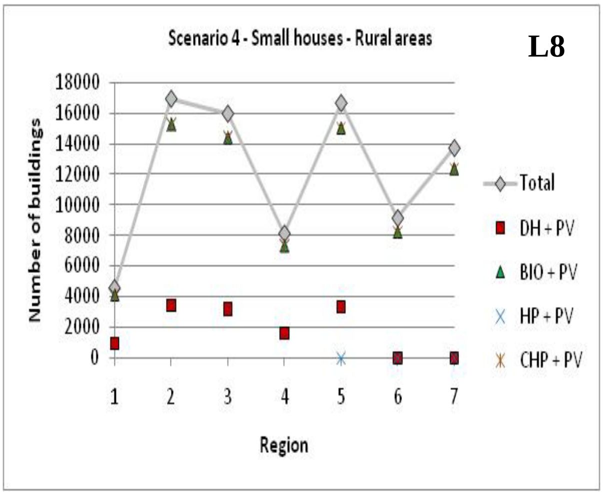


Chart 25 S4 – Uptake potential – Small houses (dense and rural) – L8 – 1:2.

The total specific energy demand in L8 is approximately 25 kWh/m^{2}year lower than in L7. This improvement in the building envelope makes a major difference for the uptake potential for two of the technologies. DH + PV does now have potential in five of the regions, while HP + PV has potential in four regions.

This further implies that upgrading or building to passive standard is in many cases not necessary in order to reach ZEB balance with a range of energy supply systems, as the results in Scenario 2 and 3 showed. On a large scale, this can mean significant differences in costs when it comes to introducing ZEBs in the small houses stock.

Multi dwelling buildings

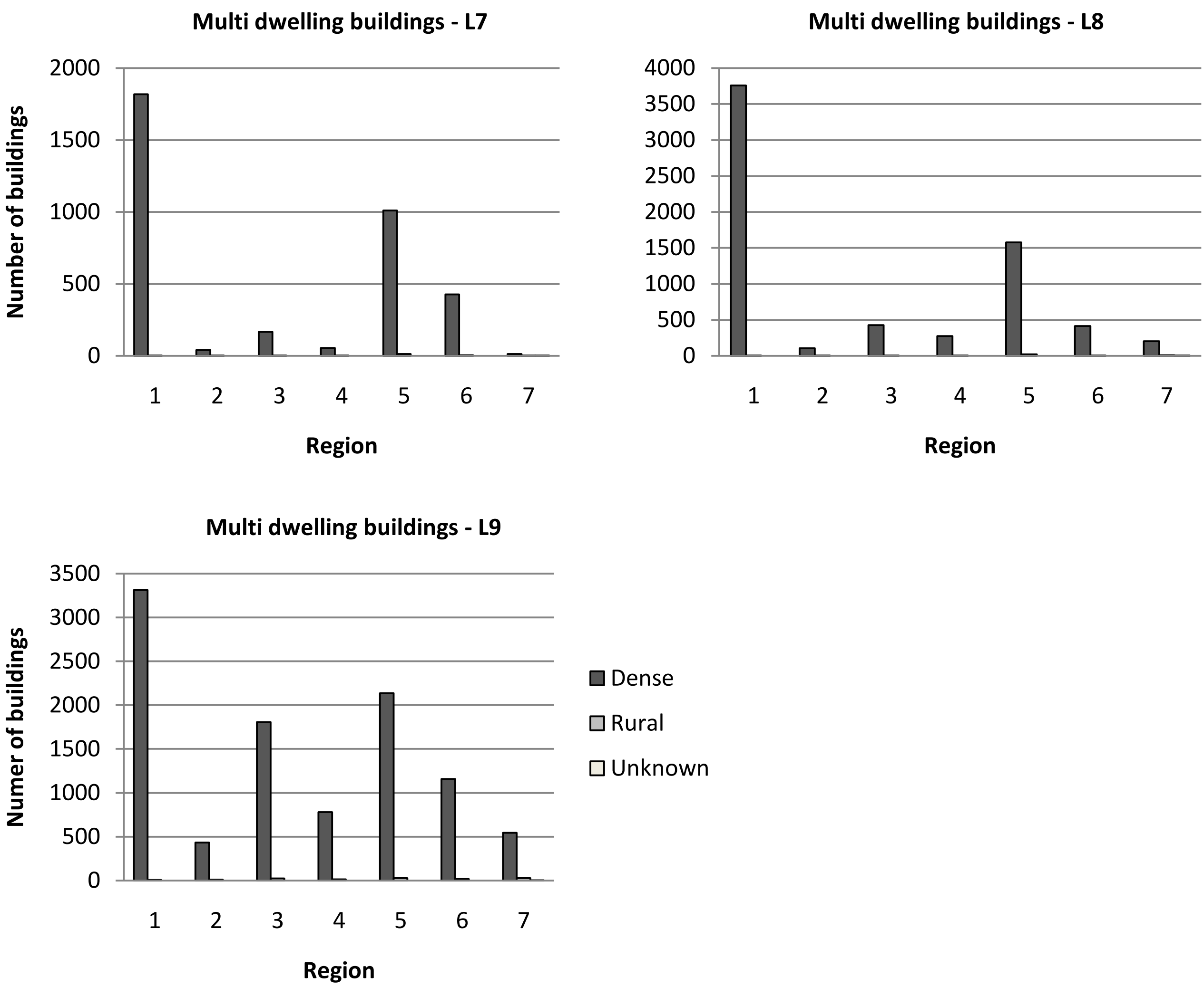


Chart 26 S4 – Multi dwelling buildings – L7, L8 and L9.

For multi dwelling buildings with ratio 1:3, BIO + PV has uptake potential in three more regions in L8 compared to L7. Besides that, the results show no differences in the potential of the various technologies.

5 DISCUSSIONS AND CONCLUSIONS

On a national level, the survey on the residential building stock showed that the vast majority of buildings in both dense and rural areas are detached houses. It did also reveal that it is necessary to focus the study on a regional level when analyzing the potential for technologies in ZEBs because of significant differences in urbanity, climate and building types between the regions. Based on the findings from the survey, it can be argued that developing suitable energy supply solutions for detached houses should be emphasized in order to see a potentially quick growth in the absolute number of ZEBs. When it comes to multi dwelling buildings, more than 99% of the buildings are placed in dense areas. Limitations in possible energy supply solutions will likely occur here, mainly because of the influence of the immediate surroundings in a densely populated area.

With the findings from the survey and other important factors affecting the rationality and viability, a set of four different energy supply systems were introduced. The calculation of the ZEB balance for each technology and energy level, showed the significance of energy-efficiency and available roof area of the buildings for especially two of the solutions. In order to be able to utilize all energy supply solutions for [available roof area/floor area] - ratios lower than 1:2, the buildings need to have energy demands lower than the ones published in the latest building codes (L7, TEK2010), as shown on figure 9.

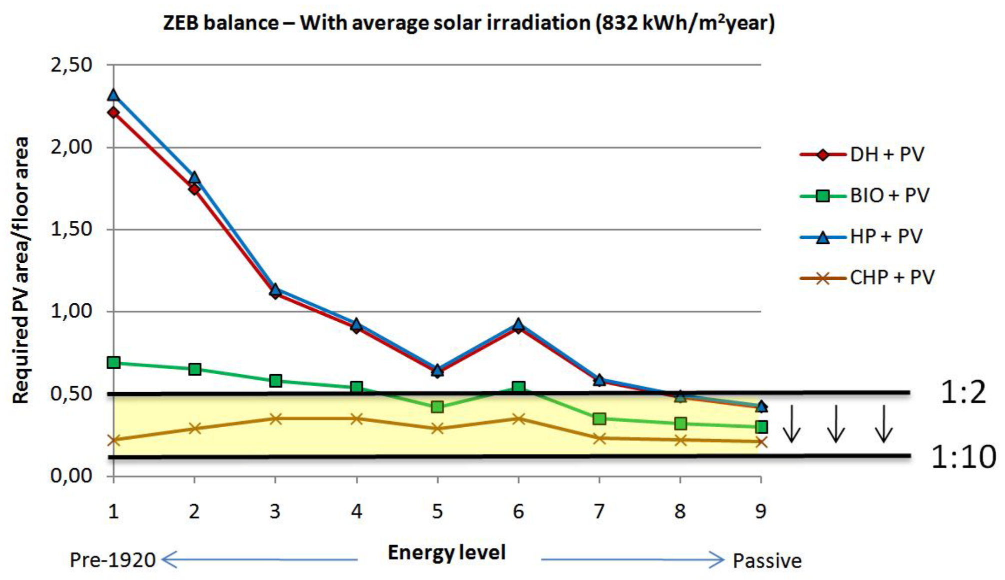


Figure 9 ZEB balance results.

This further implies that the potential for ZEBs with these technologies in the current residential building stock is low, as long as the buildings are not renovated. That was also shown in Scenario 1, where only CHP + PV and BIO + PV showed uptake potential. Further detailed analysis of every region and the highest energy levels in future scenarios was therefore done. When combining the results from Scenario 2 and Scenario 3, where analysis was done on a regional level, it is possible to see the uptake potential with respect to time.

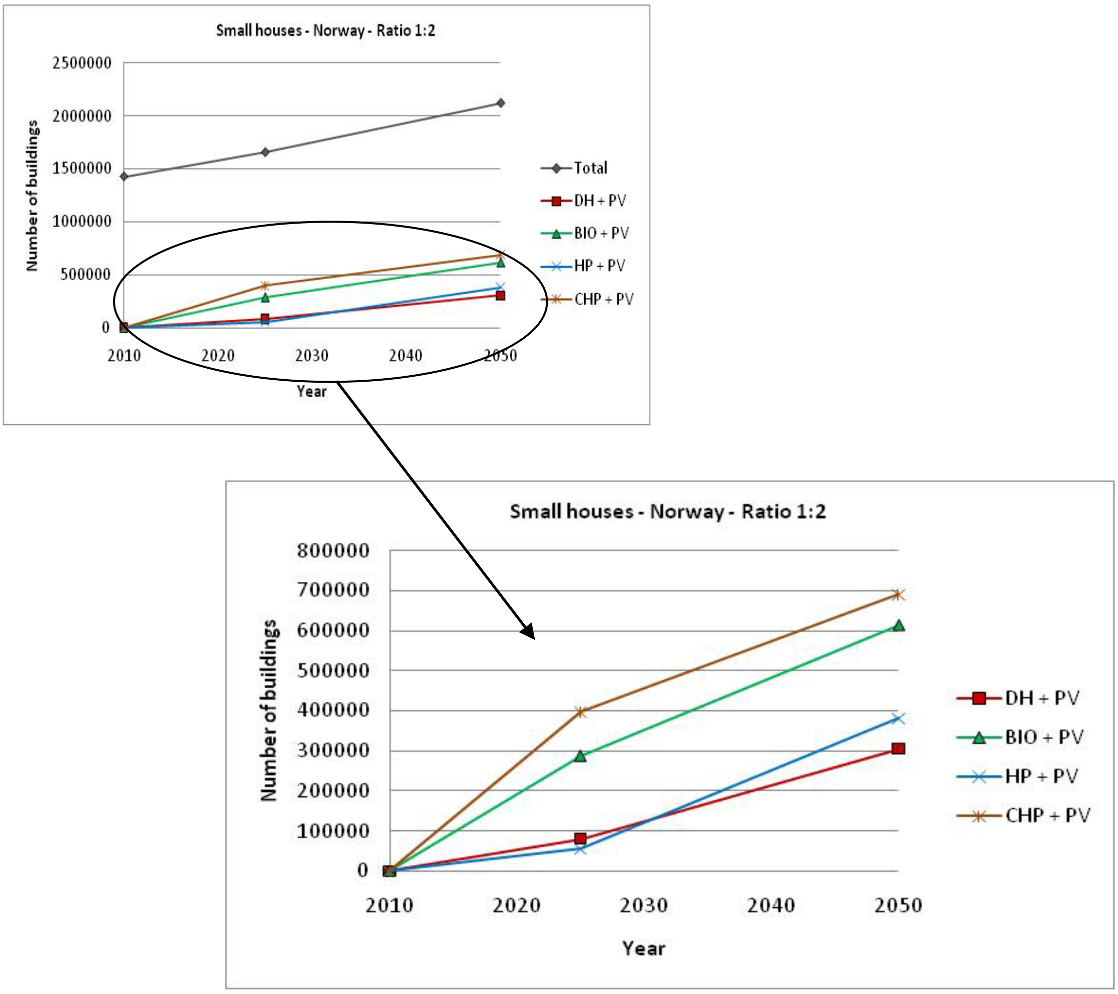


Figure 10 Uptake potential with respect to time – Small houses – 1:2.

Figure 10 shows the number of small houses that can be converted to ZEBs with the various technologies (with ratio 1:2) between year 2010 and year 2050. The development of the total small house-stock is also displayed. Up until 2025, CHP + PV and BIO + PV show rapid growth, because of the high renovation activity to L7 in this period. As the share of L9-buildings in the stock increases after 2025, the relative potential for DH + PV and HP + PV increases as well. Since HP + PV has assumed higher availability in rural areas, it actually surpasses DH + PV after a certain time. It can therefore be argued that, from these results, existing solutions with CHP and BIO should be emphasized in the nearest future to see a quick growth in the number of ZEBs. On a longer perspective, when the energy-efficiency of the residential building mass is significantly increased, attention can be extended to a number of technologies. It is especially interesting to see the development of heat pumps, where it is assumed a modest seasonal performance factor in this study, which may be substantially improved in the future.

Figure 11 shows the development of multi dwelling buildings and uptake potential of technologies (with ratio 1:3), with respect to time.

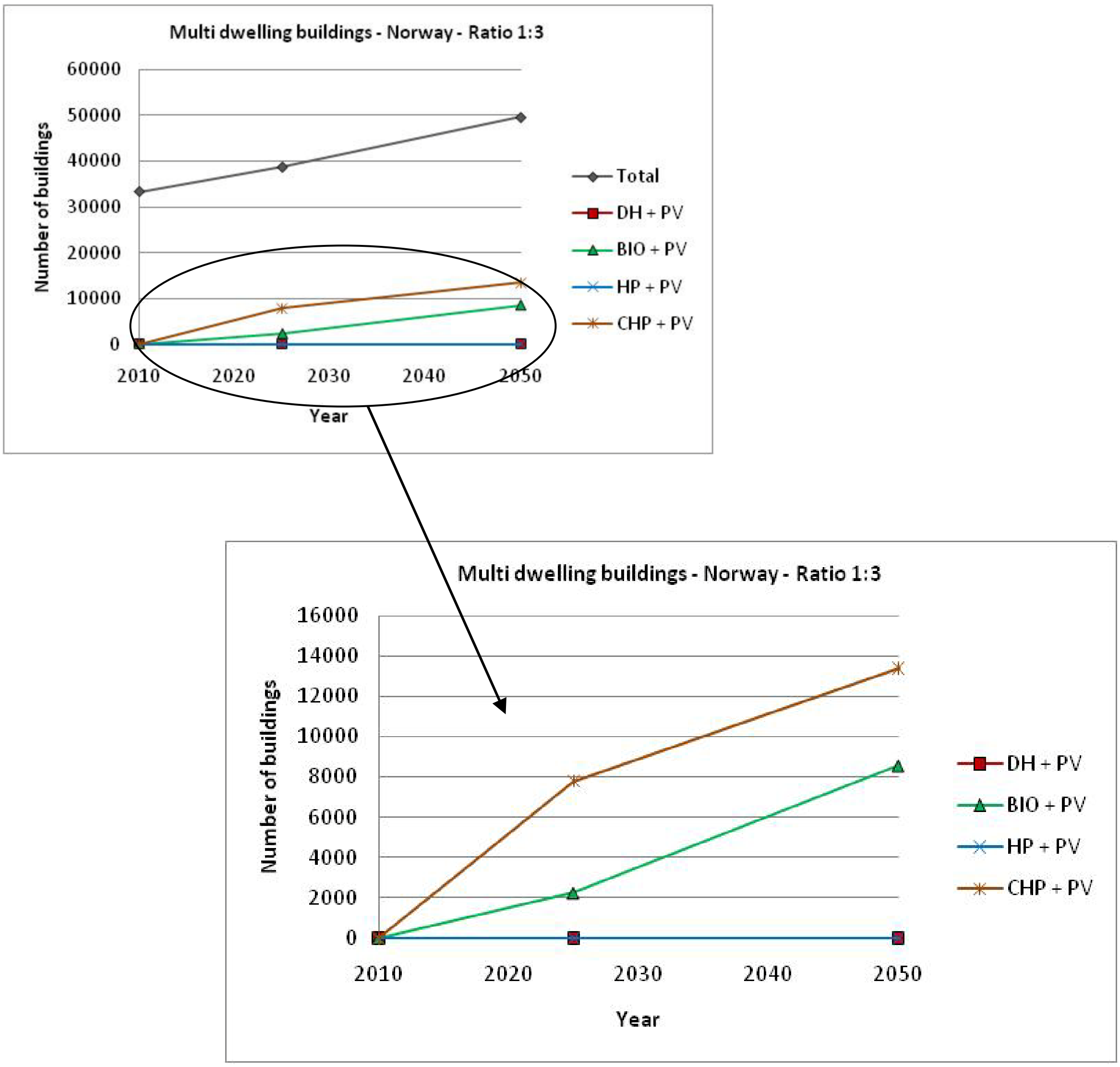


Figure 11 Uptake potential with respect to time – Multi dwelling buildings – 1:3.

In year 2050, results show that 27% of the total multi dwelling building-stock can be converted to ZEBs with CHP + PV, while BIO + PV can cover 17% of the stock. They show the same relative growth as in small houses, and it can also be argued here that these technologies should be emphasized in the nearest future to see a significant share of ZEBs within short time. For ratios equal to or below 1:4, it was only CHP + PV that showed potential in L9. With the performances and emissions assumed in this study, DH + PV and HP + PV show no uptake potential in multi dwelling buildings. It is however only minor improvements in the technologies and/or energy-efficiency of the building envelope that are required before ZEB balance is attainable, so with further R&D it is still likely that they can be used in ZEBs in the future.

Finally, the most important finding from Scenario 4 was the uptake potential for technologies in buildings of L8-standard. It showed that in several regions, renovating or building to L9-standard is not necessarily required in order to be able to utilize a range of energy supply solutions in ZEBs.

Proposal for further work

Results from this report can be used to estimate the energy savings [TWh], if the potential ZEBs are implemented in the building stock. Whether this is possible with the available resources used in the different technologies can also be studied closer. Further work related to the subject can for instance include building clusters, where joint heating plants serve several building units. This may show other results for uptake of technologies in ZEBs due to other efficiencies, emissions etc. This could again be used to compare economy and costs of joint systems against the technologies and solutions discussed in this report. Different strategies for renovation and demolition of the stock can be investigated to see how this affects the potential of technologies. It can also be interesting to study the development of technologies, and make estimations for their performance in the future to see how that influences the results.

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APPENDIX A

A.1 Data used in calculations

Regions and solar irradiation

The map and accompanying values for solar irradiation are collected from the Photovoltaic Geographical Information System(PVGIS 2011). Regions are drawn in on the map.

	Region	Yearly solar irradiation [kWh/m^{2}year]
R1	Oslo/Akershus	850
R2	Hedmark/Oppland	820
R3	South-East Norway	900
R4	Agder/Rogaland	950
R5	Western Norway	800
R6	Trøndelag	775
R7	Northern Norway	725
	Average	**832**

Table 3 Regions and yearly solar irradiation.

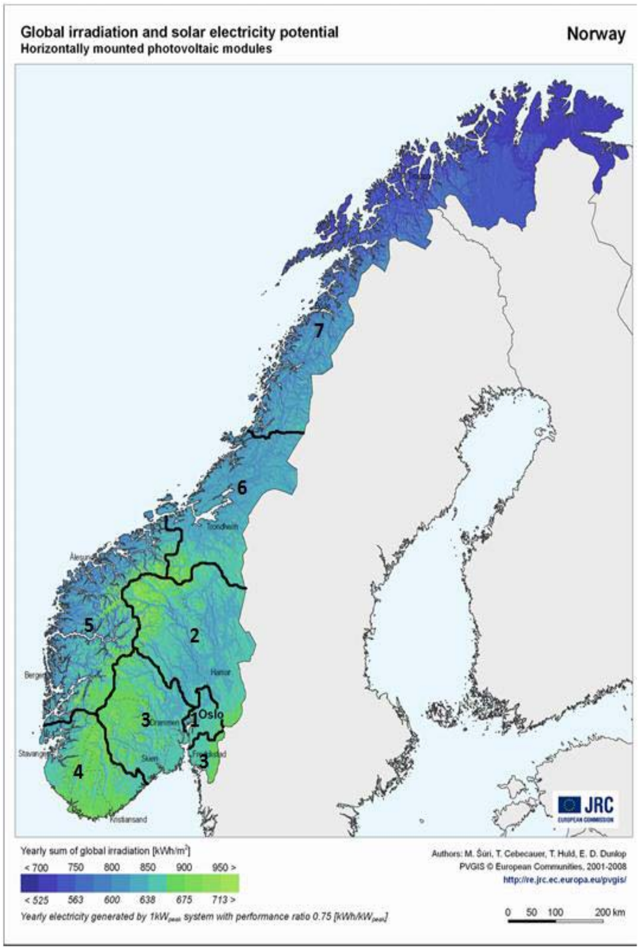


Figure 12 Global irradiation and solar electricity potential.

Equation 3.4.1

Used for calculation of specific required PV area. It is added a term above the fraction line to balance for the emissions from the thermal energy supply.

$$\frac{PVarea_{required}}{Floor_{area,heated}} = \frac{(E_{el,specific} + E_{th,specific} \bullet \frac{Q_{th}}{Q_{el,grid}})}{PV_{conversion}} [\frac{m^2 PV}{m^2\ floor}]$$

$E_{el,\ specific}$ = specific electricity demand $[\frac{kWh}{m^2 year}]$

$E_{th,\ specific}$ = specific thermal energy demand $[\frac{kWh}{m^2 year}]$

Q_{th} = CO_2 emissions from thermal energy supply $[\frac{kgCO_2}{kWh}]$

$Q_{el,\ grid}$ = 0,617 $[\frac{kgCO_2}{kWh}]$, emissions for UCPTE EL Mix(NS-EN 2008)

$PV_{conversion}$ = solar energy converted to electricity $[\frac{kWh}{m^2 PVyear}]$

Energy levels and specific energy demand

	Energy levels and specific energy demand									
	L1	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**	**L9**	
Lighting	15	20	25	25	20	25	11,4	11,4	11,4	[kWh/m^{2}year]
Appliances	20	25	30	30	25	30	17,5	17,5	17,5	[kWh/m^{2}year]
Ventilation fan	0	0	0	0	0	0	7,3	5,8	4,4	[kWh/m^{2}year]
Domestic hot water	30	30	30	30	30	30	29,8	29,8	29,8	[kWh/m^{2}year]
Room heating Ventilation heating	535	375	165	105	50	105	54	30	15	[kWh/m^{2}year]
Cooling	0	0	0	0	0	0	0	0	0	[kWh/m^{2}year]
Total specific energy demand	**600**	**450**	**250**	**190**	**125**	**190**	**120**	**94,5**	**78,1**	**[kWh/m^{2}year]**

Table 4 Energy demand for every energy level(BE 1997; BE 2010; NS 2010a; NS 2010b).

Urbanity and system applicability

Energy supply system	**DH + PV**			**BIO + PV**			**HP + PV**			**CHP + PV**		
Dense / Rural / Unknown	D	R	U	D	R	U	D	R	U	D	R	U
Heating system applicability [%]	90	20	50	70	90	50	70	90	50	50	90	50
PV applicability [%]	60	90	50	60	90	50	60	90	50	60	90	50
System applicability [%]	**60**	**20**	**50**	**60**	**90**	**50**	**60**	**90**	**50**	**50**	**90**	**50**

Table 5 Assumptions for system applicability in different urbanities.

Investigated ratios of [available roof area/floor area]

Building categories	
Small houses	**Multi dwelling**
1:2	1:3
1:3	1:5
1:4	1:7
1:5	1:10

Table 6 [Available roof area/floor area]-ratios investigated in calculations.

Estimations for demolition, renovation and new buildings

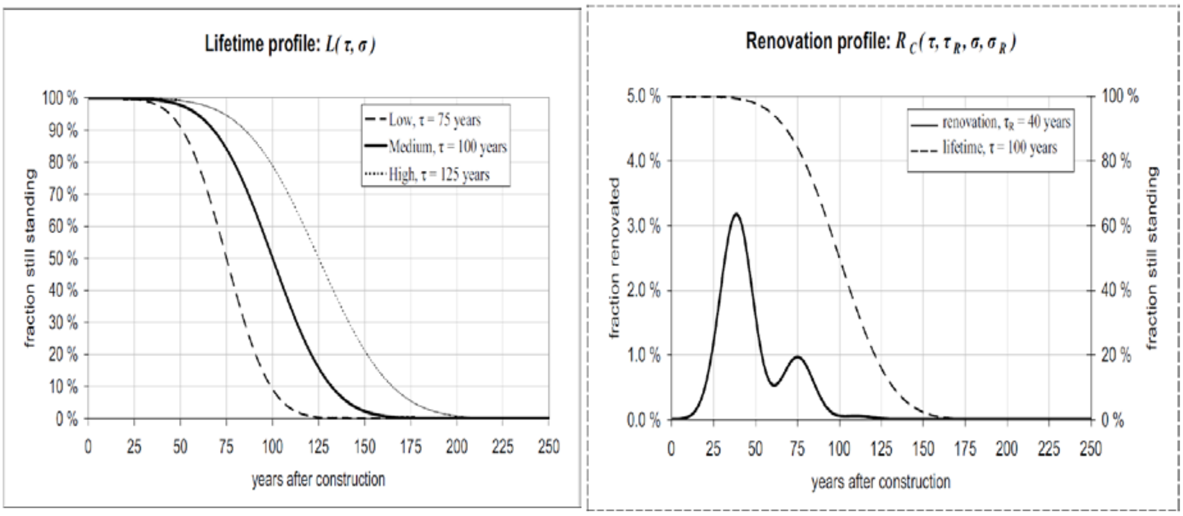


Figure 13 Lifetime and renovation profiles(Sartori 2008)

The lifetime and renovation profiles are applied to the building stock, with the following assumptions;

- Expected lifetime, τ = 75 years.
- All buildings renovated/built before 2020 is renovated/built to TEK2010 standard (L7)(BE 2010).
- All buildings renovated/built after 2020 is renovated/built to passive house standard (L9)(NS 2010a), based on the government's ambition to implement the passive house standard in the building codes by 2020(Regjeringen 2010).
- Rate of new buildings per year is assumed to be 1%, based on the average construction activity between 1996 and 2005(Sartori 2009).

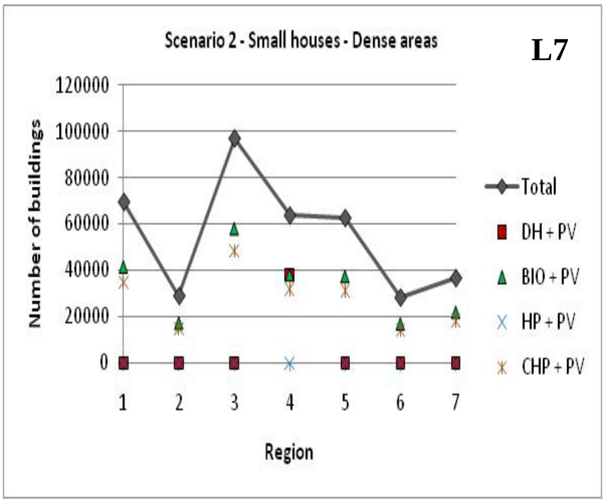
APPENDIX B

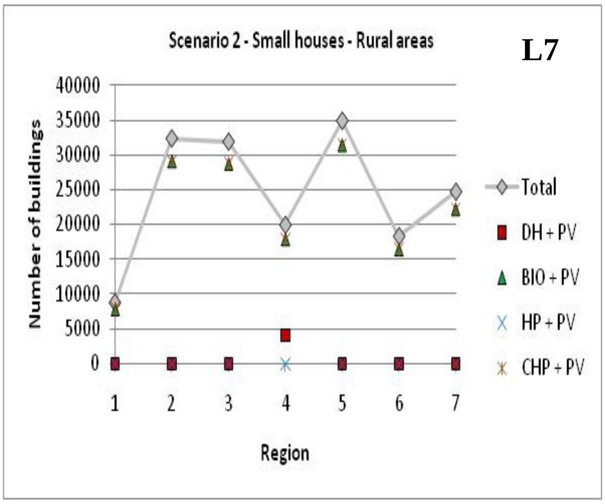
B.1 Results for system applicability

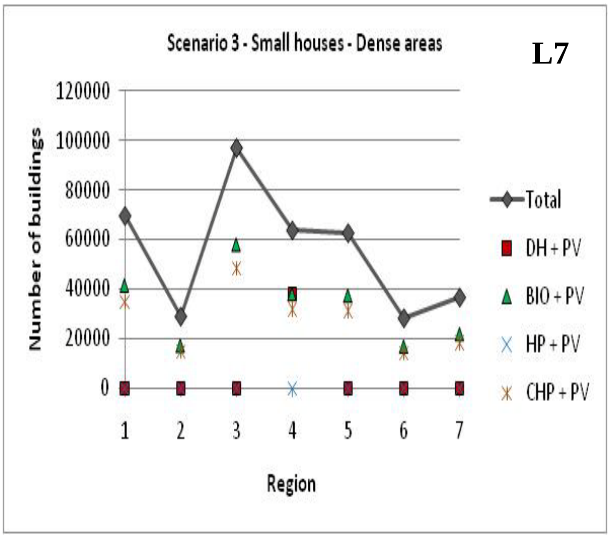
This appendix contains the technology uptake and potential buildings that can be converted to ZEBs in Scenario 2, 3 and 4 for the three highest energy levels. The charts are organized after energy level and [available roof area/floor area]-ratio.

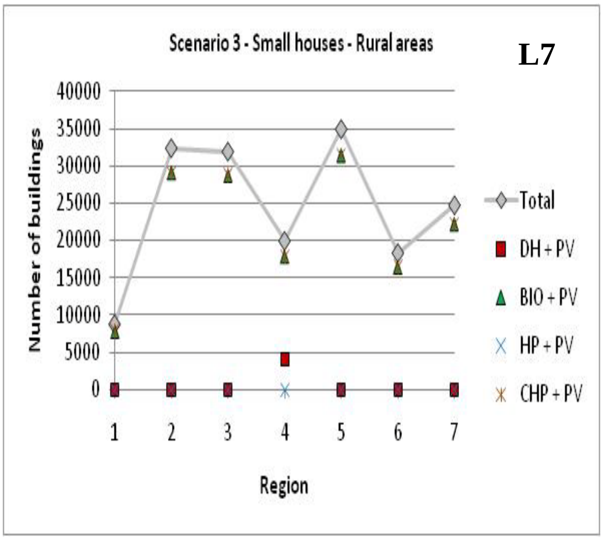
B.1.1 Energy level 7

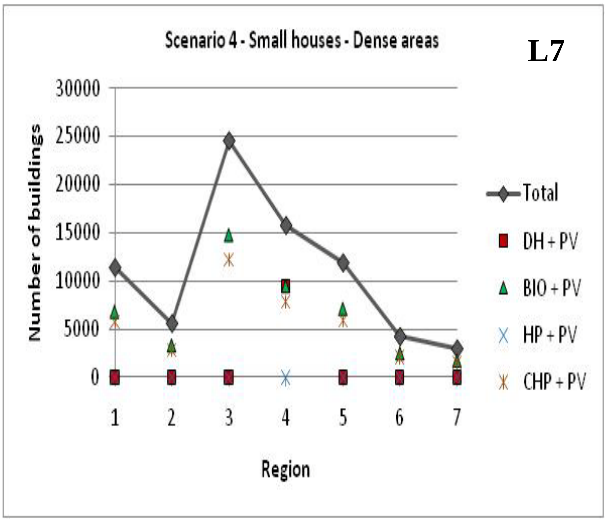
- Available roof/floor-ratio 1:2

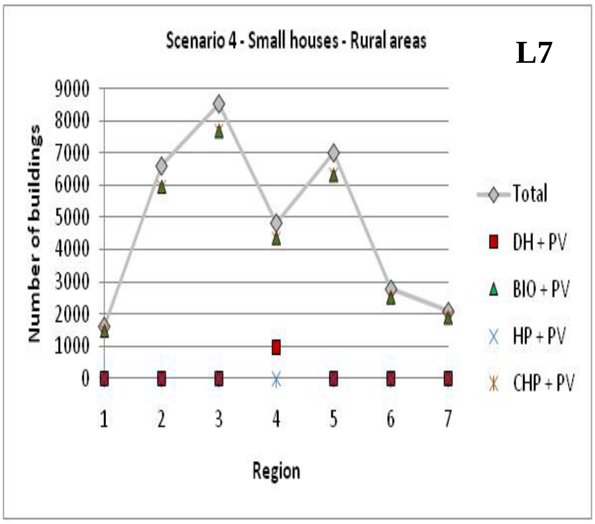




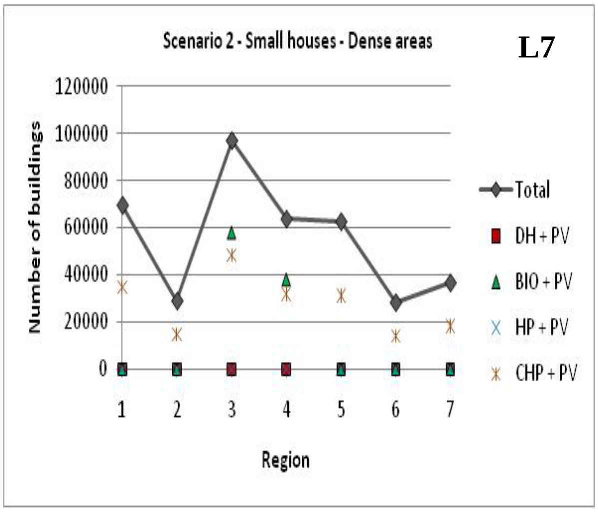


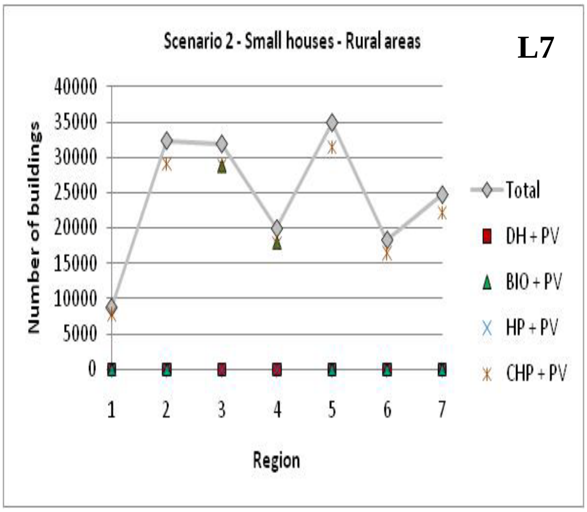


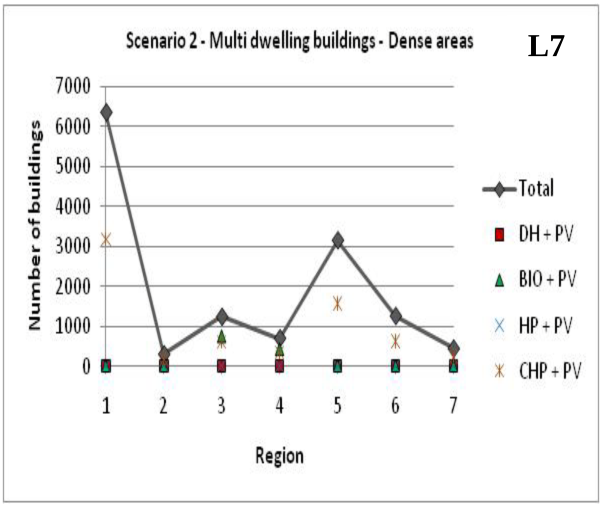


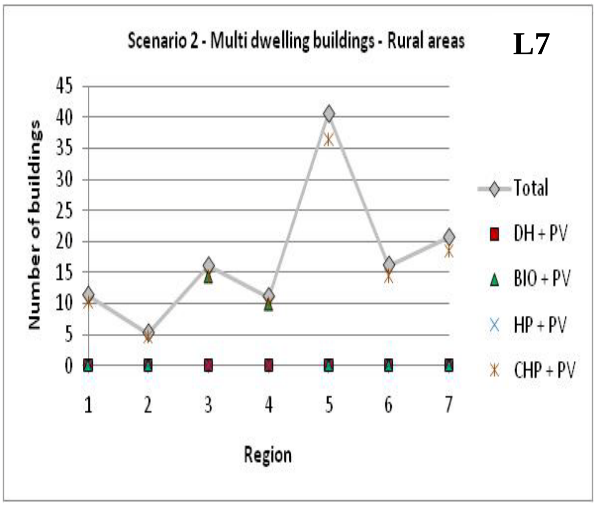


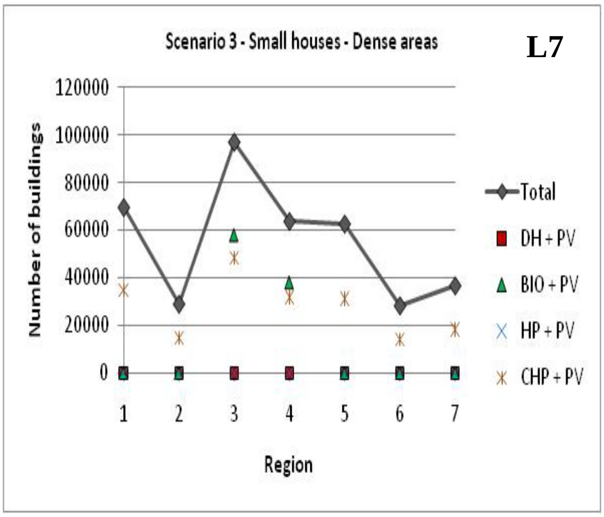
- Available roof/floor-ratio 1:3

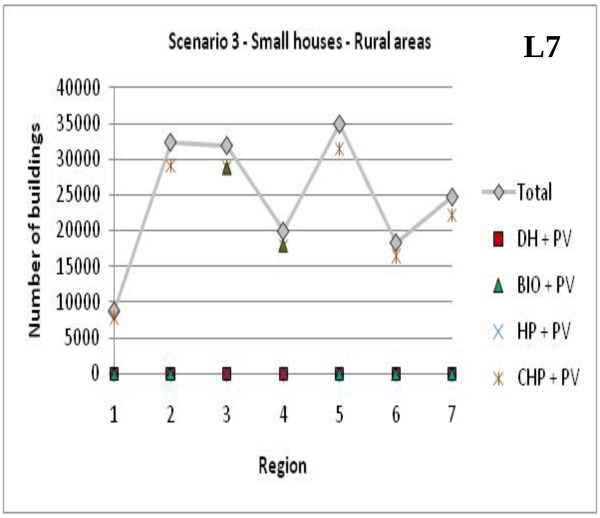


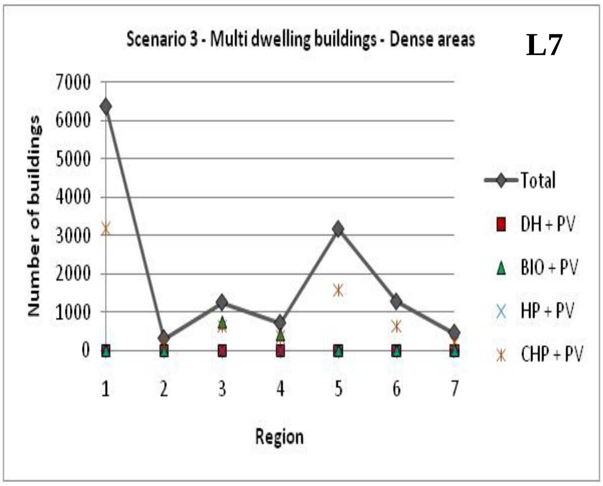


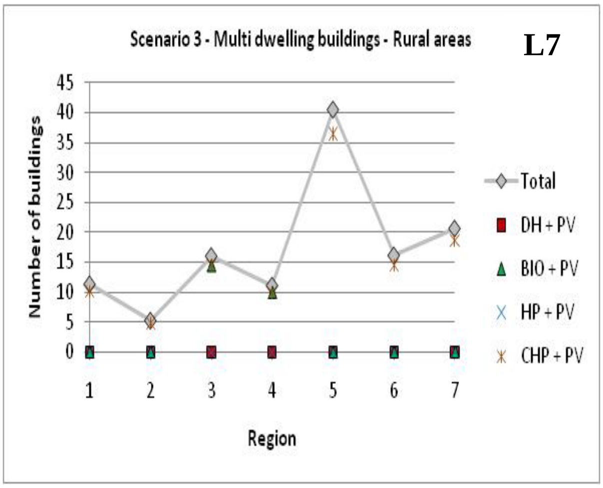


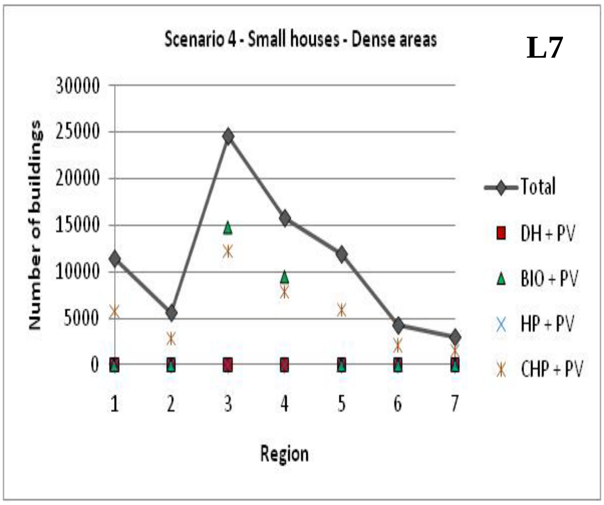


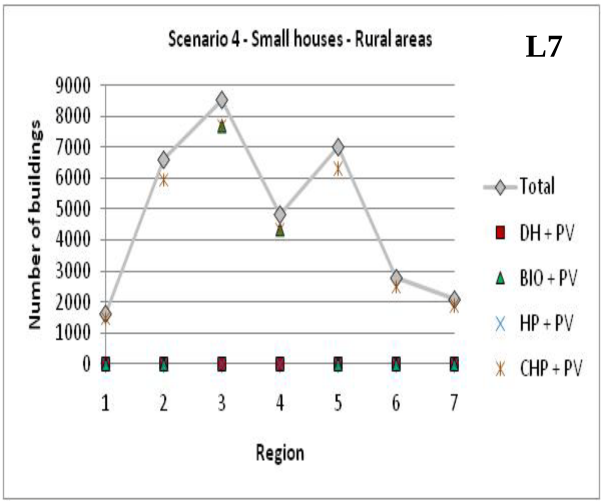

Scenario 3 - Small houses - Dense areas
L7
120000
100000
80000
60000
40000
20000
0
Number of buildings
1
2
3
4
5
6
7
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV

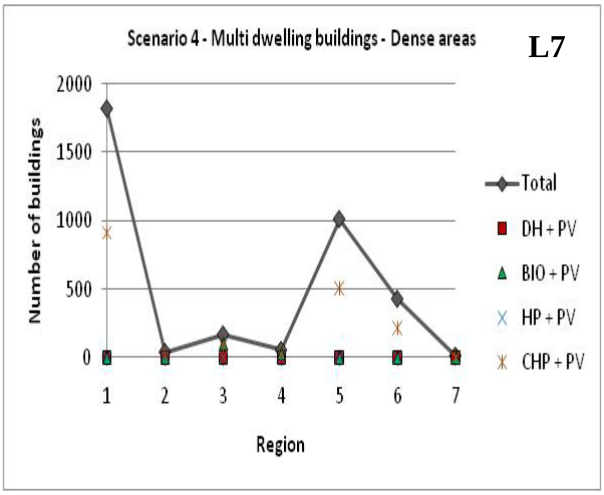

Scenario 3 - Small houses - Rural areas
L7
40000
35000
30000
25000
20000
15000
10000
5000
0
Number of buildings
1
2
3
4
5
6
7
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV

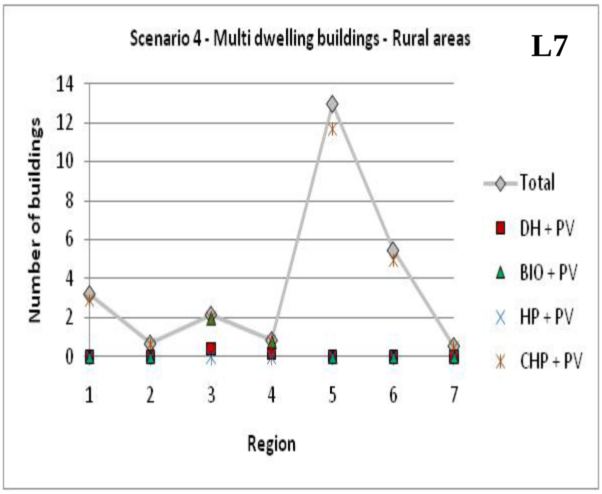

Scenario 3 - Multi dwelling buildings - Dense areas
L7
7000
6000
5000
4000
3000
2000
1000
0
Number of buildings
1
2
3
4
5
6
7
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV


Scenario 3 - Multi dwelling buildings - Rural areas
L7
45
40
35
30
25
20
15
10
5
0
Number of buildings
1
2
3
4
5
6
7
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV

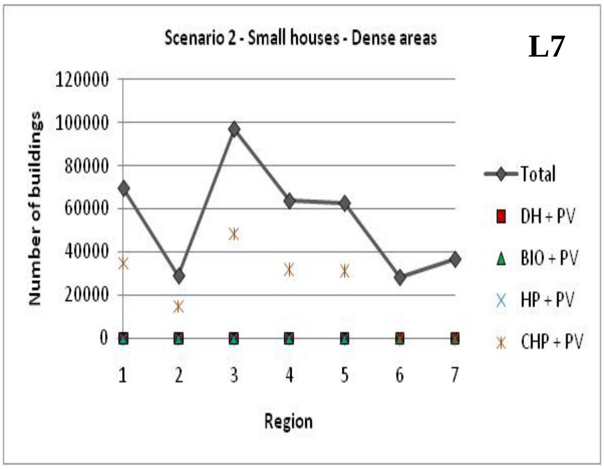

Scenario 4 - Small houses - Dense areas
L7
30000
25000
20000
15000
10000
5000
0
Number of buildings
1
2
3
4
5
6
7
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV

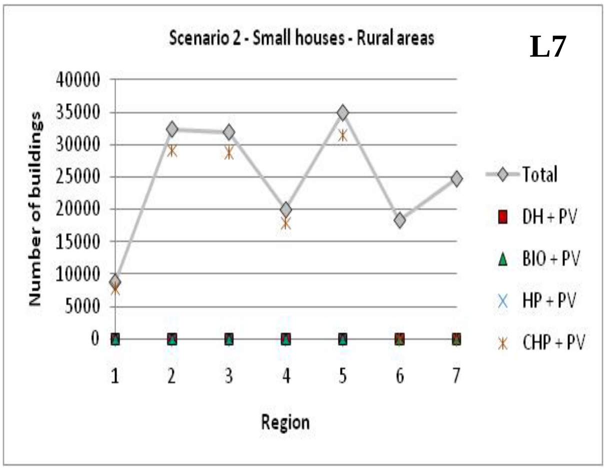

Scenario 4 - Small houses - Rural areas
L7
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Number of buildings
1
2
3
4
5
6
7
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV

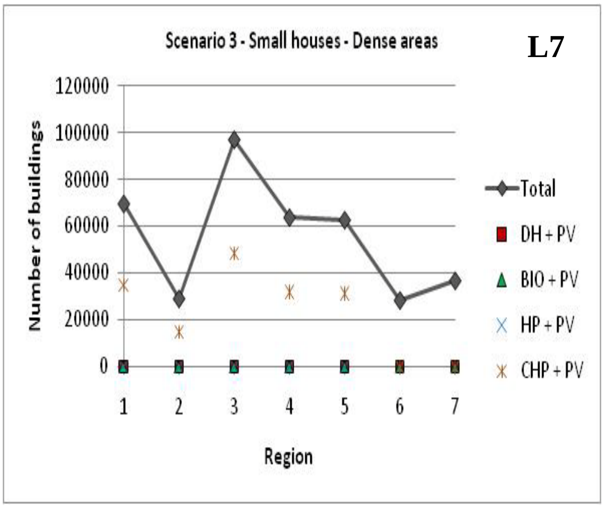


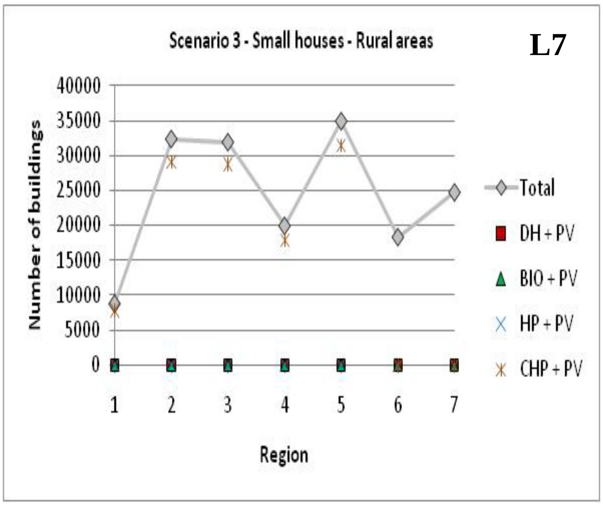


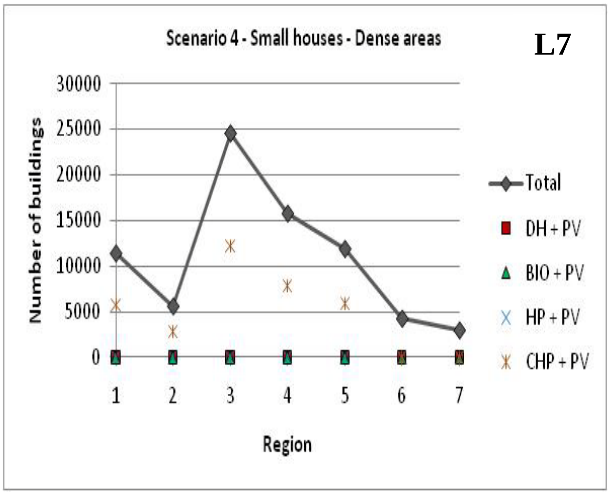
- Available roof/floor-ratio 1:4

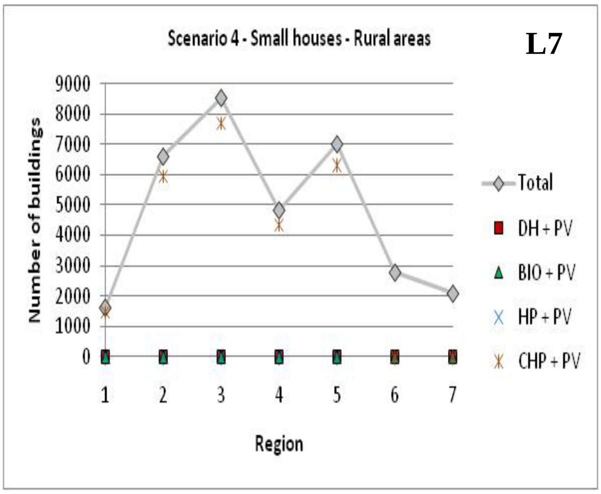




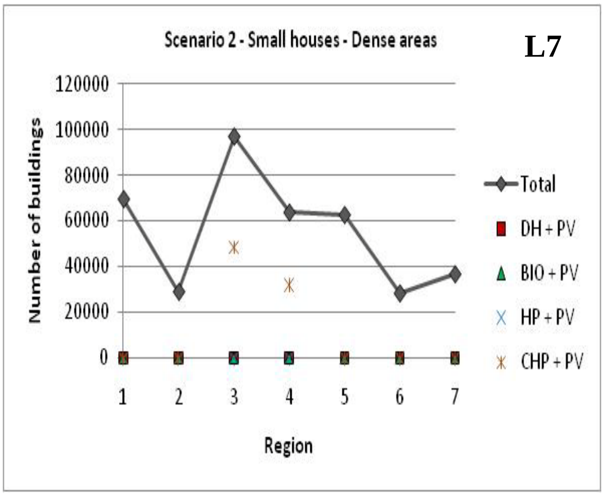


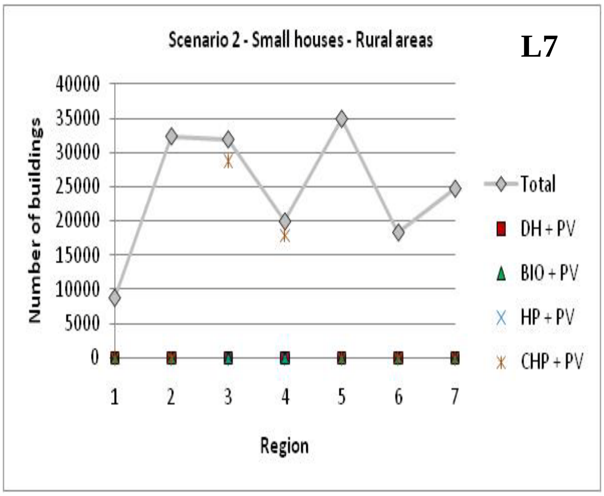


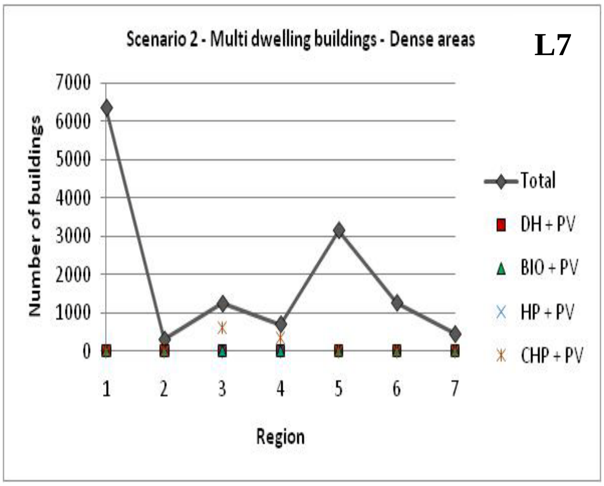


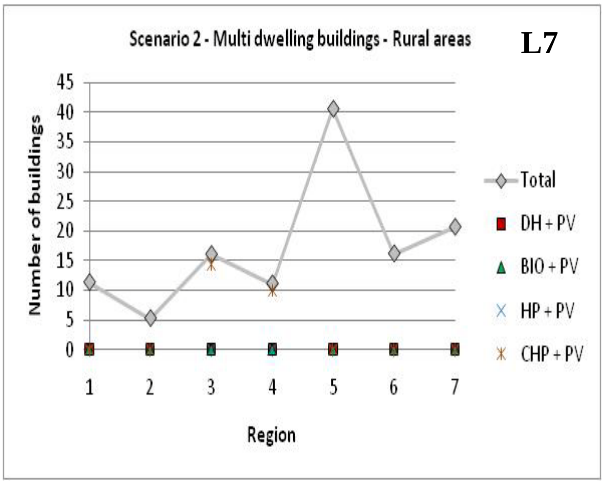


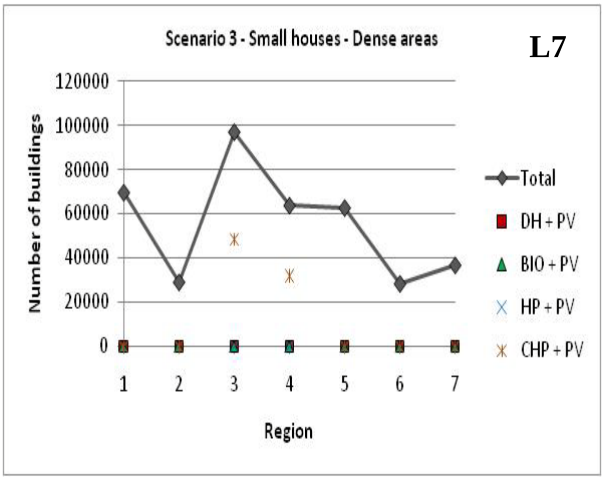
- Available roof/floor-ratio 1:5

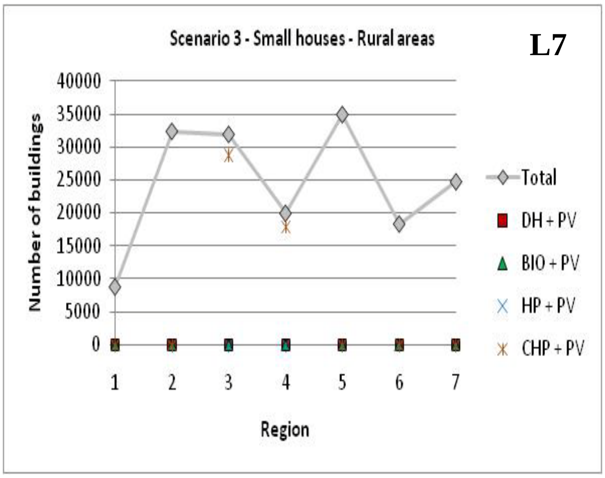


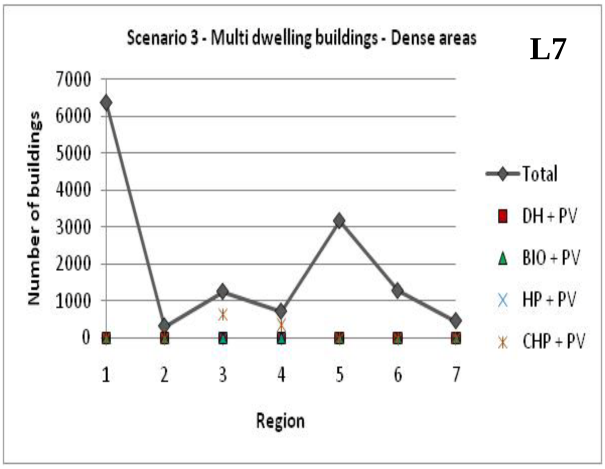


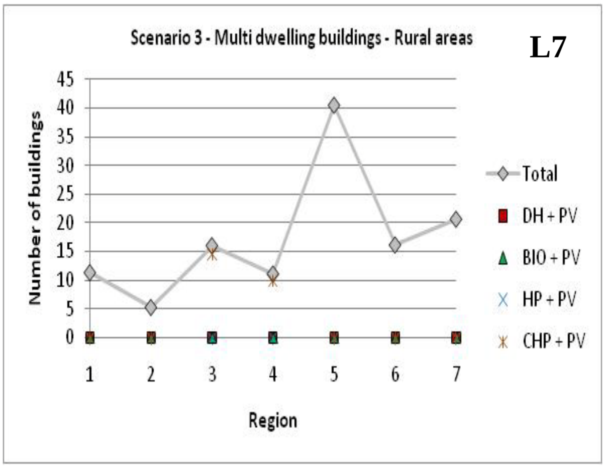


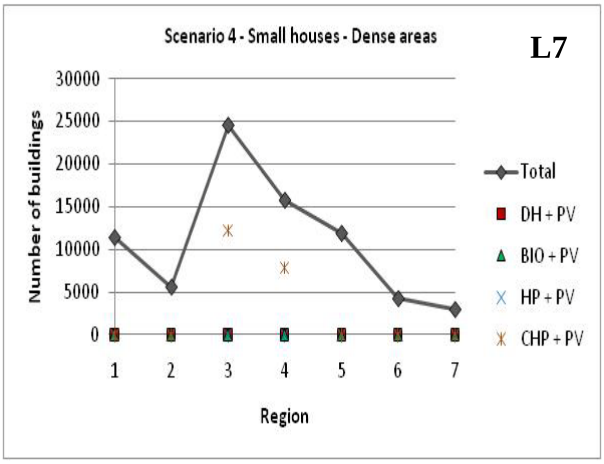


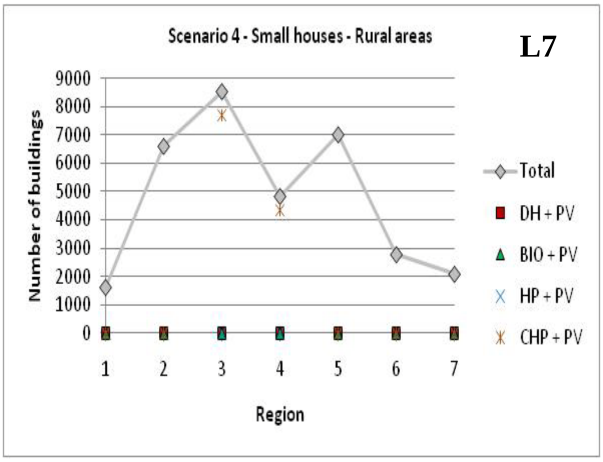

Scenario 3 - Small houses - Dense areas
L7
Number of buildings
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV

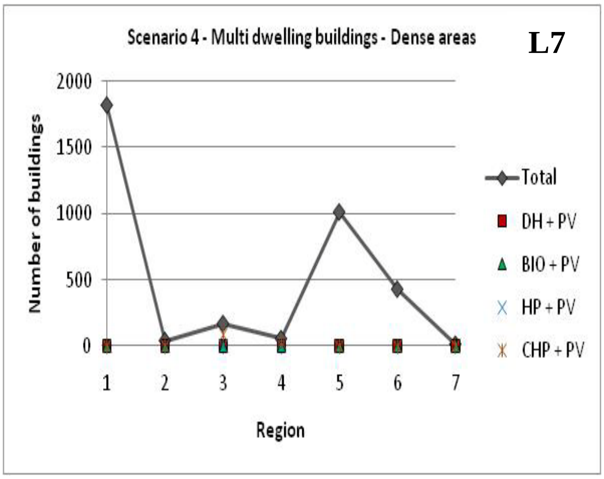

Scenario 3 - Small houses - Rural areas
L7
Number of buildings
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV

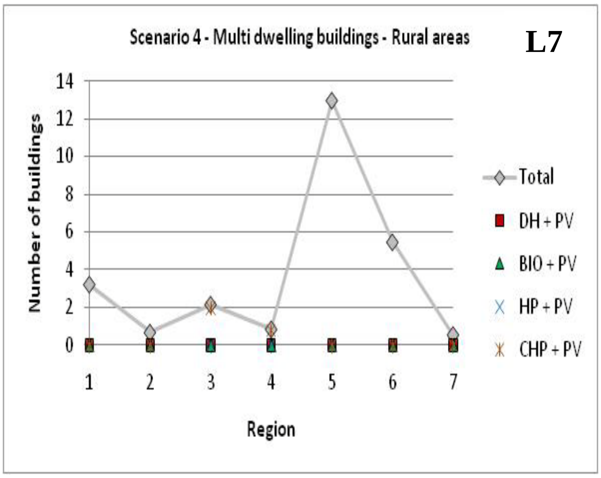

Scenario 3 - Multi dwelling buildings - Dense areas
L7
Number of buildings
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV


Scenario 3 - Multi dwelling buildings - Rural areas
L7
Number of buildings
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV

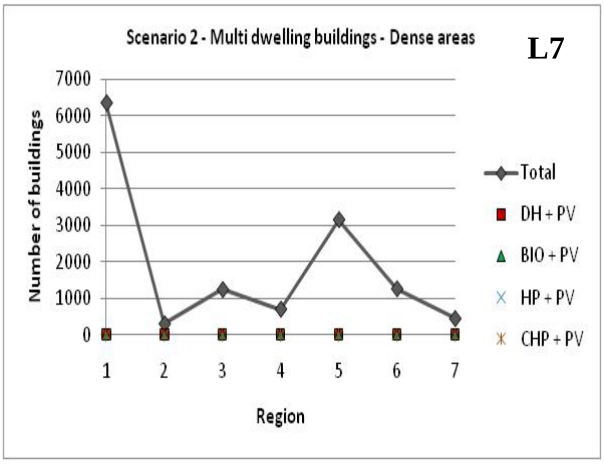

Scenario 4 - Small houses - Dense areas
L7
Number of buildings
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV

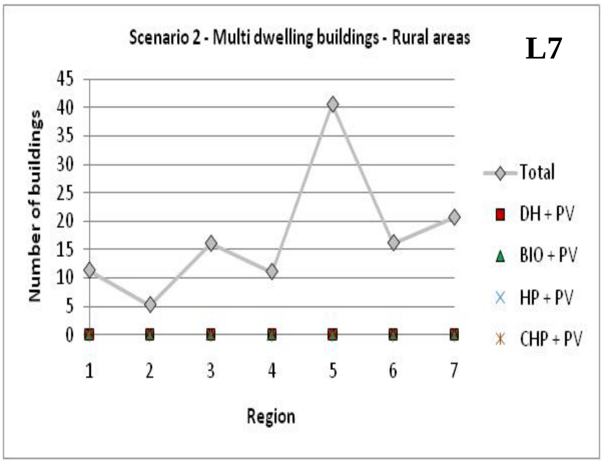

Scenario 4 - Small houses - Rural areas
L7
Number of buildings
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV

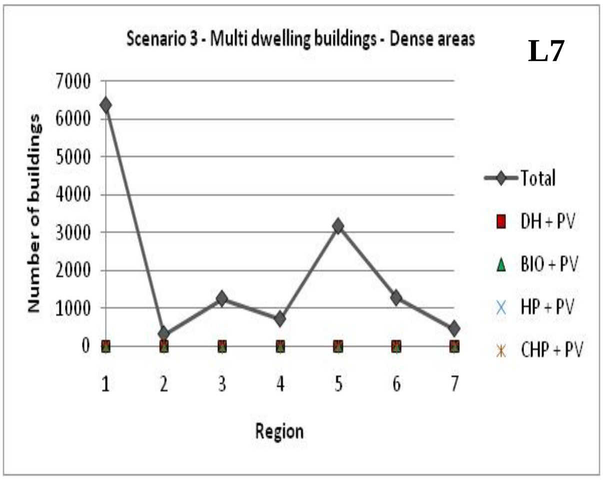


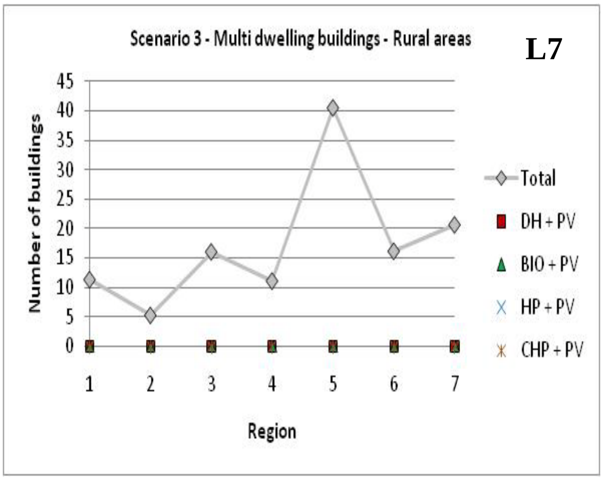


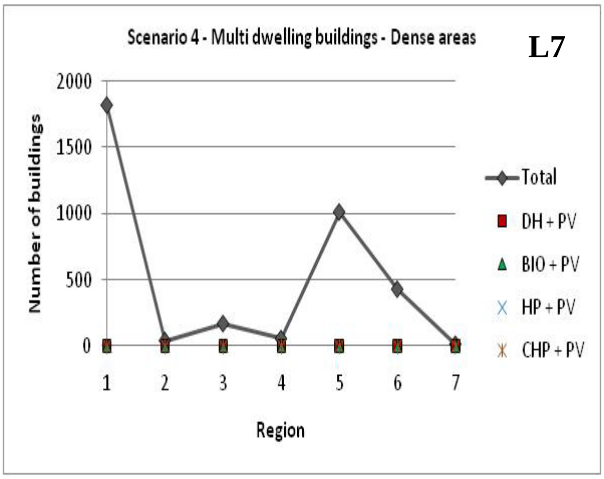
- Available roof/floor-ratio 1:7

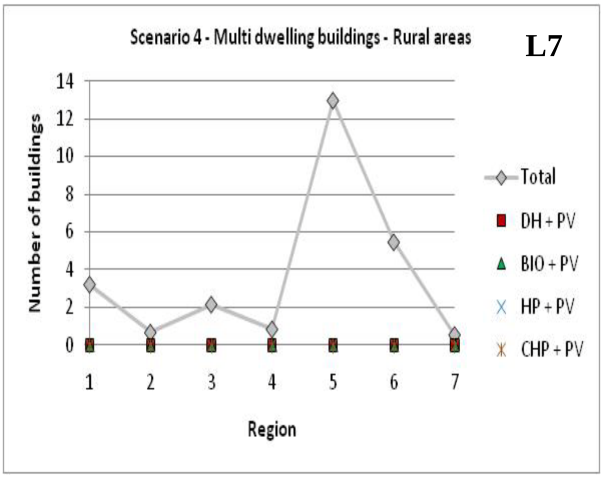




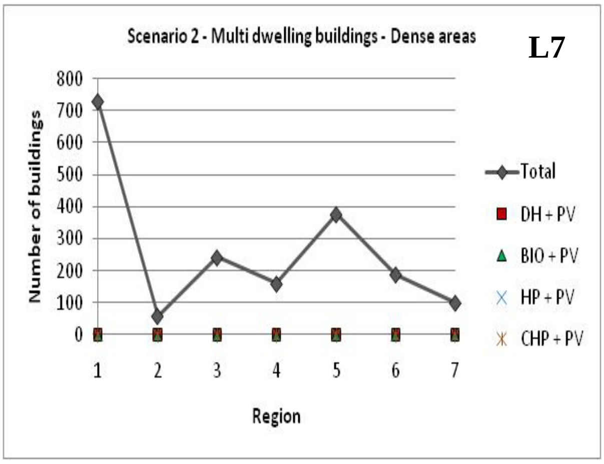


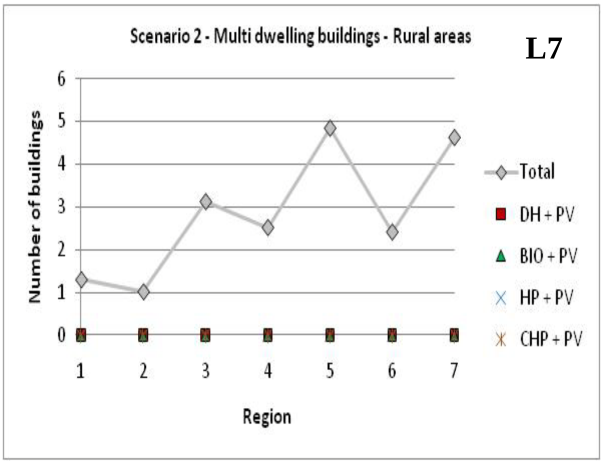


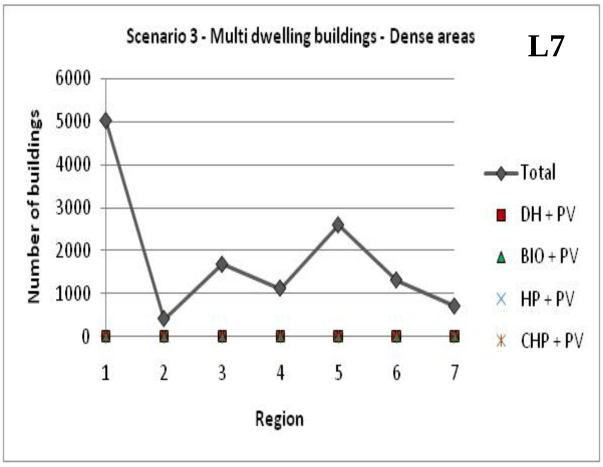


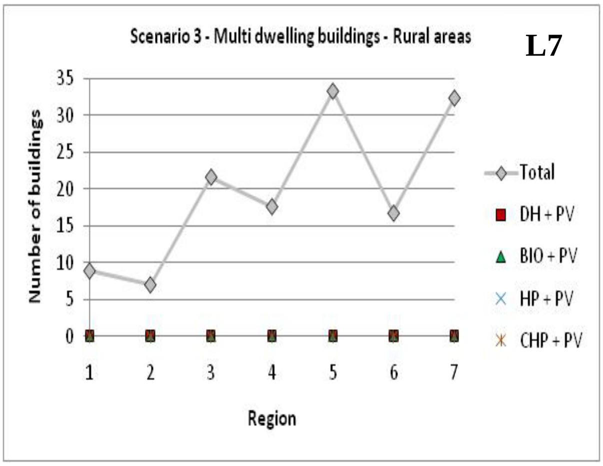


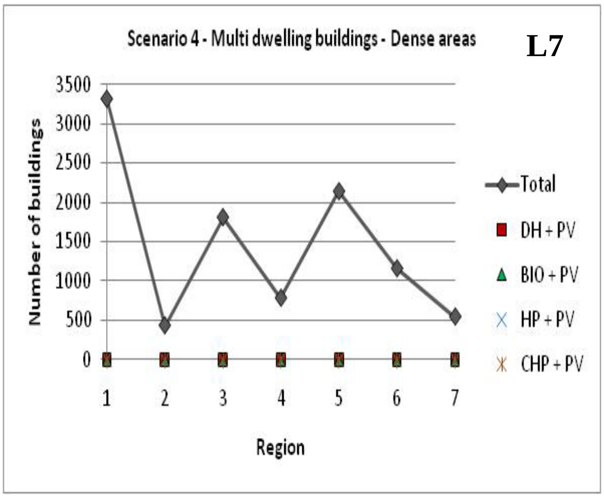
- Available roof/floor-ratio 1:10

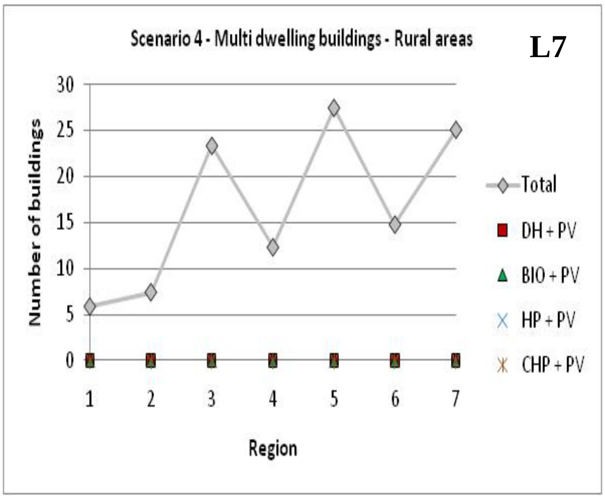






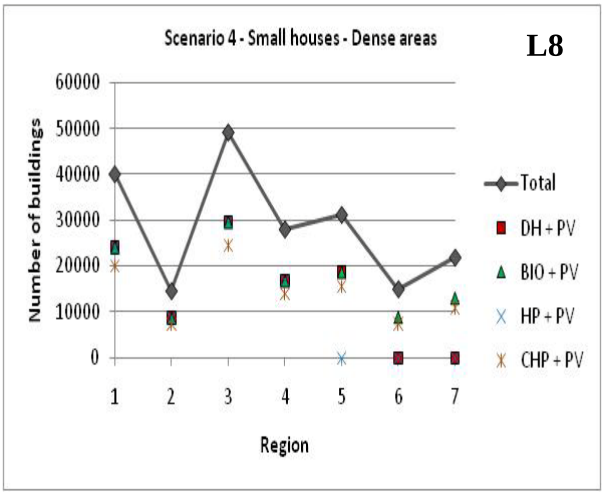


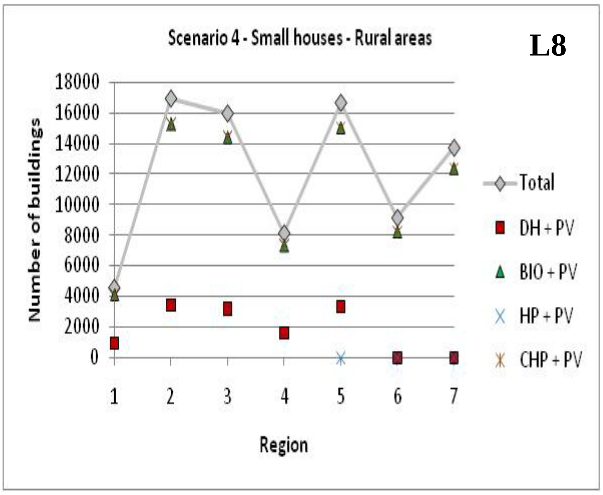




B.1.2 Energy level 8

- Available roof/floor-ratio 1:2





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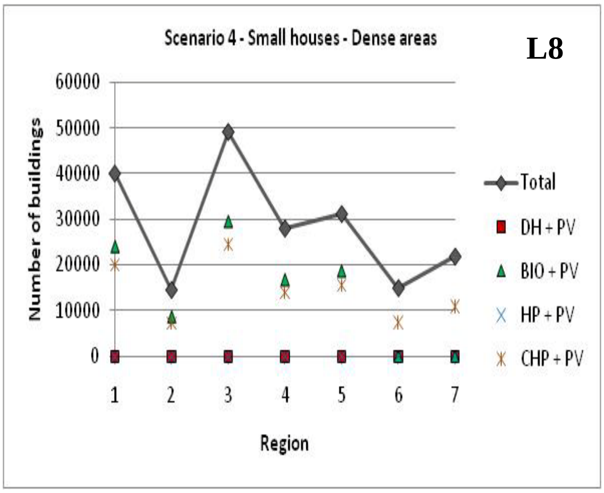
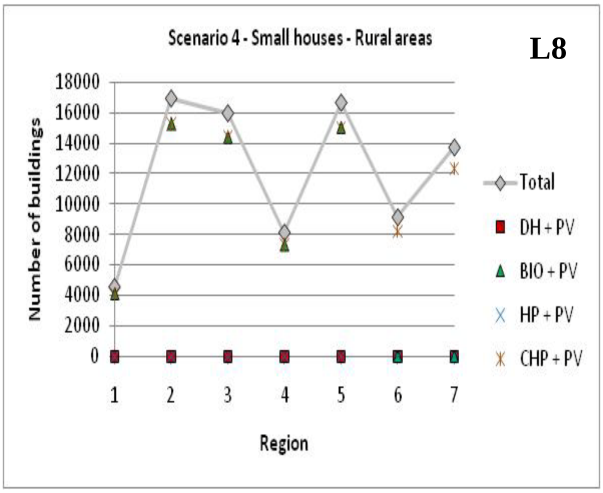
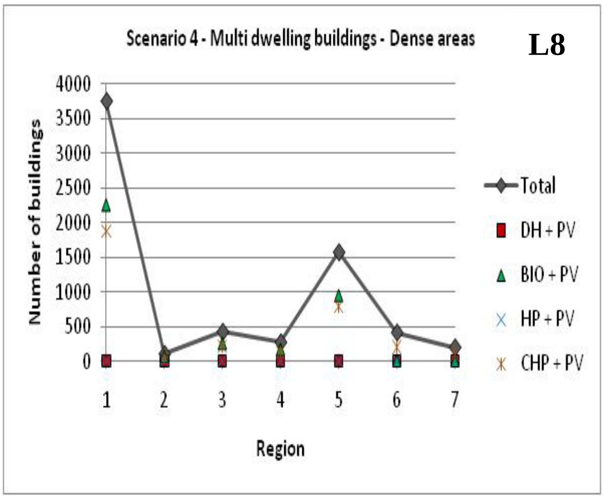
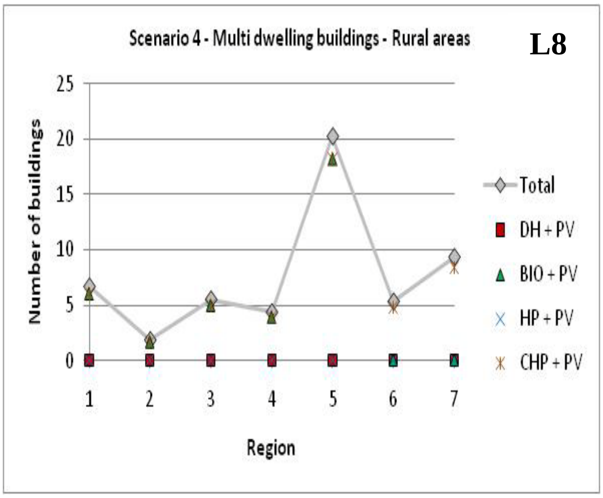
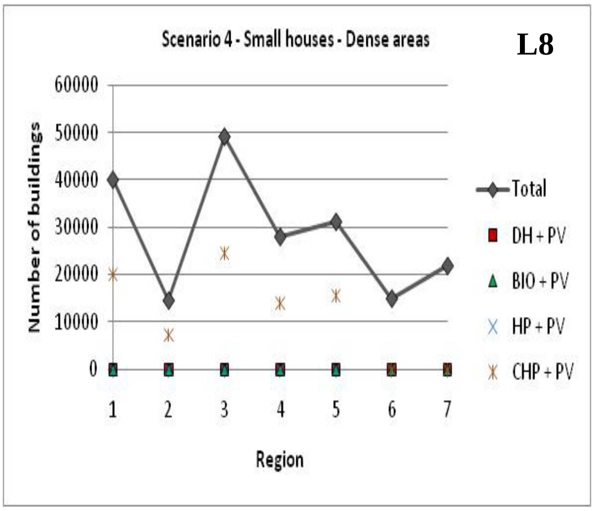


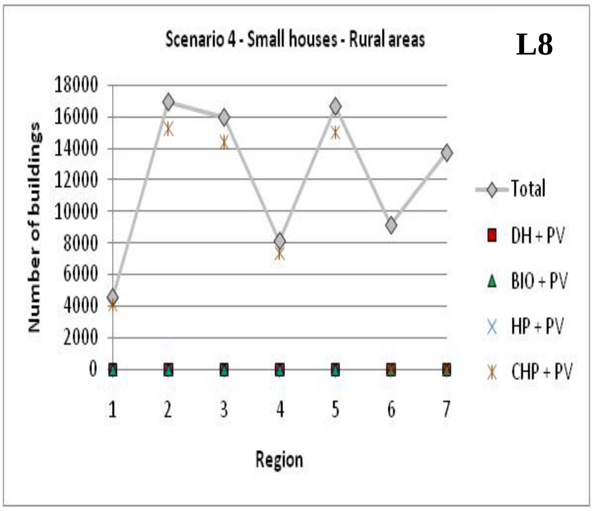




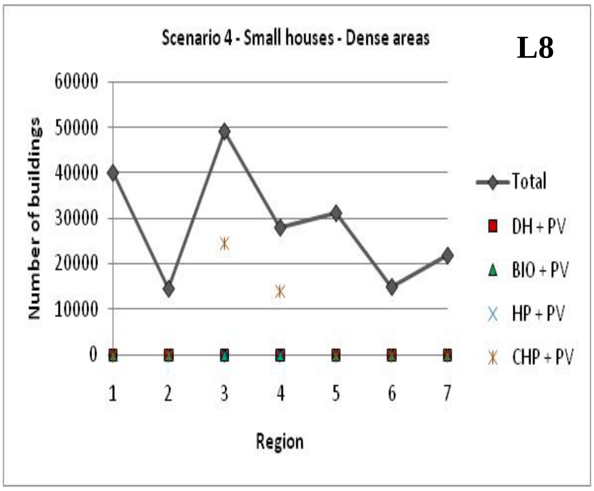


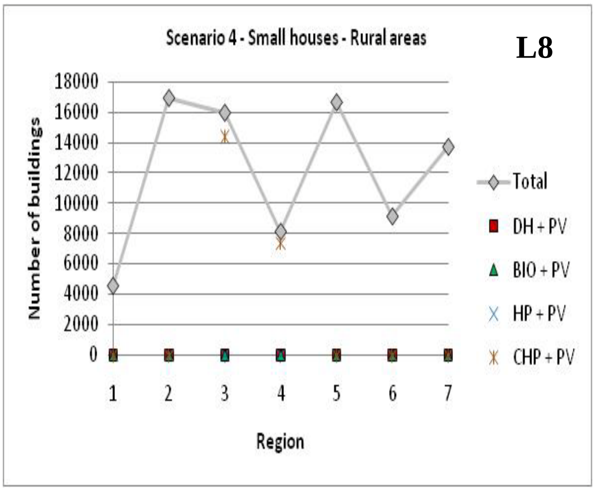
- Available roof/floor-ratio 1:4

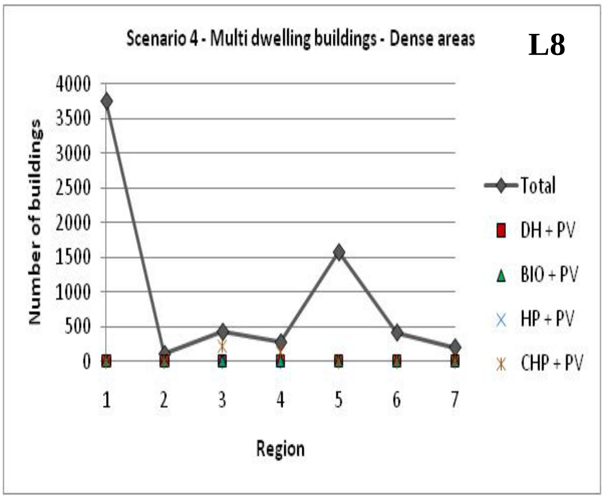


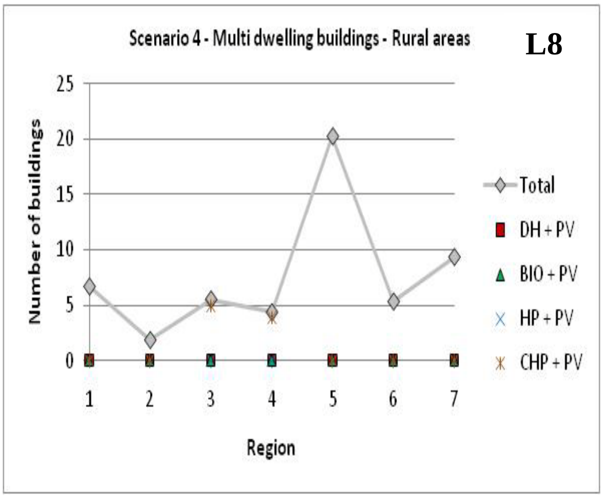


- Available roof/floor-ratio 1:5

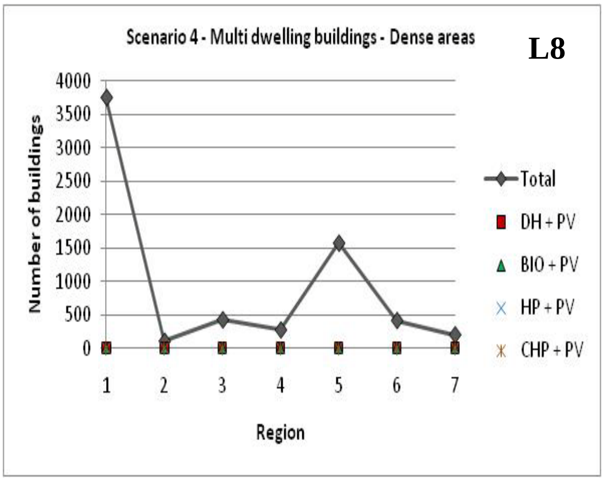


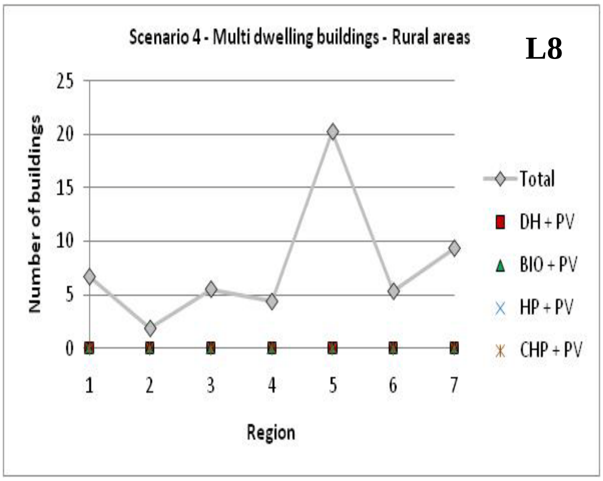




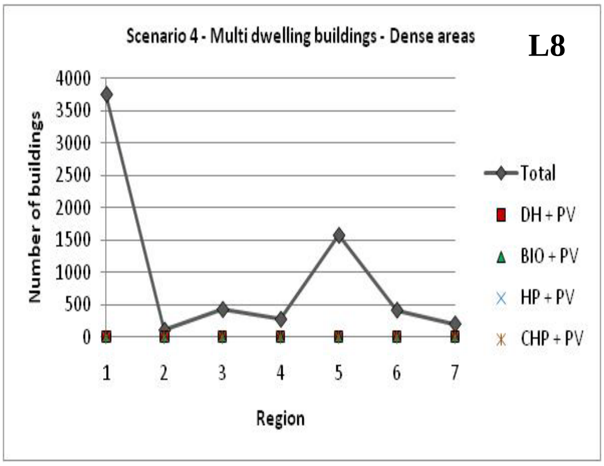


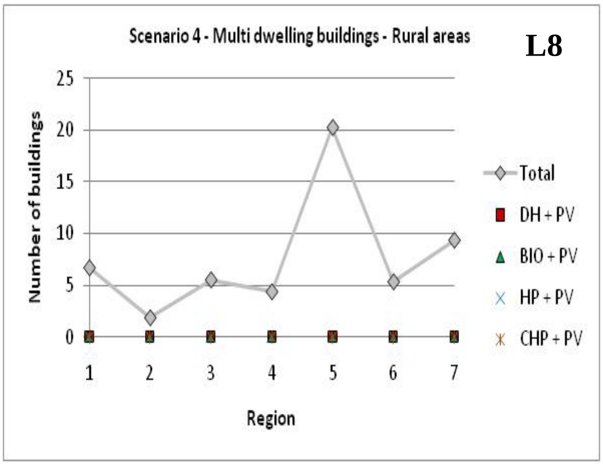
- Available roof/floor-ratio 1:7





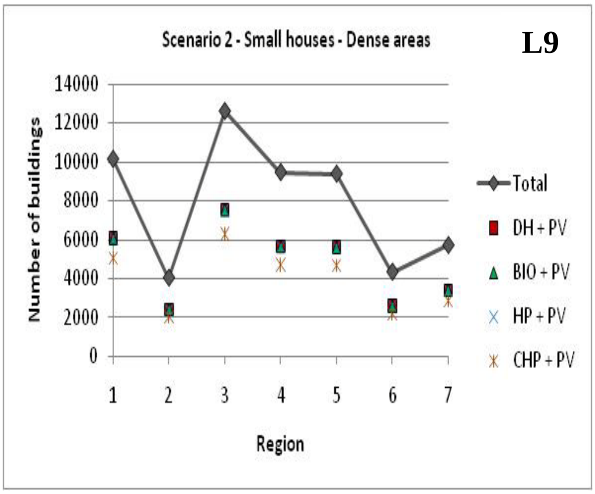
- Available roof/floor-ratio 1:10

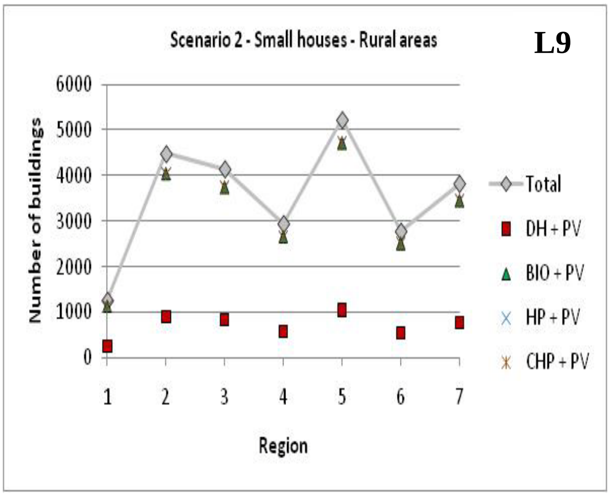


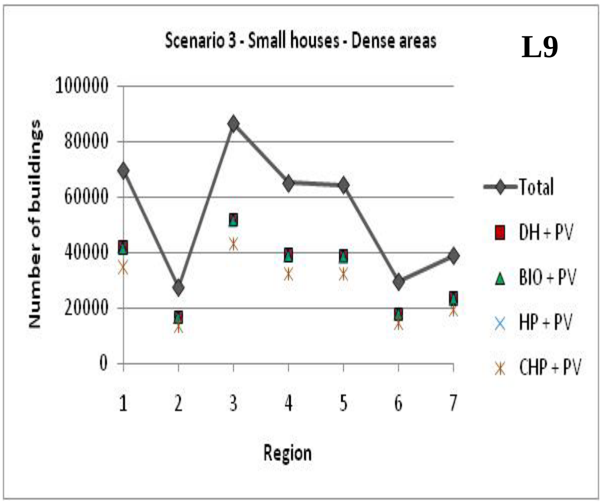


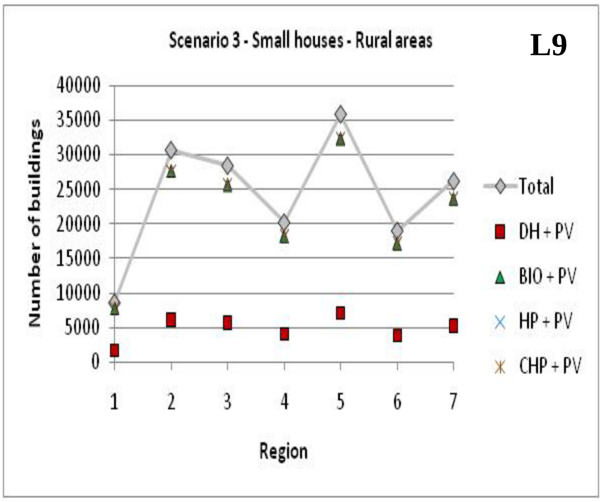
B.1.3 Energy level 9

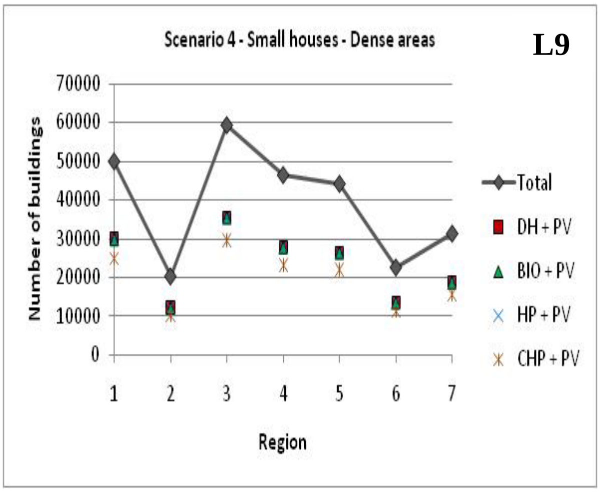
- Available roof/floor-ratio 1:2

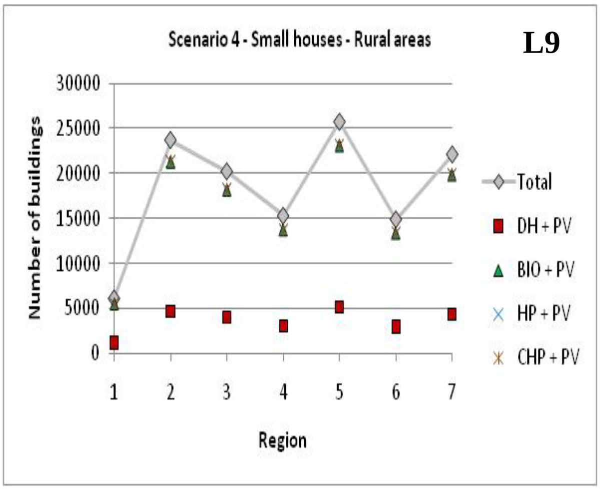




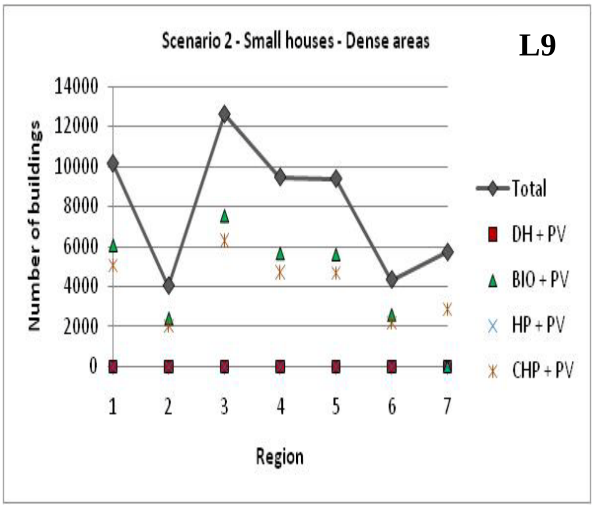


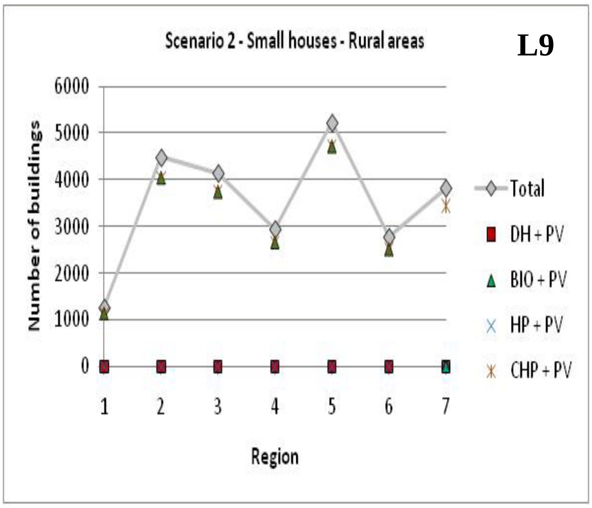


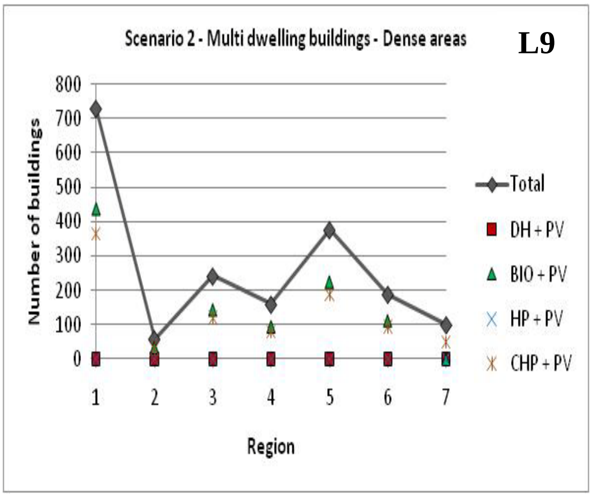


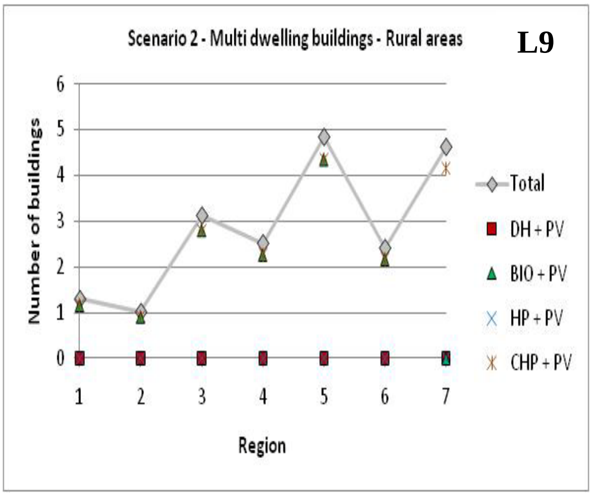


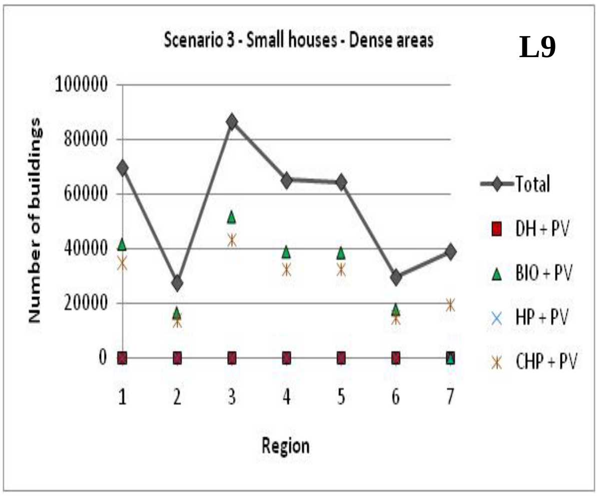
- Available roof/floor-ratio 1:3

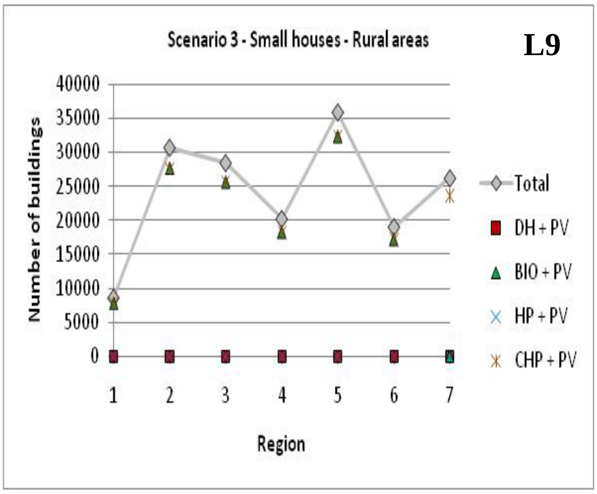


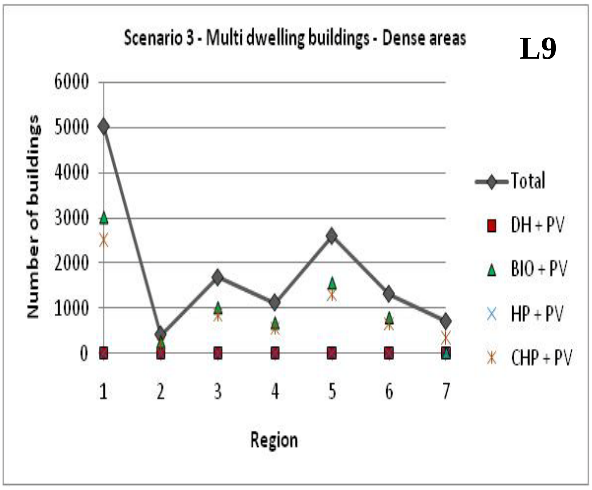


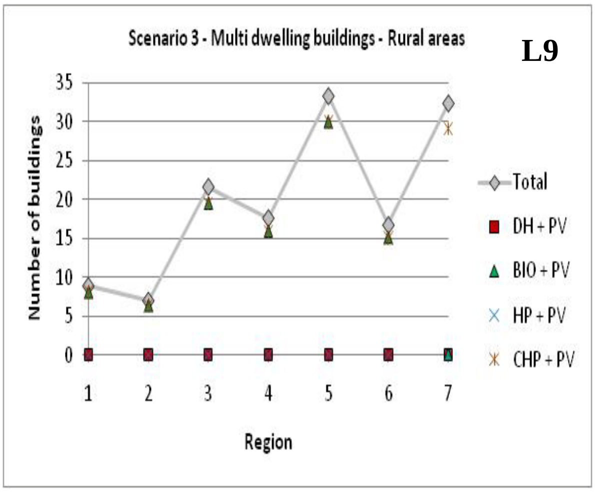


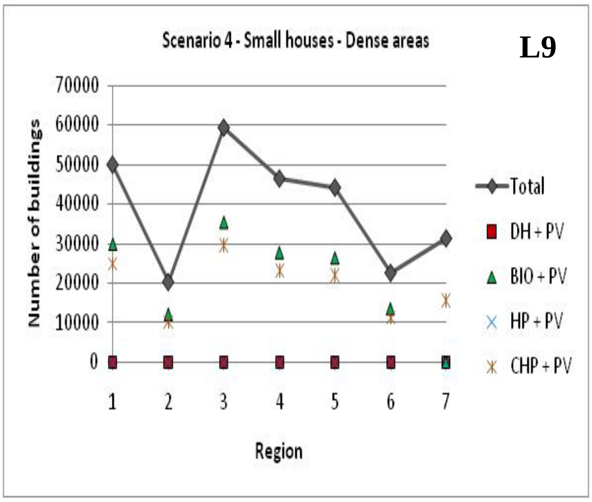


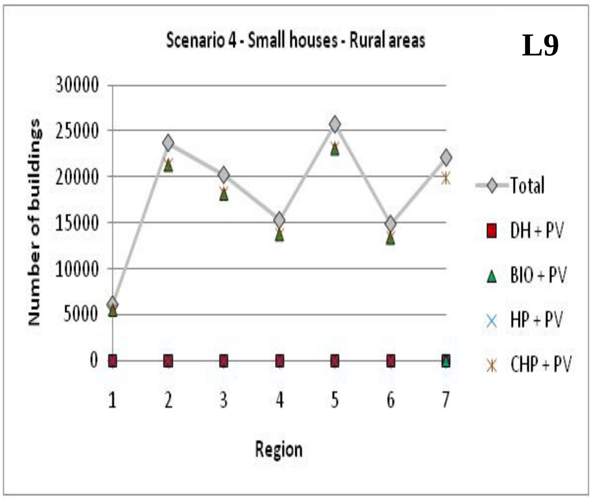


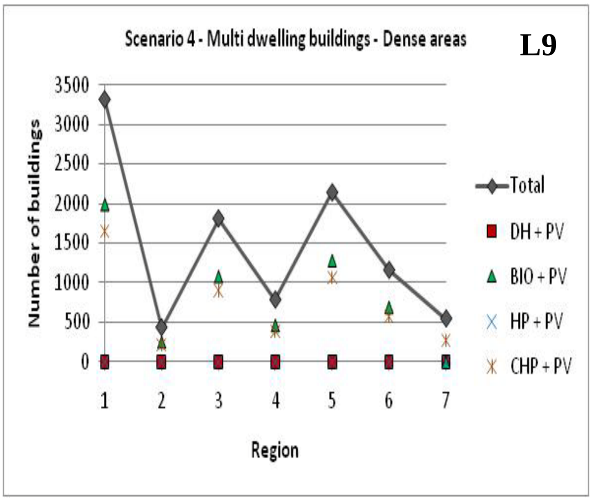


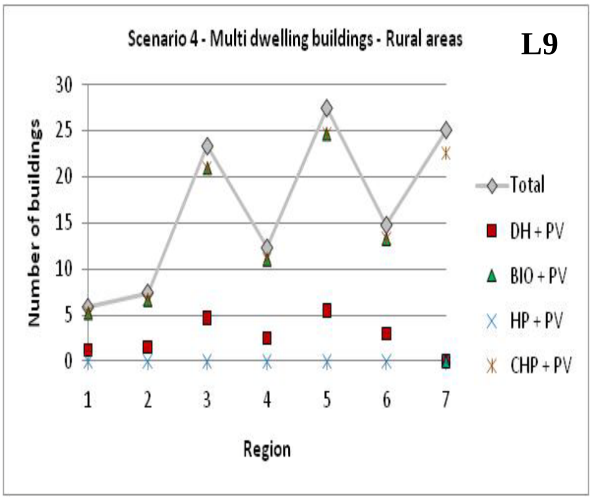

Scenario 3 - Multi dwelling buildings - Dense areas
L9
Number of buildings
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV


Scenario 3 - Multi dwelling buildings - Rural areas
L9
Number of buildings
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV

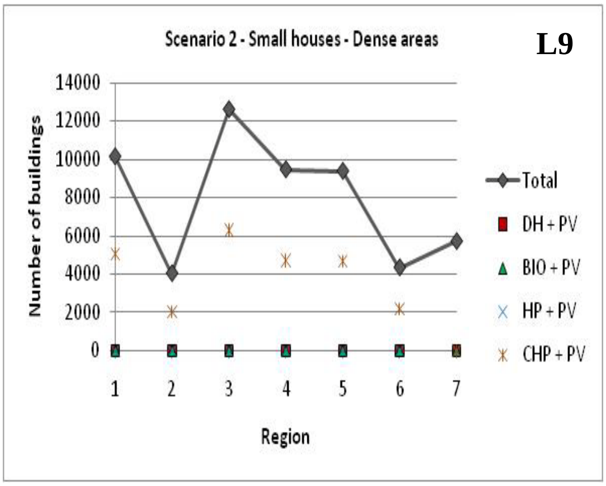

Scenario 4 - Small houses - Dense areas
L9
Number of buildings
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV

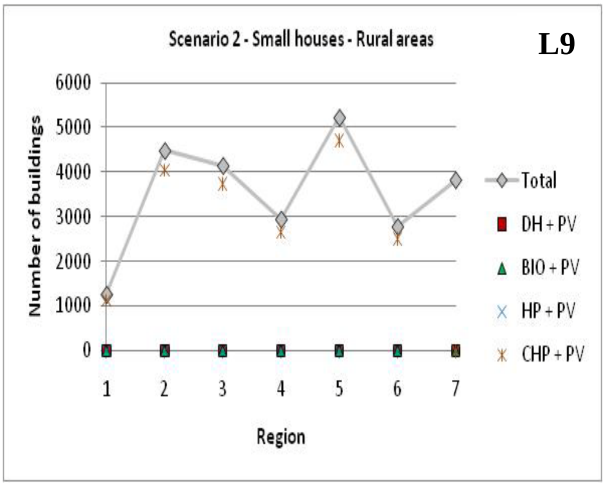

Scenario 4 - Small houses - Rural areas
L9
Number of buildings
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV

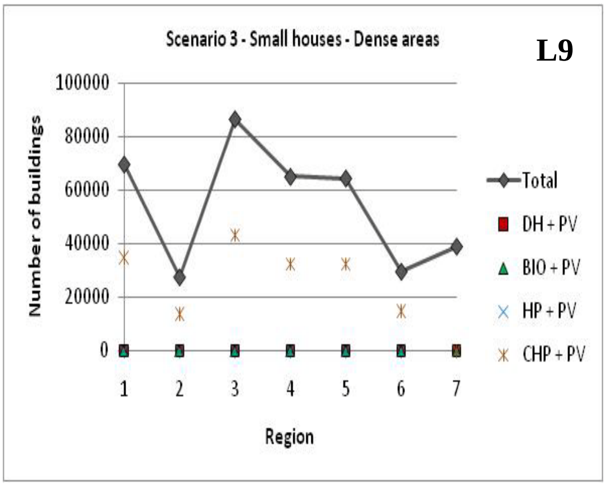

Scenario 4 - Multi dwelling buildings - Dense areas
L9
Number of buildings
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV

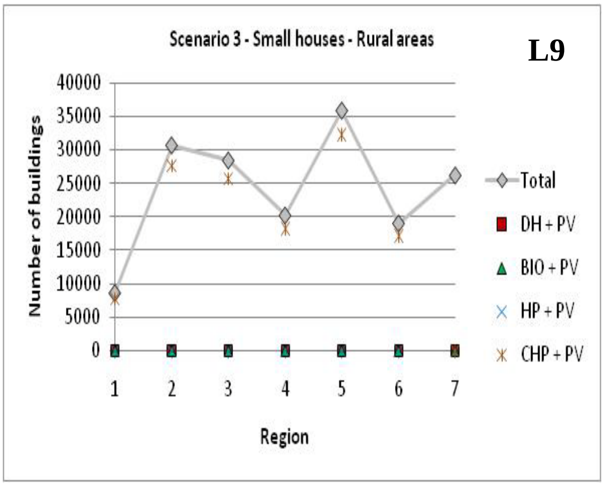

Scenario 4 - Multi dwelling buildings - Rural areas
L9
Number of buildings
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV

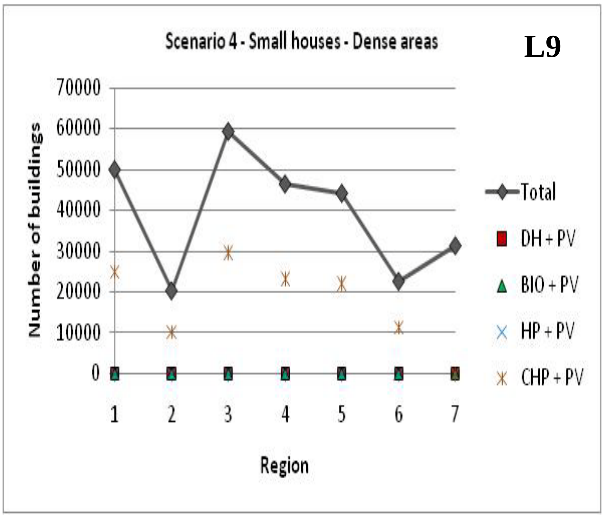
- Available roof/floor-ratio 1:4

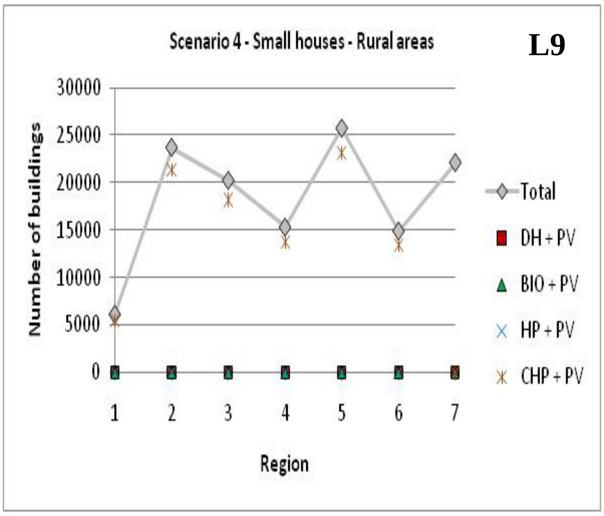












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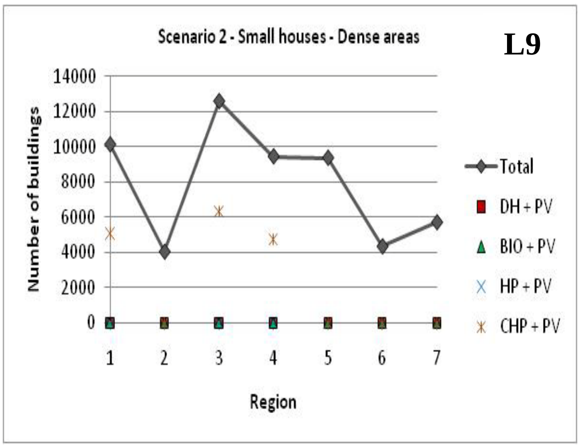
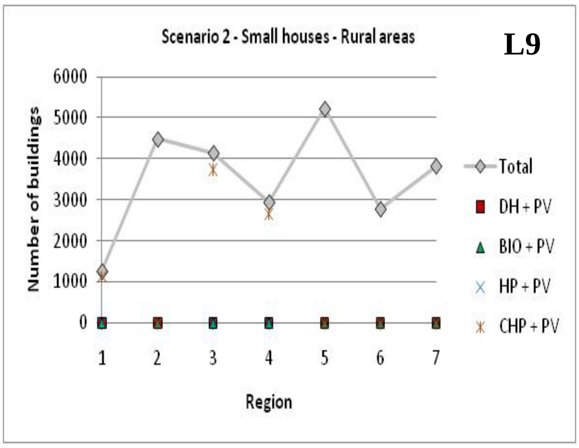
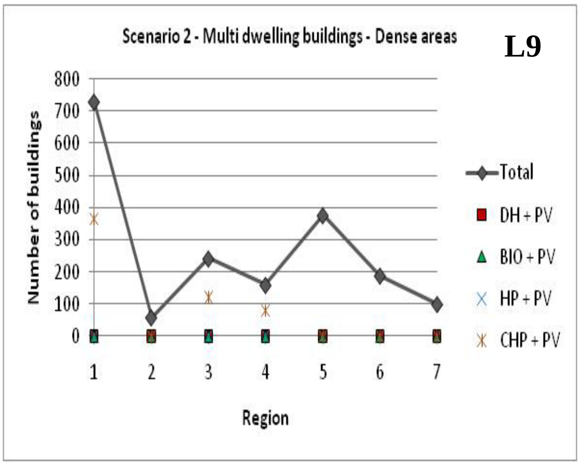
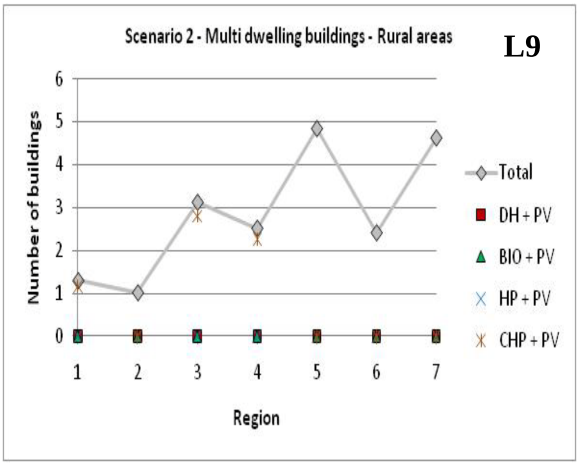
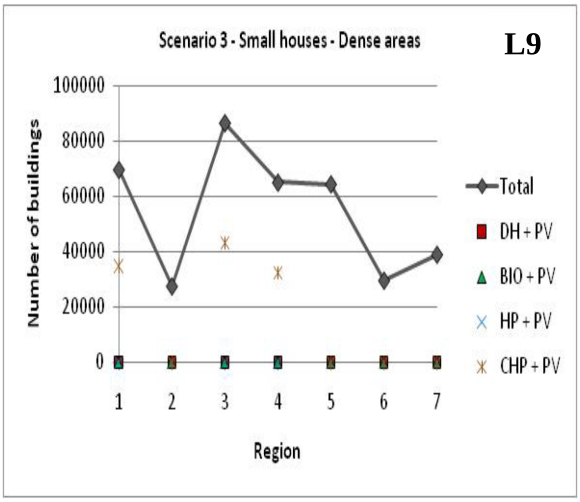
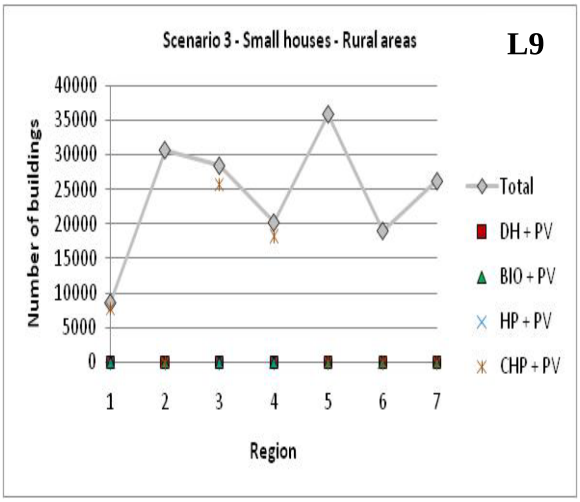


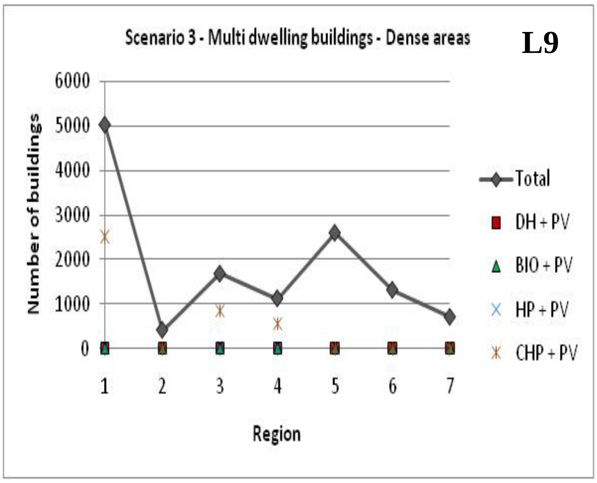


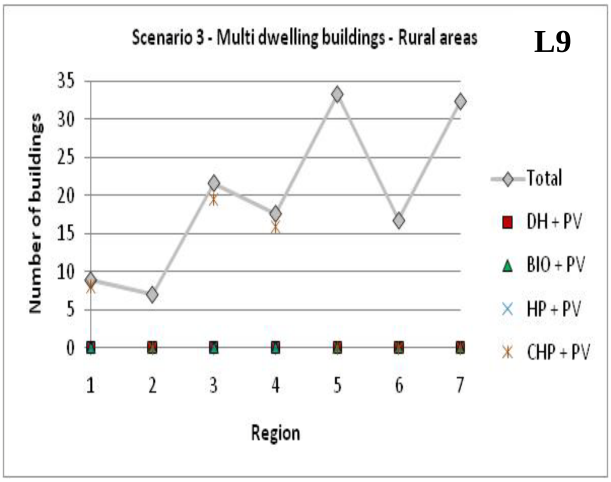


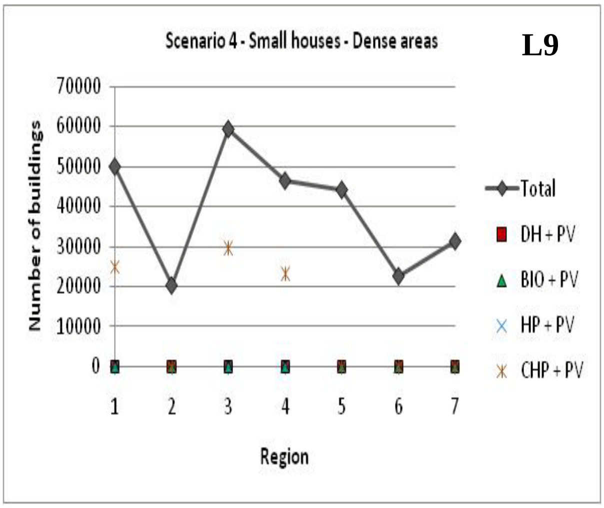


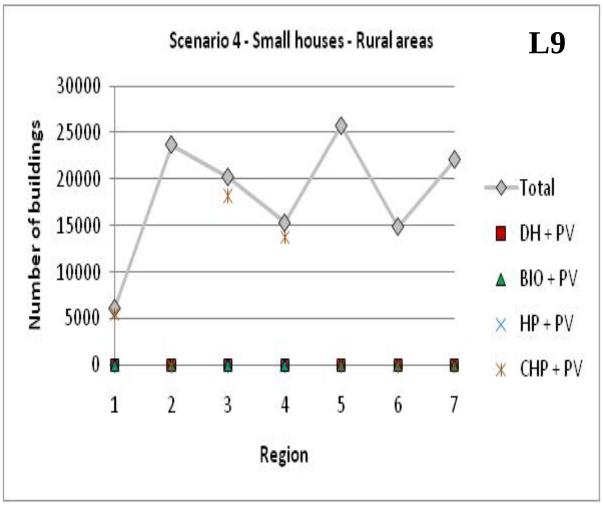


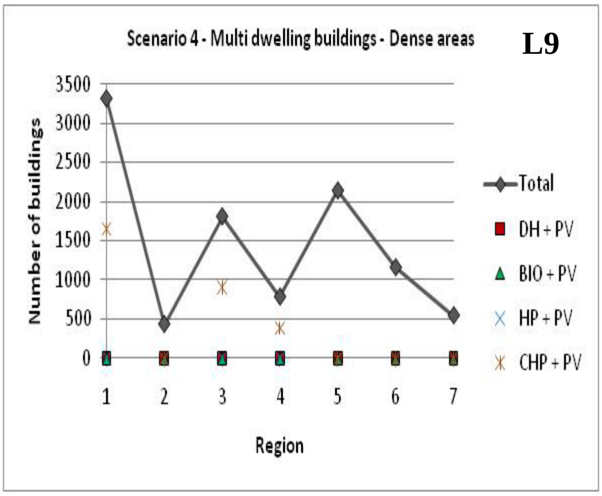


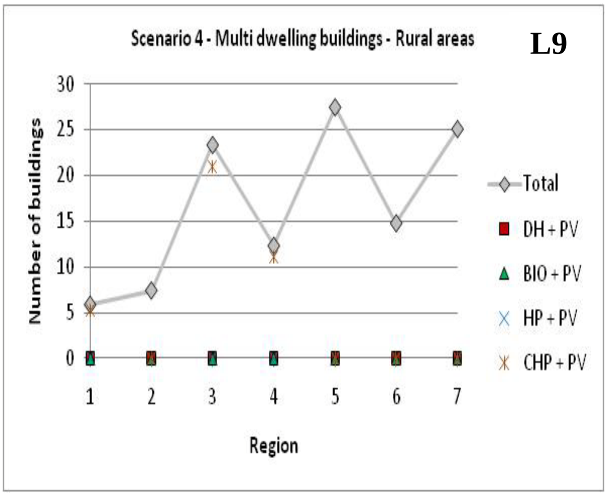

Scenario 3 - Multi dwelling buildings - Dense areas
L9
6000
5000
4000
3000
2000
1000
0
Number of buildings
1
2
3
4
5
6
7
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV


Scenario 3 - Multi dwelling buildings - Rural areas
L9
35
30
25
20
15
10
5
0
Number of buildings
1
2
3
4
5
6
7
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV

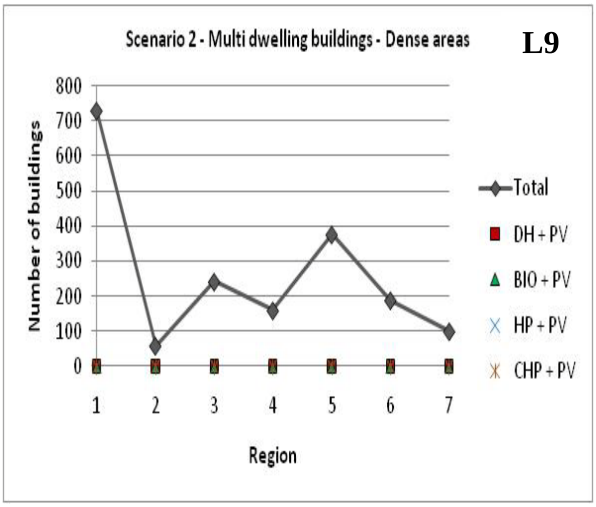

Scenario 4 - Small houses - Dense areas
L9
70000
60000
50000
40000
30000
20000
10000
0
Number of buildings
1
2
3
4
5
6
7
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV

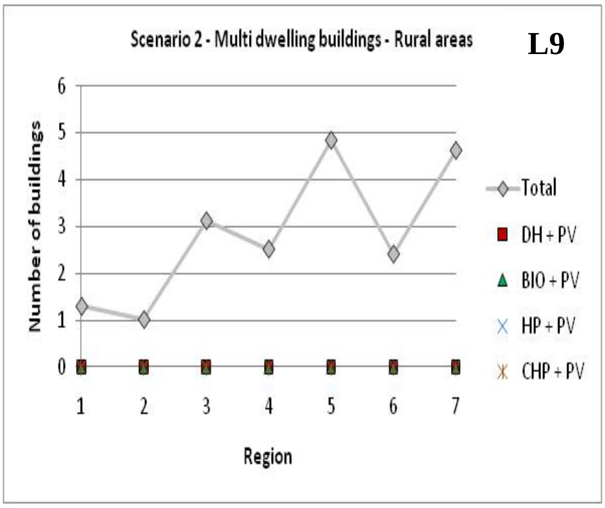

Scenario 4 - Small houses - Rural areas
L9
30000
25000
20000
15000
10000
5000
0
Number of buildings
1
2
3
4
5
6
7
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV

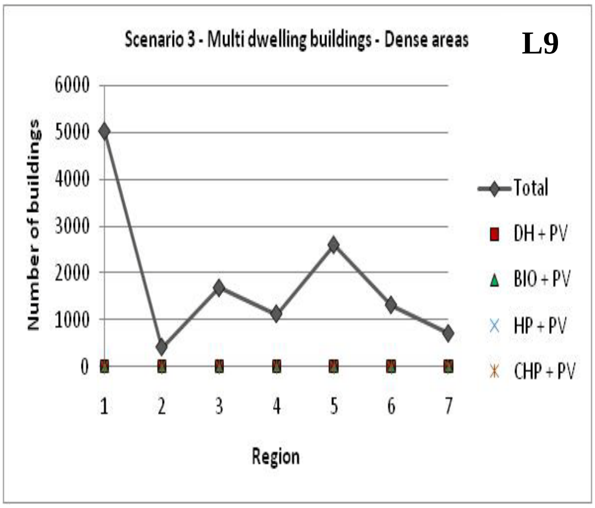

Scenario 4 - Multi dwelling buildings - Dense areas
L9
3500
3000
2500
2000
1500
1000
500
0
Number of buildings
1
2
3
4
5
6
7
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV

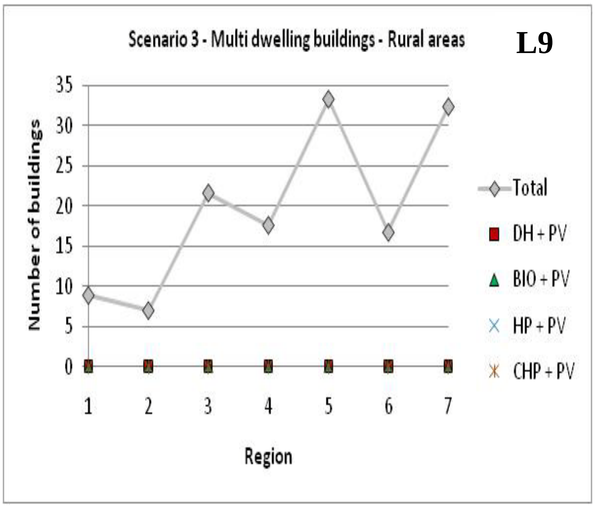

Scenario 4 - Multi dwelling buildings - Rural areas
L9
30
25
20
15
10
5
0
Number of buildings
1
2
3
4
5
6
7
Region
Total
DH + PV
BIO + PV
HP + PV
CHP + PV

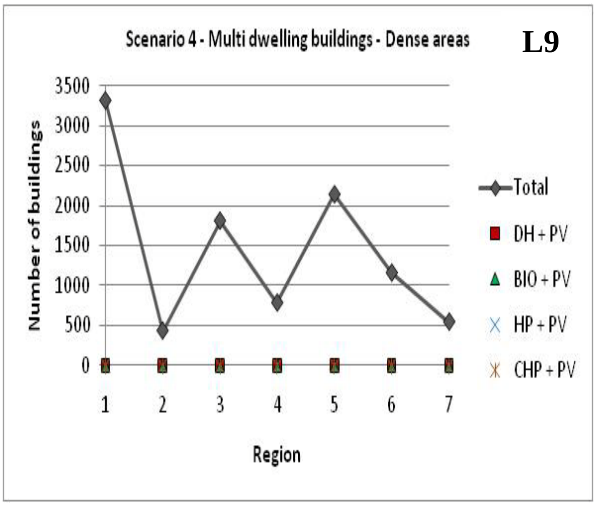
- Available roof/floor-ratio 1:7

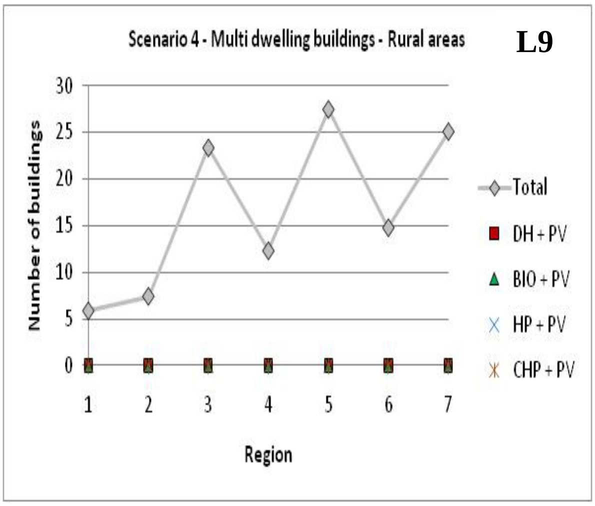




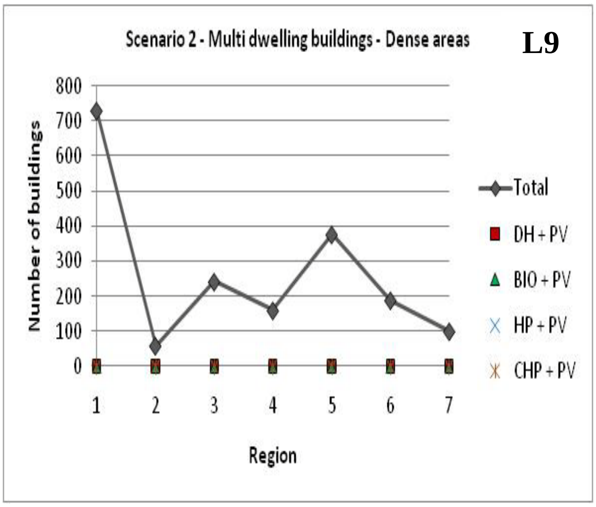


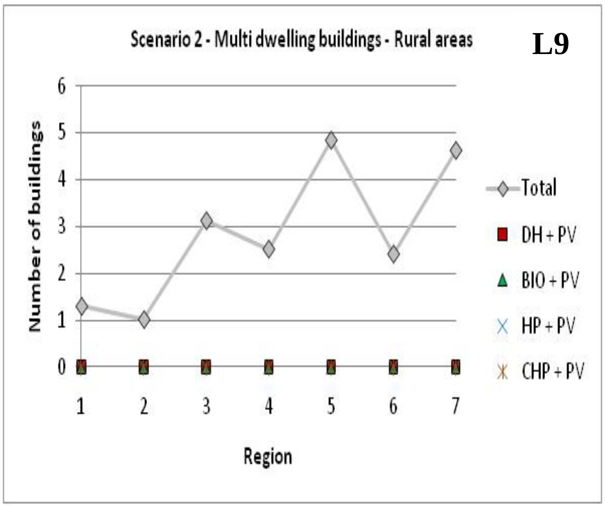


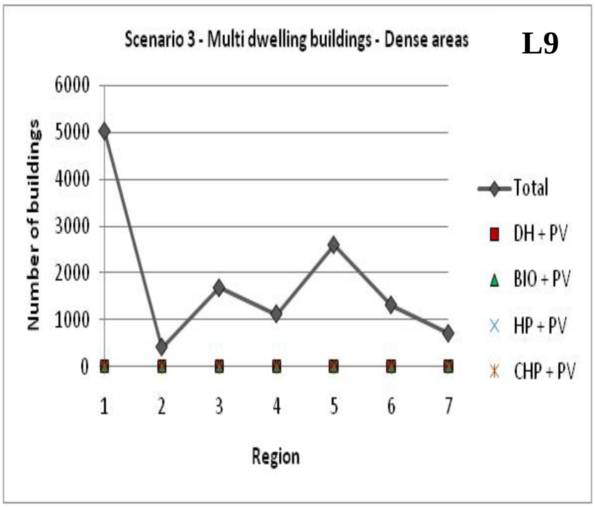


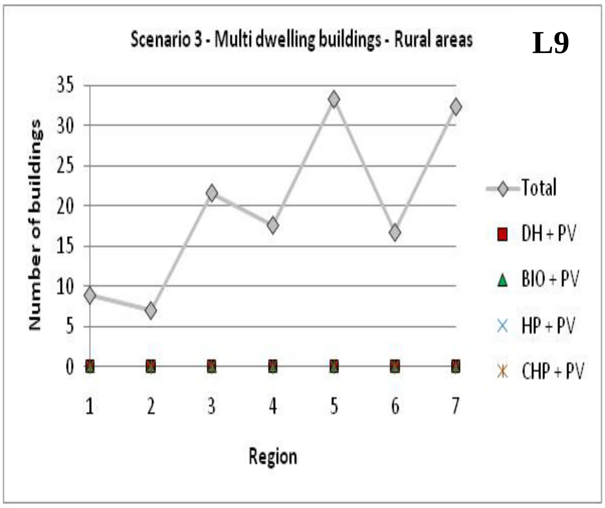


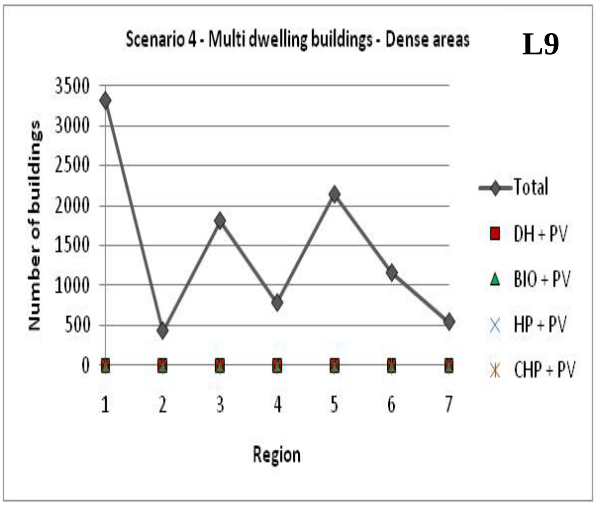
- Available roof/floor-ratio 1:10

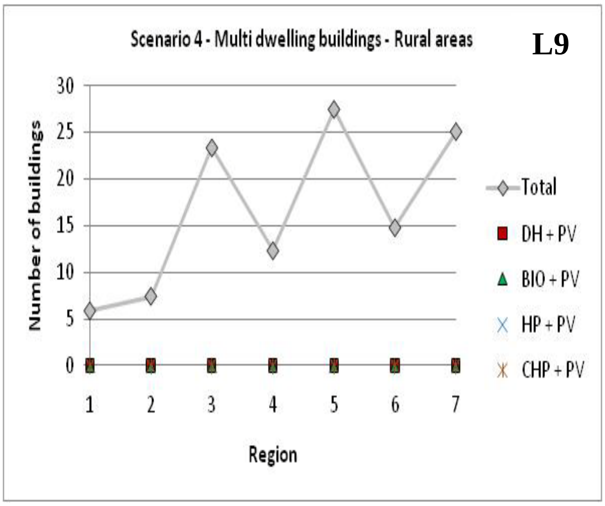












APPENDIX C

C.1 Draft for scientific journal paper

UPTAKE POTENTIAL OF RENEWABLE TECHNOLOGIES IN ZEBs - CURRENT AND FUTURE RESIDENTIAL BUILDING STOCK

ABSTRACT

The current *residential* building stock in Norway is categorized in to groups, and sorted after number of building units. The criteria used for sorting, are criteria that affect the viability and rationality of various energy supply systems. A set of four energy supply systems are studied closer; District heating + PV, Bio energy + PV, Heat pump + PV, Combined heat and power + PV. The *Zero Emission Building balance* is calculated for each solution and pre-defined energy level, to determine the required on-site electricity generation from the PV's. A model is then developed to study the potential of the solutions in the Norwegian residential building stock. The analysis is performed on future scenarios, which represent different development of the building stock with regards to new buildings, refurbishment and demolition. Results show uptake potential of all of the technologies in buildings with energy demand lower than 94,5 kWh/m^{2}year, but limitations occur as soon as [available roof area/floor area] decreases from the upper limit investigated in the study (1:2). The greatest potential is shown by CHP + PV, where ZEB conversion is possible in approximately 30% of the stock in year 2050.

1 INTRODUCTION

1.1 Objective

The main objective in this report is to investigate the uptake potential for a set of technologies in the residential building stock. To "qualify" for uptake in the stock, the technology has to be able to reach the ZEB balance defined by Sartori et al(Sartori 2010), under the limitations determined from the survey on the stock. These limitations include energy demand, geographical positioning of the building and available roof area for PV-mounting.

1.2 Methodology

Stock survey

The flow of data in the building stock survey and accompanying factors that affect the applicability of the energy supply system to each single building is shown on figure 1.

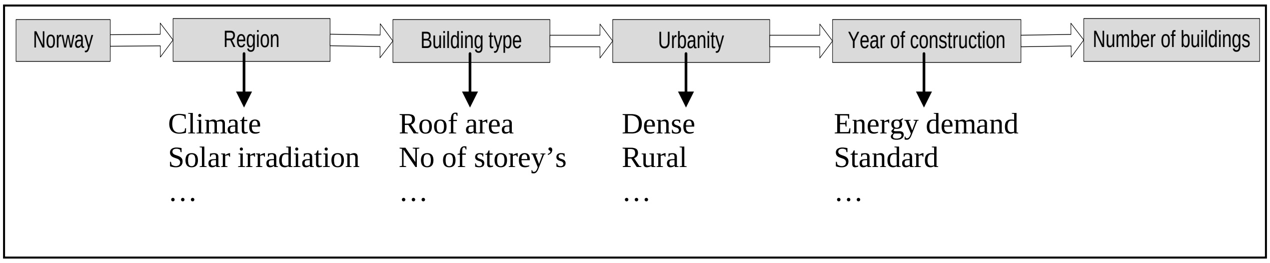


Figure 1 Sorting of buildings in survey.

A range of energy levels were then formed, based on the year of construction and building codes and standards(BE 1997; NS 2010a; NS 2010b), with accompanying specific energy demand.

Energy level	L1	L2	L3	L4	L5	L6	L7	L8	L9
Year of construction	Pre-1920	1921-1960	1961-1980	1981-2000	2001-After	Unknown	-	-	-
Code or standard	-	-	-	-	TEK1997	-	TEK2010	Low Energy 1	Passive
Specific energy demand [kWh/m^{2}year]	600	450	250	190	125	190	120	94,5	78,1

Table 1 Energy levels and related energy demand.

Energy supply system

Further, a set of four technologies were then introduced and studied closer.

- District heating (from non-domestic heating plant) + PV
- Bio (pellet-fired boiler) + PV
- Heat pump (ground/water-water) + PV
- Combined heat and power (pellet-fired, stirling engine) + PV

They were mainly chosen because of low carbon emissions, high performance and suitability in Norwegian conditions. In addition they had to have some sort of energy production to level out the emissions by feeding energy back in to the grid. In all of the solutions this energy production is provided by roof-mounted PV's on-site. The PV's cover the electricity specific demand within the building as well, while DHW heating demand and space heating demand is covered by the thermal energy carriers.

Uptake of technologies

The potential uptake of each technology was then quantified in different scenarios. Based on renovation and lifetime profiles(Sartori 2008), the development of the residential building stock was estimated up until year 2050. The building types were categorized in to two groups; small houses and multi dwelling buildings, and a range of [available roof area/floor area] ratios were investigated;

Building categories	
Small houses	**Multi dwelling**
1:2	1:3
1:3	1:5
1:4	1:7
1:5	1:10

Table 2 [Available roof area/floor area] ratios.

In addition, it was assumed applicability of the technologies based on the urbanity of the buildings, which is displayed in the results.

3 RESULTS

3.1 ZEB balance

Figure 2 shows the [required PV area/floor area] for every energy level and every technology with national average value for yearly solar irradiation. The shaded area marks the ratios of [available roof area/floor area] studied in this analysis.

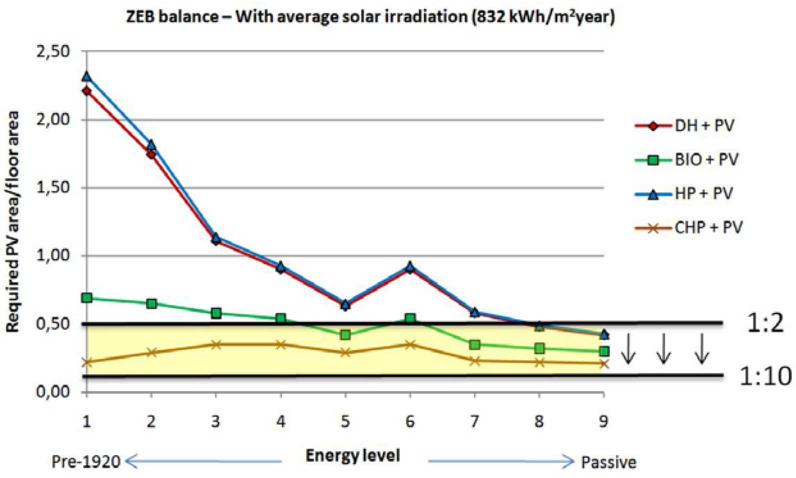


Figure 2 ZEB balance for technologies, with average solar irradiation.

If we look closer at this area below 1:2, it is only CHP + PV that has uptake potential at every energy level. In order to include all of the technologies, the standard of the building envelope has to be at least energy level 7. This figure does however not display the variations between every region, so the parameters were broken down to a more detailed level. The following three figures show how the requirements to PV area vary between the regions for L7, L8 and L9.

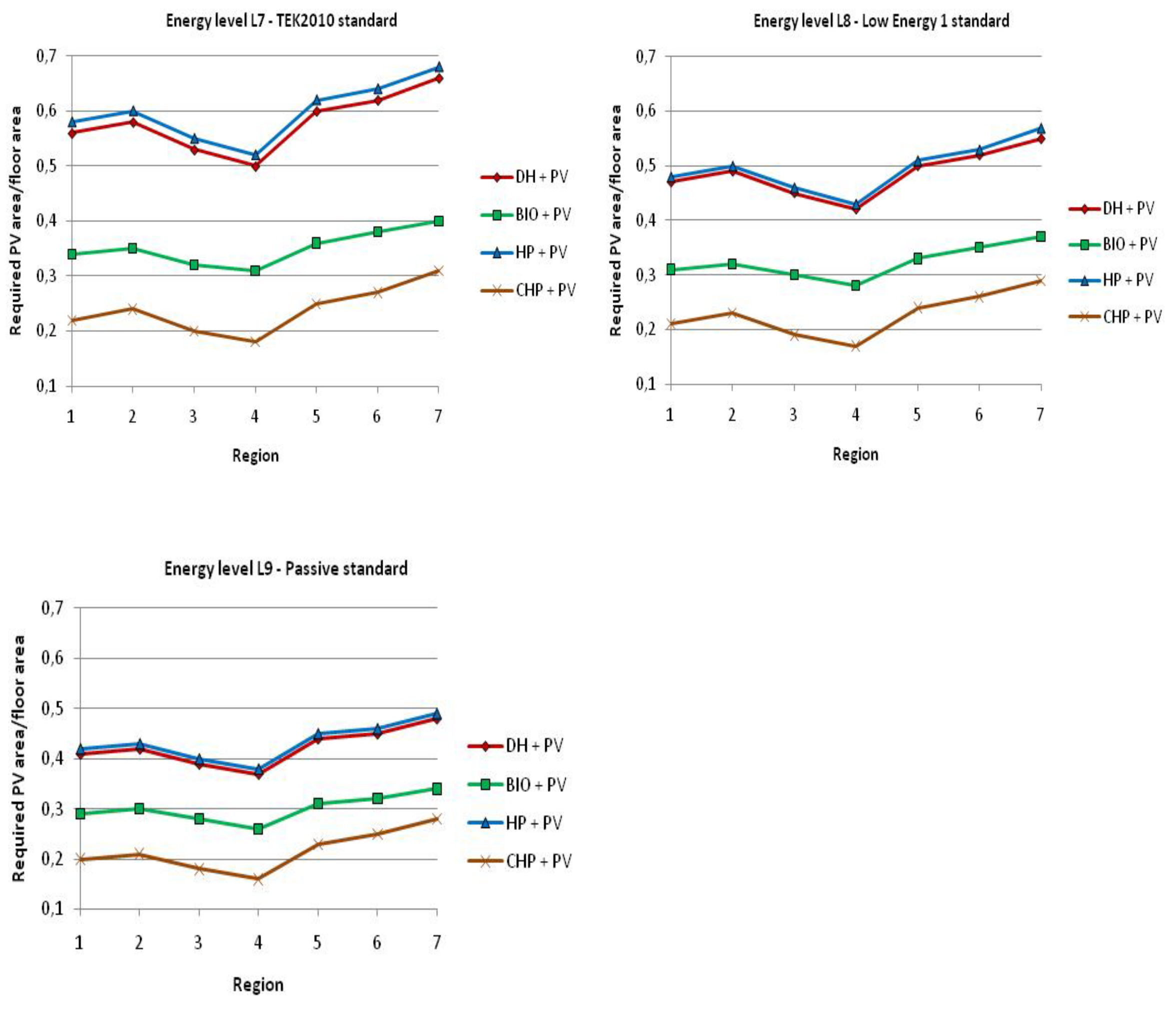


Figure 3,4,5 [Required PV area/floor area] for technologies in L7, L8 and L9.

3.2 Uptake potential

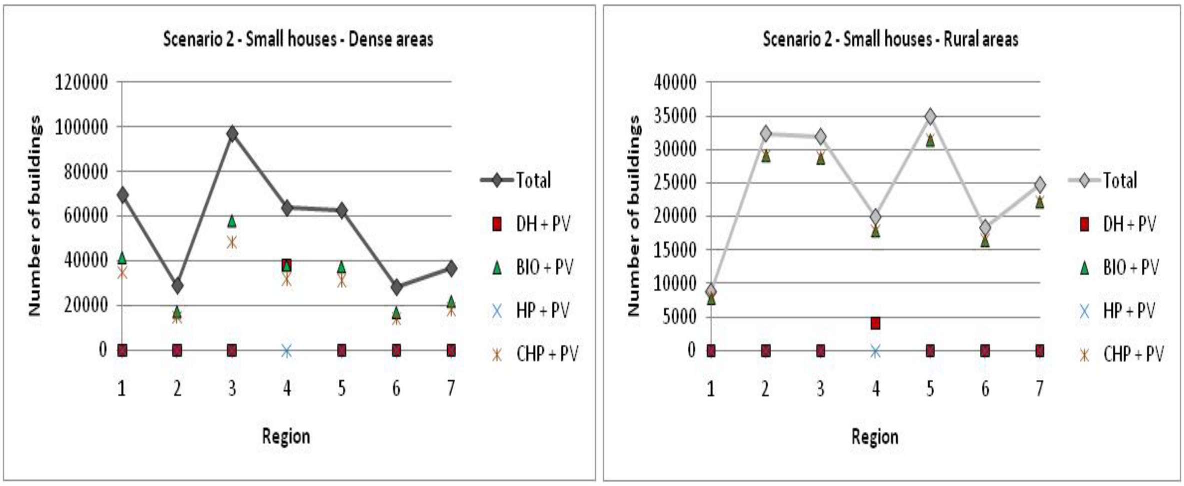


Figure 6,7 Uptake potential of technologies – Small houses (dense and rural) – L7 - Year 2025 – 1:2.

Figure 6 and 7 display the variations that occur between regions and buildings in dense and rural areas. This specific example treats the small houses with TEK2010 (L7) standard in year 2025. The total number of buildings in this category is also drawn in as a reference to the number of buildings each technology can cover. It can be seen that CHP + PV and BIO + PV can be used to convert a considerable share of this building mass to ZEBs. DH + PV has potential in the southernmost region (R4), while HP + PV cannot convert any of the buildings in this stock to ZEBs.

4 CONCLUSIONS

On a national level, the survey on the residential building stock showed that the vast majority of buildings in both dense and rural areas are detached houses. It did also reveal that it is necessary to focus the study on a regional level when analyzing the potential for technologies in ZEBs because of significant differences in urbanity, climate and building types between the regions. Based on the findings from the survey, it can be argued that developing suitable energy supply solutions for detached houses should be emphasized in order to see a potentially quick growth in the number of ZEBs. When it comes to multi dwelling buildings, more than 99% of the buildings are placed in dense areas. Limitations in possible energy supply solutions will likely occur here, mainly because of the influence of the immediate surroundings in a densely populated area.

With the findings from the survey and other important factors affecting the rationality and viability, a set of four different energy supply systems were introduced. The calculation of the ZEB balance for each technology and energy level, showed the significance of energy-efficiency and available roof area of the buildings for especially two of the solutions.

This further implies that the potential for ZEBs with these technologies in the current residential building stock is low, as long as the buildings are not renovated. The results did also show that there were only CHP + PV and BIO + PV that showed uptake potential in the current residential building stock. Further detailed analysis of every region and the highest energy levels in future scenarios was therefore done. When combining the results from the scenarios treating the future stock, where analysis was done on a regional level, it is possible to see the uptake potential with respect to time.

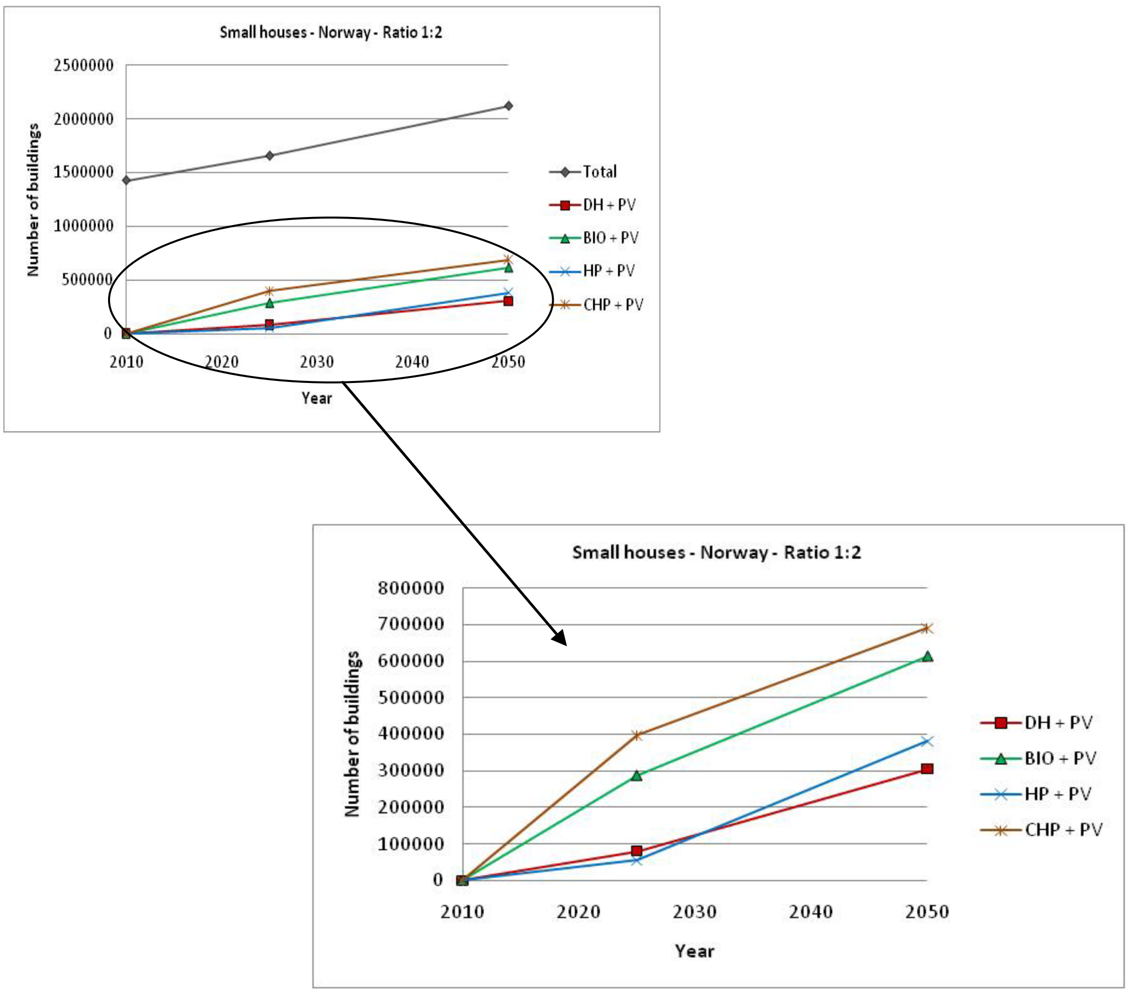


Figure 8 Uptake potential with respect to time – Small houses – 1:2.

Figure 8 shows the number of small houses that can be converted to ZEBs with the various technologies (with ratio 1:2) between year 2010 and year 2050. The development of the total small house-stock is also displayed. Up until 2025, CHP + PV and BIO + PV show rapid growth, because of the high renovation activity to L7 in this period. As the share of L9-buildings in the stock increases after 2025, the relative potential for DH + PV and HP + PV increases as well. Since HP + PV has assumed higher availability in rural areas, it actually surpasses DH + PV after a certain time. It can therefore be argued that, from these results, existing solutions with CHP and BIO should be emphasized in the nearest future to see a quick growth in the number of ZEBs. On a longer perspective, when the energy-efficiency of the residential building mass is significantly increased, attention can be extended to a number of technologies. It is especially interesting to see the development of heat pumps, where it is assumed a modest seasonal performance factor in this study, which may be substantially improved in the future.

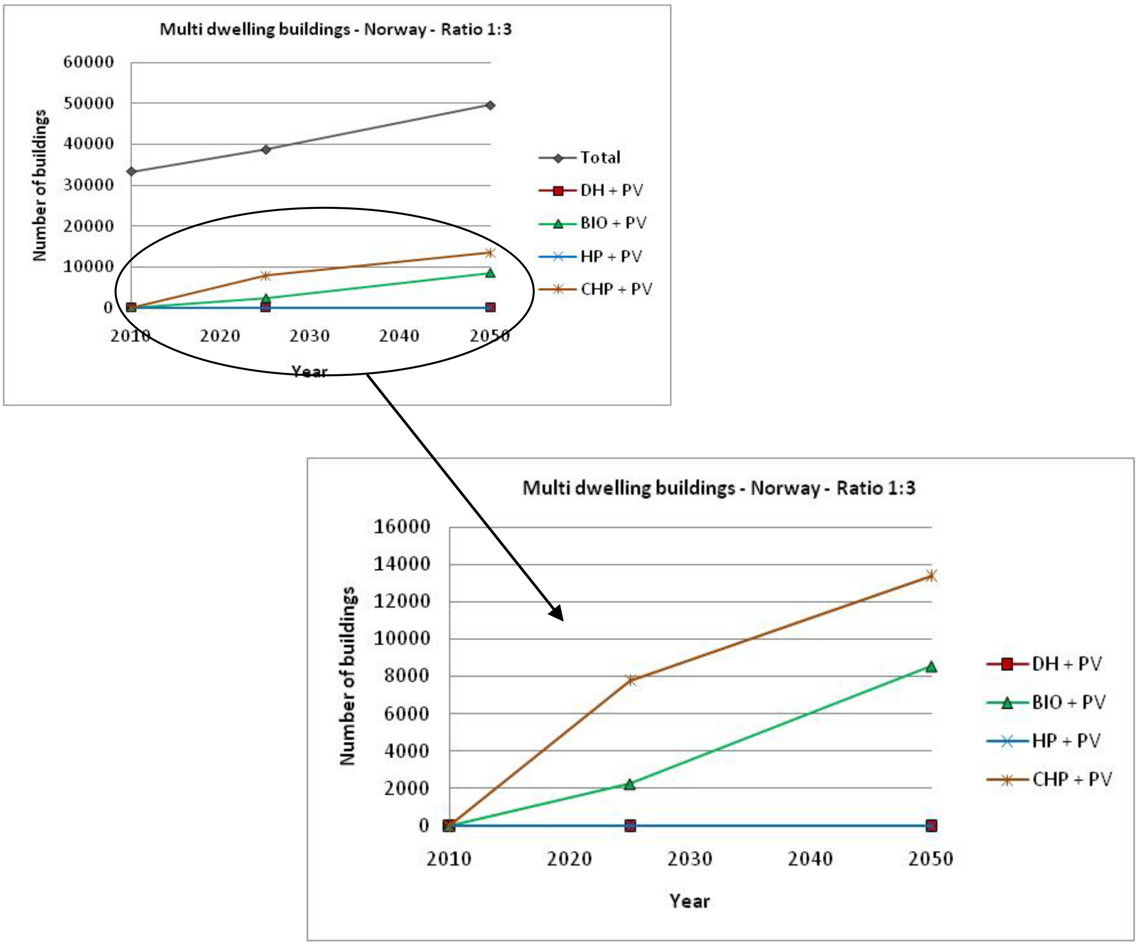


Figure 9 Uptake potential with respect to time – Multi dwelling buildings – 1:3.

Figure 9 shows the development of multi dwelling buildings and uptake potential of technologies (with ratio 1:3), with respect to time. In year 2050, results show that 27% of the total multi dwelling-stock can be converted to ZEBs with CHP + PV, while BIO + PV can cover 17% of the stock. They show the same relative growth as in small houses, and it can also be argued here that these technologies should be emphasized in the nearest future to see a significant share of ZEBs within short time. For ratios equal to or below 1:4, it was only CHP + PV that showed potential in L9. With the performances and emissions assumed in this study, DH + PV and HP + PV show no uptake potential in multi dwelling buildings. It is however only minor improvements in the technologies and/or energy-efficiency of the building envelope that are required before ZEB balance is attainable, so with further R&D it is still likely that they can be used in ZEBs in the future.