4RinEU

Reliable models for deep renovation

D3.4
WP3

Deep renovation at district scale and grid interactions

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Foreword

Despite the low energy performances of the European building stock, the yearly renovation rate and the choice to perform a building deep renovation is strongly affected by uncertainties in terms of costs and benefits in the life cycle.

The project 4RinEU faces these challenges, offering technology solutions and strategies to encourage the existing building stock transformation, fostering the use of renewable energies, and providing reliable business models to support a deep renovation.

4RinEU project minimizes failures in design and implementation, manages different stages of the deep renovation process - from the preliminary audit up to the end-of-life - and provides information on energy, comfort, users' impact, and investment performance.

The 4RinEU deep renovation strategy is based on 3 pillars:

- *technologies* - driven by robustness - to decrease net primary energy use (60 to 70% compared to pre-renovation), allowing a reduction of life cycle costs over 30 years (15% compared to a typical renovation);
- *methodologies* - driven by usability - to support the design and implementation of the technologies, encouraging all stakeholders' involvement and ensuring the reduction of the renovation time;
- *business models* - driven by reliability - to enhance the level of confidence of deep renovation investors, increasing the EU building stock transformation rate.

4RinEU technologies, tools and procedures are expected to generate significant impacts: energy savings, reduction of renovation time, improvement of occupants IEQ conditions, optimization of RES use, acceleration of EU residential building renovation rate. This will bring a revitalization of the EU construction sectors, making renovation easier, quicker and more sustainable.

4RinEU is a project funded by the European Commission under the Horizon 2020 Programme and runs for from 2016 to 2020 (extended to 2021).

The 4RinEU consortium is pleased to present this report which is one of the deliverables from the project work.

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Executive Summary

The electrification of the residential sector together with the decarbonization of the electricity generation is considered as an important step to achieve the low-carbon emissions targets. In this context, buildings cannot be seen only as an individual entity and for this reason, there is a growing interest in energy communities.

This document focuses on the analysis of the adoption of photovoltaic and solar thermal technologies, harvesting solar radiation, at the district level in three demo-cases (located in The Netherlands, Spain, Norway). The first step of the analysis was the collection of the inputs required to understand the context of each demo-case. Thanks to the contribution of the project partners it was possible to collect all the input required for the energy and economic analysis and in general to understand the normative framework of the demo-case countries.
It was shown that in the case-studies selected for the analysis, both photovoltaic and solar thermal technologies are a viable solution for covering part of the energy consumptions in the residential sector. Even if energy sharing between buildings was considered acceptable only for electricity, solar thermal and photovoltaic could be competitive solutions in the optimization process aimed at the definition of position on the available surfaces of the mentioned technology. It is thus important to account for both the technologies from the earliest stages of the design process. Since the objective function used in the optimizations was to maximize the NPV, no battery was installed in any case studies. This is because of the presence of the net-metering tariff scheme and because batteries have currently high initial costs, although they have been decreasing over the past years and the trend is expected to continue. Through the analysis of the current state and possible future scenarios consisting of different levels of energy sharing, results show that energy communities could become a driver for the adoption of distributed renewable energy generation. In all the case-studies, results show an improvement of the energy and economic KPIs for the scenario in which energy sharing is allowed at the district level. This means that energy communities could play a relevant role in the decarbonization process of the residential sector. On the other hand, it was shown how energy sharing, if not combined with an updated tariff scheme, could lead to an increase of the impact on the grid with possible technical and economic side effects.

The present report is structured as follows:

- **Section 1** is an introduction to the topic of energy districts
- **Section 2** gives an overview of the renewable energy sources in Europe and their integration into the electricity grid. We focused on the countries where the 4RinEU demo-case are located, as representative of 3 of the 6 Eureopean geo-clusters we defined (i.e. Spain, Norway and the Netherlands). We used the information provided by the demo-owners, the information related to the

renewable energy diffusion, the regulatory framework and the economic remuneration from RES are described.

- **Section 3** presents first the characteristics of the buildings and districts which will be used for simulation in Section 4. Then a description of how to generate and aggregate the electric and thermal profiles applied as inputs in simulations is presented as well.
- **Section 4** illustrates the methodology used for the energy district simulations. The section described the optimization algorithm and the control strategy applied in the simulations as well as the required inputs and the considered metrics to evaluate the advantages and disadvantages of the performed optimization for a single building or district of buildings.
- **Section 5** presents the data used and the simulation results in the demo-case countries, applying the methodology explained in Section 4. These simulations take into consideration the economic and regulation information presented in Section 2 or sometimes extend the perspective of the application to future scenarios.
- **Section 6** summarizes the considerations coming from the activities performed in task 3.4.

1 Introduction

The electrification of the energy sector and energy consumptions – such as space heating, water heating, and transportation – is needed to achieve the emission reduction goals for carbon dioxide [1]. Thus, the energy sector is radically changing due to the increasing penetration of renewable resources combined with the uptake of energy storage, the proliferation of electric vehicles and the electrification of the heating sector (through heat-pumps for example). In this scenario, the final user not only acts as a consumer but also as a producer becoming a prosumer and playing a central role in the technical and economic exploitation of the energy infrastructure.

The building itself becomes a key element in the energy infrastructure due to the capability to increase energy efficiency, reduce or modify the load consumption and host renewable generation and/or electric storage (e.g. photovoltaic and battery).

However, it is important to remark that almost 40% of the energy demand comes from the building sector, due to old construction with low energy efficiency overall Europe [2]. This suggests a significant renovation and efficiency potential of residential, commercial and industrial buildings to achieve the climate targets. Focusing on a residential level, the construction retrofitting (e.g. envelope, windows…) can improve the efficiency of the building and reduce the energy demand (mainly thermal for residential buildings). This intervention can be also associated with smart use of households thanks to house automation and to the installation of a renewable source, e.g. photovoltaic system to cover the electricity needed. However, it is fundamental to consider that a building is not an isolated system, but it is integrated into a rural or urban geographical context. Recently there is a growing interest in energy communities, as documented by the increasing trend of publications in this topic [3], and to provide interventions that do not address only a single building. This concept is important to introduce the ***building energy district*** in this report, inspired by the definition in [4]. "*A building energy district identifies a group of buildings interconnected to the same energy infrastructure, such that the change of behaviour/energy performance of each building affects both the energy infrastructure and the other buildings of the whole district*". This definition suggests that there is not a direct correspondence between a geographical district and an energy district, even if in some cases they can overlap. More in detail the above definition suggests that an energy district of buildings could exist in two situations:

1) When all the buildings are connected to the same physical infrastructure, such as to the same district heating system or secondary substation in the case of the electric grid.
2) When there is a virtual or market aggregation among the buildings through smart devices that track the behaviour (consumption and production) of each building.

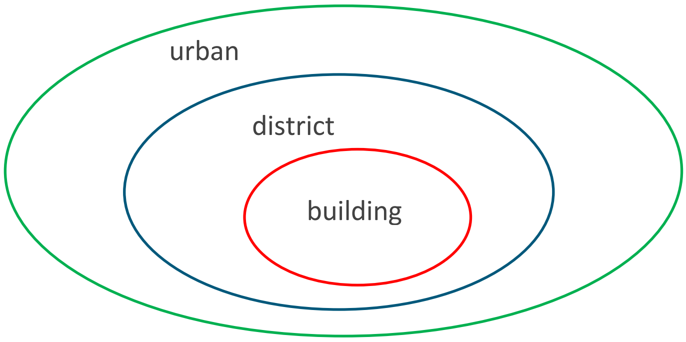


Figure 1. Representation of different spatial scales for building, district and urban

As mentioned, nowadays, each prosumer is able also to produce locally the electricity it consumes or use it to cover part of its demand, store it in a battery, or inject it into the grid to use it at a later stage. The diffusion of prosumers, also under the incentive to increase renewable energy at building scale, inspired the recent European directive, called "Winter package" [5], which proposes to "aggregate" domestic users in ***local energy communities***. This "cluster" of buildings, in the future, should replicate some of the tasks generally done to the Distribution System Operator (DSO), such as regulating power flows or participate in the market. Even if the regulation is still undergoing, the need to assess the technical and economic benefits of increased self-consumption, diminish the exchange with the grid and have an estimation of the payback period is already of interest, as demonstrated in recent papers [6], [7].

Within this context, looking at a building as an element of an energy district opens new opportunities for the integration of renewable energy. Buildings have a central role in the future energy system and energy transition. In this part of the 4RinEU project, we describe the current technical and economic regulations and status for renewable energy in the three demo-case European countries. This is preparatory work to the scenarios presented in this deliverable, showing the analysis performed with an evolution of the tool Early-ReNo described in detail in deliverable D2.5 of this project, where the optimization of solar thermal and photovoltaic systems will be compared in two cases: the case of a single building and the case of aggregate demand. The inputs are based on the information provided by the project partners for each country.

1.1 Objectives of the report

This report aims to describe some possible scenarios and present analyses on how the integration and interaction between renewable energy sources and electricity grid can impact on technical and economic revenues for energy districts in the three 4RinEU demo-case countries.

The main objectives of the report are:

- Give an introduction of the current position in terms of regulation, economic and technical aspects of renewable energies uptake, mainly at building scale and connection with the distribution grid and the relevance of self-consumption, energy sharing and ancillary service at single and multiple buildings.

- Describe how the electricity and thermal profiles can be created and aggregated as inputs for the simulation analysis.
- Present the methodology applied for district optimization of RES generation, the control strategy used for energy storage and the metrics adopted in the analysis.
- Evaluate the impact on the local grid of both the aggregated and the single-building configurations.
- Report the simulation results and the comparison in terms of technical and economic KPI between a single building and multiple building community, to understand the advantages and disadvantages of the two approaches.

2 Renewable energy and grid integrations

In this section, the objectives have been to collect information directly from the project partners about technical and economic aspects related to the renewable energy integration/installation in their country, mainly at the building level and the grid interaction. A questionnaire has been prepared with the following questions and sent to the demo-owners and scientific advisors of each demo-case. The submitted questions are listed below.

- Technical aspects
  - *Which is the largest renewable energy (RE) installed in buildings?*
  - *Is there any incentive to install RE in your Country? (e.g. feed-in-tariff)*
  - *If yes, what kind of incentives exists?*
  - *Are there any technical norms about RE connection to the electrical grid?*
  - *If technical norms exist, please provide the main requirements related to maximum and minimum voltage, maximum/minimum current, frequency, harmonics*
  - *Is the self-consumption encouraged in your Country? If yes, how it works? (e.g. financing storage installations, paying the surplus of energy, ...)*
  - *Could the energy surplus from RE be injected into the electrical grid?*
  - *Does it allow energy sharing (mainly from RE) within the neighbourhood?*
  - *Is there any regulation to manage the energy exchange between different buildings?*
  - *Is it possible to use RE (for example PV) to support grid operations? (i.e. ancillary service)*
  - *If yes, what kind of ancillary service is encouraged? (e.g. frequency or voltage regulation)*

- Economic aspects
  - *Which is the cost of electricity for residential building?*
  - *The cost of electricity depends on daily-hour? If yes how?*
  - *Is the cost of electricity change depending on the user typology? (i.e. residential, office, commercial, industrial…)*
  - *Is there any net-metering/net-billing rule for the energy injected into the grid?*
  - *Which is the cost of the energy sell to the grid?*
  - *Is there any economic remuneration for ancillary services?*

The answers provided by the project partners are summarized in Sec. 2.1, 2.2, 2.3 for the Spanish, Norwegian and Dutch context respectively. This information was very useful to understand the current state of each country related to renewable energy (mainly PV) and to take into consideration as a starting point for the simulations of future scenarios with energy districts in the following sections.

2.1 Spanish context

2.1.1 Renewable Energy incentives and grid-interactions

In Spain, at least for the residential sector, the most installed renewable energy systems are solar thermal for district heating and domestic hot water (DHW), because it became mandatory at the national level since 2007. In some cities, for example in Barcelona, it was mandatory before 2007 thanks to a local ordinance which incentivized renewable sources applications.

Differently, for tertiary buildings (commercial, offices, public ones), the 2007 regulations make mandatory to install solar photovoltaic panels on the roofs, facades or parking areas to cover part of the electricity demand (usually considerably high for tertiary buildings) with solar energy.

This scenario remains unchanged in general terms since the 2007 regulations. Minor updates were carried out in 2013 and 2017 but did not change the core of the document. The recent version of the Código Técnico de la Edificación released in December 2019 [8], adds some modifications regarding the photovoltaic section. These additions are summarized below:

1) Now the PV obligation applies to all uses (tertiary) above 3000 sqm. The previous versions only affected to some uses.
2) There is no limitation or restrictions regarding shadowing for PV integration.
3) PV power to be installed will be always between 30kW and 100kW.
4) Two new calculation methods are proposed, one for the minimum power and another one for the maximum power, to not be surpassed.

It means that the minimum power to be installed is 10W/sqm for every tertiary use with a constructed surface over 3000sqm.

The new 2019 regulations regarding energy consumption lower the primary energy consumption, both the total primary energy consumption and the non-renewable primary energy consumption. These new requirements imply an increasing relevance of the on-site renewable energy system.

New residential buildings	**Winter climatic zone**				
	A	**B**	**C**	**D**	**E**
Non-renewable primary energy consumption in kWh/m2 year	25	28	32	38	43
Total primary energy consumption in kWh/m2 year	50	56	64	76	86

New tertiary building	**Winter climatic zone**				
	A	**B**	**C**	**D**	**E**
Non-renewable primary energy consumption in kWh/m^2 year	55 + 8 CFI	50 + 8 CFI	35 + 8 CFI	20 + 8 CFI	10+ 8 CFI
Total primary energy consumption in kWh/m^2 year	155 + 9 CFI	150 + 9 CFI	140 + 9 CFI	130 + 9 CFI	120 + 9 CFI

Table 1: Primary energy consumption requirements from the new 2019 Spanish regulation [8]

In the past years, the diffusion of renewable energy has been supported by national or European incentives. Today, in the case of PV installations, there are no longer the incentives that were in force a few years ago. In past years there was the possibility to sell the energy production (mainly surplus) to the grid, but at the pool price, i.e. the buy price of the non-renewable energy. Furthermore, at this moment the owner is forced to pay a fee for the installation, depending on the installed peak power. There are some oriented subsides in some regions and for elements of the PV installations [9]. No benefits in terms of incentives exist for solar thermal systems.

To improve the energy performance of buildings (including the introduction of RES) in case of deep renovation, it is possible to ask for some subsidies, as the FEDER [10] funding but they are limited to the global amount of money available in this program. This funding scheme is based on the demonstration of improving the energy certification of the building. Another successful funding scheme that will be maintained and improved until 2030 is the PAREER [11] funding (Programa de Ayudas para la Rehabilitación Energética de Edificios Existentes) which focuses on the refurbishment of the building envelope. At the regional level (e.g. Catalonia) [12] other subsidies exist related to battery energy storage systems (BESS) combined with PV plants to increase the quantity of energy consumed on-site.

Until 2019 the most common RES installation is grid-connected photovoltaic systems which are regulated by the Royal Decree 1699/2011 [13] for the small electrical power generators. Connection to the low voltage grid is regulated by Royal Decree 842/2002 [14].
From a technical point of view, the regulations set some requirements for the connection to the grid: the power factor (cosϕ) should be as close as possible to the unit and, in any case, higher than 0.98 when the plant works at powers greater than 25% of its nominal power. The operations of the plants are regulated by the European Norms EN50160 “Voltage Characteristics in Public Distribution Systems” [15] which sets the maximum and minimum frequency connection protections (50.5 Hz and 48 Hz with a maximum timing of 0.5 and 3 seconds respectively) and the maximum and minimum voltage between phases (1.15 Un and 0.85 Un).

The use of RES for ancillary services is for the moment not allowed for small scale generators. The use of power produced by RES to support grid operations is for the moment mainly exploited by PV under research and development projects [16] but still far away from real operations at least in 2018 [17].

The perspective for a close future is well described in the recent draft version of the *Plan Nacional Integrado de Energía y Clima 2021 – 2030*. [18] To reach the decarbonization targets expected in 2030 some promotion measures for renewable energy are proposed:
Measure 1 New electricity production plants with renewable energy.
During the period 2021-2030, the installation of an additional capacity of electricity generation with renewables of 59 GW is foreseen. The following mechanisms are planned for the development of new renewable facilities:

- Calls for auctions for the assignment of a specific remuneration scheme

- Local participation in renewable generation projects
- Specific programs for developing technologies
- Specific program for extra-peninsular territories

Measure 2 Demand management, storage and flexibility.

The integration of the new planned renewable power substantially modifies the power generation model, which evolves from one of centralized generation with a predominantly passive demand to a new model in which it is necessary to manage the generation variability using all the tools available for it, both large-scale storage within the generation systems themselves or outside them, and demand management that makes the consumption curve more flexible, adapting it to the generation.

- Development of the regulatory and regulatory framework for demand management
- Development of regulatory framework and storage momentum
- Boosting the coupling of sectors
- Energy resources management distributed in local markets
- Options and signals suitable for the consumer
- Advice, promotion of active clients and activation of other agents involved
- Development of qualified human resources
- One-stop-shop and simplification of procedures in processes related to demand management and renewable energy integration
- Pilot projects for demand and storage management

Measure 3 Updating of the electrical grid for renewable integration.

The production of electricity through renewable energy sources in Spain represented 46% of the installed power in the whole of the generator park at the end of 2017. Spain was in 2017 in the sixth position for renewable energy generation in Europe. The Plan includes an objective for the coverage with renewable energy of 74% of the electricity consumption by 2030. For this, the following instruments are provided:

- Adaptation of the planning of transport and distribution power networks
- Digitalization and regulatory frameworks for management
- Review and definition of network connection capacity
- New and revised operating procedures

Measure 4 Develop of self-consumption with renewable energies and distributed generation.

The following mechanisms are foreseen to promote the development of self-consumption:

- Preparation of a National Self-Consumption Strategy for the period 2021-2030.
- Promotion of soft financing to facilitate the mobilization of private investment
- Promotion of management by third parties or energy services model
- Promotion measures from the local administrative level
- Boosting self-consumption in vulnerable households for the mitigation of energy poverty
- Manual for self-consumption in urban environments

Measure 6 Framework for thermal renewable energy.

Energy consumption for thermal uses in 2015 in Spain accounted for more than 33% of total final energy consumption. In that same year, the contribution of renewable energies in the consumption of heat and cold stood at around 16.8%. To achieve the objectives of this Plan, it will be necessary to double this contribution in 2030. The revision of the Renewable Energy Directive establishes that the Member States must take the necessary measures to increase the share of renewable energies in the consumption of heat and cold by 1, 3% per year from the value reached in the year 2020:

- Evaluation of the potential for the use of renewable energy and residual heat and cold in the heat and cold networks and other uses.
- Mechanisms that guarantee a minimum share of renewable energy in the thermal use sector following Article 23 of Directive 2018/2001 / EU
- Integration of thermal renewable energy in the building
- Aid programs (loans and grants) will create specific lines for i) the renovation of the installed solar thermal park, ii) High-efficiency ambient energy equipment replacing obsolete systems, iii) Renewal of biomass equipment with other high-performance systems, iv) Geothermal energy installations through heat pump and direct use, v) Hybridization of renewable technologies for reach the nZEB, vi) Integral, standardized and compact heat and cold thermal installations.

Measure 7 Renovation plan for electricity generation plants based on renewable energies.

During the 2021-2030 decade, approximately 22 GW of renewable electric power will have exceeded its regulatory lifespan. Without a specific plan for the technological renewal of these projects, it is foreseeable that there will be a reduction in the installed power of renewable origin. The following mechanisms are foreseen:

- Administrative simplification with a simplified and fast permitting regime
- Opening of coordination tables with the regional governments
- Calls for auctions for the assignment of a specific remuneration scheme to technological renewal projects
- Regulation of the end of concession of hydroelectric power plants

Measure 10 Promotion of the bilateral contract for renewable electricity energy.

In addition to the mechanisms provided for in the specific measures of public procurement of renewable energy and promotion of the proactive role of the consumer, mechanisms will be analysed to encourage long-term bilateral contracting with renewable energy producers, as instruments to reduce the risk of such operations or minimum contributions for certain large energy consumers.

Measure 11 Local energy communities.

Spanish regulations will accept the two legal definitions given by European regulations:

- Renewable energy community (defined in Directive 2018/2001 regarding the promotion of the use of energy from renewable sources).
- Citizen energy community (defined in Directive 2019/944 on common rules for the operation of the internal electricity market).

Measure 12 Renewable energy public contracts.

In December 2018, the Spanish Council of Ministers approved the Ecological Public Procurement Plan and the General State Administration, setting the objective of contracting electricity with 100% renewable source in 2025, for all electrical consumption of buildings and services of the General State Administration.

2.1.2 Self-consumption and energy sharing

Until the new Royal Decree 244/2019 [19], new PV installations and self-consumption were not considerably encouraged in Spain. Taxes associated with the use of the common grid discouraged the installation of RE in residential buildings. The previous regulation. the Royal Decree 900/2015 regulates the administrative, technical and financial conditions of the forms of supply of electricity with self-consumption and production with self-consumption. Two types/modalities of self-consumers were considered [20], [21]:

- **Type 1** was limited to below 100kW installed capacity, was legally considered to be a mere consumer, and no reward was granted for exporting any surplus electricity to the grid.
- **Type 2** was legally treated as both consumer and producer. Here, the self-producer was perceived as an entrepreneur and was legally considered to be just like any other producer, i.e. PV self-consumption is thus considered to be a form of economic production rather than a form of saving.

This Royal Decree 900/2015 [22] has a very controversial article (art 4.3.) that did not allow sharing the electricity produced by a PV plant with various consumers. That affects directly the applications of a solar PV plant in a housing building as the demo case one.
The article 4.3 of RD 900/2015 establishes that "*In no case can a generator be connected to the internal grid of several consumers.*" As a result, the installation of a community photovoltaic panel to generate energy and its connection to various consumers would be contrary to this Royal Decree.
Back on 2 June, after a demand by Catalonia, Spain's Constitutional Court declared partially void Royal Decree 900/2015 which prohibited the sharing of energy production facilities between several users in Spain. Spanish autonomous regions now have the choice to enact legislation to regulate shared self-consumption. This would allow both for self-consumption and for several neighbours to share and receive energy from a single rooftop solar system.

Since April 5, 2019, Royal Decree 244/2019 [19] regulates the administrative, technical and economic conditions of the electric energy self-consumption. In RD 244/2019 two types of self-consumption are established:

1. *Self-consumption without surpluses*. In this mode, a mechanism that prevents the injection of excess energy into the transport or distribution network must be installed.
2. *Self-consumption with surpluses*. Here, the production facilities may, in addition to supplying energy for self-consumption, inject excess energy into the transport and distribution networks.

This last category, *self-consumption with surpluses* has two types:

- Type A Consumer and producer choose to take advantage of surplus compensation. The following conditions must be met:
    i. Renewable primary energy source.
    ii. Total installed power cannot exceed 100 kW.
    iii. The consumer has signed a supply contract for associated consumption and auxiliary consumptions with utility.
    iv. Consumer and associate producer have signed a self-consumption surplus compensation contract.
    v. The production facility does not have an additional or specific remuneration regime.
- Type B. All cases of self-consumption with surpluses that do not meet any of the requirements of type a or that voluntarily opt for this modality.

Self-consumption is also classified as individual or collective, in the latter case, all consumers associated with the same generator must be of the same type of self-consumption. The production facility close to those of consumption must meet the following conditions:

- That they are connected to the internal network of the associated consumers or connected to them through direct lines.
- That they are connected to the low voltage network derived from the same transformation centre.
- That both are connected at low voltage and at a distance less than 500 meters.
- That they are located in the same cadastral reference according to their first 14 digits.

In collective self-consumption, all references made in the Royal Decree to hourly energy consumption, self-consumption, net generation and surplus are understood to be individualized. Fixed distribution coefficients of the generated energy are defined, also applicable to surplus energy, among consumers who participate in collective self-consumption.

Although it is defined in the *Plan Nacional Integrado de Energía y Clima 2021 – 2030* (see the previous chapter) this is still a draft and actually, the Spanish legislation does not establish a definition for the energy community. In European legislation this concept already appears in 2016 with two different denominations:

- Local energy community or citizen energy community, which we find within the legislation regarding common standards for the internal electricity market.
- Renewable energy community, which is defined in the context of legislation regarding the promotion of the use of energy from renewable sources.

For further explanations, refer to the Guide for the Development of Instruments for the Promotion of Local Energy Communities of IDAE (The Institute for Diversification and Saving of Energy) to consult the evolution of the definition of energy communities. As for the legislation of energy communities, there is currently no clear regulatory framework at the national level for them. However, the recent actions carried out by IDAE and the

Spanish government regarding energy transition are indicators that are likely to be legislated in this area soon.

Given the current absence of a regulatory framework, the legislation that can be considered as the foundation on which to build an energy community would be the Royal Law Decree 2018 [23], where the right to shared self-consumption was established, and the aforementioned RD 244/2019 on energy consumption.
As mentioned earlier, the current regulations establish that the distribution coefficient must be fixed, limiting the possibilities of self-consumption in a scenario in which the distribution coefficient is dynamic. Along these lines, the Fifth Provision of Annex I of RD 244/2019 already indicates the intention of the competent authority to modify the Royal Decree soon to allow the implementation of dynamic distribution coefficients for collective self-consumption.

The other big step forward published in the BOE 23/12/2019 is the definition of the figure of the aggregator. In a few words, the aggregator tracks electricity consumption and transmission system operators' requirements in real-time. Depending on the consumption period, the aggregator can ask the companies to shut down or reduce electricity consumption to save energy. For example, during peak periods. Then, it is possible to sell this electricity to other customers that require it. This way the aggregator keeps the grid right balanced to optimize the energy use and cost.

Some data to illustrate the 2019 renewable energy generation in Spain [24]:

- During 2019 the installed renewable energy capacity was increased by 12.9%. It meant a total capacity increase of 5.6% in Spain.
- This new renewable energy installation allowed the production of 97 826 GWh/year of renewable production nationwide. It means a 37.5% share in the generation mix.

2.1.3 Economic aspects

The cost of electricity for residential buildings strictly depends on the utility and specific contracts. An indicative cost of electricity is 0.12 €/kWh and a contracted power cost of 3.1702 €/kW/month plus 25% of taxes. However, according to the utility company and contract the cost of electricity may change during day (average is around 0.13 €/kWh) and night tariff (average is around 0.08 €/kWh) [25]. These values are meant for residential end-customer, indeed if you consider a different type of user (for example industrial or commercial buildings) the cost of electricity can significantly change. Electricity prices are the main factor affected by the regulation. For a self-consumption installation, there are two relevant prices: the variable part of the retail price at which the electricity is bought from the grid (*ps*), and the price at which the surplus electricity is sold to the electricity system (*pg*). Thus, profitability is determined by the value of the self-consumed electricity (implying a saving), and the price of the surplus electricity exported to the grid (representing a source of revenue). The regulation affects prices in two ways: on one hand,

the backup charge (δ) reduces the savings derived from self-consumption (which would otherwise be equivalent to the variable part of the retail price). On the other hand, regulation can establish the net price at which surplus electricity is sold to the grid (*pg*), as it specifies the grid access charge (γ) and generation tax (λ), both of which are charged base on the gross price of the surplus electricity exported to the grid [21]. Revenues are only realized by commercial and industrial segments since the residential segment is not rewarded for the surplus electricity exported to the grid.
For commercial and industrial segments, the revenues are equivalent to the amount of electricity exported to the grid multiplied by the wholesale electricity price (€0.042 /kWh) minus the grid access charge (€0.5 /MWh) and the electricity tax (7%). Savings depend on the retail electricity prices, which are the sum of the fixed part of electricity costs, the variable part and the value-added tax (VAT)[14].

		Transitional charge for self-consumed energy €/kW					
	Access Toll	**Period 1**	**Period 2**	**Period 3**	**Period 4**	**Period 5**	**Period 6**
2.0 A	**Pc ≤ 10 kW**	0.044504					
2.0 DHA	**Pc ≤ 10 kW**	0.058489	0.007368				
2.0 DHS	**Pc ≤ 10 kW**	0.059269	0.007650	0.007344			
2.1 A	**Pc ≤ 15 kW**	0.0562					
2.1 DHA	**10 < Pc ≤ 15 kW**	0.069426	0.016716				
2.1 DHS	**10 < Pc ≤ 15 kW**	0.070206	0.019507	0.012602			
3.0 A	**Pc > 15 kW**	0.021957	0.015040	0.010183			
3.1 A	**1kV to 36kV**	0.016699	0.011411	0.013268			
6.1 A	**1kV to 30kV**	0.012995	0.012837	0.008996	0.010431	0.011206	0.007951
6.1 B	**30kV to 36kV**	0.012995	0.009531	0.008541	0.009527	0.010623	0.00758
6.2	**36kV to 72.5kV**	0.014139	0.012915	0.009197	0.009622	0.009936	0.00747
6.3	**72.5kV to 145kV**	0.016527	0.014150	0.009832	0.009751	0.009893	0.007501
6.4	**Greater or equal to 145kV**	0.012995	0.009871	0.00903	0.00903	0.009477	0.007328

Table 2: Primary energy consumption requirements from the new 2019 Spanish regulation

2.2 Norwegian context

2.2.1 Renewable Energy incentives and grid-interactions

In Norway, the most common small-scale renewable electricity technology is photovoltaic systems. There exist some incentives for both private and commercial to install RES, both large scale and small scale. For residential buildings, the main incentives are provided by Enova (owned by the Ministry of Climate and Environment) which contributes to reducing greenhouse gas emissions, to the development of clean energy technologies and strengthened security of supply [26]. Enova provides investment support to residential PV systems up to 15 kWp. Some municipalities also have support schemes to complement Enova. Larger PV systems can become a part of the Norwegian-Swedish Electricity Certificate Market, a common plan with Sweden for the installation of large-scale production plants like hydropower, wind farms, solar farms, or large scale solar on buildings. In the certificate market, registered production plants get a market price for the electricity produced. The market price varies and has been between about 0.04 and 0.2 NOK/kWh during the last couple of years (1 NOK is equal to about 0.1 €).

The RES grid connections must follow the grid operator's requirements in terms of quantity and power quality. The limits in terms of voltage, frequency and maximum power depend on the grid operator but are well regulated by the Standards. Indeed one of the largest grid operators Hafslund Nett has the following requirements for prosumers [27]: REN-blad 0342 (up to 25 kWp) and VDE 4105-2011 (over 25 kWp).

The VDE 4105:2011 titled "Power generation systems connected to the low-voltage distribution network" indicates the technical minimum requirements for the connection to and parallel operation with low-voltage distribution grid [28]. To respect the technical requirements for voltage, frequency and power the PV generators should be connected to the grid using an inverter with EN 50438:2013 certification which specifies the "Requirements for micro-generation plants to be connected in parallel with public low-voltage distribution networks" [29].

In Norway today (2020), it is not possible to support grid operations through ancillary services for small RES generator (only possible for larger industrial energy users).

2.2.2 Self-consumption and energy sharing

The grid operator is required to receive production from a prosumer at any time (if it is not more than 100 kW). Prosumers are also exempted from paying certain tariffs (the feed-in tariff). However, there are no requirements for the grid operator to pay for this production from the prosumer. This means that a prosumer will need to negotiate a deal with an electricity supplier to get a decent price for the production. This is often the electricity spot price, but without grid tariffs and taxes which are also parts of the electricity market price. In this term, self-consumption is usually the most financial option. At this moment, energy sharing between close buildings is not regulated and is not allowed either physical or through virtual exchange.

2.2.3 Economic aspects

The cost of electricity for the residential sector is about 0.8 NOK/kWh (approximately 0.08 €/kWh), consisting of electricity spot price, grid tariffs and taxes. For the grid tariff, the Norwegian authorities (through NVE) is planning to introduce a power-dependent share, so customers using little energy (kWh) but high power (kWh/h) will pay a higher share of the grid costs. After the smart meter deployment, prices during the day could vary. In Norway, the electricity cost is strictly related to the user typology. Residential users pay the electricity as explained above, while larger electricity users have special tariffs including a power tariff. For power (kWh/h), the customers pay a price depending on their power peak during the month or the year. Power peaks are often more expensive during the winter than during the summer.

Prosumers are exempted from paying certain tariffs (the feed-in tariff) while large scale RE production unit will need to pay all tariffs [30]. The income from the energy sold to the grid depends on the agreement with the electricity supplier. Smaller/residential customers with PV systems can typically get a higher price for the PV electricity, compared with customers with larger/commercial PV systems, which typically get the electricity spot price as well as compensation for reduced electricity losses in the grid.

2.3 Dutch context

2.3.1 Renewable Energy incentives and grid-interactions

In the Netherlands the largest renewable energy source installed in buildings is PV. There is also a considerable application of biomass to heat modestly insulated buildings. There are multiple incentives to install RES in the Netherlands. For example, the use of PV for the households is promoted by using the feed-in tariff up to the total electricity use. The feed-in tariff today is specified as net-metering, which should be gradually reduced by 2023. PV for large users (e.g. commercial and industrial) can benefit from a 15 years bonus on electricity generation based on a tender system.

Other RE technologies are promoted via subsidies, e.g. solar thermal, heat pump and biomass. Almost all PV systems are grid-connected. Limitations are the capacity of the building connection and capacity of the grid. System capacity is a barrier for large scale projects. Therefore, large systems can experience delays until the network provider has been able to adjust the local electricity infrastructure. The connection to the distribution grid is regulated by the technical norm NEN 1010:2015, chapter 712. The size of the connection of a standard new home is 3*25A but, in existing buildings, often smaller connections do exist: 1*25A, 1*35A, or 1*40A. If one would need a larger connection the yearly costs increases by over 600 Euro per year.

2.3.2 Self-consumption and energy sharing

The PV self-consumption, mainly using the combination with a storage system, is not particularly encouraged due to the presence of net-metering financing mechanism and this becomes particularly true when the price of the electricity bought to cover the building demand is close to the valorization of the electricity into the grid. However, after 2023 the net-metering will gradually fade out, and then the storage market will gradually increase because making self-consumption larger and convenient from a technical and economic point of view.

From a neighbourhood point of view, there is the possibility to request a tax reduction if one user participates in PV installed in the same neighbourhood defined by the postal code. Currently, the energy exchange between peers is not regulated but in future, this will change with the European directive going on the direction of renewable energy communities. From the ancillary service point of view, there is a managerial issue because network providers are not allowed to act as an energy provider. However, there are some ongoing pilot projects with net buffering with storage systems in local grids.

2.3.3 Economic aspects

In the Netherlands, the cost of electricity varies according to the contracts which are typically based on tariffs and rates on a periodical basis (e.g. quarterly, yearly, three-years). The cost of electricity for residential users is around 0.20€/kWh , where roughly

0.06€/kWh is the electricity price and 0.14€/kWh for energy taxation. For large energy consumers, costs related to energy taxation can be lower. The Dutch energy taxation system has thresholds at 10.000, 50.000, 10 mln kWh and above 10 mln kWh. For consumers above 10 mln kWh there are lower rates for companies than for private persons. The last category of consumers only pays € 0.006 for energy taxation. Therefore, the total electricity price is much lower for end users with a higher consumption.

The net-metering regulation is limited by the size of the connection and is available up to connections of 3*80A thus it is mainly interesting for small connections. If the produced energy is larger than the purchased energy, the value of the outflow is at the level of the basic price of electricity. This varies from 0,06 to 0,10 per kWh depending on the electricity contract. After 2023 the net metering will gradually phase out, resulting in the situation that outgoing PV produced electricity will be valued at market prices. This will stimulate the adoption of energy storage mechanisms.

3 Energy profiles generation

In general, there are several methodologies to define loads profiles of energy demands and energy consumptions (i.e. energy profiles) at a neighbourhood, district or urban scale (supported by GIS tools or other simplified methods). The selection of the final methodology to be used usually relies on the reliability requirements on the final obtained results.

In most of the existing methodologies, there are three main concepts to define the energy profile at different topographic scales:

- ✓ Actual building typologies. These could be defined from the existing detailed information for specific neighbourhoods, districts or urban cases (i.e. building local census data), or by using building archetypes (with or without local characterization).
- ✓ Building typologies distribution. From the existing building typologies, it should be defined their distribution per type in the requested neighbourhoods, districts or urban cases. That means mainly, how many buildings per typology exist in the requested physical framework and which is its relative position (buildings orientation and distance among buildings or building density). Again, this could be solved from the most real data and by using GIS techniques or by using simplified methods as defining the percentage of buildings per typology and limited density scenarios.
- ✓ Energy profiles calculation. From the above, different approaches could be implemented to obtain the desired energy profiles at different topographic levels: from the addition of static referred values to the dynamic simulation of the overall buildings, or the implementation of stochastic models to combine the results of individual building simulations. A valid alternative is the use of behaviour-based models where real human activities and needs are modelled for the calculation of the demand profiles.

3.1 Residential electric and thermal profiles

3.1.1 Districts

During the project 4RinEU, a small number of representative building archetypes were identified for each of the case studies. Considering the purpose of this task (Deep renovation at district scale and grid integrations), it was necessary to define a reference district for each of the case studies. Thus, the reference districts were defined considering the characteristics of the most prevalent building typology of the demo-case countries.
The finally implemented methodology is a balance between the available resources and the expected results reliability for the main purposes of the task: to define the potential on energy savings of the implementation of the 4RinEU solution at different topographical levels. When possible, the reference district was divided in neighbourhoods composed by a limited number of buildings as shown for example in Figure 2 for the Norwegian case

study. Simulations were done both at district and neighbourhood level and results compared to see the effect of different configurations of the energy community.

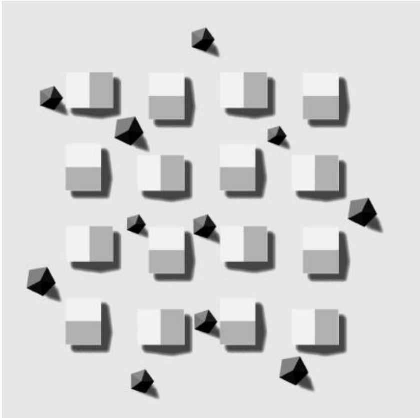
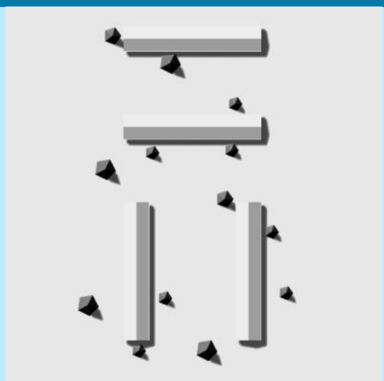


Figure 2: Reference district of the Norwegian case study

In Table 3 the simplified 3D models of the reference districts used for each case-study were reported together with the prevalent building typology. As shown, the Norwegian district is composed of single-family houses, the Dutch district is composed of terraced houses while the Spanish reference district is composed of both single-family and multi-family houses.

Case-study	Characteristics	District
Netherlands	Terraced house Neighbourhood: a terraced house composed of four households District: four terraced houses	
Norway	Single-family house Neighbourhood: four single-family houses District: sixteen single-family houses	

Spain	Single-family and multi-family house Neighbourhood: a multi-family and four single-family houses District: two neighbourhoods	

Table 3: Reference districts

3.1.2 Electric and thermal profiles

In the first phases, the building archetypes of the reference districts were simulated with the dynamic simulation software, TRNSYS. From the dynamic simulations, both the thermal and the electric profiles were obtained. However, the limits of such an approach emerged during the analysis of the benefit of energy sharing. The number of selected archetypes used in the simulations is critical to observe the advantage of energy sharing at the district level. The benefit of the transition between single building to energy communities increases at the increasing of the heterogeneity of the demands and it could not be simulated with the initial approach. For this reason, it was decided to adopt a different strategy for the calculation of the electric profiles. To overcome this problem and due to the lack of measured profiles, the electric demands were obtained with LoadProfileGenerator (LPG) [31], a behaviour-based tool for the calculation of realistic residential profiles. The tool can model the needs and activities of a wide number of different households. It accounts for the most common electric devices used in the residential sector such as lighting, computers, TV, oven and many others. Different households were simulated for each case-study to obtain a heterogeneous sample (different families composed by workers, retired, kids, etc.). Due to the simplicity of the model implemented in LPG for the simulation of thermal needs, it was preferred to exclude thermal demands in the calculation of the electric load (heating and cooling need not covered by electric devices). This assumption was considered acceptable according to the final energy consumption data shown in Figure 3 (Eurostat, 2017): on average in Europe, only 5% of energy consumptions for space heating are covered by electricity. This data well describes the Spanish and Dutch contexts while for the Norwegian case-study it is important to highlight that space-heating is covered by more than 50% by electricity due to the low cost of electric energy in Norway. However, for consistency with the other case-studies and maintain the required heterogeneity of electric demand profiles required to highlight the benefit of energy sharing (see 3.1.2), it was assumed also for Norway that the heating demands are not covered by electric devices. On the other hand, even if cooling needs are entirely covered by electricity, the cumulative energy consumption related to space cooling consists only of a small part of the total consumptions of the residential sector (Figure 4). For all the countries of the case-studies (Netherlands, Spain and Norway), energy used for space cooling is lower than 1% of the total energy consumptions.

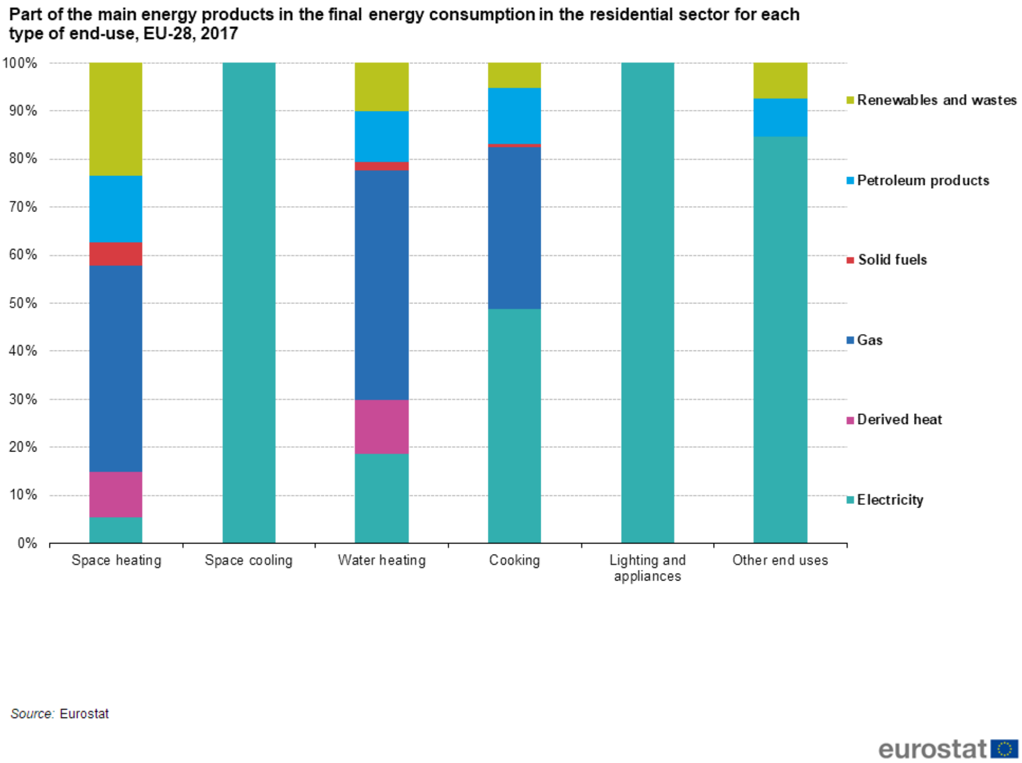


Figure 3: Final energy consumption in the residential sector for each type of end-use. Source: Eurostat

Share of final energy consumption in the residential sector by type of end-use, 2017
(%)

	Space heating	Space cooling	Water heating	Cooking	Lighting and appliances	Other end uses
EU-28	**64.1**	**0.3**	**14.8**	**5.6**	**14.4**	**0.9**
Belgium	73.8	0.1	11.4	1.7	12.7	0.4
Bulgaria	54.3	0.5	17.2	8.4	19.7	0.0
Czechia	69.0	0.1	16.2	6.3	7.0	1.5
Denmark	62.5	0.0	21.2	1.8	14.2	0.2
Germany	67.1	0.2	16.1	6.4	9.3	0.9
Estonia	:	:	:	:	:	:
Ireland	58.9	0.0	19.8	2.4	18.0	1.0
Greece	56.2	4.4	13.5	4.9	21.0	0.0
Spain	43.4	0.9	19.1	7.7	28.9	0.0
France	66.1	0.2	11.1	5.4	17.3	0.0
Croatia	68.7	1.8	10.0	6.5	13.0	0.0
Italy	67.5	0.7	11.9	6.3	12.3	1.4
Cyprus	:	:	:	:	:	:
Latvia	65.6	0.0	18.6	7.2	8.0	0.6
Lithuania	70.3	0.0	9.2	6.5	14.0	0.0
Luxembourg	79.3	0.2	7.1	2.3	11.0	0.0
Hungary	74.0	0.1	12.0	4.5	9.4	0.0
Malta	15.0	8.3	19.8	12.0	43.7	1.2
Netherlands	63.6	0.2	16.7	2.1	17.4	0.1
Austria	69.9	0.0	14.9	2.7	10.4	2.2
Poland	66.0	0.0	16.1	8.1	9.8	0.0
Portugal	21.2	0.7	19.1	39.5	19.6	0.0
Romania	63.4	0.3	13.4	9.5	13.4	0.0
Slovenia	63.7	0.5	16.0	4.1	15.8	0.0
Slovakia	68.3	0.1	14.3	5.6	11.7	0.0
Finland	65.8	0.1	14.9	1.0	12.2	5.9
Sweden	54.5	0.0	13.6	1.5	19.1	11.3
United Kingdom	62.1	0.0	17.2	3.0	17.7	0.0
Norway	43.8	0.0	14.2	0.0	37.1	4.9
North Macedonia	63.3	1.9	11.5	9.3	14.0	0.0
Albania	31.7	5.5	21.4	29.8	11.7	0.0
Serbia	60.2	0.5	14.4	7.3	17.7	0.0
Kosovo*	71.3	3.5	6.5	7.1	9.3	2.2
Moldova	70.7	0.1	10.0	11.2	8.0	0.0
Georgia	58.8	0.3	11.3	17.4	12.1	0.0

(*) This designation is without prejudice to positions on status, and is in line with UNSCR 1244 and the ICJ Opinion on the Kosovo declaration of independence.
(:) not available

Source: Eurostat

eurostat

Figure 4: Share of final energy consumption in the residential sector by type of end-use. Source: Eurostat

Thus, LPG was used to simulate all the residential consumers available in the tool for each of the demo-case country. It follows the complete list of households included in LPG:

[0] CHR01 Couple both at Work
[1] CHR02 Couple, 30 - 64 age, with work
[2] CHR03 Family, 1 child, both at work
[3] CHR04 Couple, 30 - 64 years, 1 at work, 1 at home
[4] CHR05 Family, 3 children, both with work
[5] CHR06 Jobless
[6] CHR07 Single with work
[7] CHR08 Single woman, 2 children, with work
[8] CHR09 Single woman, 30 - 64 years, with work
[9] CHR10 Single man, 30 - 64 age, shift worker
[10] CHR11 Student, Female, Philosophy
[11] CHR12 Student 2, Male, Philosophy
[12] CHR13 Student with Work
[13] CHR14 3 adults: Couple, 30- 64 years, both at work + Senior at home
[14] CHR15 Multigenerational Home: working couple, 2 children, 2 seniors
[15] CHR16 Couple over 65 years
[16] CHR17 Shiftworker Couple
[17] CHR18 Family, 2 children, parents without work
[18] CHR19 Couple, 30 - 64 years, both at work, with home help
[19] CHR20 one at work, one work home, 3 children
[20] CHR21 Couple, 30 - 64 years, shift worker
[21] CHR22 Single woman, 1 child, with work
[22] CHR23 Single man over 65 years
[23] CHR24 Single woman over 65 years
[24] CHR25 Single woman under 30 years with work
[25] CHR26 Single woman under 30 years without work
[26] CHR27 Family both at work, 2 children
[27] CHR28 Single man under 30 years without work
[28] CHR29 Single man under 30 years with work
[29] CHR30 Single, Retired Man
[30] CHR31 Single, Retired Woman
[31] CHR32 Couple under 30 years without work
[32] CHR33 Couple under 30 years with work
[33] CHR34 Couple under 30 years, one at work, one at home
[34] CHR35 Single woman, 30 - 64 years, with work
[35] CHR36 Single woman, 30 - 64 years, without work
[36] CHR37 Single man, 30 - 64 years, with work
[37] CHR38 Single man, 30 - 64 years, without work
[38] CHR39 Couple, 30 - 64 years, with work
[39] CHR40 Couple, 30 - 64 years, without work
[40] CHR41 Family with 3 children, both at work
[41] CHR42 Single man with 2 children, with work
[42] CHR43 Single man with 1 child, with work
[43] CHR44 Family with 2 children, 1 at work, 1 at home
[44] CHR45 Family with 1 child, 1 at work, 1 at home
[45] CHR46 Single woman, 1 child, without work
[46] CHR47 Single woman, 2 children, without work

[47] CHR48 Family with 2 children, without work
[48] CHR49 Family with 1 child, without work
[49] CHR50 Single woman with 3 children, without work
[50] CHR51 Couple over 65 years II
[51] CHR52 Student Flatsharing
[52] CHR53 2 Parents, 1 Working, 2 Children
[53] CHR54 Retired Couple, no work
[54] CHR55 Couple with work around 40
[55] CHR56 Couple with 2 children, husband at work
[56] CHR57 Family with 2 Children, Man at work
[57] CHR58 Retired Couple, no work, no cooking
[58] CHR59 Family, 3 children, parents without work
[59] CHR60 Family, 1 toddler, one at work, one at home
[60] CHR61 Family, 1 child, both at work, early living pattern
[61] CHS01 Couple with 2 Children, Dad Employed
[62] CHS04 Retired Couple, no work
[63] CHS12 Shiftworker Couple
[64] OR01 Single Person Office

In the end, the obtained profiles were assigned to the households of the reference district (a demand profile for each single-family house, one for each apartment for the multi-family houses). The result of using this approach is a realistic representation of the real demand variability, a necessary requirement for highlighting the benefit related to energy sharing [32]. Profiles were generated with a time resolution of one minute and hourly resampled to match the requirements for the inputs of the tool used for the analysis and discussed in Section 0. As shown in Figure 5, this process smooths the shapes of the demands, but it is considered a crucial step for the reduction of the computational time required for optimization. In Figure 5, the electric demands of three different households were reported with a minute and hourly timestep.

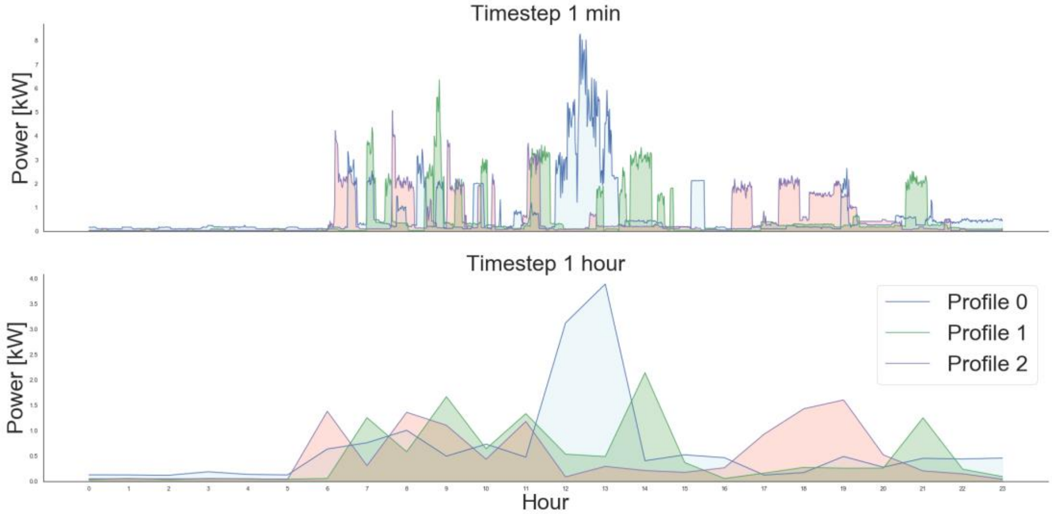


Figure 5: Electric demands

4 Energy district simulations

This section presents the methodology implemented in a specific tool used to optimize the renewable energy sources not only at the building level but also in an urban neighbourhood. We will refer to this tool in the rest of the document as Early-ReNo for the district. Finally, Early-ReNo for the district was used to study the effect of energy sharing for districts composed by a different number of buildings with the aim of highlight the advantages of energy communities in three different contexts.

In summary, the aim of the analysis presented in the following sections is:

1) Evaluate the effect of including the solar thermal (ST) technology in the optimization of renewable energy sources at the district level.
2) Compare the results in photovoltaic (PV) and battery optimization achieved considering the buildings independent or as an energy community able to share their energy flows and the related impact on the local grid
3) Consider different energy district configurations and compare the solutions in case of both individual buildings and community buildings
4) Evaluate the impact of different configurations of the energy community on the local grid

4.1 Methodology

To suggest an adequate capacity for the ST and PV systems and the well-performing areas where to place them, the optimization tool (Early-ReNo for districts) needs a list of all potential module positions (i.e. a cloud of points where a collector can potentially be installed).

Out of the whole number of potential positions (Figure 6), the tool selects some to be occupied by ST and PV collectors while optimizing also the battery capacity. The resulting system is obtained optimizing a certain objective, for example, the net present value (NPV) after a certain number of years. The results of the optimization are the size of the ST and PV plant, the position of the modules and the capacity of the battery.

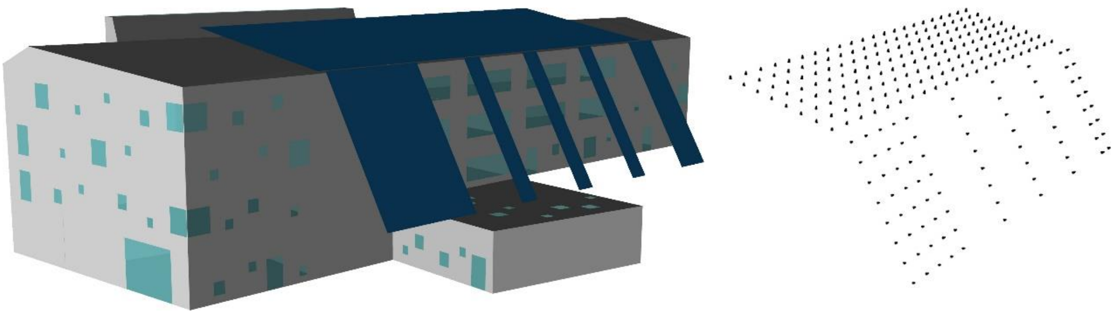


Figure 6 - Cloud of points for the building model [33]

The module of Early-ReNo related to photovoltaic requires a series of inputs to find the proper optimal configuration of panels to minimize or maximize the chosen objective function.
In Figure 7 is represented the conceptual scheme of the PV module of the tool, where the optimization algorithm is the main core.

Figure 7: Conceptual schema of the PV module

Similarly, the ST module requires a series of inputs to find the best position and the optimal number of solar collectors to cover the demand for DHW production. Moreover, the tool selects only the modules which respect some minimum performance thresholds. It follows a brief description of the inputs of the ST and PV modules.

4.1.1 Inputs

- **Cloud of points** which consists of a series of coordinates and directions to describe the sensors where the irradiation would be calculated
- **Irradiation matrix** [kW/m^2] that should be calculated over each position and direction of the cloud of points, this will form the irradiation matrix. The irradiation matrix can be calculated over the cloud of points with various method and tools, such as RADIANCE-based software, starting from weather files and location
- **Area** [m^2] and **efficiency** [%] of the considered PV modules
- **Electricity demand** [kW] is given by the single or cumulative hourly power consumption, usually expressed in [kW] and coming from measured data or generated with electric demand generators such as LoadProfileGenerator (LPG) [31] or calculated from dynamic energy simulations.
- **Price of electricity** [€/kWh] depending on the European country
- **Price net-metered** [€/kWh] remuneration of the injected power in the grid until the production is equal to the consumption
- **Cost of PV** [€/kWp] price of the photovoltaic system considering modules and inverter
- **Cost of BESS** [€/kWp] price of battery energy storage system considering battery system, management system and converters
- **Number of desirable years for NPV** (Net-present value). This input is usually chosen like the PV lifetime (i.e. 25 years).
- **Discount rate**
- **Cost for operation and maintenance** for both PV and BESS systems
- **Cost of the ST collectors** [€/m^2]
- **Yearly average ambient temperature** [°C]
- **Latitude** [deg]

- **Minimum performance thresholds**, minimum efficiency, irradiance, target solar fraction
  Hot water daily consumption per person [l/day]
- **PV degradation** which represents the decline of performance of the system during the time
- **Electricity demand growth** this indicates the increase or decrease of electric demand during the considered years to compute the NPV
- **Cost of electricity,** can increase or decrease during the period for NPV computation
- **Price of sold electricity,** can increase or decrease during the period for NPV computation

4.1.2 ST optimization

Due to the high complexity of district heating modelling, it was not possible to extend the optimization of the solar thermal system at the district level. For this reason, solar collectors were optimized at the single-building level and the selected surfaces subtracted to the ones eligible for PV installation. The algorithm selects the modules with good solar exposure which satisfies some minimum performance thresholds to cover the domestic hot water needs of the building ensuring good economic KPIs. Thus, even if the ST plants are not connected in an energy network, it is important to include this technology in the evaluations. The reason is that ST could modify the area eligible for PV installation with a consequent impact on the KPIs. This is particularly true in case of complex shading scenarios or badly exposed buildings in which the area with good solar exposure is limited. In these cases, ST could drastically decrease the area available for PV installation.

4.1.3 PV optimization

The optimization algorithm used to optimize the PV modules is based on a simple direct search [34] iterated to improve its solution: the initial condition is a system of 0 [kWp] capacity, a first attempt capacity is then found by the direct search and added on the chosen façade among the available ones (in this case roof or facade). The PV capacity added is the solution for this cycle of the direct search, but it will be the starting point for the next cycle. In other words, once the capacity is added, the direct search is repeated but with the new capacity as a starting point instead of the empty system. The process can then be interpreted as painting a PV system on the surface of the building, where the parameters for each stroke are capacity and façade (e.g 62 kWp, roof).

4.1.4 Control strategy

The control strategy of the electric energy storage is explained in Figure 8. The battery was considered ideal and thus, the efficiency of the storage was set equal to 1. Time-dependent losses, thermal effects and ageing were neglected. Better models for electric storage, both in terms of ideality and smart control strategies, should be incorporated in the future.

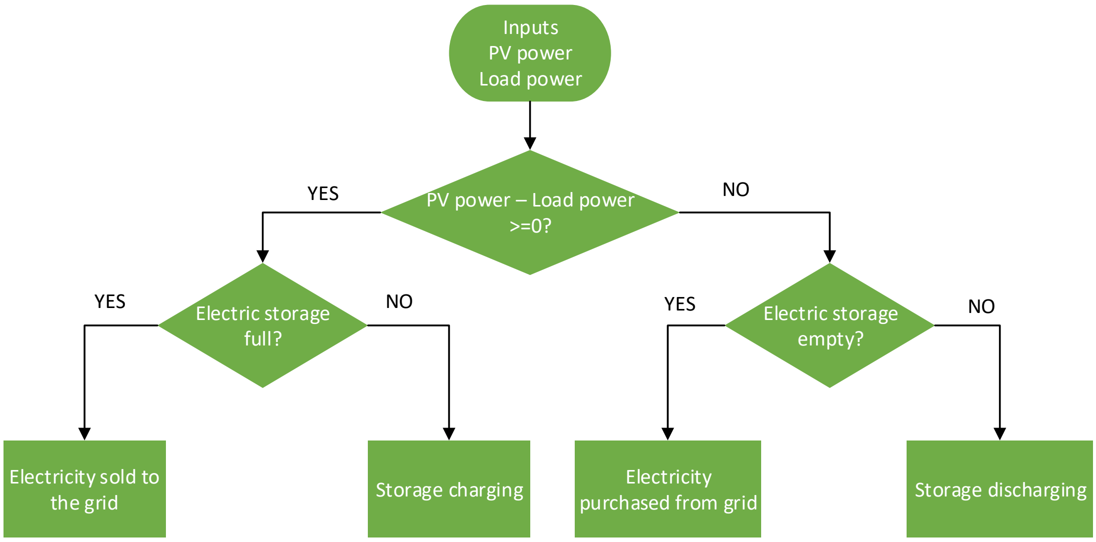


Figure 8: Control strategy of the storage [33]

4.1.5 Metrics

The goal of the optimizations is to evaluate and improve both energy and economic indicators to understand the benefits of interactions of renewable energy at the district level.

The identified key performance indicators are:

- **Self-consumption** (SC), defined as the percentage of the electricity consumed on-site over the total PV production
- **Self-sufficiency** (SS), defined as the percentage of the electricity consumed on-site over the total demand
- **Energy from and to the grid**, the energy exchanged between the buildings and the grid
- **The cumulative energy produced by PV**
- **The net present value** at the end of the period considered
- **Impact on the grid** evaluated with the average, the maximum value, the standard deviation and the mean hourly variation of the injected power normalized to the PV capacity
- **Demand covered** for DHW production expressed as a percentage
- **Internal rate of return** of the investment for ST

4.1.6 Impact on the grid

The impact on the grid was evaluated for all the configurations (single building, neighbourhood and district). The impact was evaluated through the calculation of five parameters related to the power injected into the grid external to the energy community:

- **Mean injected power**, the average power injected in the grid considering only the hours in which the PV plant is producing
- **Percentage of injected power** compared to the produced energy
- **Maximum power injected into the grid**
- **Standard deviation of the injected power**

- **Mean injected power ramp rate**, quantifies how fast the injected power changes in time.

To simplify the comparison, all the parameters were normalized to the system capacity. The firsts two parameters are useful to understand if the system is usually overproducing. The maximum value describes peak conditions. The standard deviation describes the variability of the injected power: from the grid point of view, a low value is desired. The mean hourly variation describes how fast the injected power varies in time, a low value is desirable here too.

It is important to consider that the optimizations were performed with an hourly timestep. This is a commonly adopted assumption in optimization tasks. However, from the electric grid point of view, it introduces relevant approximation drastically smothering the power flows between the grid and the buildings. Moreover, the grid impact is only evaluated in terms of power and the current-voltage regulations are neglected (simplified PV, battery and grid models). For these reasons, the KPIs connected to the grid impact were not used for the calculation of the objective function inside the optimization algorithm but they were used to give a first idea of the interaction between buildings and the grid for the optimal solution. For the early-design phase, this assumption was considered a good compromise between computational speed and complexity.

5 Energy district simulation results

In the following sections, the methodology illustrated in Paragraph 4.1 has been applied to a reference district from the case-studies. The inputs required for the simulations have been collected by the project partners. For each case study, the results of the optimization at different levels have been compared and discussed. Inputs were reported as a table, while a more detailed overview was reported in Chapter 0. Results were divided into three sections, each of them dedicated to the corresponding case-study.

5.1 Dutch case-study

The reference district of Dutch case-study was considered as composed of four terraced houses with different orientations (two of them have a North-South oriented roof, the other two are East-West exposed). Each terraced house was divided into four households. For each household, a profile generated with LPG was assigned (profiles 0-3 to the first terraced house, 4-7 to the second, 8-11 to the third, 12-15 to the last building). Only rooftop surfaces were considered as available for PV and ST optimization.

5.1.1 Inputs

Table 4 summarizes the techno-economic inputs used for the optimization of the Dutch case-study collected from the project partners or set according to the developer's expertise.

Parameter	Description	Values
Area PV [m^2]	Area of a PV module	1.44 m^2
Efficiency of PV [%]	Efficiency of PV modules	16.5%
Price of electricity [€/kWh]	Cost of domestic electricity for the final user	Average €0,21 per kWh
Premium of net metering [€/kWh]	Remuneration for the electricity injected into the grid from PV surplus.	0.09 €/kWh
Cost of PV [€/kWp]	Cost of typical photovoltaic per kWp	1250 €/kWp
Cost of battery [€/kWh]	The typical cost for batteries	670 €/kWh
Discount rate	Discount rate of the investment	3%
Cost for operation and maintenance (O&M) [€/kWp] per year	Cost for O&M for PV and if present also for battery	€0-35 €/kWp
DHW consumption	Hot water daily consumption per person	28 l/day [8]
Cost of solar collectors	Cost of solar collectors per unit area	544 €/m^2
Latitude	Geographic coordinate	52

Average temperature	Average outdoor temperature	11 °C
Target solar fraction	Target demand covered	60%
Years	Years for economic analysis	25

Table 4: Inputs for the Dutch case-study

5.1.2 Results

The solar thermal module of Early-ReNo for districts was used for the optimization of the ST modules installed for each household. In Table 5 the results of the optimization were reported. For all the households the tool suggested the installation of ST modules for both North-South and East-West oriented buildings. In general, the average area per person of installed modules of houses with North-South exposed roofs is lower than the one for East-West oriented roofs due to the higher irradiation. Therefore, the IRR (Internal Rate of Return) calculated on 25 years of South exposed solar thermal plants is higher compared to one with East or West-oriented roofs. The percentage of demand covered is always around 42%.

Household	Number of persons	ST area [m2]	Area/persons [m2/persons]	Demand covered [%]	IRR25 [%]
Household 0	2	1.8	0.9	41	10.96
Household 1	2	1.8	0.9	41	10.68
Household 2	3	2.4	0.8	39	11.51
Household 3	2	1.8	0.9	41	11.02
Household 4	5	4.2	0.84	39	10.84
Household 5	1	1.2	1.2	48	10.94
Household 6	1	1.2	1.2	48	10.98
Household 7	3	2.4	0.8	39	11.5
Household 8	1	1.2	1.2	43	8.63
Household 9	1	1.2	1.2	43	8.63
Household 10	1	1.2	1.2	43	8.63
Household 11	1	1.2	1.2	43	8.63
Household 12	1	1.2	1.2	43	8.63
Household 13	3	3.6	1.2	42	8.02
Household 14	6	6.6	1.1	39	7.68
Household 15	2	2.4	1.2	43	8.35

Table 5: ST results – The Netherlands

Surfaces not selected for the installation of ST modules were analyzed with the module for PV optimization. Three levels of energy sharing were considered: single household, terraced house and district. Results of optimizations are reported in Table 6 and Table 7.

Household	PV [kWp]	EES [kWh]	SC [%]	SS [%]	NPV_{25} [€]
Household 0	2.14	0	46	19	931
Household 1	1.19	0	50	16	514
Household 2	2.61	0	42	19	879

Household 3	3.09	0	49	39	1620
Household 4	2.14	0	49	20	1066
Household 5	1.43	0	45	34	899
Household 6	0.95	0	53	18	611
Household 7	2.38	0	49	23	1203
Household 8	0.48	0	69	14	201
Household 9	0.71	0	67	9	274
Household 10	0.48	0	81	18	292
Household 11	0.48	0	61	17	134
Household 12	0.71	0	72	16	330
Household 13	2.14	0	62	16	530
Household 14	6.89	0	72	32	2866
Household 15	0.71	0	64	12	248

Table 6: Results for single households – The Netherlands

Household	PV [kWp]	EES [kWh]	SC [%]	SS [%]	NPV_{25} [€]
Terraced 1	10.97	0	51	30	6113
Terraced 2	7.47	0	52	26	4522
Terraced 3	2.8	0	71	18	1286
Terraced 4	12.61	0	73	31	6236
District	34.56	0	60	30	25596

Table 7: Results with energy sharing – The Netherlands

To compare the results of single-household optimization and district optimization, the NPVs after 25 years and the PV capacity of all the households were summed while the SC and SS indexes were averaged. The comparison between different levels of aggregation is presented in Table 8 in terms of percentage variation compared to the single-household optimization, used as a reference.

	Households	Terraced houses	District
PV installed [kWp]	28.5	33.9	34.6
NPV_{25} [€]	12596	18156	25596
SC [%]	58	62	60
SP [%]	20	26.3	30
Variation PV installed [%]	-	+18.6	+21.1
Variation NPV [%]	-	+44.1	+103.2
Variation SC compared to households [%]	-	+6.4	+2.6
Variation SS compared to households [%]	-	+30.4	+49.1

Table 8: Comparison of results – The Netherlands

At the increasing of the scale of energy sharing, the tool suggests the installation of bigger PV plants. In general, it is possible to observe an improvement of the energy-related and economic KPIs due to the aggregation of demands and production. All indexes are already improved if energy sharing is allowed at the building level (terraced house). Moreover, district energy sharing drastically improves the NPV_{25} (+103.2) and SS (+49.1%) mainly

due to the optimal positioning of PV modules (due to net-billing, only South facing surfaces with high annual irradiation were selected as shown in Figure 11).
From the grid point of view, except for the average Ramp Rate, all the KPIs increases due to energy sharing. The cause is mainly attributable to the better performing selected areas and the tariff framework. Net billing promotes the injection of energy into the grid during overproduction periods, because it can be purchased at a reduced price during the night or winter period. One of the issues related to the adoption of net billing is that it does not account for the contemporaneity of PV production and electric consumptions and the problems related to grid balancing. This is one of the motivations why net billing might be replaced by new tariff frameworks in the future. On the other hand, going from single-household to district energy sharing, the average Ramp Rate decreases as shown in Table 9, according to the smothering effect caused by the higher number of profiles used in the aggregation process.

Injected power	Households	Terraced houses	District
Standard deviation [W/kWp]	139	134	146
Maximum [W/kWp]	605	587	641
RR [W/h/kWp]	24.1	21.2	20.6
Average [W/kWp]	180	176	199
Variation stdv compared to households [%]	-	-3.5	+5.2
Variation max compared to households [%]	-	-3.1	+6.0
Variation average compared to households [%]	-	-2.4	+10.4
Variation RR compared to households [%]	-	-12.1	-14.5

Table 9: Impact on the grid – The Netherlands

5.1.3 Considerations

The tool suggested the installation of solar thermal modules in all households. When available, it selected South oriented roofs to maximize the irradiation on the surfaces. As will be discussed in the following section, also the PV module tends to select South oriented surfaces to maximize the energy production (due to the presence of the net billing scheme, maximum production is preferred to self-consumption). Since in our methodology (because of practical computational reasons) ST has the priority on the selection of the surfaces, part of the most irradiated area was not available for PV installation. In general, it could be concluded that for the Dutch case-study, ST can be considered as a viable solution for covering part of the DHW demand.
Several important aspects emerged from the optimization of PV. Firstly, it emerged the economic advantage of aggregation highlighted by the sensible increasing of the NPV. Optimization at the terraced house level caused an increase of the NPV by +44.1% and by +103.2% if we consider optimization at the district level. This is mainly caused by the fact that there is a wider availability of well-exposed surfaces. For example, due to the presence of the net billing scheme, when the entire district is optimized, the PV modules

were only installed on South-facing roofs (see Figure 11) to maximize the PV production (net billing decreases the importance of load matching). Of course, this was not possible at a lower scale, particularly for houses with only East-West exposed roofs (as shown in Figure 9 and Figure 10). Moreover, due to the presence of net billing, the battery capacity suggested by the tool is always zero since the grid could be seen as an infinite capacity storage. This has a strong effect on the indexes related to the impact on the grid as shown in Table 9. The tool recognizes the economic advantage of injecting energy into the grid (until a certain threshold). Since the tool can select better-irradiated areas, the normalized average injected power for the district case is 10.4% higher than the average value calculated on single households. A clear improvement is seen for the average RR index (measures how fast the injected power varies in time) which is decreased by more than 10%; this can be explained by the smoothing effect caused by the aggregation of electric demand and production (slower variations). From the electric energy point of view, energy sharing has a positive impact causing an improvement of the economic KPIs.

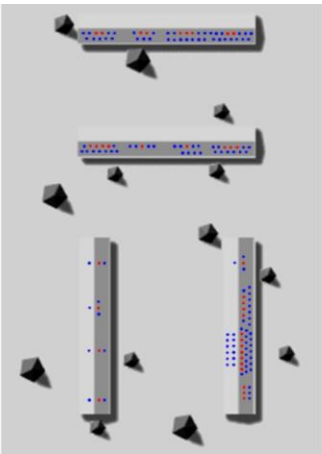


Figure 9: single household

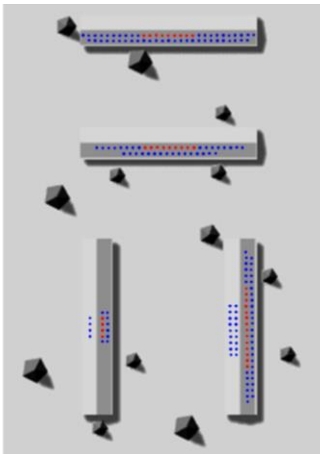


Figure 10: terraced house

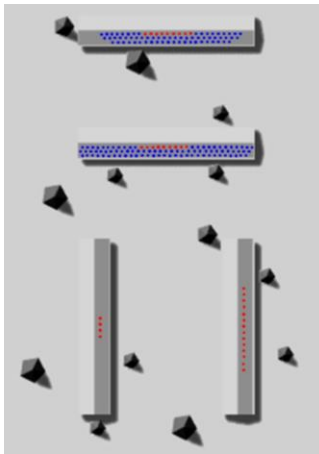


Figure 11: district

ST modules in red, PV modules in blue

5.2 Spanish case-study

The reference district used to represent the Spanish context is composed of two multifamily houses divided into 20 households and eight single-family houses. An electric consumption profile generated with LPG is assigned to each household. Moreover, the district is subdivided in two neighbourhoods composed by a multi-family house and four single-family houses. For the single-family houses, only rooftop surfaces were considered for PV and ST installation while for the multi-family houses also facades were considered.

5.2.1 Inputs

Table 10 summarizes the techno-economic inputs used for the optimization of the Spanish case-study collected from the project partners.

Parameter	Description	Values
Area PV [m^2]	Area of a PV module	1.44 m^2
Efficiency of PV [%]	Efficiency of PV modules	16.5%
Price of electricity [€/kWh]	Cost of domestic electricity for the final user	Average €0,14 per kWh
Premium of net metering [€/kWh]	Remuneration for the electricity injected into the grid from PV surplus.	0 €/kWh
Cost of PV [€/kWp]	Cost of typical photovoltaic per kWp	1200 €/kWp
Cost of battery [€/kWh]	The typical cost for batteries	800 €/kWh
Discount rate	Discount rate of the investment	3%
Cost for operation and maintenance (O&M) [€/kWp] per year	Cost for O&M for PV and if present also for battery	€0-35 €/kWp
DHW consumption	Hot water daily consumption per person	28 l/day
Cost of solar collectors	Cost of solar collectors per unit area	503 €/m^2
Latitude	Geographic coordinate	39
Average temperature	Average outdoor temperature	18 °C
Target solar fraction	Target demand covered	60%
Years	Years for economic analysis	25

Table 10: Inputs for the Spanish case-study

5.2.2 Results

Similarly to the Dutch case-study, the first step of the analysis is the optimization of the solar thermal systems for domestic hot water production. Even in Spain, it was assumed that solar thermal is installed independently between buildings. However, for the multi-family house, it was assumed that the production of domestic hot water can be shared between households. Thus, the solar thermal system is optimized at building level (20 households for the multi-family houses) while the PV system is optimized for each building, at neighbourhood and the district level. In Table 11 the results of the optimization of the ST systems for the Spanish case study were reported.

Household	Number of persons	ST area [m^2]	Area/persons [m^2/persons]	Demand covered [%]	IRR25 [%]
Multi-family 1	49	21	0.43	38	19.48
Multi-family 2	45	19.2	0.43	38	19.52
Household 41	2	1.2	0.6	44	17.73
Household 42	1	0.6	0.6	45	18.36
Household 43	1	0.6	0.6	45	18.42
Household 44	1	0.6	0.6	45	18.85

Household 45	1	0.6	0.6	45	18.1
Household 46	4	1.8	0.45	38	18.76
Household 47	1	0.6	0.6	45	18.39
Household 48	1	0.6	0.6	45	18.45

Table 11: ST results - Spain

For all the buildings, the tool suggests the installation of solar thermal modules. The mean percentage of domestic hot water demand covered is equal to 42.8% with an average of 0.55 m^2 of ST surface per person. With respect to the Dutch case-study, the installed solar thermal area per person is reduced by 50% mainly due to the higher solar resource availability. Therefore, the IRR of the investment for the ST plant is significantly improved (+90% on average). The surfaces not selected for the installation of ST modules were optimized for the installation of PV modules. We considered also for Spain different scenarios of energy sharing: single building (multi-family houses and single-family houses), neighbourhoods (a multi-family house and four single-family houses) and district. In Table 3 the results of the PV optimization of the Spanish case-study were reported in an aggregated form (PV installed and NPV summed, SC and SP averaged).

	Building	Neighbourhoods	District
PV installed [kWp]	50	52.8	53
NPV_{25} [€]	48944.1	53443.7	55448.8
SC [%]	79.7	82.7	83.6
SS [%]	17.8	32	33
Variation PV installed [%]	-	+5.6	+6.1
Variation NPV [%]	-	+9.2	+13.3
Variation SC [%]	-	+3.8	+5.0
Variation SS [%]	-	+79.8	+85.4

Table 12: Comparison of results - Spain

For the Spanish case-study, results were strongly influenced by the tariff scheme (fixed tariff was considered, no net-billing). The tariff framework has a strong effect particularly on the SC and SS indexes at building level: the optimal solution from an economic point of view consisted of a system where most of the produced energy is self-consumed. The absence of net-billing increased the importance of direct self-consumption. Going from single building to district energy sharing level, it was possible to observe an increase of the energy KPIs such as the SS (+85%), the total capacity installed (+5.6% for neighbourhoods, +6.1% for the district, see Figures Figure 12, Figure 13 and Figure 14) and the NPV after 25 years (+9.2% for neighbourhoods and +13.3% for districts). No battery was installed.

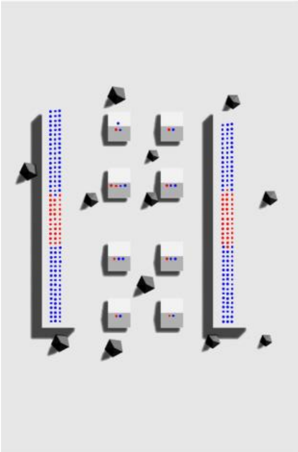


Figure 12: single building

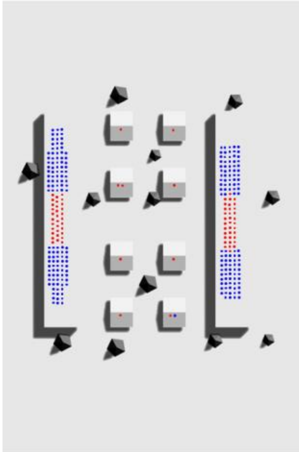


Figure 13: neighbourhoods

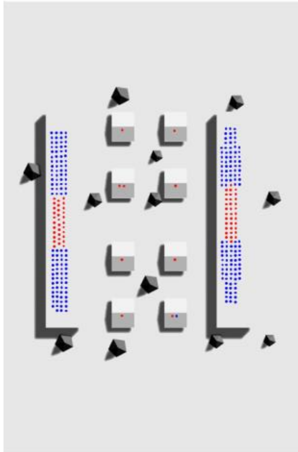


Figure 14: district

ST modules in red, PV modules in blue

From the grid point of view, all the KPIs accounting of the impact on the external grid were significantly reduced considering energy sharing. The major effect can be seen for the reduction of the average injected power (-42.7% if energy sharing is allowed at the district level). This positive effect can be attributed to the combination of energy sharing and a tariff scheme that promotes direct self-consumption.

Injected power	Buildings	Neighbourhoods	District
Standard deviation [W/kWp]	122.3	102.9	95.5
Maximum [W/kWp]	501.2	451.8	425.3
RR [W/h/kWp]	25.8	17.4	14.8
Average [W/kWp]	190.7	158.3	150.2
Variation stdv [%]	-	-15.8	-21.9
Variation max [%]	-	-9.9	-15.1
Variation average [%]	-	-32.6	-42.7
Variation RR [%]	-	-17.0	-21.2

Table 13: Impact on the grid - Spain

5.2.3 Considerations

In Spain, both the optimization of the ST and PV technologies gave positive results. Thanks to the highly available solar resource, for the district under analysis, ST can cover more than 40% of the heating demand for domestic hot water production. From an economic point of view, results confirmed that ST in Spain is a convenient technology (average IRR > 18%). From the photovoltaic point of view, energy sharing has a positive impact on all the economic and energy-related KPIs (NPV +13%, SS +85% at district level). Moreover, results showed how the tariff scheme can influence the impact on the external grid. Thanks to the fixed tariff scheme, direct self-consumption is preferred with respect to injecting energy into the grid and purchased it in a second moment. This effect is confirmed by the decreasing of all the KPIs related to the impact on the grid (for example, average injected power -42%).

5.3 Norwegian case-study

The reference district used for the analysis of the Norwegian demo-case is composed of sixteen single-family houses. Only rooftop surfaces were considered as available for PV and ST optimization. For the Norwegian context, the neighbourhoods were defined as a group of four houses. Thus, the analysis was done considering three levels of energy sharing: single building, neighbourhoods and district.

5.3.1 Inputs

According to the considerations reported in paragraph 2.2, the electricity price used in the analysis was increased with respect to the actual status. The reason for this choice was to consider future scenarios where the price of electricity will probably increase. Considering the actual price of electricity (0.08 €/kWh) only very small PV plants are installed and the effect of energy sharing at the district level is not clear. Additionally, it was assumed a uniform cost of PV with respect to the other demo-cases assuming a slight decrease in prices in future years. Table 14 summarizes the techno-economic inputs used for the optimization of the Norwegian case-study collected from the project partners. Net-metering was not considered.

Parameter	Description	Values
Area PV [m^2]	Area of a PV module	1.44 m^2
Efficiency of PV [%]	Efficiency of PV modules	16.5%
Price of electricity [€/kWh]	Cost of domestic electricity for the final user	Average €0,10 per kWh
Premium of net metering [€/kWh]	Remuneration for the electricity injected into the grid from PV surplus.	0.05 €/kWh
Cost of PV [€/kWp]	Cost of typical photovoltaic per kWp	1250 €/kWp
Cost of battery [€/kWh]	The typical cost for batteries	500 €/kWh
Discount rate	Discount rate of the investment	3%
Cost for operation and maintenance (O&M) [€/kWp] per year	Cost for O&M for PV and if present also for battery	€0-35 €/kWp
DHW consumption	Hot water daily consumption per person	28 l/day
Cost of solar collectors	Cost of solar collectors per unit area	641 €/m^2
Latitude	Geographic coordinate	59
Average temperature	Average outdoor temperature	6.5 °C
Target solar fraction	Target demand covered	60%

Years	Years for economic analysis	25

Table 14: Inputs for the Norwegian case-study

5.3.2 Results

Even for the Norwegian case-study, the first step for the optimization of the installation of RES at the district level is the analysis regarding the ST technology. As for Spain and Netherlands, district heating was not considered a viable solution and the ST systems were optimized at single-building level (single-family house in this case). In Table 15 the results of the optimization of the ST systems were reported.

Household	Number of persons	ST area [m^2]	Area/persons [m^2/persons]	Demand covered [%]	IRR25 [%]
Single-family 1	2	2.4	1.2	41	3.85
Single-family 2	3	2.4	0.8	38	6.64
Single-family 3	2	2.4	1.2	42	3.98
Single-family 4	5	4.2	0.84	38	6.14
Single-family 5	1	1.2	1.2	47	6.2
Single-family 6	1	1.2	1.2	43	4.37
Single-family 7	3	2.4	0.8	38	6.66
Single-family 8	1	1.2	1.2	43	4.36
Single-family 9	1	1.2	1.2	43	4.37
Single-family 10	1	1.2	1.2	47	6.21
Single-family 11	1	1.2	1.2	43	4.42
Single-family 12	1	1.2	1.2	47	6.24
Single-family 13	3	2.4	0.8	38	6.78
Single-family 14	6	6.6	1.1	38	3.34
Single-family 15	2	1.8	0.9	40	6.3
Single-family 16	2	2.4	1.2	42	4.08

Table 15: ST results - Norway

For the Norwegian case-study, the tool suggests the installation of solar thermal modules to cover part of the demand to produce domestic hot water. However, due to the lower irradiance connected to the geographical position of the demo-case and the lower energy costs, the IRR calculated on 25 years (5.25% on average) is significantly lower with respect to the Spanish (18.6%) and Dutch (9.72%) case-study. On the other hand, the ratio ST area/person increases to guarantee the same degree of demand coverage (on average 41.75% for Norway).

Even for Norway, surfaces not selected for the installation of ST modules were used for the optimization of the photovoltaic systems at building, neighbourhoods and district level. Table 16 summarizes the results aggregated by the level of energy sharing allowed in the optimization. No battery was installed.

	SF house	Neighbourhoods	District
PV installed [kWp]	2.1	8.4	11.7
NPV_{25} [€]	292.7	1482.2	2195.4
SC [%]	39.3	93.0	93.2
SS [%]	3.1	11.0	16.0
Variation PV installed [%]	-	+301.9	+458.4
Variation NPV [%]	-	+406.5	+650.2
Variation SC [%]	-	+136.6	+137.1
Variation SS [%]	-	+252.0	+412.0

Table 16: Comparison of results - Norway

Even in Norway, energy sharing has a positive effect on all the KPIs, both from the energy and economic point of view. Since the solar resource in Norway is lower than in the other countries, the optimal systems are generally undersized as shown by the low values of SS (the energy produced is only a small percentage of the energy consumed). On the other hand, energy sharing (percentages reported refer to the district level) drastically improves the economic performances of the systems (NPV +650.2%), causing an increase of the optimal system size (+458.4%, Figure 17). The effect is an improvement of the energy-related KPIs, particularly for the SS index which represents the percentage of the demand covered by the RES (from 3% to 16%). All the KPIs connected to the impact on the grid are increased for the configurations in which energy sharing is allowed. This effect can be explained by the fact that most of the energy produced is self-consumed (SC>93%). Thus, the grid impact KPIs are calculated only on a small percentage of the energy produced and injected into the grid (7%). Moreover, the energy injected is related to limit conditions (peak of production when the demand is low). From the technical point of view, this effect must be taken into consideration when designing undersized systems (that, in this case, are the most beneficial from the economic point of view): most of the energy is usually self-consumed but variations related to the power injected can be significant during specific conditions.

Injected power	Buildings	Neighbourhoods	District
Standard deviation [W/kWp]	52.3	117.7	106.8
Maximum [W/kWp]	239.0	501.8	462.1
RR [W/h/kWp]	4.5	8.8	7.7
Average [W/kWp]	76.6	158.8	144.6
Variation stdv [%]	-	+125.0	+104.1
Variation max [%]	-	+110.0	+93.3
Variation average [%]	-	+93.3	+69.5
Variation RR [%]	-	+107.2	+88.6

Table 17: Impact on the grid - Norway

Figure 15: SF house

Figure 16: neighbourhoods

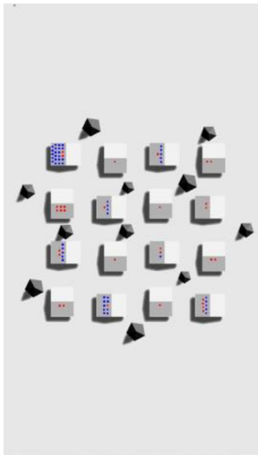


Figure 17: district

ST modules in red, PV modules in blue

5.3.3 Considerations

The analysis of the Norwegian case-study presented in the previous paragraph is based on the hypothesis of a district composed of single-family houses. From the solar-thermal point of view, results show that even in Northern countries ST could be a viable solution to produce part of the domestic hot water. With respect to the other countries used in this analysis, the lower solar resource and energy costs of Norway causes a decreasing of the IRR, but it remains positive. Thanks to the composition of the reference district (single-family house), the optimization of the PV technology of the Norwegian case-study highlights the benefit of energy sharing. Both the economic and energy KPIs are drastically improved considering the possibility of sharing demand and production at the district level. The most important benefit is seen for the SS index (from 3% to 16%) confirming that energy sharing can be an important driver for the decarbonization of the residential sector. Since the economically optimal PV systems are slightly undersized from the energy point of view (SC>93%), KPIs related to the grid impact could increase if energy sharing is allowed. An option to decrease these fluctuations and mitigate the peaks of power injected into the grid could be to consider the installation of batteries.

6 Conclusions

This document focuses on the analysis of the adoption of photovoltaic and solar thermal technologies, harvesting solar radiation, at the district level in three demo-cases (located in The Netherlands, Spain, Norway). The first step of the analysis was the collection of the inputs required to understand the context of each demo-case. Thanks to the contribution of the project partners it was possible to collect all the input required for the energy and economic analysis and in general to understand the normative framework of the demo-case countries.

It was shown that in the case-studies selected for the analysis, both photovoltaic and solar thermal technologies are a viable solution for covering part of the energy consumptions in the residential sector. Even if energy sharing between buildings was considered acceptable only for electricity, solar thermal and photovoltaic could be competitive solutions in the optimization process aimed at the definition of position on the available surfaces of the mentioned technology. It is thus important to account for both the technologies from the earliest stages of the design process. Since the objective function used in the optimizations was to maximize the NPV, no battery was installed in any case studies. This is because of the presence of the net-metering tariff scheme and because batteries have currently high initial costs, although they have been decreasing over the past years and the trend is expected to continue. Through the analysis of the current state and possible future scenarios consisting of different levels of energy sharing, results show that energy communities could become a driver for the adoption of distributed renewable energy generation. In all the case-studies, results show an improvement of the energy and economic KPIs for the scenario in which energy sharing is allowed at the district level. This means that energy communities could play a relevant role in the decarbonization process of the residential sector. On the other hand, it was shown how energy sharing, if not combined with an updated tariff scheme, could lead to an increase of the impact on the grid with possible technical and economic side effects.

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