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Master of Science – Energy Engineering

Smart Villages and Energy Communities: a real case study in Valle d'Aosta

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Table of Contents

List of Figures

List of Tables

Sommario

Spesso le aree montane, isolate, scarsamente popolate o rurali sono state trascurate dalla comunità scientifica e dai decisori politici nella trattazione delle norme sul cambiamento climatico, ma queste aree possono avere un potenziale interessante nel contesto della transizione energetica, specialmente considerando la crescente domanda globale di energia. Negli ultimi anni, l'Unione Europea ha promosso iniziative a favore di queste aree, quali il progetto INTERREG "Smart Alpine Space" che si focalizza sull'idea di Smart Village, concetto complementare alle Smart Cities per quanto riguarda le piccole comunità, e il Clean Energy Package, che fornisce ai cittadini anche una regolamentazione in materia di comunità energetiche. Con questo lavoro di tesi si analizza un caso di applicazione reale di questi due strumenti, i quali incoraggiano la partecipazione dei cittadini alle attività della comunità e promuovono un consumo consapevole e condiviso dell'energia.
Da una collaborazione tra Poliedra, consorzio del Politecnico di Milano, e la regione Valle d'Aosta, è stato implementato nella regione un caso reale di approccio Smart Villages, i cui risultati sono stati trattati tramite un metodo di ranking e hanno confermato l'impegno regionale a raggiungere gli ambiziosi obiettivi di diventare carbon e fossil fuel free per il 2040. Il lavoro è stato portato avanti a livello locale, con uno Smartness Assessment inviato all'Unité des Communes Grand Paradis, che ha evidenziato la volontà del territorio di aumentare la sua produzione di energia rinnovabile.
Forti di questa volontà politica, nella medesima area i due comuni di Avise e Arvier sono stati selezionati per simulare un caso reale di comunità energetica: è stata fatta una analisi di lungo periodo sui benefici economici di una diversa trasposizione italiana delle normative espresse nelle direttive del Clean Energy Package, in particolare introducendo la possibilità ad utenti di cabine secondarie diverse di essere membri della stessa comunità energetica. Un modello precedentemente sviluppato è stato adattato a questo caso ed è stato utilizzato per simulare i flussi di energia tra gli utenti e i relativi flussi di cassa. Tramite un'ottimizzazione MILP si sono determinati in ogni casistica l'installazione della capacità ottimale dei pannelli fotovoltaici e dei sistemi di immagazzinamento dell'energia. Inoltre, è stata approfondita la possibilità di supportare parzialmente o totalmente la decarbonizzazione del riscaldamento nei due comuni.

Parole chiave: Smart Village, comunità energetiche, energia rinnovabile, MILP

Abstract

Often mountain, isolated, sparsely populated, or rural areas have been neglected by scholars and policymakers in climate change policy discussions, but these areas can have interesting potential when assessing a capillary transition to renewable energy exploitation, especially considering the increasing global demand of energy. In the last few years, the European Union promoted initiatives favouring these areas, as the INTERREG project "Smart Alpine Space", focused on the Smart Villages concept, which is complementary to Smart Cities but concerning little communities, and as the Clean Energy Package, which amongst other initiatives contains rules regarding energy communities. With this thesis work, a real case study focused on the application of these two tools is analysed, which promotes citizens participation to a wide range of collective actions in the community and promote an informed and shared usage of energy.

From a collaboration between Poliedra, consortium of Politecnico di Milano, and Valle d'Aosta, a real case study of Smart Villages' approach was implemented in the Region, and the results, evaluated through a ranking method, confirmed the regional commitment in reaching the ambitious objectives of becoming carbon and fossil fuel free by 2040. Then, the work moved to a local level, submitting a Smartness Assessment to Grand Paradis Unité des Communes, which highlighted the willingness of the territory in increasing renewable energy production.

Acknowledged by this political will, in the same test area the two municipalities of Avise and Arvier were selected for comparing in a long-term analysis the economic benefits of a different Italian transposition of regulations and directives expressed in the Clean Energy Package, in particular considering the possibility to users of different secondary substations to become members of the same energy community.

A previous developed model was adapted to this case and was used to simulate energy fluxes between the users and the relative cash flows. Thanks to a MILP optimization for each case the optimal installation capacity of PV panels and storage systems was determined. Then, the possibility of partially or totally supporting the decarbonization of heating systems was investigated.

Key Words: Smart Village, Energy Community, renewable energy, MILP

Extended Abstract

Over the past years scholars and policymakers when addressing the issue of climate change focused mainly on the national and global levels of governance more than local climate actions, neglecting this last topic from climate change policy discussions, in particular talking about rural or isolated areas [1]. These areas can have interesting potential when assessing a capillary transition to renewable energy exploitation especially considering the increasing global demand of energy [2]. The General Assembly of the United Nations adopted seventeen Sustainable Development Goals (SDGs) to be reached by 2030, two of which particularly aim in this direction [3]. The seventh target which addresses access to affordable, reliable, sustainable and modern energy for all and the eleventh target, cantered on sustainable cities and communities.
In this context, the present thesis work has focused on the concepts of Smart Villages and Energy Communities which introduce a wide range of collective energy actions that involve citizens' participation, also in the energy system, and that could help in reaching these goals. The work is the result of the collaboration between Poliedra, the Energy Department of Politecnico di Milano and Autonomous Region of Valle d'Aosta. From the second half of 2020, Poliedra, consortium of the Politecnico di Milano and partner of the Interreg Alpine project "Alpine Space SmartVillages", is supporting the autonomous Italian region of Val d'Aosta in defining the 2021-2027 European Programme, in which digital technologies could help in improving life quality of the more isolated communities.
In the same region the topic of energy communities is discussed: Energy Communities could accelerate the energy transition to clean energy resources in the Region, engaging also mountain and isolated areas, creating awareness on renewable energy production and strengthening communities.

Smart Villages

The European Journey on Smart Villages

Smart Villages (SVs) are about citizens in rural areas, determined in finding practical solutions to transform their local area, using digital technologies when necessary. SVs can help in connecting different territories, rural or urban, by strengthening cooperation between groups of communities, but also by creating bottom-up alliances between different rural partners and actors, including both private and public sector [4].
Smart Villages were discussed in European institutions and many conferences and documents evidenced their potential, as the "Cork Declaration 2.0 – A Better Life in Rural Areas" addressed to the European policy makers in September 2016 [5], or the document "EU action for Smart Villages" in April 2017, in which Smart Villages' approach is not proposed as a one-size-fits-all solution, but rather as a tool that could empower local strengths with digital technologies, recognizing that every area should be in the position of making use of ICTs (Information and Communication Technologies), to improve local

economy and basic services [6]. Moreover, in 2018 with the "Bled declaration for a Smarter Future of the Rural Areas in EU" the interest in the Smart Villages initiative is stated, by promoting digital and social transformation, supporting, rebuilding and developing strong rural communities throughout the Union [7].

Definition of Smart Villages and Main Problems of rural areas

There is not a unique definition of Smart Villages, considering that this concept depends on socio-cultural structures, different circumstances, societal problematics and reflects difficulties encountered by each individual community [8]. In 2018 an actual working definition was proposed in which Smart Villages are seen as communities in rural areas that use innovative solutions to improve their resilience, building on local strengths and opportunities, relying on participatory approach and by mobilising solutions offered by digital technologies [9].

This approach should be seen as an opportunity to improve the quality of life of inhabitants of rural areas and not as a showcase for cutting-edge technology, bearing in mind that the main goal are the people and their communities and offering the chance to create a participation model adaptable to meet the needs in the considered local context, dealing with different challenges through a bottom-up approach.

To analyse Smart Villages seven smart dimensions are taken in account, recalling from Smart Cities' literature [42]: Smart Economy, Smart Environment, Smart Mobility, Smart Living, Smart People, Smart Governance.

Energy communities

The Clean Energy Package (CEP) was completed in May 2019, embedding eight Regulations and Directives, including the dimensions of energy security, internal energy market, energy efficiency, decarbonization of the economy and research, innovation, and competitiveness [10] and setting the ambitious targets for 2030 in the direction of a ~~free~~ carbon free economy. The Renewable Energy Directive (RED II) EU 2018/2001 is part of the CEP: it comes into force in December 2018 and it should be transposed into national law by all the 28 Member States by the 30th of June 2021 [11]. This Directive states definitions of the various part embedded in the energy balance, recognizing their role in the market, including energy communities, which are distinguished between Renewable Energy Communities (RECs) and Citizen Energy Communities (CECs) with differences summarized in the following table [51].

Summary of differences between RECs and CECs from [51]

	Renewable Energy Communities (RECs)	Citizen Energy Communities (CECs)
Members	Residential, tertiary sector, Public Administration, small or medium industries	Residential, tertiary sector, Public Administration, small industries
Type of energy	Electric and thermic energies, only from renewable sources	Only electric energy, both from renewable and not renewable sources

Perimeter of action	Proximity	No constraint, also cross border participation is possible
Authorized activities	Production, selling, self-consuming, storing, sharing, access to the market	Production, selling, self-consuming, storing, sharing, access to the market, distribution, supply, services as energy efficiency or recharging cars

The Italian temporary and partial transposition of RED II was given in February 2020 in the so called *Decreto Milleproroghe* [12], in which energy communities were defined only as RECs with limitations on power output for renewable plants (≤ 200 kW) as well as requiring users of RECs to be connected to the same secondary substation and for collective renewable self-consumers users to be in the same building. Also, concerning incentives, these are foreseen only for plants entered into operation after the decree actuation. This decree was then updated with an implementation decree in September 2020 by Mise, stating about the incentives for renewable power plants, then in August 2020 with a deliberation by ARERA acknowledging self-consumption and energy communities and then in December 2020 with technical rules by GSE.

Energy communities and Smart Villages

Energy Communities and Smart Villages are both based on empowering people: the process starts from the bottom with participatory approach, by informing the community of the opportunity to gain benefits for different sectors, from environment to social cohesion, or from mobility to health. In fact, Smart Villages strategies could enable the formation of successful energy communities in rural areas, helping with the decarbonization process, with advantages, as the possibility to have an income that could be reinvested in social innovation, or also into smart tourism projects, promoting the local zone, or into reinforcing the local economy resilience, maybe helping the most vulnerable part of population.

Proposed methodology for energy communities' simulations.

A model developed in a previous master thesis which optimizes the capacity of PV panels and storage solutions to maximise the NPV of an investment in an energy community has been adapted to this case and utilized for the analysis in subject. Analysing energy flow, at the instant t the available energy for the community $E_{com}^{avail}(t)$ is the sum of energy produced by the k PV panels as in (1), while the requested energy $E_{com}^{req}(t)$ is the sum of the i user load, as in (2).

$$E_{com}^{avail}(t) = \sum_{k\in EC} \left|E_k^{gen}(t)\right| \tag{1}$$

$$E_{com}^{req}(t) = \sum_{i\in EC} E_i^{load}(t) \tag{2}$$

It is also possible to compute the energy shared within the community at the instant t $E_{com}^{shared}(t)$ (3), the energy need by the community $E_{com}^{need}(t)$ (4) and the energy in surplus $E_{com}^{surpl}(t)$ (5):

$$E_{com}^{shared}(t) = \min\left(E_{com}^{avail}(t), E_{com}^{req}(t)\right) \quad (3)$$
$$E_{com}^{need}(t) = E_{com}^{load}(t) - E_{com}^{shared}(t) \quad (4)$$
$$E_{com}^{surpl}(t) = E_{com}^{avail}(t) - E_{com}^{shared}(t) \quad (5)$$

Concerning the charging and the discharging of the batteries, if the energy surplus is lower than the storable energy (6), which depends on the capacity of the battery b and on the state of charge SOC (9), the battery is charged (7), and the new state of charge is evaluated (9). Instead, if the energy surplus is lower than the storable energy (10), the battery is discharged up to the depth of discharge (11,13). Charging and discharging processes are limited by the characteristics of the batteries as the capacity b and the C_{rate} and by the efficiencies of charging and discharging.

$$\text{If } E_{com}^{surpl}(t) < b - SOC(t-1) \quad (6)$$
$$E^{ch}(t) = \min\left(\frac{b}{C_{rate}}; E_{com}^{surpl}(t) * \eta_{ch}\right) \quad (7)$$
$$E_{com}^{int}(t) = 0 \quad (8)$$
$$SOC(t) = SOC(t-1) + E^{ch}(t) \quad (9)$$

$$\text{If } E_{com}^{surpl}(t) \geq b - SOC(t-1) \quad (10)$$
$$E^{ch}(t) = \min\left(\frac{b}{C_{rate}}; b - SOC(t-1) * \eta_{ch}\right) \quad (11)$$
$$E_{com}^{int}(t) = E_{com}^{surpl}(t) - E^{ch}(t) \quad (12)$$
$$SOC(t) = b \quad (13)$$

Variables in the model are the capacity of the battery b and the PV capacity for each available roof k, contained in the available set of roofs S, which are defined as $x_k \forall k \in S$ Constrains include the energy balance (14), the self-consumed energy (15), the energy sold to the grid (16), the energy withdrawn from the grid (17):

$$\sum_k E_k^{gen}(t) * x_k + E^{with}(t) + E^{dis}(t) = E^{load}(t) + E^{int}(t) + E^{ch}(t) \quad (14)$$
$$E^{self}(t) = min\left(\sum_i E_i^{load}(t); \sum_k E_k^{gen}(t) * x_k\right) \quad (15)$$
$$E^{int}(t) = max\left(0; \sum_k E_k^{gen}(t) * x_k - E^{self}(t) - E^{ch}(t)\right) \quad (16)$$
$$E^{with}(t) = max\left(0; \sum_i E_i^{load}(t) - E^{self}(t) - E^{dis}(t)\right) \quad (17)$$

The capacity installed is equal or less than the maximum power that could be installed (18) and for each roof the capacity should be null or positive (19):

$$x_k \leq P_k^{max} \quad (18)$$
$$x_k \geq 0 \quad (19)$$

Constraints given by the batteries regard the state of charge at different times (20), the maximum charge (21), the maximum discharge (22), the maximum power in charge and discharge (23) and by the battery reposition costs (26) and maximum capacity of the storage systems (27):

$$SOC(t) = \begin{cases} b * SOC_{initial} - \dfrac{E^{dis}(t)}{\eta_{dis}} + E^{ch}(t) * \eta_{ch} & if\ t = 1 \\ SOC(t-1) - \dfrac{E^{dis}(t)}{\eta_{dis}} + E^{ch}(t) * \eta_{ch} & if\ t > 1 \end{cases} \quad (20)$$

$$SOC \ \leq b \quad (21)$$

$$SOC \ \geq b * DoD \quad (22)$$

$$P_{stor}^{max} = \frac{b}{T_{ch/dis}^{max}} \quad (23)$$

$$E^{ch}(t) \leq P_{stor}^{max} * \Delta t \quad (24)$$

$$E^{dis}(t) \leq P_{stor}^{max} * \Delta t \quad (25)$$

$$C_{batt}^{rep} = \sum_{t} (E^{ch}(t) + E^{dis}(t)) * \ c_{batt,rep}^{unitary} \quad (26)$$

$$c_{batt,rep}^{unitary} = \frac{C_{batt}^{replaceable}}{N^{cycles} * 2 * (1 - DoD)}$$

$$b \leq 5kWh * n_{users} \quad (27)$$

Objective function (28) maximizes the NPV over a period of time l: it considers the costs of PVs installation and of the batteries, and the actualized cash flow over a period of time l, where SES_i shared energy saving index: this index valorises the energy shared between community's members.

$$\begin{aligned} \max(NPV) = & -\sum\nolimits_{k} C_{k}^{fix} * x_k \ - C_{batt}^{fix} * b \\ & + \sum\nolimits_{l} \left(\frac{-\sum_k C_k^{var} * x_k \ - C_{batt}^{var} * b - C_{batt}^{rep} - C_{admin}}{(1+k)^l} \right. \\ & \left. + \frac{\left(E^{load}(t) - E^{with}(t)\right) * SES_i + E_t^{inj} * p_{zonal}(t)}{(1+k)^l} \right) \end{aligned} \quad (28)$$

Within the present work the model has been updated by scaling up the modelling capacity to treat from approximately ten users up to one thousand users, also by enabling data input from pre-processed real datasets provided by local authorities. The data processing tool, designed in Python language as it is the model, takes the data and a reference profile, then generates the annual hourly load profiles for each user making the data readable for the model. Moreover, the model was rendered capable of using GIS analysis results on target locations to calculate the features of the roofs, as available areas, azimuth angles, tilt angles, evaluating the best surfaces where to place the PV panels, summarising the outputs and making them readable.

The case of Valle d'Aosta Region

Smart Villages: regional and local Smartness Assessment

The collaboration between Poliedra and Valle d'Aosta Region focused on creating a system to identify policies and work guidelines to promote actions and measures concerning "Smart Villages" to be included in the 2021-2027 European Programme. Initially, good practices are collected following the three Design Thinking principles [13], which are desirability, involving what is desirable and needed by the local population; viability, providing a solution which could be supported economically in a short and long term and feasibility, having technologies, knowledges, and policies to actualise the solution provided. After collecting a complete picture of the main needs, a Smartness Assessment based on the seven smart dimensions previously discussed was prepared: for each dimension seven statements are present. It was submitted in December 2020 to the main stakeholders, which are the fourteen Departments of the Region and the Regional General Secretary. They had to compile the part of the questionnaire referred to their different competences and areas of interest, plus Smart Governance which was mandatory for each Department.
Looking at results, the high total score in Smart Environment shows that all the Departments agree in moving together to reach the ambitious objectives of the Region for 2040 with a great interest for sustainability, addressing this challenge from different sides. Smart Economy captured a great interest having a high score. The dimension of Smart Governance, which was mandatory in compiling for each Department, is crucial to help public administration (PA) in digitalizing, with advantages both for the citizens and for the different offices. A lot of talks have been made about digitalization of the PA and this topic is also included in the first mission of Italy's Piano Nazionale di Ripresa e Resilienza (PNRR). Smart Mobility in the last place was penalized especially by a strong difference in approaching the questionnaire by some Departments.

Smart Environment	9.73
Smart Economy	9.35
Smart Governance	7.57
Smart People	7.30
Smart Living	5.11
Smart Mobility	5.06

Results of the Regional SA: sum of utilities for each dimension

Highest score is reached by the third statement of Smart Economy: in Italy's Piano Nazionale di Ripresa e Resilienza (PNRR) almost double the funds for Digitalization in PA are allocated to Digitalization, Innovation and competitivity in the productive system. This is reflected in these results.

First five statements		
Smart Dimension	*Number of statement*	*Utilities*
Smart Economy	3	2.33
Smart Environment	6	2.16
Smart Governance	3	2.09
Smart Governance	2	1.88
Smart Environment	5	1.85

First five statements for each dimension

In a Smart Village approach the territory should be considered as central, as it could be seen by the score of the sixth statement of Smart Environment, taking care of the territory is essential in a mountain region to prevent problems: making citizens aware of digital risks and involve the community in prevention measures, also through digital platform, could help in controlling the regional area. Third highest score is related to digitalization of practices between the PA and citizens or private societies: this could speed up bureaucracy and help those citizens who live in remote places. Results are proposed to the Valle d'Aosta Region as guidelines to define principles for actions to be included in the new Regional Programme 2021-2027.

First two maximum values for each dimension		
Smart Economy		
3	Support digital literacy and digital soft skills spreading. Facilitate the usage of web services to industries.	2.33
1	Develop actions and strategies supporting digital innovation of productive processes, in particular conserning small companies	1.70
Smart Environment		
6	Invest in citizens education, promoting the territory preservation and the active participation through digital platforms	2.16
5	Increase economic attractiveness and the delevopment of new entrepreneurships in marginal areas through innovation and digitalization	1.85
Smart Mobility		
1	Encourage sustenaible intermodality in transport	1.19
7	Invest in sustainable mobility, in particular cycling, by creating new routes or reinforcing pre-existent ones	1.03
Smart Living		
2	Promote actions and strategies to have digital educative and formative services	1.63
3	Promote actions/strategies to provide in proximity services, in particular for rural areas	0.77
Smart People		
7	Promote in population Valdostan identity and cultural heritage through digital means of communication	1.46
6	Invest in initiatives supporting young enterpreneurs, in particular concerning digital innovation	1.34
Smart Governance		
3	Invest to digitalise practices for citizens and companies	2.09
2	Promote digitalization of practices and processes of PA at every level	1.88

Result of the Regional SA: for each Smart Dimension two first statements

To continue the work, Poliedra elaborated a Smartness Assessment for the Grand Paradis Unité des Communes, which highlighted a strong interest for Smart Mobility (29%) and Smart Environment (27%) and stated that one of the main goals of the Unité des Communes is to increase the renewable energy production, taking in consideration mainly hydro and photovoltaic power plants, with an interest in the theme of energy communities. For these reasons, the next subchapter is based on a real case study on energy communities in the territory of the Grand Paradis Unité des Communes.

Energy communities in Grand Paradis Unité des Communes Valdotaines

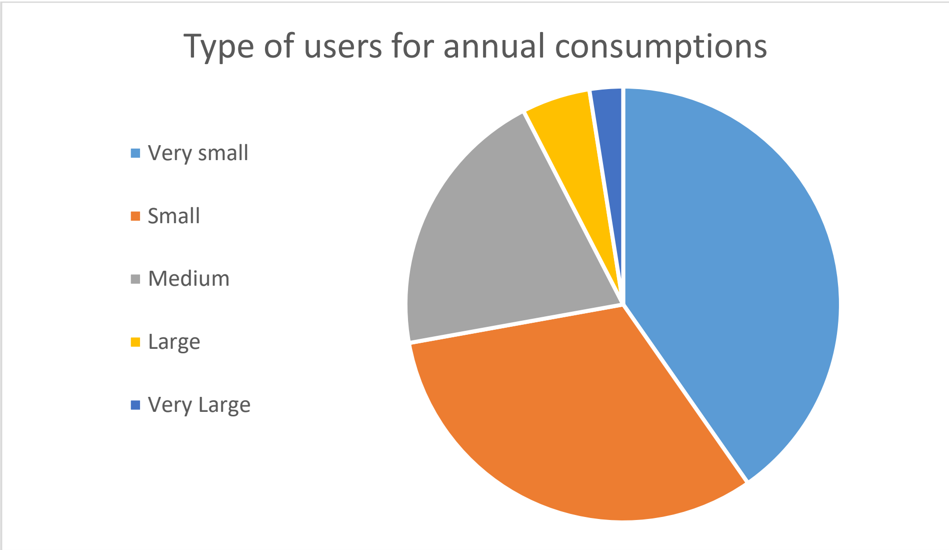
Evaluating PV distributed generation.

In a distributed energy generation optic, considering users as prosumers, the available areas for building integrated photovoltaic technology are evaluated thanks to an analysis on QGIS 3.18.2 with GRASS 7.8.5 conducted on a Windows computer, filtering buildings and coupling them with the closest secondary substation using Voronoi Polygons, as found in literature [14]. All the roofs are considered two pitched, reasonably divided in half on the shortest side, with PV panels on the longest side and with tilt angles randomly chosen between 19° and 24° for each roof, following building regulations. Suitable roofs are selected on the basis or their azimuth angles, considering 0° as South, 90° as West, -90° as East and 180°as North: if a side is North oriented, it is not chosen, while it is the opposite if it is South oriented. Moreover, if a side is oriented East or West, it is taken, unless it is North-East or North-West. The area of the roofs is evaluated with QGIS, divided in the two pitches and corrected with the cosine of the tilt angle and correction factors, that take in account the presence of chimneys, aerials, windows and others on the roofs and the shadowing between the buildings.

Roof area is divided by $8\ sqm/kW$ to find the power produced by the PV [15], investment costs of the PV panels are $1{,}55\ €/W$ [16], while the investment for Lithium-ion batteries is considered as 144€/kWh [17]. Crystalline silicon grid connected PVs are considered and the energy potential of a one-kilowatt peak system is estimated from PV-GIS.

Evaluating load profiles: electric and heating demand.

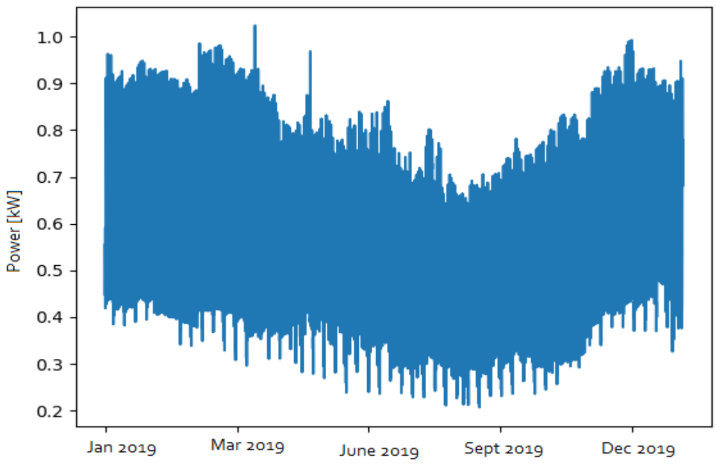
Data about users are referred to 2019 and are subdivided into the three time slots called "*fasce orarie*" set by ARERA, the Italian Regulatory Authority for Energy, Networks and Environment. Following the EUROSTAT's, here are reported the different types of users present in the two municipalities of Avise and Arvier [18]:



Types of users for annual consumptions in Avise and Arvier

For each user and for every month, three coefficients, one for every time windows' given by ARERA, are calculated to fit the available data with the reference data, which is an hourly profile representing the medium profile of the secondary substations present in Valle d'Aosta region: these coefficients are multiplied with the hourly reference profile to obtain the hourly profiles for the energy communities.
As an example, the coefficient for the time window $F1$ is calculated as follows for a user k, in a month i:

$$Coeff\ F1_{k,i} = \frac{Monthly\ consumptions\ in\ F1_{k,\ i}}{\sum_{j=1}^{last\ day\ of\ month\ i} consumes\ of\ reference\ profile\ in\ F1} \quad (29)$$



Representation of hourly load profile of a user

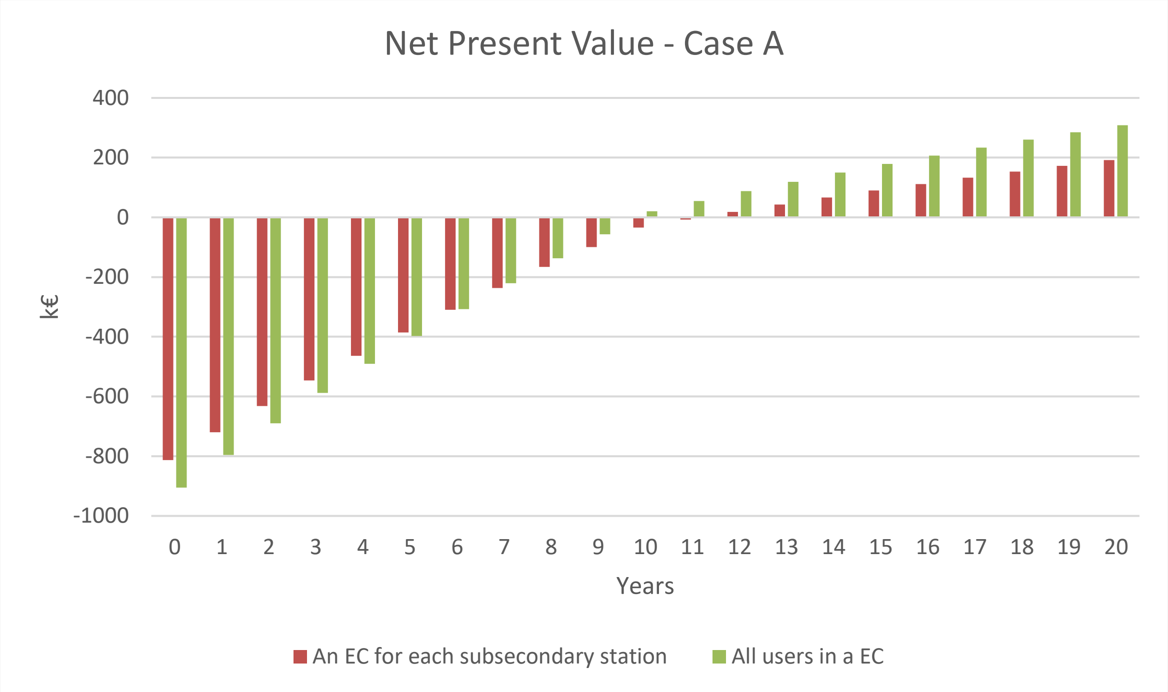
The heating profiles of non-electrified sources of heating to be decarbonized are taken from a previous thesis, in which a model reconstructed with a 15-minute resolution the heating demand profiles of the 74 municipalities of Valle d'Aosta [19]. The electrification case considers all the loads, electric and heating, together for the two municipalities, variating the percentage of electrification of the profiles.

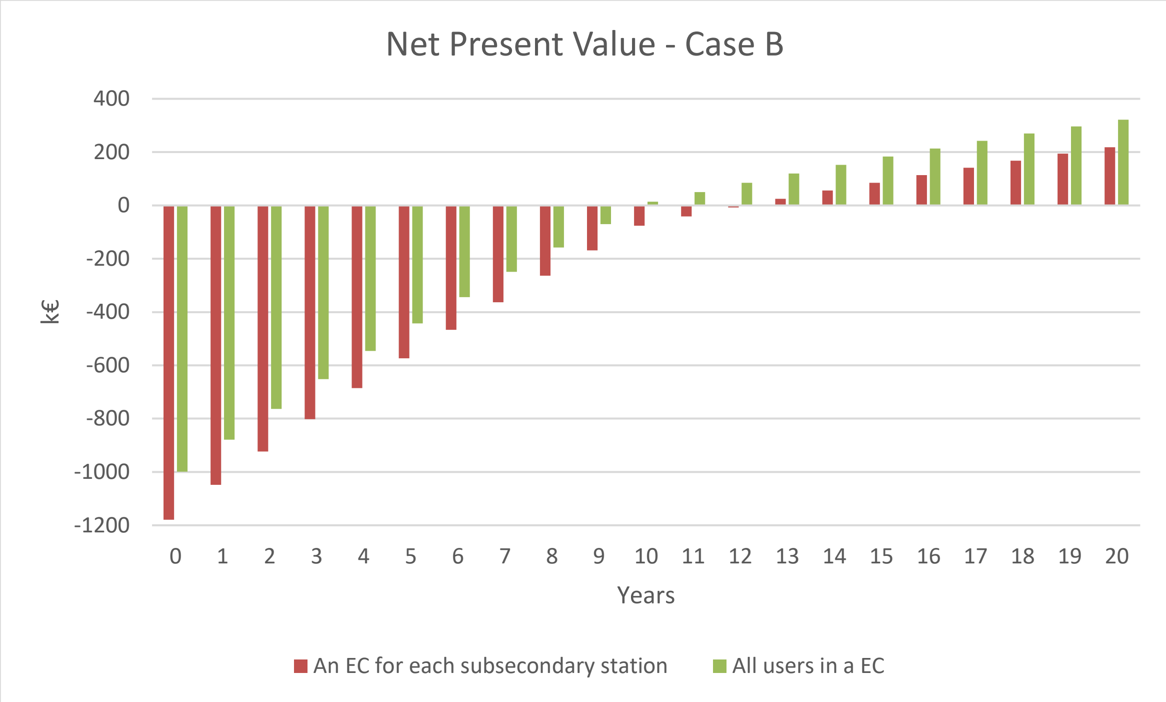
Results of the long-term analysis

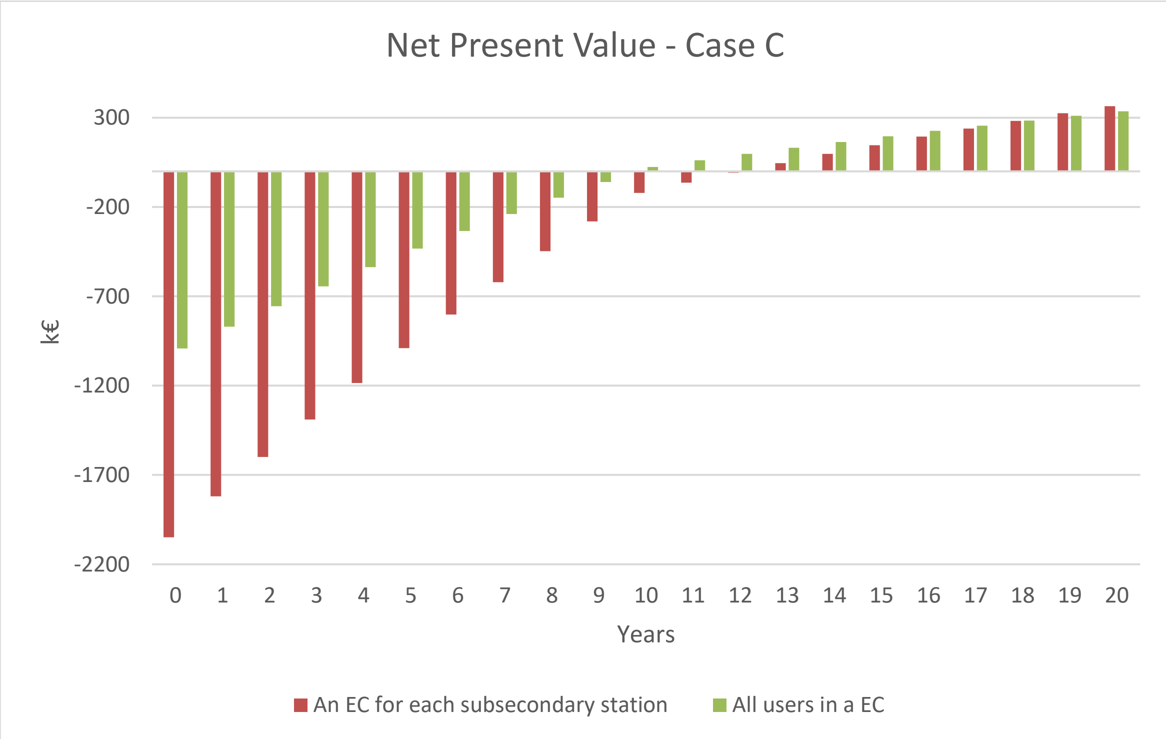
Two evaluations are conducted: the first one includes the possibility of having for each secondary substation an energy community, as it is stated in the current Italian regulatory framework, while the second one considers all users as referred to a single energy community, which could be a possible future transposition of the CEP in Italy. In both simulations three cases are considered, in which battery costs varying as follows:

	Case A	Case B	Case C
Storage investment cost [€/kWh]	300	150	75
Storage reposition cost [€/kWh]	200	100	50

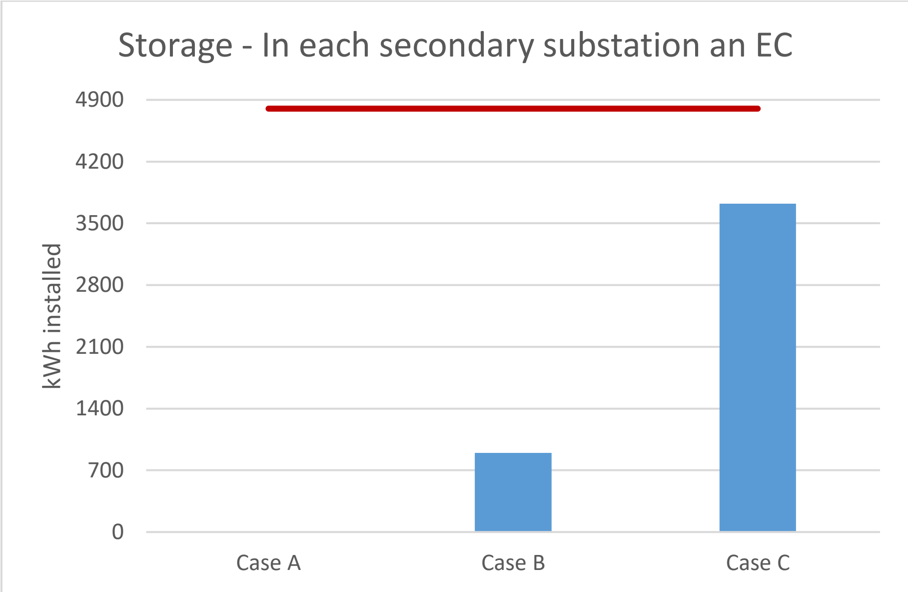
It is supposed that all the inhabitants of the two municipalities are members of the energy communities and that all the present roofs which could be suitable for PVs installation are available.



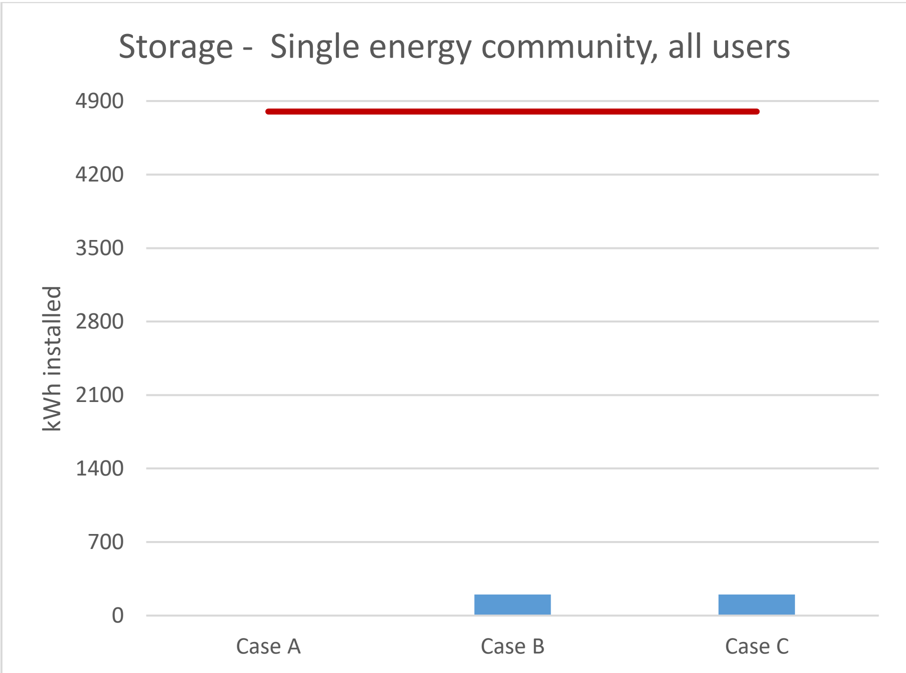




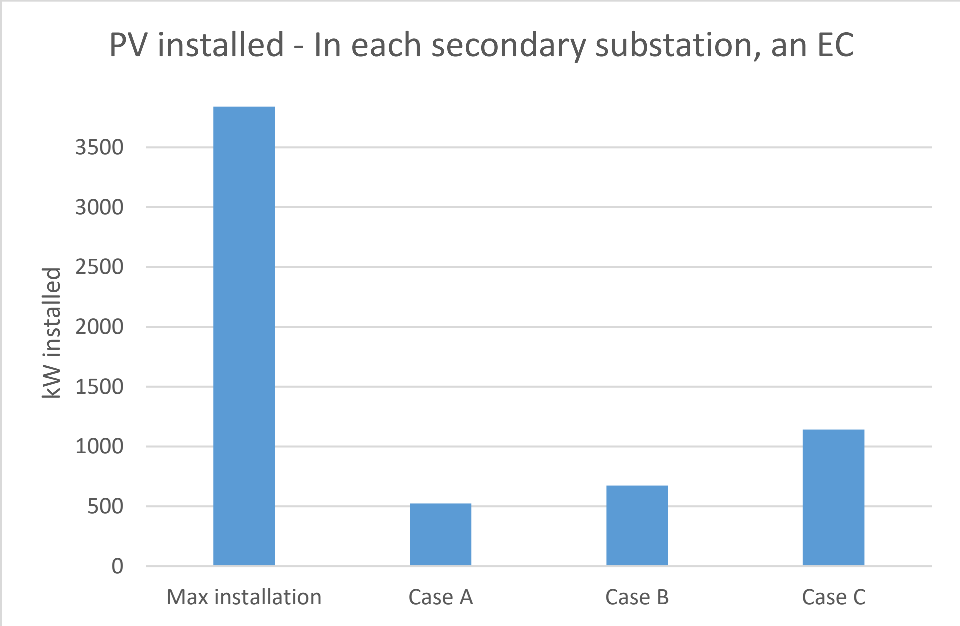
After 20 years in cases A and B the configuration where all the users are in a single energy community gives back the higher NPV and the NPV which become positive sooner. In case C the difference between the two configurations is less than $1k€$ which does not justify the possibility of choosing the case with an energy community for each secondary substation, considering that it presents double the investment at year 0 and that it turns into a positive NPV later than the other configuration.

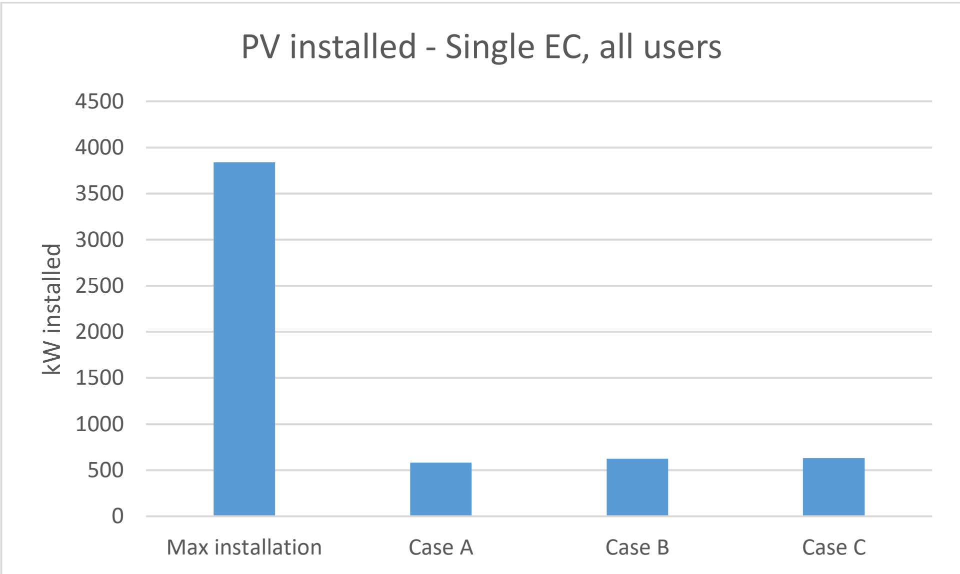


Storage in case A, B, C in the configuration including an energy community for each secondary substation

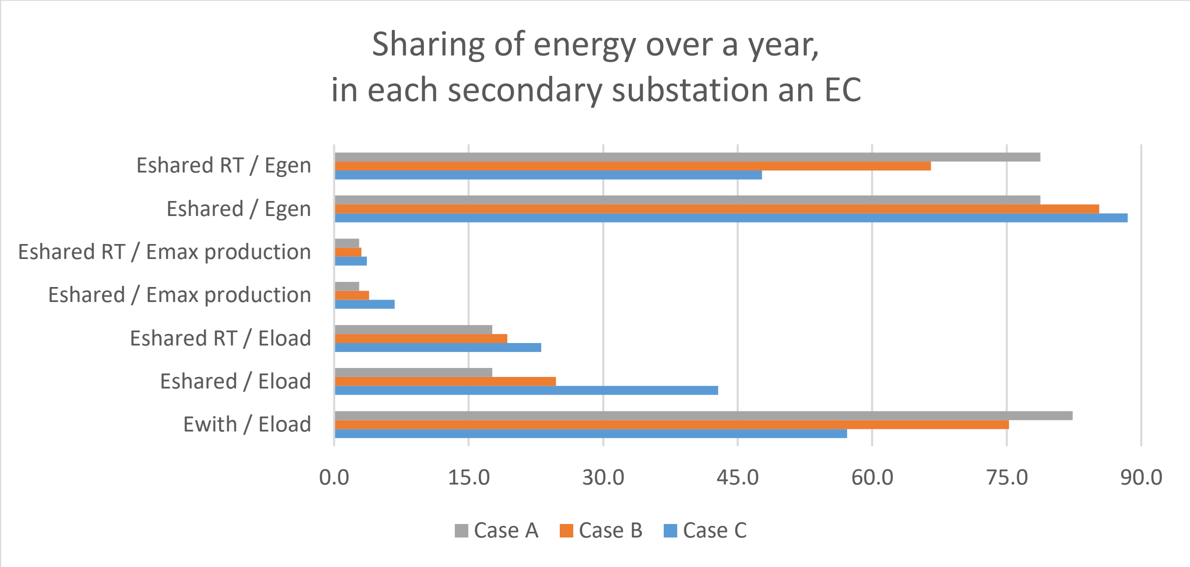


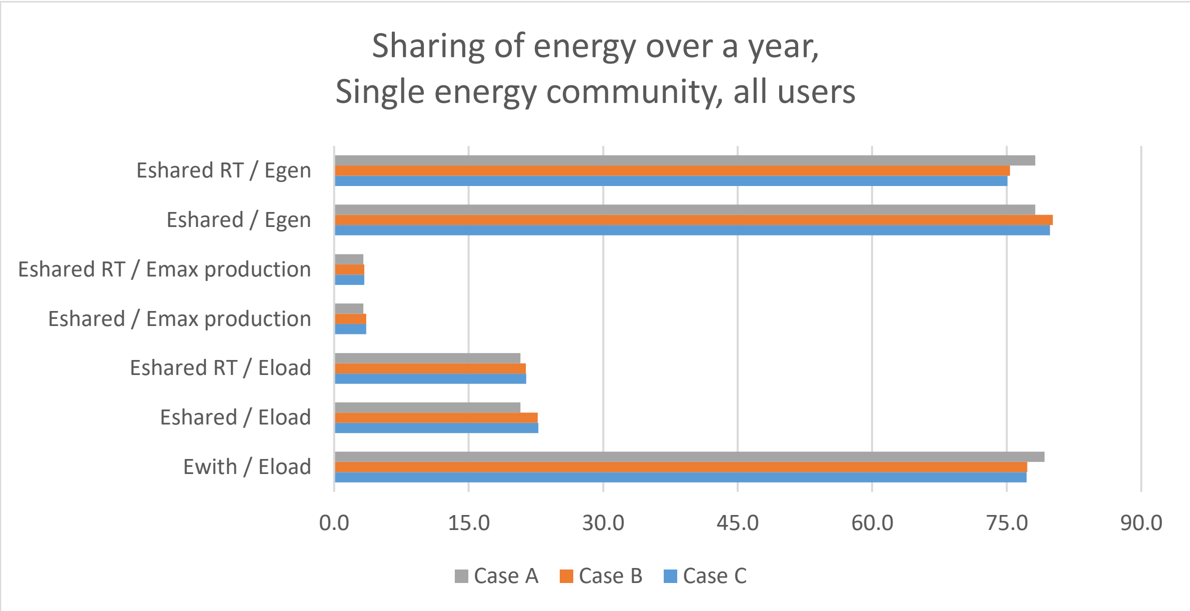
Storage in case A, B, C in the configuration including a single energy community





The PVs installed increase with the decrease in the batteries costs and depends on the storage installed, which is not chosen in case A for both configurations.

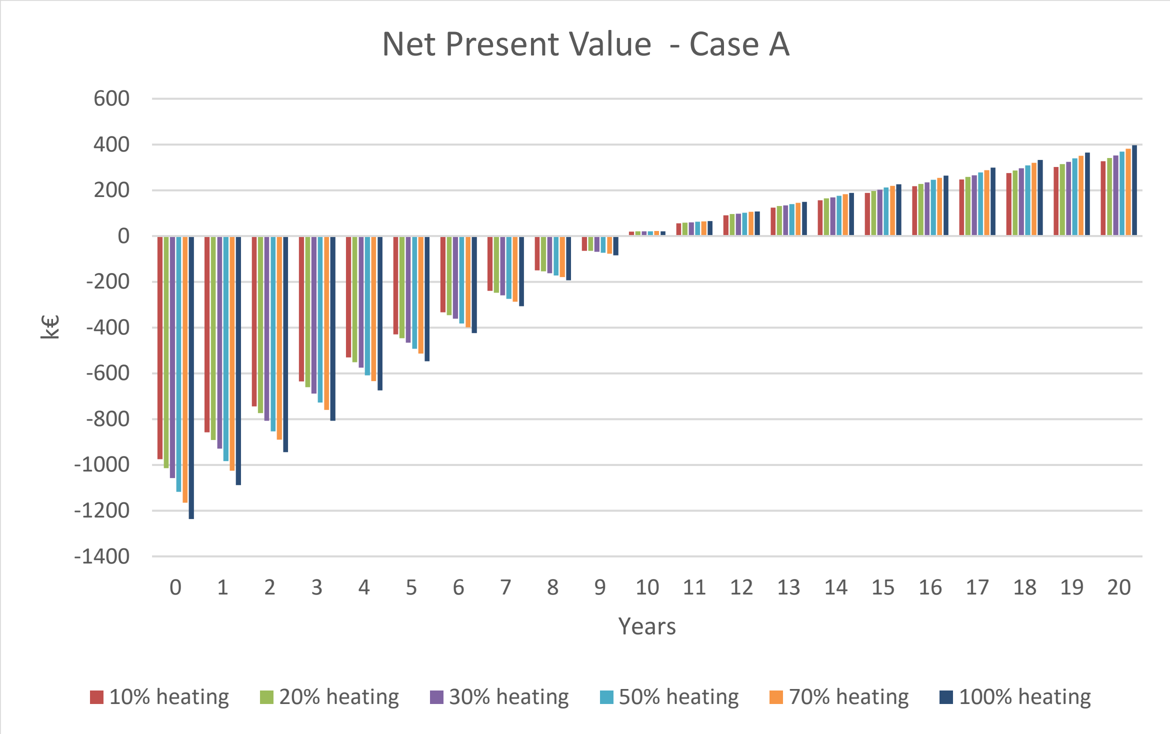


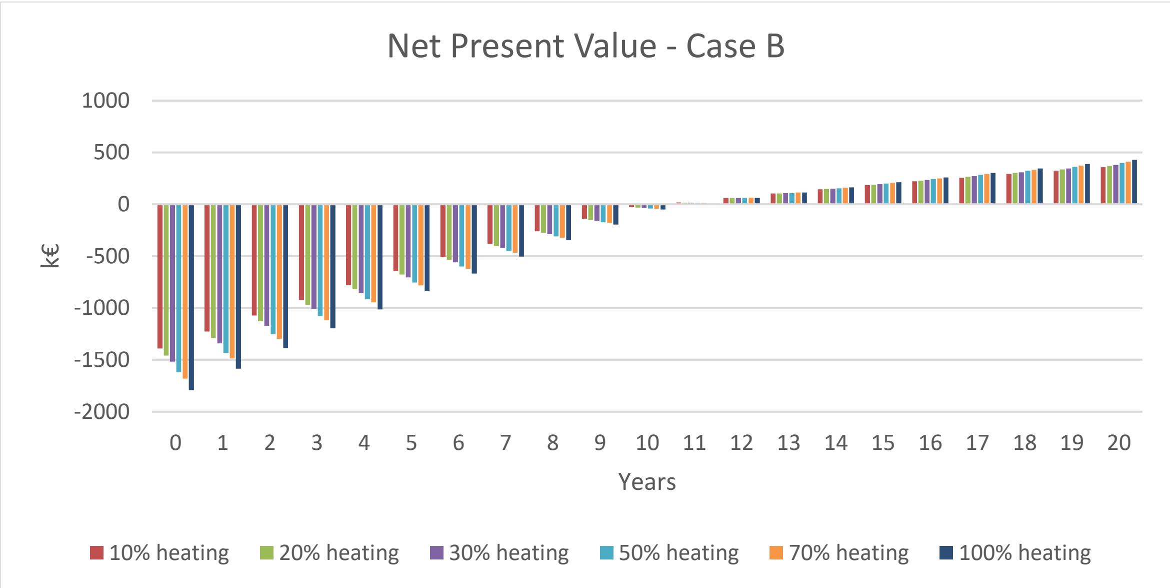


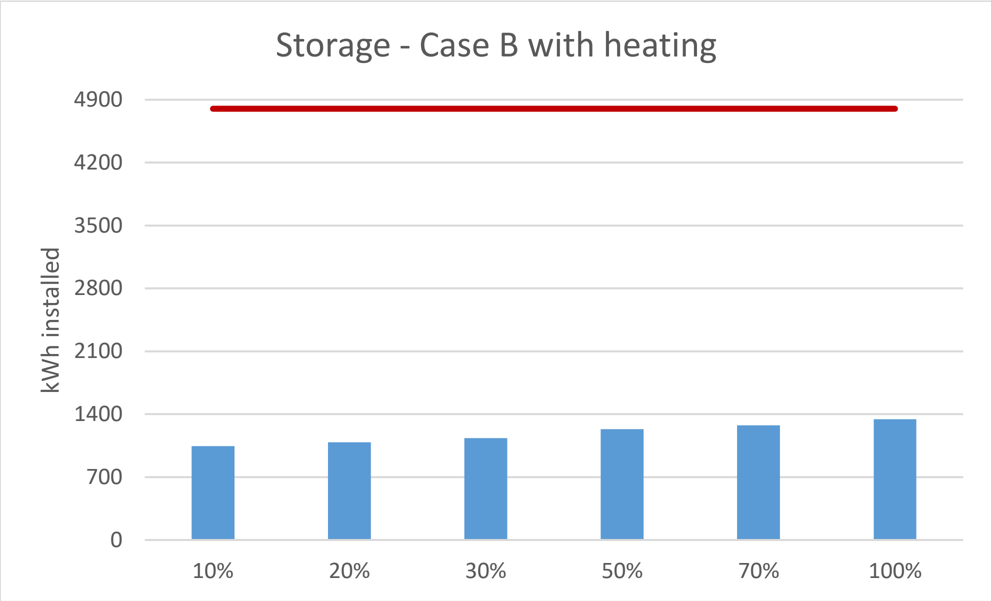
The sharing of energy in real time in a single community including all the users is higher respect to the other configuration, since the exchanges of energy are optimized, while the energy shared respect to the energy load is equal or lower.

Results of the long-term analysis adding heating loads.

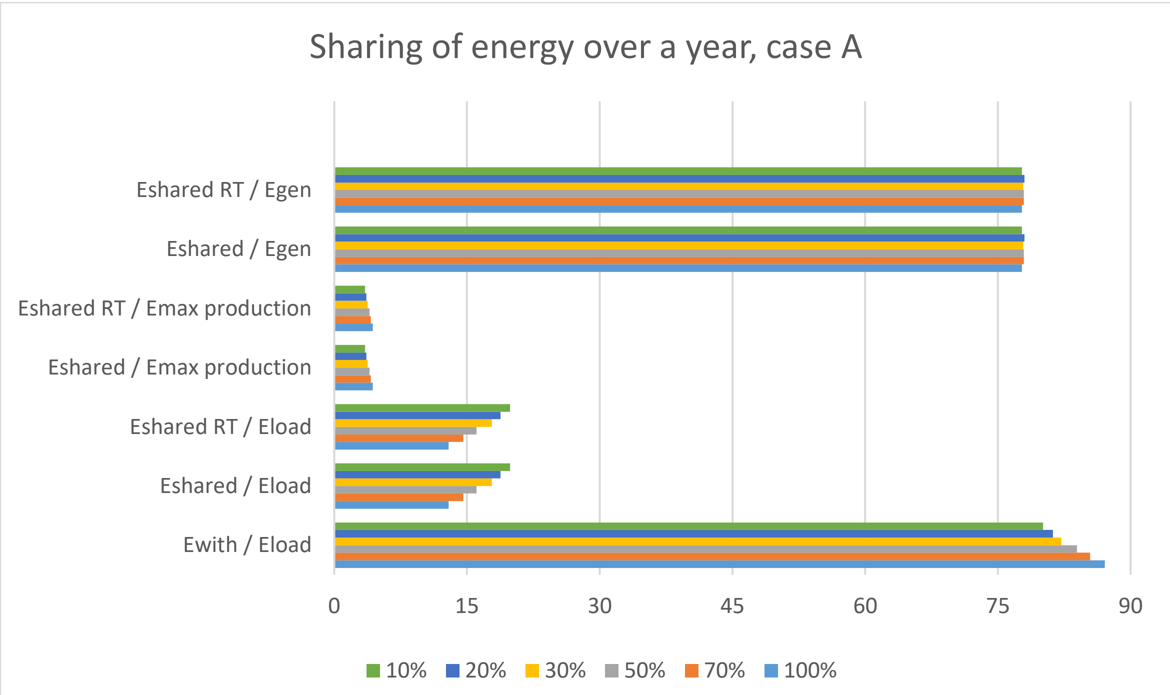
In this long-term analysis, it is added to the loads the possibility of supporting partially or totally the heating system if electrified at different percentages, varying the costs of batteries as stated before, distinguishing only between case A and B. The Net Present Values of both cases result higher than the cases without heating and NPV increase with the decrease in battery costs. For all the percentages of heating in both cases the NPVs turn positive at the same year. Also in this configuration, in case A storage is not chosen, while in case B are present higher values than the configuration without heating.

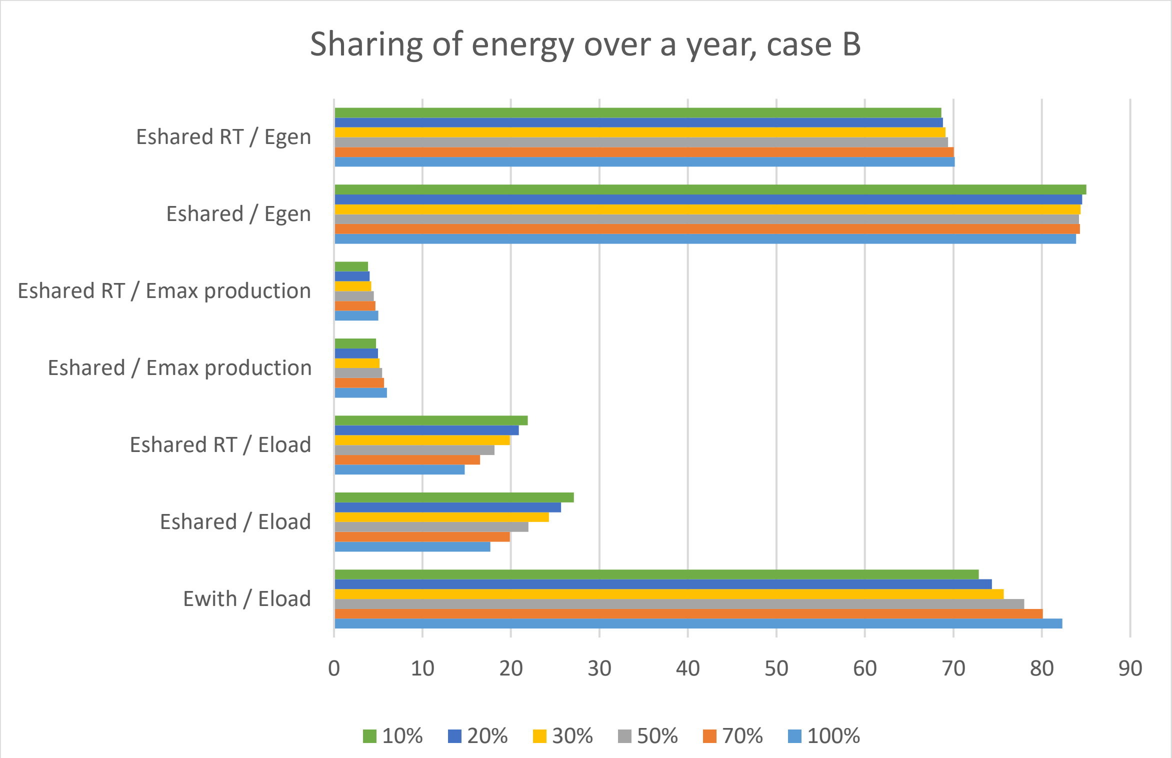

Net Present Value - Case A
600
400
200
0
-200
-400
-600
-800
-1000
-1200
-1400
k€
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Years
10% heating
20% heating
30% heating
50% heating
70% heating
100% heating


Net Present Value - Case B
1000
500
0
-500
-1000
-1500
-2000
k€
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Years
10% heating
20% heating
30% heating
50% heating
70% heating
100% heating



The values of energy sharing respect to the generated energy are almost equal to the configuration without heating. The shared energy respect to the energy load decreases increasing the percentage of heating, both for case A and B, while it increases withdrawn energy.





Conclusions

This thesis conducted an analysis in the Valle d'Aosta territory using Smart Villages approach and simulating an energy community. Results of the regional Smartness Assessment confirmed the regional effort in reaching ambitious objectives as becoming carbon free and fossil free in 2040 and results from the Smartness Assessment in UdC Grand Paradis the commitment in increasing renewable energy production, also expressing interest in knowing more about energy communities, which are studied and simulated in two municipalities in that area. The possibility of overcoming the current Italian regulations by including users of different secondary substations in the same energy community could improve the Net Present Value (NPV) of the investment and give sooner a positive NPV, which could be important for small investors as private citizens or little municipalities. This increase is due to the optimization of energy exchanges between users, not oversizing PVs and batteries. Moreover, a single energy community could engage better the population, comparing to the possibility of having a lot of them.

Then, it is investigated the possibility of supporting partially or totally the heating loads of the two municipalities, and varying batteries costs simulating the trends: the outcomes give back higher Net Present Values after 20 years, making it a feasible possibility to support the partial or total decarbonization of the heating system.

It would be interesting to understand which percentage of the population of Avise and Arvier should participate in energy community to make it economically feasible, having coupled data of users and their roofs, or simulating this data. A more precise estimate of the available spaces for PV panels could be done.

Chapter 1

Introduction

The past year presented unprecedented challenges for the global community. The COVID-19 pandemic struck extremely fast and directly affected many factors of our day-to-day life. What started out as a “distant” and scarcely comprehended issue of a single country, quickly came to challenge the fabric of modern society on a global scale. The approach of the pandemic problem by the western institutions could be compared with the approach of the global community towards climate change, as initially the will to understand the issue and provide radical preventive actions was little since no immediate threats were perceived. Also, similarly to climate change policy any strong preventive action taken by political leaders towards a potential spread of COVID-19 was largely met with hostility from the general public, the industrial sector and the local institutions which did not want to change their habits or business models for an unclear and debated threat.

What inevitably set the difference of response between the two issues is the time frame in which they develop their effects: whereas changes in climate affect complicated natural systems which react with diverse delays, an uncontrolled pandemic has a fast, direct and measurable impact and this required drastic collective actions, involving all levels of society. This is also due to the scale of the effects, again similarly to the climate change issue, a pandemic affects all the population without distinction of ethnicity or social class, leaving only the wealthier countries with the capability to react or adapt efficiently.

The events of the last year exposed the weaknesses of our society, but also demonstrated how the world is capable of providing effective responses when there are strong economic and political driving forces and when scientific research is trusted [20]. The global response model to COVID-19 called on many levels of actions from the supranational to the local, outlining the importance of world institutions, country leaders, and single citizens alike. This multilevel approach has shown to be effective and, considering the similarities of the two issues, could bring promising results if applied in tackling climate change.

Over the past years scholars and policymakers focused on the national and global levels of governance more than local climate governances, neglecting this last topic from climate change policy discussions, in particular talking about rural or isolated areas [1]. These areas can have interesting potential when assessing a capillary transition to renewable energy exploitation especially considering the increasing global demand of energy, represented in Figure 1 [2].

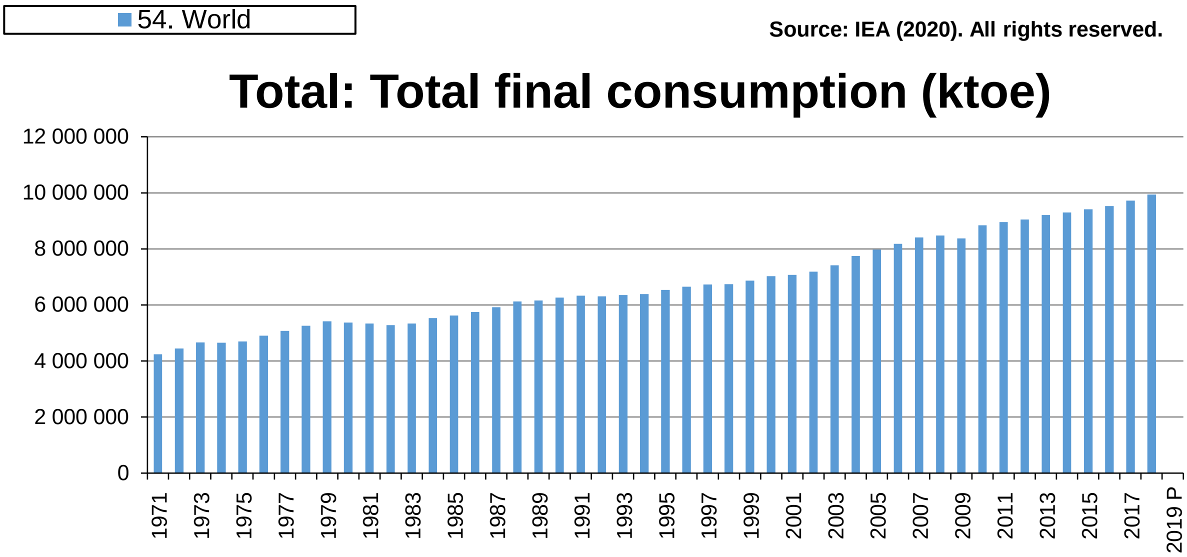


Figure 1: IEA, World total energy consumption, 2020

In this context, the present thesis work has focused on the concepts of Smart Villages and Energy Communities which introduce a wide range of collective energy actions that involve citizens' participation, also in the energy system. The work is the result of the collaboration between Poliedra, the Energy Department of Politecnico di Milano and Autonomous Region of Valle d'Aosta. From the second half of 2020, Poliedra, consortium of the Politecnico di Milano and partner of the Interreg Alpine project "Alpine Space SmartVillages", is supporting the autonomous Italian region of Val d'Aosta in defining the 2021-2027 European Programme, also to promote a smart transition of the region, in which, after identifying strengths and weakness of the territory, digital technologies could help in improving life quality of the communities.
In the same region the topic of energy communities is discussed: Energy Communities could accelerate the energy transition to clean energy resources in the Region, engaging also mountain and isolated areas, creating awareness on renewable energy production and strengthening communities.
The role of rural and sparsely populated areas towards a sustainable development is outlined in various strategic policies of institutions worldwide. According to the World Urbanization Prospects by the United Nations, more than half the world population lives in urban areas and, by 2050, it will become roughly two thirds [21] and it is possible to see from EUROSTAT's report from 2020 that 29% of EU population live in peripheral areas [22]. From the same report it is known that in 2019 in EU 48% of adults living in rural areas had basic or above basic digital skills, rising to 55% for adults living in towns and suburbs and peaking at 62% for adults in cities [22], with the same pattern in almost all the European countries. To invert this tendency and help rural areas grow and raise employment and living standards, the EU's Rural Development policy has set three overarching objectives: improving the competitiveness of agriculture, achieving the sustainable management of natural resources and climate action and a balanced territorial development of rural areas. Smart Villages strategies mainly contribute to the third objective but can also benefit the other two. The European Union's Cohesion policy also shares these objectives; therefore,

the European Regional Development Fund (ERDF) and the European Social Fund (ESF) can work to complement the European Agricultural Fund for Rural Development (EAFRD) in supporting Smart Villages. Smart Villages could also help in meeting one of the seventeen Sustainable Development Goals (SDGs), included in the 2030 Agenda for Sustainable Development or #EnVision2030, adopted by the General Assembly of the United Nations [3], in particular the eleventh goal about sustainable cities and communities.

Figure 2 - Illustration of the seventeen Sustainable Development Goals by [3]

Within the Italian regulatory context, the implementation of smart villages and energy communities is also part of the strategic objectives of the Italian implementation plan of the Next Generation called “Piano Nazionale di Ripresa e Resilienza”, which embodies the response of European countries to the economic crisis caused by the COVID-19 breakthrough. The plan can be grouped in three major areas: digitalization and innovation, ecological transition and social inclusivity.
The digitalization and innovation of processes, products and services represents a determinant factor is the transformation of the country and must characterize all reform policy of the plan. Italy has accumulated considerable delay in this field, both in citizens digital competence and in usage of digital technologies in the productive system and public services. Recovering this setback and promoting investments in technology, infrastructure and digital processes is essential to promote the Italian and European competitiveness. The ecological transition must be at the basis of the new development model of Italy and Europe. Actions to reduce pollutants and GHG emissions, to prevent and contrast land deterioration and to minimize the impact of industrial activities on the environment is necessary to raise the quality of life for the present and future generations. Also, from the economic point of view, the ecological transition can constitute and important factor to increase the competitiveness of the Italian productive system, promote the creation of new businesses with high added value and favour stable jobs.
The third strategic axis focuses on social inclusion. Granting a full social inclusion is fundamental to enhance territorial cohesion and overcome profound inequalities, especially highlighted by the COVID-19 pandemic. There are three main priorities: gender equality, valorisation and protection of the young generation and equal development of territories. Female empowerment and contrast to gender discrimination, increase of

competence and professional prospects for the young population as well as the economic growth of the south of Italy must be taken into consideration transversally in all components of the plan [23].

In this moment of history there is an unprecedented economic and political impulse towards sustainable development and the opportunities to meet part of the increasing world energy demand with efficient and smart energy production must be seized. The objectives of this thesis work are to see the process of a Smart Villages' approach in a real mountain area, its results and the possibility of developing Energy Communities in the same territory in different configurations, by appreciating the cooperation between these two tools in building at a local level a response to climate change issues, which could be socially inclusive, which could empowers single groups of citizens and which is capable of fully exploiting the technical benefits of digitalization and innovation.

Chapter 2

Smart Villages

Throughout the years the concept of living in a smart area has been correlated to urbanization. Rural areas were not contemplated in the literature, nor were methods to use ICTs in villages, until Smart Villages' approach took place. Smart Villages are about citizens in rural areas, determined in finding practical solutions to transform their local area, using digital technologies when necessary. SVs can help in connecting different territories, rural or urban, by strengthening cooperation between groups of communities, but also by creating bottom-up alliances between different rural partners and actors, including both private and public sector [4].
In this chapter a complete definition of Smart Villages and the origin of this concept are presented. The main problems of rural areas are listed, and the concept of Smart Village is compared with that of Smart City. The INTERREG Alpine Space project, Smart Villages, smart digital transformation of villages in the Alpine Space is also presented and its results are illustrated. In the end, the methodology used to analyse Smart Villages is presented.

2.1 Smart Villages context

2.1.1 EU: from Cork 2.0 to Smart Villages Network

To analyse the origin of the Smart Village concept in EU, it is useful to recap some important meetings and documents.
Building on the 1996 Cork declaration "A living countryside", in September 2016 the "Cork 2.0 European Conference on Rural Development" took place in Ireland, organized by the European Commission, and it focused on how to react to the current challenges and opportunities facing Europe's rural and marginalized areas: more than 300 policy makers and stakeholders participated. It resulted in the "Cork Declaration 2.0 – A Better Life in Rural Areas" addressed to the European policy makers, setting ten policy recommendations and highlighting the problem of the digital divide between rural and urban spaces as well as the need to have integrated approaches between different policy fields. Moreover, youth drain, and rural exodus were also openly presented as crucial problems to be solved in order have rural growth and to make rural areas attractive for people to live and work in throughout the different stages of their life [5].
The concept of Smart Villages was then elaborated in an initiative launched by the European Commission, together with the European Parliament, in April 2017, called "EU

action for Smart Villages" to reflect on villages of the future [6]. In this document, the Smart Villages' approach is not proposed as a one-size-fits-all solution, but rather as a tool that could empower local strengths with digital technologies, recognizing that every area should be in the position of making use of ICTs (Information and Communication Technologies), to improve local economy and basic services. Sixteen initiatives were announced in the report, regarding digital policies, research, transport, energy, rural development, regional development. In addition to the already present funds such as Common Agricultural Policy (CAP), Rural development policy, EU Cohesion Policy, new funds were presented as the European Innovation Partnership for Agriculture (EIP-AGRI), helping in developing in the field of forestry and food production, and The European Network for Rural Development (ENRD). Workshops, seminars, conferences, thematic groups are suggested to enhance the knowledge of this approach. To highlight some projects suggested thanks to this conference:

- SMARTA (Smart Rural Transport 'Areas'): it analysed the different challenges of mobility in the different European rural areas, identified good practices, works and monitors pilot areas, shared and discussed results, planned the interconnections between sustainable shared mobility and public transport in rural areas [24].
- Smart Eco-Social Villages: a pilot project to map opportunities and challenges on Smart Villages, studying the characteristics of the villages and identifying good practices, with a particular focus on connectivity and digital solutions [25].

The Smart Village concept continued to evolve, becoming a priority for EU. The paper "Bled declaration for a Smarter Future of the Rural Areas in EU" is based on the meeting at Bled in Slovenia on April 13th in 2018 and on previous documents, such as the Cork 2.0 declaration. This document states the interest in the Smart Villages initiative to promote digital and social transformation, also to help in redesigning the future of food and farming, at the same time supporting, rebuilding and developing strong rural communities throughout the Union [7].

Moreover, in 2018 the Smart Village Network was launched, to connect villages and associations across Europe, to exchange information and experiences [26].

2.1.2 Definition of Smart Villages

There is not a unique definition of Smart Villages, considering that this concept depends on socio-cultural structures, different circumstances, societal problematics and reflects difficulties encountered by each individual community [8]. Keeping this concept in mind, we can also see that, if we want to cooperate to enhance Smart Villages approach, we need an acknowledged common ground from where we can start working.

In 2018 after an on-line consultation and a two day expert workshop held in Brussels, an actual working definition of Smart Villages was agreed upon. This result has arrived also thanks to the work done on Smart Villages by a thematic group (TG) between October 2017 and July 2020, considering this topic as a sub-theme of the broader European Network for Rural Development (ENRD) thematic work on 'Smart and Competitive Rural Areas' [27]. The result is composed by a core definition and the explanation of the key terms, here reported [9].

*"Smart Villages are **communities in rural areas** that use innovative solutions to improve their resilience, building on local strengths and opportunities. They rely on a **participatory approach** to develop and implement their strategy to improve their economic, social and/or environmental conditions, in particular by mobilising solutions offered by **digital technologies**. Smart Villages benefit from cooperation and alliances with other communities and actors in rural and urban areas. The initiation and the implementation of **Smart Village strategies** may build on existing initiatives and can be funded by a variety of public and private sources."*

Key terms in bold are explained as follows:

"**Communities in rural areas** can include one or several human settlements, without any restrictions regarding the administrative boundaries or the number of inhabitants. As regards eligibility conditions for support, Member States may use definitions of rural areas as provided for by the OECD, EUROSTAT or other definitions."

"A **participatory approach** means an active participation of the local community in the drawing up and decision-making regarding the Smart Village strategy. During the implementation phase, the participatory approach will ensure that the needs for capacity building and for training of people are properly addressed."

"**Digital technologies** include, for example, information and communication technologies, the exploitation of big data or innovations related to the use of the Internet of Things (IoT). They act as a lever to enable Smart Villages to become more agile, make better use of their resources and improve the attractiveness of rural areas and the quality of life of rural residents. The use of digital technologies is not a precondition for becoming a Smart Village. Where possible, high-speed broadband will facilitate the deployment of the digital solutions."

"**Smart Village strategies** respond to the challenges and needs of their territory by building on their local strengths and assets. Strategies must determine short, medium and long-term goals. Progress must be measurable through performance indicators that will be set in a roadmap. These roadmaps should be reviewed at regular intervals to allow continuous improvement. Strategies may aim, for example: to improve access to services (in various fields such as health, training or transport), to enhance business opportunities and create jobs, to the development of short food supply chains and farming practices, to the development of renewable energies, to development of a circular economy, to a better exploitation of natural resources, to adapt to climate change, to preserve the environment and biodiversity, to a better valorisation of the cultural heritage for a greater tourist attractiveness etc."

Regarding the cited IoT, considering the importance of it in Smart Villages, here a definition is proposed: "the IoT describes a worldwide network of billions or trillions of objects that can be collected from the worldwide physical environment, propagated via the Internet, and transmitted to end-users. Services are available for users to interact with these smart objects over the Internet, query their states, as well as their associated information, and even control their actions" [28].

Smart Villages approach should be seen as an opportunity to improve the quality of life of inhabitants of rural areas and not as a showcase for cutting-edge technology, bearing in mind that the main goal are the people and their communities. Technologies and digitalization are powerful tools to help rural areas in becoming attractive for people, bringing services, specialized jobs, and a favourable climate for entrepreneurship, reducing the digital gap between rural and urban areas. The Smart Village project offers the chance to create a participation model adaptable to meet the needs in the considered local context, dealing with different challenges through a bottom-up approach.

2.1.3 Main problem of rural areas

The ENDR thematic group on Smart Villages carried out a scoping exercise in October 2017, from which it was clear that the "circle of decline" is present in many rural areas. As represented in the Figure 2, two mutually reinforcing trends are present: firstly, a shortage of jobs and sustainable business activity; and secondly, inadequate, and declining services. This expression was in the first instance presented by the Organization for Economic Cooperation and Development (OECD), studying the reasons for a weaker economic performance in rural areas [13]. European rural areas are different in landscape, occupational levels, composition of the population, but usually share the characteristics of having a low population density and relative remoteness respect to major urban centres: a combination that generates some level of disparity respect to urban regions.

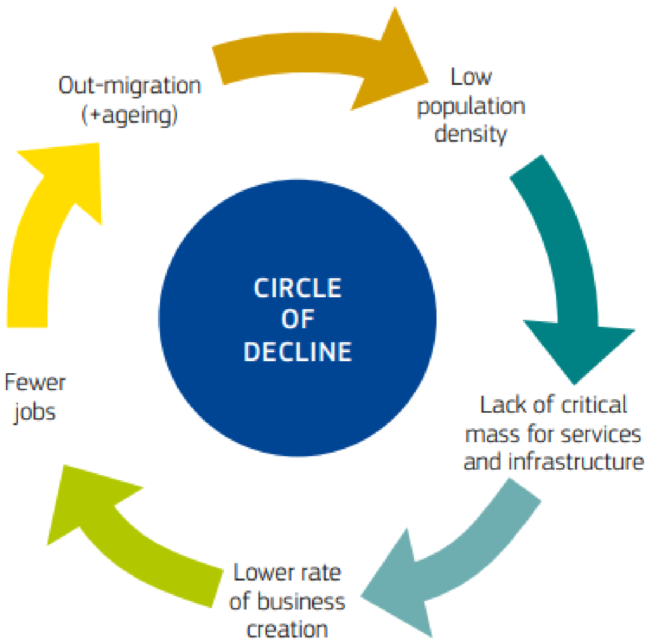


Figure 2 -Circle of Decline by ENRD Thematic Group working on Smart Villages

The population balance disruption in rural areas is a well-known and increasing phenomenon: if in the past these areas were exporters of population to urban regions, now they are losing residents, in particular younger ones. Out migration to urban areas leads to an aging population, an increase of basic assistance services demand, such as health care, and to a lower average of labor productivity, which decreases the possibility of newcomers in these areas. Elderly people remain in rural areas, usually alone, and, if internet is present in their area, it is not assured that they know how to use electronic devices [29]. Another remarkable problem for rural areas is connected to education: if students

attending school up to upper secondary education is typically around or above the national averages, in predominantly rural regions this value decreases for tertiary education. Students are forced to leave their hometown to pursue a college degree, then not coming back, because of a not adequate offer of qualified jobs.
Moreover, in remote areas usually providers of the private sector are not encouraged to invest due to the high unit cost for delivery of services and infrastructures and the low potential and actual returns on their money. This does not help in generating new employment opportunities: unemployment and lack of services often lead to rural exodus. It is important that rural communities have the opportunity to choose to use services and infrastructures for their areas, which should be accessible and at a reasonable cost.
Other crucial problems concern the lack of opportunities for women and the weakness in skills and human capital compared to urban areas.
In a report about digital transformation for rural areas, ENDR highlights four conditions that managing authorities need to ensure in their territory to support Smart Villages [30]:

1) *Fast access to internet.* It is important both to have a good, stable infrastructure and to develop soft skills for the citizens to use it in the best way.
2) *Local stakeholders should be involved through different mechanisms in the identification of digital needs and in the co-creation of digital solutions need to be in place*. Problems of rural areas also included the communication with local people to make them aware of what initiatives are happening and make them participate, creating something desirable for the community. Then, once involved, a digital roadmap is needed to increase the competences in digital technologies of residents, public players, and business should increase their competences in digital technologies, until contributing to the co-design of new services and actions.
3) *Access to intermediate bodies, as hubs, fab labs, co working spaces, could support digital transition*, for example by developing local capacity in innovation. A place where it is possible to share different contribution and co-create smart products is important in the digital transformation.
4) *Cooperation with other players needs to be supported*. Usually, digital innovation is driven by big corporations, universities, or research institution. A rural village lives in a different ecosystem: it should cooperate with local and national, social and economic structures.

Different actions should be referred also to the maturity level of the considered village: in an early maturity level, large investments are needed both to bring digital infrastructures to the area and to increase digital competences of local stakeholders. The type of investment will change as the digitalization level of the village increases, needing a combination of soft and hard skills to become digital players not only locally [30].
Rural areas face common challenges, but it is important to evaluate the heterogeneity in the development of these different place, considering different factors such as globalization or new migration patterns that could become opportunity for growth. In addition to this, the presence of broadband infrastructures could help with attending online lectures, or in enhancing telemedicine, or allowing smart working, which could

help people to stay in rural areas. Moreover, from a tourism point of view, the ability to promote the presence clean environment, attractive landscapes and cultural heritage could be a growing factor. In conclusion, it is possible to state the rural is not a synonym of decline, but policy makers and politicians should arrange conditions to help rural populations.

2.2 Comparing Smart Villages and Smart Cities

There is not a unique definition of Smart Cities either. According to Cohen, “Smart Cities use information and communication technologies to deliver services to their citizens. Smart cities use information and communication technologies (ICTs) to be more intelligent and efficient in the use of resources, resulting in cost and energy savings, improved service delivery and quality of life, and reduced environmental footprint—all supporting innovation and the low-carbon economy” [31].

The expansion of Big Data and the evolution of Internet of Things (IoT) technologies are making Smart Cities initiatives more feasible [32]. With actual technologies given by IoT and ICTs what it looked like a future possibility is now a reality.

While the research on smart cities shows new interdisciplinary studies in this field, the same is not happening for Smart Villages [33], on which there is an underdiscussed literature on usage of technologies. To cite some works, in [34], the author discuss how IoT technologies used in Smart Cities could be used in Smart Villages, focusing on different requirements of rural areas and providing solutions from Smart Buildings to Smart Farming and Smart Education. In [35] the authors propose applications of IoT to empower Smart Villages as natural resources and energy, transport and mobility, government, economy and many others.

It is necessary to remember that the transition to smart infrastructures is complex but necessary also in the case of sparsely populated areas. Smart Villages could have an advantage in this transformation, considering that local and regional knowledge could help to identify challenges and their possible solutions [36]. The possibility of having many spaces could encourage investments in new infrastructures, which can be developed using new technologies, following the Sustainable Development Goals to make them efficient from an energy perspective.

Moreover, it is fundamental to not consider Smart Villages and Smart Cities in contrast to each other: opportunities and weaknesses of these different territories could cooperate to assure a better quality of life for their inhabitants, sharing methodologies and approaches to problems. Imagining Smart Villages as independent entities could lead to a partial understanding of the framework, not considering the interspatial dimension in which SV and SC affect each other.

2.3 Smart Villages project

2.3.1 EUSALP

Talking about the Smart Villages project, it is necessary to define EUSALP. The EU Strategy for the Alpine Region, also called EUSALP, is a macroregional strategy including an integrated framework, endorsed by the European Council. Common challenges faced by countries in the same geographical areas are treated with cooperation, achieving economic social and territorial cohesion [37]. Sectoral policies highlighted by EUSALP are translated into regional scales, co-creating the future of Europe, enhancing the attractiveness and competitiveness of the Alpine Space.
Economy, accessibility, resources and governance are four pillars expressed through nine action groups (AG) projects, which are financed through AlpGov and started working in 2016.
Reporting the definitions from EUSALP's site, the nine Action Groups are:

- AG1, to develop an effective research and innovation ecosystem;
- AG2, to increase the economic potential of strategic sectors;
- AG3, to improve the adequacy of labour market, education and training in strategic sectors;
- AG4, to promote inter-modality and interoperability in passenger and freight transport;
- AG5, to connect people electronically and promote accessibility to public services;
- AG6, to preserve and valorise natural resources, including water and cultural resources;
- AG7, to develop ecological connectivity in the whole EUSALP territory;
- AG8, to improve risk management and to better manage climate change, including major natural risks prevention;
- AG9, to make the territory a model region for energy efficiency and renewable energy.

2.3.2 The project

Action Group AG5 launched an Alpine Space Program project from April 2018 to April 2021 on Smart Villages, which is one of the major strategic initiatives of this action group. The project Smart Villages, Smart Digital Transformation of Villages in the Alpine Space, aims to empower rural and isolated communities thanks to the opportunities given by ICT, applying the Smart Villages approach. In order to make this project effective, the Regional Stakeholders Groups (RGS) as policy makers, business, academia and civil society should all be involved.
In June 2018 in Maribor, Slovenia, the Interreg Alpine Space project SmartVillages organised its KickOff Meeting, in which all representatives of the involved project partners

were present to discuss the deadlines, responsibilities and tasks. The nine test areas were outlined:

1. Municipality of Löffingen, Germany
2. Pitzal Valley, Austria
3. Bodensee area and Lake Constance Region, Germany
4. Padna Village, Solčava and Kungota Municipality, Slovenia
5. Pomurje Region, Slovenia
6. Valli del SOL Intermunicipality, Italy
7. Royans-Vercors Intermunicipality, France
8. Pomurje Region - SmartiS City, d.o.o. SIC (SLO)
9. Luzern West Region, Swiss

Figure 3 - Test Ares in the INTERREG Alpine Space Smart Villages project

In November 2018 Poliedra organized in Milan the project's Steering Committee and the Capacity Building Seminar to structure the work of the Regional Stakeholder Groups. The aim of the meeting was also to define more precisely the characteristics of the Smartness Assessment, in particular about defining the smartness with indicators, and to state the necessity to include Good Practices to inspire the smart transition. Moreover, responsibilities were subdivided between different project partners: Poliedra was chosen the Work Package Leader for WPT-1, in which it is determined how advanced are the Test Areas in the smart transition process and their own Smart Specialization strategy.
Many meetings occurred during the project, in presence and then online, finalized to share the different results and propose new methodologies to analyse the work done.
On the 29th April 2021 the project ended, and results were presented by the thirteen project partners in six alpine countries in an online meeting. Also, it was presented the

“digital exchange platform” (DEP) and the “SmartVillages Charter”. The DEP is a deliverable of AG5 with a double aim: the first one is a collection of good practices, divided into the seven dimensions of smartness, which will be presented in further chapters. Everyone can access these materials and can send individual contributions, contributing via the same website. A recap of the methods and results obtained by the different Test Areas is also present. The second purpose is to let everybody to assess the smartness of the place where they live with a complete questionnaire present on the website, which helps in understanding the areas in which the community is better performing and where it is necessary to improve. A toolbox with methods and techniques provides ideas on how to improve the “smartness”. The platform is actually available in English, Italian, French, German, Slovenian language [38]. The “SmartVillages Charter” is a document in which the signatories encourage each other in continuing the work on smartness for rural and alpine villages, giving continuity to the achievements reached and collaborating in a new alpine network for sharing good practices. Digital Alps conference on 27 and 28 of May was the natural continuation of this project [39].

2.3.3 Covid-19 and Smart Villages

During Alpine Space Program Smart Villages, it was asked to the Test Areas to report if any successful Covid 19 coping strategies was implemented, here reported as good practices.
Around Lake Constance during lockdown the cohesion of people was strong despite borders closure, with an increase in attention for the territory and for local supply of food. Bodensee Standort Marketing created a B2B platform to highlight regional supply chains and offer both services and resources, with the opportunity also for other services to be added, as delivery, even for companies that had never experience this service before [40]. Moreover, to give support and information to companies a hotline was created and regular newsletters about evolution of restrictions and news were sent to the population.
Many companies move online or created social-media pages to promote their products or services. Local administration meetings moved online, as it was for Royans Vercors Intermunicipality. In the French Alpine Space Fab Labs coordinated for a decentralized production of more than five hundred thousand visors with opensource plans and 3D-printers [41].

With lockdowns all around the world online teaching was experimented, exposing problems regarding internet infrastructures, or families not owning enough digital devices. As an example, in the Test Area of Campo Ligure distributed laptops to family in needs, with the goal also to continue in taking advantages of online teaching in case of red or orange alert for weather conditions, which are very frequent during autumn or winter in these areas.
In general, with a lower density of population, the possibility of having vast outdoor spaces, a strong idea of community, despite the usually not adequate healthcare services, rural areas reacted well during the first months of Covid outbreak.

2.4 Measure the level of "smartness" of a Smart Village

After describing the boundaries of the Smart Villages' definition, it is essential to find a model to quantify the "smartness" of a Test Area selected. Numbers are needed to compare different Test Areas, judging strengths and weaknesses of every area, and to give guidelines to policy makers and stakeholders on the way forward to enhance the smartness.
Considering the lack of works on Smart Villages and the intimate relationship with Smart Cities explicated before, it is possible to consult the Smart Cities' literature to adapt one of its models to this topic [42].
Regarding studies of ranking approaches of Smart Cities, it is important to mention Giffinger's work in 2007, who elaborated six relevant characteristics embedded in his analysis: mobility, governance, economy, environment, living and people [43]. Those six characteristics were subdivided into 31 factors, which reflect the fundamentals about the characteristics. Moreover, every factor is represented by indicators, which defines empirically the specifics.
In this thesis a multidimensional model is used to evaluate and assess the smartness of areas under consideration, therefore six characteristics, here called dimensions, are formulated:

- *Smart Economy:* it represents the presence of creative and innovative companies, the diffusion of ICT technologies, or the employment rate.
- *Smart Environment:* this dimension includes an evaluation of RES production and use, the possibility of a zero-waste economy and the relationship between the environment and the citizens. It also encompasses the presence of Energy Communities.
- *Smart Mobility:* it represents the mobility in the area under consideration, considering public and shared transport, or other sustainable ways of moving, as electric or hybrid vehicles.
- *Smart Living:* services to the population, as healthcare services, internet coverage or basic services to the citizen are evaluated in this dimension.
- *Smart People:* in this dimension it is possible to consider the level of participation of citizens in public life, as it could be in decisional processes, or in active associations. It also represents the level of digital literacy or if there is an issue related to depopulation and ageing.
- *Smart Governance:* in this dimension the relationship between public administration and citizens is investigated, highlighting for example the e-government services, the possibility of participative approach in decision making, or the ways of communication between those two.

Each dimension is subdivided into indicators, defined differently to capture the needs of the specific areas under consideration.
To elaborate results obtained in different questionnaires, different Multi-Criteria Decision Aiding (MCDA) methods are used. In particular, the family of ELECTRE methods is

considered, where ELECTRE is an acronym that stands for "ELimination Et Choix Traduisant la REalité" or "ELimination Et Choice Translating REality". This family of methods was created by Bernard Roy, who distinguished three basic problematics [44, 45]:

- Choosing: given a finite set of alternatives or actions A, it is necessary to choose a subset of the best alternatives $A' \subseteq A$, as small as possible. If the problem consists in an optimization problem, the choice will be for just an element of A'.

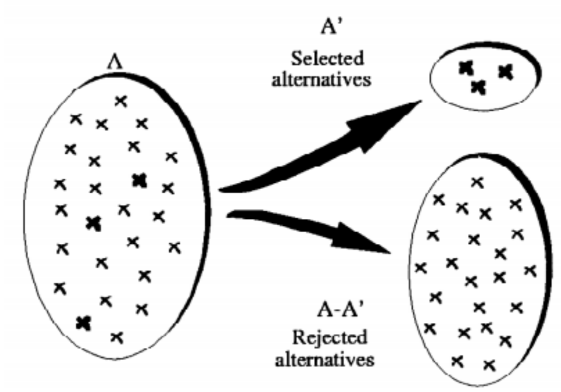


Figure 4 - One of the three problematics distinguished in the ELECTRE methods: choosing.

- Sorting: given a set of alternatives A, it is possible to assign each alternative to predefined and ordered categories. The assignment of the alternatives is based on the intrinsic value of the group and not to the comparison between the alternatives.

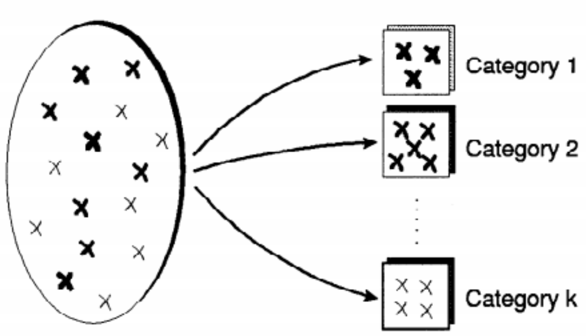


Figure 5 - One of the three problematics distinguished in the ELECTRE methods: sorting.

- Ranking: given a set of alternatives A, it is possible to establish a preference pre-order, which could be partial or complete. In this way, a rank order is given, from the best to the worst.

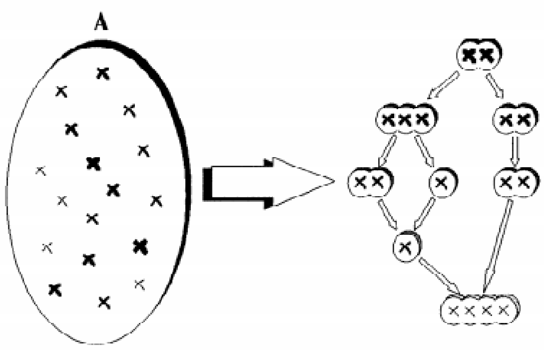


Figure 6 - One of the three problematics distinguished in the ELECTRE methods: ranking.

For choosing problems ELECTRE-I is recommended, while ELECTRE TRI method, recently called ELECTRE TRI-B method [46], introduced in 1992 is advised for sorting. In this thesis a ranking method is used, and the methodology of this method will be further discussed.
It is possible to already introduce some terms that will be useful later, such as [46]:

- Decision Maker (DM): this term represents those for whom the decision aiding must be provided. The DM is able to provide the performance of each action, interacting with the analyst.
- Analyst: this figure denotes a facilitator of the decision aiding process, who must perform her/his role in interaction with the DM.

Chapter 3

Energy Communities

In this chapter the challenging journey of European Union to decarbonization is outlined, citing the key points during years to reach the goal of a green Europe. In this context, the concept of Energy Community is defined, both in the form of Citizens Energy Communities (CECs) and Renewable Energy Community (RECs), also by deepening its legal Italian framework. Then, the enabling technological framework for energy communities is summarised.
At the end of the chapter, a comparison between Energy Communities and Smart Villages is proposed.

3.1 A green Europe

The European Union (EU) is promoting a sustainable future with long term strategies, by signing agreements with other countries, and by promoting environmentally friendly policies and incentives on decarbonization.
The will to face climate change was first formally expressed in 1997 by UN with the first legally binding instrument for cutting greenhouse gas emissions called Kyoto Protocol, undersigned by United Nations Framework Convention on Climate Change (UNFCCC) Parties, in which EU and all its member countries participate.
After Kyoto Protocol, the EU set the challenging goals of achieving by 2020 a 20% greenhouse gases reduction respect to 1990 levels, 20% of energy production obtained by renewable sources and 20% of improvement in energy efficiency. These goals were subdivided between member states, taking into considerations the initial situation, the economic indicators, and the capability to reach the goals of the different countries.
Then, in 2015 the global climate Paris Agreement was adopted by all UNFCCC Parties during the Paris climate conference COP21. This agreement invited to a concerted global response to hold the global temperature increase to well below 2°C and pursuing efforts to limit it to 1,5°C.
In October 2017, the European Council invited the European Commission "to prepare by COP24 a mid-century zero emissions strategy for the EU". The goal of zero net emissions of greenhouse gases by 2050, becoming the first climate-neutral continent, plus economic growth decoupled from resource usage, and the willingness of no person and no place left behind were announced by EU in December 2019, contained in the European Green Deal presented by the President of the European Commission von der Leyen, with its main

features summarised in Figure 7. The action plan of the European Green Deal includes the restoration of biodiversity, the reduction of the pollution and the promotion of an efficient usage of resources, also thanks to circular economy, through a social fair transition [47]. The urgent and critical challenge of those times could be transformed into an opportunity for Europe, being the global leader in this transformation [48].
Concerning the clean energy policy area, key principles regard the increase of renewables in energy production and the promotion of energy efficiency, while assuring secure and affordable energy for Europe. In the future a fully integrated, connected, and digitalised EU energy market.

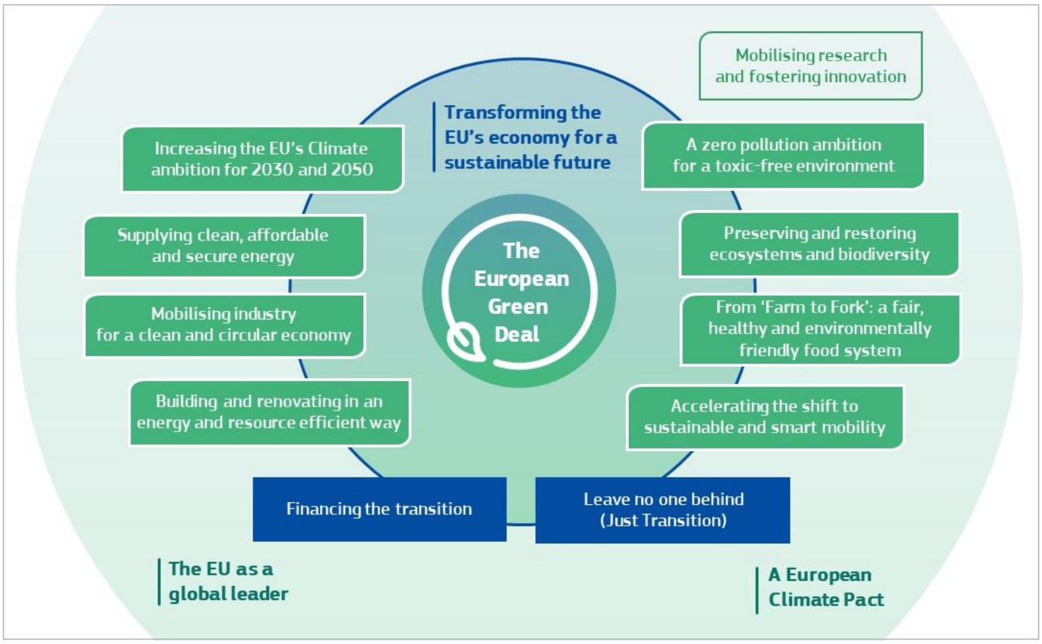


Figure 7 - European Green Deal – Image by European Commission

3.2 Clean Energy for all European Package in Italy

Based on European Commission proposal in 2016, the Clean Energy for all Europeans Package (CEP) was completed in May 2019, with a significant update of the European energy policies embedding eight Regulations and Directives, including the dimensions of energy security, internal energy market, energy efficiency, decarbonization of the economy and research, innovation, and competitiveness, here listed [10]:

- Renewable Energy Directive (EU) 2018/2001
- Energy Performance of Buildings Directive (EU) 2018/844
- Energy Efficiency Directive (EU) 2018/2002
- Governance of the Energy Union and Climate Action Regulation (EU) 2018/1999.
- Electricity Regulation (EU) 2019/943
- Electricity Directive (EU) 2019/944

- Regulation on Risk-Preparedness in the Electricity Sector (EU) 2019/941
- Regulation on the European Union Agency for the Cooperation of Energy Regulators (EU) 2019/942

European countries have about two years from the finalization of CEP to convert the directives in new national laws. The Clean Energy Package is also called the “Winter Package”.
The CEP set ambitious targets for 2030 in the direction of a free carbon economy, with the clause of a possible upward revision of these targets in 2023:

- to be at least one third more efficient in energy usage, precisely 32,5%
- to cut at least 40% of greenhouse gas emissions
- to have at least 32% of renewable in energy consumption.

From CEP’s Governance of the Energy Union and Climate Action Regulation following the Governance of the Energy Union and Climate Action Regulation, each European country drafted a National Energy and Climate Plan (NECP) for 2021-2030 to ensure the possibility for Europe to meet the Paris Agreement Commitment, outlining how to meet their respective targets on all the five mutually reinforcing dimensions of EU, which are:

- *Security, solidarity and trust*. EU countries should cooperate to diversify the sources of energy, while ensuring energy security through solidarity and cooperation
- *A fully integrated internal energy market.* Infrastructures are needed to meet this challenging target, as well as regulations.
- *Energy efficiency*. To decrease the consumes, and so the greenhouse gas emissions, it is important to make more efficient what is already present. Moreover, this could create new jobs and growth in the country.
- *Climate action, decarbonising the economy*. It is necessary to act rapidly to meet the Paris Agreement.
- *Research, innovation and competitiveness*. New solutions and technologies are important to speed up the energy transition process.

The NECPs should be evaluated by EU Commission, outlining a long-term strategy for at least the next 30 years. Italian NECP is called “Piano Nazionale Integrato per l’Energia e il Clima” or PNIEC, submitted in January 2020 [49].
The CEP enables a legislative framework for citizens and renewable energy communities, but the key to make energy communities successful is given by CEP’s transposition into national laws, identifying concrete support measures [50].

3.2.1 The transposition of Renewable Energy Directive (RED II) in Italy

The Renewable Energy Directive (RED II) EU 2018/2001 is part of the CEP: it comes into force in December 2018 and should be transposed into national law by all the 28 Member States by the 30th of June 2021 [11].

Figure 8 - The journery from RED II to and Italian transposition, from [51]

This directive states definitions of the various part embedded in the energy balance, recognizing their role in the market. The discussion about Energy Communities takes place in article 22, where these are defined as Renewable Energy Communities (RECs). The directive introduces a governance model for the ECs also with the possibility of energy sharing within them. Moreover, in article 21 prosumers are defined, called renewables self-consumers, giving them the rights to generate renewable energy, including for their own consumption, store and sell their excess production, while maintain rights and obligations as final consumers.
On June 2019 the Directive (EU) 2019/944 was published concerning common rules for the internal market for electricity, in which Citizen Energy Communities (CECs) are defined. The distinguish between Renewable Energy Communities and Citizen Energy Communities is explained in the next paragraph. Article 15 is focused on active consumers: it states that the rights of consumers who want to participate in the energy market should be the same of the actual energy producers. The consumer becomes a prosumer, with an active role in the energy transition and aware of its importance in a decentralized electrical system. It also encourages to simplify procedures for decentralised services, and for producing and storing energy from renewable sources, also by not charging them of excessive fees.
A temporary and partial transposition of RED II was given on 28th February 2020 in the so called *Decreto Milleproroghe* (law decree n.162/2019, article 42-bis, comma 9) [12]. Energy communities were defined only as RECs with the following limitations concerning its partecipants:

- Renewable plants should not produce more than 200 kW.
- Users of a Renewable Energy Communities should all be connected to the same secondary substation, while for collective renewable self-consumers users should be in the same building.

- Incentives for renewable plants which are to be part of the community are given only to plants which enter into operation after the decree enters into force (1st of May 2020).

On the 16th of September 2020, the implementation decree by the Ministry for Economic Development, for shot MiSE, was approved and converted into law n.8/2020. This implementation decree covers the actuation of *Decreto Milleproroghe* and incentives for the renewables power plants, which are given for 20 years and managed by the Italian Manager of Energy Services, in Italian *Gestore dei Servizi Energetici* (GSE):

- 100 €/MWh for collective renewable self-consumption.
- 110 €/MWh for renewable energy communities.

The law n.8/2020 defines the shared energy in each period of time as the minimum of the electric energy produced by renewable plants and the electric energy used by the community members including storage systems in this evaluation, both for collective renewable self-consumption and RECs. The sharing of energy is possible thanks to the existing distribution grid. Moreover, rights and duties of members are listed, as the possibility to terminate the contract with the EC anytime, but participating in the finalization of the agreed investments.

On 4 August 2020, the Italian Regulatory Authority for Energy, Networks and Environment (ARERA) with the deliberation 318/2020/R/EEL acknowledge self-consumption and energy communities. A virtual regulatory model is used to recognize economic benefits from site consumption of locally produced electric energy [52].

In December 2020 GSE published the technical rules to obtain incentives for energy communities, the preconditions for access to these incentives, the standard contract and the timings to receive incentives.

3.2.2 Definition of Energy Communities

Energy Communities have been precisely defined, distinguishing between CECs and RECs. Article 2, Comma 11 in the Electricity Market directive Directive EU/2019/944 defines the first kind of Energy Community, the CECs or Citizen Energy Communities [53]:

'Citizen energy community' means a legal entity that:

(a) is based on voluntary and open participation and is effectively controlled by members or shareholders that are natural persons, local authorities, including municipalities, or small enterprises;

(b) has for its primary purpose to provide environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates rather than to generate financial profits;

(c) may engage in generation, including from renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services or charging services for electric vehicles or provide other energy services to its members or shareholders.

In the Renewable Energy Directive (RED-II) EU/2018/2001, Article 2, Comma 16 [54], the second kind of energy communities are defined as RECs or Renewable Energy Communities:

'Renewable energy community' means a legal entity:
(a) which, in accordance with the applicable national law, is based on open and voluntary participation, is autonomous, and is effectively controlled by shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that legal entity;
(b) the shareholders or members of which are natural persons, SMEs or local authorities, including municipalities;
(c) the primary purpose of which is to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits.
Both CECs and RECs are legal entities based on open and voluntary participation, effectively controlled by its members. They are non-commercial type of market actors: Member States should ensure that they can operate across the market on the same field as the traditional energy producers. The primary purpose is in both cases to generate benefits for its members or for the local areas of operation, more than economic profit. RECs could be seen as a subset or a type of CECs, considering that RECs have more stringent rules, as the geographical limitations and the stricter eligibility requirements [55]. The proximity requirements of RECs should reinforce the sense of community and it is decided by each member state: actually, different restrictions based on network, distance, administrative or ad hoc are implemented.
CECs include only electric energy, differently from RECs which include also gas or heat, Moreover RECs limit participation only to renewable technologies, differently from CECs.
In Table 1 the main differences between RECs and CECs are summarized [51].

Table 1 - Summary of differences between RECs and CECs from [51]

	Renewable Energy Communities (RECs)	Citizen Energy Communities (CECs)
Members	Residential, tertiary sector, Public Administration, small or medium industries	Residential, tertiary sector, Public Administration, small industries
Type of energy	Electric and thermic energies, only from renewable sources	Only electric energy, both from renewable and not renewable sources
Perimeter of action	Proximity	No constraint, also cross border participation is possible
Authorized activities	Production, selling, self-consuming, storing, sharing, access to the market	Production, selling, self-consuming, storing, sharing, access to the market, distribution, supply, services as energy efficiency or recharging cars

Private companies from the energy sector cannot be part of energy communities in order to ensure that ECs remain no-profit.
Energy communities could be formed because of economic, social, environmental, technical or political aspects. Strong drivers are represented by economic incentives and

the possibility of cheaper electricity bills, but the process start mainly because of other reasons, as a desire of self-sufficiency, or of local determination. Environmental concerns and the willingness of a more sustainable usage of energy could also increase the engagement of citizens in the process, while empowering the local community and enhancing the process of democratic decision making [50] , [56]. The active participation of citizens in the electric market could help locally in overcoming social acceptance of renewable energy projects and in attracting private investments that could bring benefits as employment growth and reduction of fuel poverty [57]. To make participation to energy communities accessible to all consumers, it is important to support low income and vulnerable citizens in joining ECs.

3.3 Enabling technologies for energy communities

The enabling framework for energy communities includes both a legal framework and a technological one. Different technological features are needed to make an energy community possible.
In this subchapter, photovoltaic systems and storage technologies are treated considering the focus of the model on this configuration.

3.3.1 PV power plants

A residential PV plant is formed by the solar panels, composed by solar modules and solar cells, one or more DC-AC inverters, a supporting infrastructure defined as balance of system (BOS) and, eventually, a storage system. Other components, as smart metering, are possible to be installed. A PV power plant usually lasts 20/25 years, with little necessity of maintenance and a good resistance to weather [15]. Thanks to the photovoltaic effect, a physical and chemical phenomenon that occurs in many semiconductor materials, PV panels can generate voltage and electricity when exposed to light.
Photovoltaic power plants could be grid connected, or stand-alone. In case of a stand-alone PV plant storage systems are essential since the plant is not connected to the distribution systems. A third possibility is represented by hybrid systems, which are grid connected, but the connection with the distribution systems is used only when it is not possible to produce locally electricity, or when the storage systems is exhaust.
Residential PV power plants could help in reaching NZEBs net zero energy buildings.

PV Panels

PV panels can have different configurations: rooftop PV, which could be fixed or with the possibility of varying the tilt angle, are the most used in urban context. If there is any available space, PV panels could be ground mounted, and, if water bodies are present, floating configuration could be chosen, both in water reservoirs or in marine water, with near shore or offshore plants.
Modern technologies used especially for new buildings include Building Applied Photovoltaic (BAPV), Building Integrated Photovoltaic (BIPV) and Building Integrated Photovoltaic Thermal (BIPVT). BAPVs are added to the structure not having a direct effect on the structure’s function, while BIPV/T can be integrated in the building by replacing

construction materials. BIPVTs could be air-based systems, water-based systems, concentrating systems or systems involving a phase change working medium, making it possible to recover also thermal power [58].

Solar cells

Solar cells can be categorized into three generations, depending on the used materials and on the commercial development. In the following list, main technologies are cited [59]:

- First generation solar cells. Based on silicon wafers, this type of cell, which is also called crystalline silicon, could be subdivided into two groups, which are single/monocrystalline silicon solar cells and poly/multi crystalline silicon solar cells. The first subgroup is obtained by Si crystals and its efficiency lies between 14% and 18%. The second group is obtained by mixing different crystals. This cell's efficiency strongly decreases with the increase in temperature. Thanks to the abundance of silicon and the low price of this technology, this solution is the most present on the market.
- Second generation solar cells. Based on thin film PV technologies, these cells are more economical than first generation, but still in early commercial development. They include subgroups as amorphous (a-Si), based on low-cost polymer and flexible substrates, CdTe, which is one of the most important between thin films from an economical point for view, and CIGS, semiconductor which comprises four elements.
- Third generation solar cells. In this category technologies still under development are included, as concentrated PV and organic cells, which are not totally ready for the market.

Too high or too low temperatures, weather, foiling could influence solar cells' efficiency.

Storage systems

Storage is used in decentralised systems to load levelling, peak shaving, limiting overgeneration or to improve power quality. The development of storage systems will be useful to increase renewable sharing, helping in reaching the goals of renewable energy consumptions.

Different technologies are present, main ones include pumped hydro, compressed air energy storage (CAES), and electrochemical storage [60].

Pumped hydro is the more mature technology: when the demand is lower, it pumps water from a lower reservoir to an upper one, from where it pumped into turbines to produce energy, with a high reliability. Pumps could be single units or separated. The great advantage of this technology is the possibility of a switch within minutes from pumping to energy production, which occurs very frequently during the day, differently from thermal plants which are not so fast. Disadvantages regard the massive construction works needed for the power plant and the environmental impact.

Compressed air storage foresees the compression and storage of air in a reservoir, thanks to a compressor using during low request of energy. Electricity is then generated by a gas turbine, fed with the compressed air.

Electrochemical storage generates electricity from chemical reactions. It is the most common type of storage coupled with PV systems. Batteries usually are lead-acid or lithium-ion chemistries, with some discussion of flow batteries. First type is the cheapest one, most versatile and most common, but with a bad performance at low and high temperatures, a short lifetime, and the necessity of a periodic maintenance, while the second has higher efficiency, up to 99%, and faster charging/discharging cycles [61].

3.3.2 Italian Scenario for photovoltaic power plants

The production of PV power plants depends directly on the irradiation. Talking about the Italian scenario, it is essential to look at the average irradiation present on the territory.

Figure 9 Photovoltaic power potential of Italy, © 2019 The World Bank, Source: Global Solar Atlas 2.0, Solar resource data: Solargis [56]

The whole Italian country has favorable conditions for installing solar power plants, with a higher solar radiation in South Italy respect to the North.

At the end of 2019 from a report by GSE S.p.A. it results that 880’090 photovoltaic plants are installed in Italy with an installed power of 20’865 MW [15]: 97,5% are connected to low tension, representing 37,1% of total power.
It is interesting to see the regional distribution of the PV plants reported in Figure 10: 29,5% of plants are between Lombardy and Veneto, while the region with the highest installed power is Apulia. Basilicata, Molise, and Valle d’Aosta are the region with the lower number of plants. The difference in installation is given by different factors: characteristics of the territory, the weather, the availability of suitable areas for PV plants.
The commitment of the government stated in the PNIEC is to reach 50GW of photovoltaic production by 2030 [62].

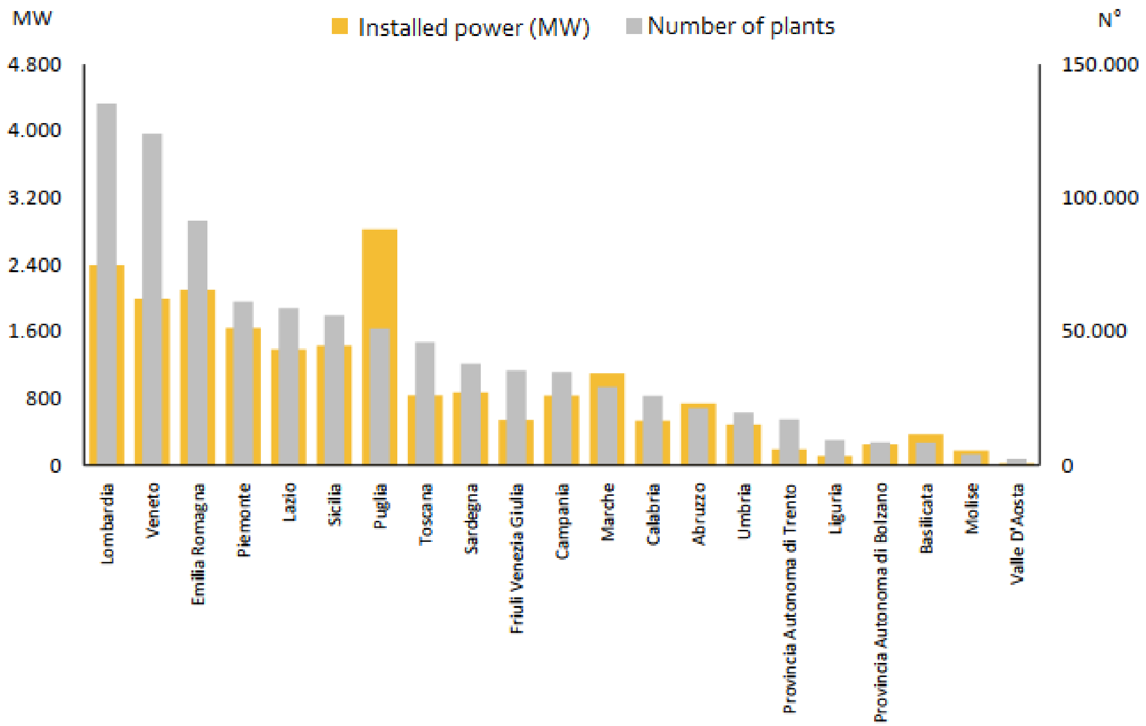


Figure 10 - Regional distribution of numerosity and installed power in Italy at the end of 2019, from [15]

Storage systems could help in using efficiently self-produced energy: at the end of 2019 about 118MW of storage were installed with an increasing trend from previous years. In the PNIEC it is stated the commitment in installing new pumped hydro storage plants to increase flexibility of the system, while increasing the share of variable renewable production, as photovoltaic, considering the possibility to use them when the higher load is requested, after programming the pumping in hours with lower loads. Moreover, it is necessary to increase usage of electrochemical storage, both centralized and distributed [49].

3.3.3 Available roof area for PV panels and their exposition

NREL reviewed 35 studies and 6 patents to estimate potential generation from PV systems and divided them into three different categories [63]: constant value methods, manual selection methods and GIS-based methods. Main advantages and disadvantages are listed in Table 2:

Table 2 – Methods to estimate potential generation from PV systems from [63]

	Description	Advantages	Disadvantages
Constant value methods	Estimate a multiplier used for the entire area	Quick Rooftop area is easy to compute	Rooftop characteristics not considered Difficult results to validate
Manual selection methods	Rooftops are selected manually from different sources, as aerial photographs	Assumptions made on specific knowledge of regions and buildings Detail-specific	Time intensive Not easily replicable across regions
GIS-based methods	GIS softwares determine high suitability areas for PV given some input from the user	Detail-specific Replicable Possibility of automation	Time intensive Computer resource intensive

In this thesis a combination of these methods is used: GIS-based methods are used to select buildings and evaluate their azimuth angles, while manual selection methods corrected the selection of the buildings. Moreover, constant value methods are used to correct the area found for the different buildings.

About the direction in which placing the PV panels, roofs facing the South are usually chosen in the Northern hemisphere [64]. Several studies address benefits of facing PV panels in other directions than South, with very different outcomes. Usually PV panels are placed only on a side of the roof, but 2D configuration is possible. In "Benefit Evaluation of PV Orientation for Individual Residential Consumers" [65], consumers are subdivided into different classes, corresponding to Eurostat's classification [18]:

- Very small consumers: annual consumption less than1000 kWh
- Small consumers: annual consumption between 1000 kWh and 2500 kWh
- Medium consumers: annual consumption between 2500 kWh and 5000 kWh
- Large consumers: between 5000 kWh and 15000 kWh annual consumption
- Very large consumers: more than 15000 kWh annual consumption

Small consumers usually have their peak of consumes in the morning, while medium and large consumers have their peak demand in the evening. This difference is important when deciding the PV position, considering that a South oriented panel and an East or West oriented panel have their peak of production in different hours. Analysing a large dataset of consumption profiles and different possibilities of orientation, optimal 2D configuration is found as the east/west oriented, especially for medium and large consumers. In this article both sides have the same spread of PV, while from a practical point of view this could be difficult to obtain due to different objects and obstacles present on the roofs, but it is a valid first approximation.

3.3.4 Examples of energy communities

JRC analysed twenty-four case studies of energy communities: in 2019 the outcomes include that the widespread technologies are wind and solar technologies [50].
Solar initiatives are more common in countries as Spain or the south of France where the conditions for PV usage are favourable, both in terms of solar radiation (kWh/year) and temperatures, but also in European countries as Germany, Netherlands or Belgium where the weather conditions are theoretically not optimal but where positive policies concerning energy produced from renewable sources are incentivized. Moreover, the possibility of installing solar power both on houses, or on public buildings, or also on farms, increases the available spaces for the energy production. Hydroelectric based energy communities are less frequent, but can ensure reliability, as demonstrated in Isle of Eigg in Scotland in an off-grid hybrid scheme including hydro, solar and wind [66].
Higher income countries in North Europe present more energy communities than South Centre and East Europe, evidencing that income levels have a role too in the developing of energy communities.
In this paragraph, some examples of Italian energy communities are presented.

Energy Community of Magliano Alpi: Energy City Hall
In Cuneo's province the Renewable Energy Community of Magliano Alpi "Energy City Hall" takes place [67]: founded on the 18th of December 2020 and put into operation from March 2021, it was the first REC established after the publication of last Italian ECs legislations. The City Hall is the main prosumer with a 20kW PV plant on the roof of the city hall and six other users are associated, which are four families, two local companies, by association's fee of 25 euros per year. In the little municipality of about 2100 inhabitants, new plants will be installed in the next years and new energy communities are planned for 2021, one referred to the local sport centre and one to the industrial facility. It is part of RESCoop, the European federation of Energy Communities [68]. From the starting of the community, Magliano Alpi received requests of collaboration from other municipalities, also from places far from the area.

Energy Community by Energy Pinerolo Consortium
In the same Region, but in another province, the Energy Pinerolo Consortium (CPE) is present, in the surrounding of Pinerolo [69]. One of its current projects is an energy community, including different type of members, as private citizens, companies and public entities. In particular, up to now are involved six municipalities (Cantalupa, Frossasco, Roletto, San Pietro Val Lemina, Scalenghe, Vigone), five companies, six group of citizens (one for each municipality).
From Politecnico di Torino's estimate, the energy community should consume about 17 GWh/year and produce the same amount of energy with renewable power plants. The

community will include fifteen not domestic PV plants, hydroelectric power plants (450kW) and biogas production from organic waste. Moreover, a cogeneration plant with high efficiency is implemented [70].

Alpine REC Tirano - Sernio
Tirano and Sernio in Sodrio's province are part of a pilot project by RSE becoming one of the first alpine REC in Italy, with a production of both thermal and electrical energy [71].
In Tirano's municipality three MV producers (three are co-generators), five photovoltaic power plants and 192 prosumers with private PV plants are present, plus a district heating biomass fuelled, managed thanks to a sustainable usage of local woods, producing a thermal power of 58MWt and of electric power1,1 MW. Thanks to the energy community Tirano will share its energy production with Sernio. The EC will supply 34'443 MWh of thermal energy and 30'200 MWh of electric energy to about 6800 PODs.
The goals of this project include to increase the resiliency of the electric lines and the energetic autonomy, while promoting the territory with a major attractiveness for industries, creating new jobs especially for younger people in mountain areas.

3.4 Energy communities and Smart Villages

After describing the characteristics of Energy Communities and Smart Villages, in this sub-chapter the relationship between these two concepts is investigated.
Energy Communities and Smart Villages are both based on empowering people: the process starts from the bottom with participatory approach, by informing the community of the opportunity to gain benefits for different sectors, from environment to social cohesion, or from mobility to health. In fact, Smart Villages strategies could enable the formation of successful energy communities in rural areas with advantages, as the possibility to have an income that could be reinvested in social innovation, or also into smart tourism projects, promoting the local zone, or into reinforcing the local economy resilience, maybe helping the most vulnerable part of population. This last concept could be referred to one of the three general objectives of the CAP Strategic Plan (SP), which states "to strengthen the socio-economic fabric of rural areas", and to the Specific Objective 8 for creating "Vibrant Rural Areas" by "promoting employment, growth, social inclusion and local development in rural areas, including bio-economy and sustainable forestry".
The relationship between ECs and SVs has been investigated during the 10th meeting of the ENRD Thematic Group on the 22nd of January 2020 in Brussels, Belgium [72]. During this meeting 49 stakeholders from 20 Member States were invited to discuss about Smart Village approach could help the decarbonization, facilitating the establishment of Energy Communities. Dirk Vansintjan, president of the European federation of citizen energy cooperatives REScoop, pointed out that with right legal frameworks RECs can develop quickly, as it is for Denmark in which in January 2020 it was possible to count 2100 wind cooperatives and 340 district heating cooperatives directly owned by consumers.
From this meeting, recommendations emerged for accelerating the energy transition in rural areas through future policies solutions:

1. Project awareness: create awareness and build community and municipal buy-in for renewable energy projects. It is essential to have transparent communication and facilitation to involve local stakeholders, as in the case of eleven Spanish LAGs that develop Enegest, a free tool to know energy local costs and possible savings.
2. Project emergence and development: set up effective systems for providing technical assistance and capacity building for rural communities interested in developing a REC. As an example, the Community and Renewable Energy Scheme (CARES) managed by Local Energy Scotland provides advice and flexible funding packages for developing RECs.
3. Project construction and operation: start small with seed funding that spreads risk and allows testing the business model of projects. In the first stage of development and testing funds are present and they will increase once this phase is successful.
4. Regulatory environment: set target indicators and ensure a stable regulatory framework that supports the long-term viability RECs. Indicators could be tailored on the different situations, to understand if interventions are done in an efficient way. For example, the Scottish Government had a goal of 500 MW of energy produced by RECs by 2020, which was exceeded and increased to 1GW for 2020 and 2GW by 2030, with positive progress toward this target [73]. To support RECs in long term it is essential to monitor the transposition of RECs in the different Member States, assuring the presence of enabling conditions.

Smart Villages and Energy Communities could bring advantages to rural areas, empowering their citizens and giving tools to increase their autonomy.

Chapter 4

Proposed methodology for energy communities' simulations

In this chapter the methodology used in this thesis is illustrated.
The final goal is to compare in a long-term output different configurations of energy communities, to understand the economic outcomes in the different cases, as following the actual transposition of the Clean Energy Package in Italy and supposing less strict rules.
A model developed in a previous master thesis in Energy Engineering is taken in account for this work [74]: it aims to simulate reliably the introduction of ECs in the Italian scenario, recreating energy fluxes between the users, the interaction of the users with the national grid and the valorisation of the self-consumed energy. In this thesis, this model was taken and adapted to a real case in Avise and Arvier, two municipalities of Valle d'Aosta Region. Inputs were created from regional data and QGIS analysis, then simulations with different parameters were performed.
PV and BESS installed in the simulated energy communities are sized with Mixed Integer Linear Programming (MILP) optimization algorithms, optimized to maximize the Net Present Value (NPV) of the investments in energy communities.
In the model, the energy is completely shared with the community, also sharing totally between the community the expenses and the savings.
The model is written in Python, an open-source language.

4.1 Community establishment

The users act collectively in the community, and they own together the PV plants, which are installed where it is most suitable considering exposition, inclination, available spaces and other parameters, and, if the optimization model requires it, a storage system, here considered as battery energy storage system (BESS). In this subchapter energy flows and cash flows are taken into account.
With respect to the energy flows, the energy generated by PV panels is shared with the members of the community: considering that also the bills and the costs are shared among the members, it does not matter which users receive the produced energy, because the benefit is collective. Surplus energy not needed by the users is used to charge the BESS, then when totally charged it is exchanged with the grid, producing a revenue.
Analysing from a mathematical point of view, it is possible to write this problem with formulas. At the instant t the available energy for the community $E_{com}^{avail}(t)$ is the sum of

energy produced by the k PV panels, while the requested energy $E_{com}^{req}(t)$ is the sum of the i user load.

$$E_{com}^{avail}(t) = \sum_{k \in EC} \left|E_k^{gen}(t)\right| \tag{4.1}$$

$$E_{com}^{req}(t) = \sum_{i \in EC} E_i^{load}(t) \tag{4.2}$$

It is also possible to compute the energy shared within the community at the instant t $E_{com}^{shared}(t)$, as the energy need by the community $E_{com}^{need}(t)$ and the energy in surplus $E_{com}^{surpl}(t)$:

$$E_{com}^{shared}(t) = \min\left(E_{com}^{avail}(t), E_{com}^{req}(t)\right) \tag{4.3}$$

$$E_{com}^{need}(t) = E_{com}^{load}(t) - E_{com}^{shared}(t) \tag{4.4}$$

$$E_{com}^{surpl}(t) = E_{com}^{avail}(t) - E_{com}^{shared}(t) \tag{4.5}$$

The two parameters of energy need, and surplus are fundamental when evaluating the hourly behaviour of the energy storage system.
Concerning the battery, it is charged with an inward energy flow $E^{ch}(t)$, discharged by an outward energy flow $E^{dis}(t)$ and its state of charge is represented by $SOC(t)$, which varies between a maximum capacity b and the minimum depth of discharge $DoD * b$.
If a surplus of energy is present, it charges the battery considering its physical limits as C_{rate} and the efficiency of charging η_{ch}. The energy injected into the grid $E_{com}^{int}(t)$ is null and the new state of charge depends on the charging energy $E^{ch}(t)$.

$$\text{If } E_{com}^{surpl}(t) < b - SOC(t-1) \tag{4.6}$$

$$E^{ch}(t) = \min\left(\frac{b}{C_{rate}}; E_{com}^{surpl}(t) * \eta_{ch}\right) \tag{4.7}$$

$$E_{com}^{int}(t) = 0 \tag{4.8}$$

$$SOC(t) = SOC(t-1) + E^{ch}(t) \tag{4.9}$$

If the surplus of energy is bigger than the amount of energy that could be stored in the battery, the charging energy $E^{ch}(t)$ is evaluated, then the difference between the surplus energy $E_{com}^{surpl}(t)$ and the charging energy is sold in the grid. The new state of charge of the battery is the maximum possible value.

$$\text{If } E_{com}^{surpl}(t) \geq b - SOC(t-1) \tag{4.10}$$

$$E^{ch}(t) = \min\left(\frac{b}{C_{rate}}; b - SOC(t-1) * \eta_{ch}\right) \tag{4.11}$$

$$E_{com}^{int}(t) = E_{com}^{surpl}(t) - E^{ch}(t) \tag{4.12}$$

$$SOC(t) = b \tag{4.13}$$

For the discharging process, the logic is similar. When the community requires energy $E_{com}^{need}(t)$, the battery is discharged to satisfy this request, limited by the C_{rate} and the minimum depth of discharge DoD. From the grid, no energy$E_{com}^{with}(t)$ is withdrawn and the new state of charge involve the energy discharged $E^{dis}(t)$ by the battery.

$$\text{If } E_{com}^{need}(t) < SOC(t-1) - DoD * b \tag{4.14}$$

$$E^{dis}(t) = \min\left(\frac{b}{C_{rate}}; SOC(t-1) - \frac{E_{com}^{need}(t)}{\eta_{dis}}\right) \tag{4.15}$$

$$E_{com}^{with}(t) = 0 \tag{4.16}$$

$$SOC(t) = SOC(t-1) - E^{dis}(t) \tag{4.17}$$

If the energy needed by the community $E_{com}^{need}(t)$ is bigger than what the battery can provide, the battery is discharged until reaching the minimum value as $SOC(t)$ and from the grid energy is withdrawn $E_{com}^{with}(t)$, subtracting the discharged energy $E^{dis}(t)$ to the energy needed.

$$\text{If } E_{com}^{need}(t) \geq SOC(t-1) - DoD * b \tag{4.18}$$

$$E^{dis}(t) = \min\left(\frac{b}{C_{rate}}; SOC(t-1) - \frac{DoD * b}{\eta_{dis}}\right) \tag{4.19}$$

$$E_{com}^{with}(t) = E_{com}^{need}(t) - E^{dis}(t) \tag{4.20}$$

$$SOC(t) = DoD * b \tag{4.21}$$

The second step in the mathematical description of the community is the definition of the cash flow of the EC. In this case, the expenses, the savings and the revenues are shared between the different members, as well as the propriety of the power plants and of the storage systems. It is important to mention the Shared Energy Saving index (SES_i), which in the cash flows values the saving obtained by the sharing of energy in the community, and to consider that here the Self-Consumption Saving index (SCS_i) is not applicable since there is any user who possess a power plant and self-consumes his energy.

4.2 Capacity optimization

In this optimization model, the variables involved are the capacity of the PVs and of a battery storage system, if needed. The two variables are evaluated considering the sharing of energy between the members, which are subjected of constraints given by the grid and by the BESS. The objective function which maximises the NPV for the energy community is reported at the end.

4.2.1 Variables

PV Capacity

The capacity of the installed PV represents the solution to the optimization problem. For each available roof k, contained in the available set of roofs S, the tool could choose to use the whole area, part of it, or to choose to do not use it.

$$x_k \forall \mathrm{k} \in \mathrm{S} \tag{4.22}$$

Capacity of the battery

A single battery system is considered, whose capacity b is expressed in kWh.

4.2.2 Constraints

Energy balance

The energy balance inside the EC with BESS must be respected: the summation of the energy generated by the installed PVs $E_k^{gen}(t)$ multiplied by the capacity installed on each roof k, plus the energy withdraw from the grid $E^{with}(t)$ and the discharged energy from the battery E^{dis} must be equal in each instant t to the summation of the energy required by the loads $E^{load}(t)$, the energy sold to the grid $E^{int}(t)$ and the charging energy $E^{ch}(t)$.

$$\sum_k E_k^{gen}(t) * x_k + E^{with}(t) + E^{dis}(t) = E^{load}(t) + E^{int}(t) + E^{ch}(t) \tag{4.23}$$

Self-consumed energy by the EC

The self-consumed energy at instant t $E^{self}(t)$ is the minimum between the summation of the energy required by the loads of the systems $E_i^{load}(t)$ and the produced energy in the EC $E_k^{gen}(t)$:

$$E^{self}(t) = min\left(\sum_i E_i^{load}(t)\,;\sum_k E_k^{gen}(t) * x_k\right) \tag{4.24}$$

Energy sold to the grid

The energy sold into the grid $E^{int}(t)$ is the maximum value between a null value and the difference between the energy generated $E_k^{gen}(t)$, the self-consumed energy by the EC $E^{self}(t)$ and the energy used for the battery charging $E^{ch}(t)$:

$$E^{int}(t) = max\left(0; \sum_k E_k^{gen}(t) * x_k - E^{self}(t) - E^{ch}(t)\right) \tag{4.25}$$

Energy withdrawn from the grid

The energy withdrawn from the grid $E^{with}(t)$ is evaluated, as the maximum between 0 and the difference between the consumed energy by the users $E_i^{load}(t)$, the self-consumed energy by the EC $E^{self}(t)$and the energy discharged by the battery $E^{dis}(t)$:

$$E^{with}(t) = max\left(0; \sum_i E_i^{load}(t) - E^{self}(t) - E^{dis}(t)\right) \tag{4.26}$$

Available surfaces on the roofs

The maximum spaces occupied by PV panels is equal or lower than the available space, therefore the capacity installed for each panel x_k is equal or less than the maximum power P_k^{max}that could be produced:

$$x_k \leq P_k^{max} \tag{4.27}$$

Not negative solutions for PV

For each roof the capacity installed x_k is equal or greater to zero:

$$x_k \geq 0 \tag{4.28}$$

4.2.3 BESS constraints

Definition state of charge

With this constrain the system evaluates the state of charge of the battery for each period of analysis: the $SOC(t)$ is given by $SOC(t-1)$ plus the charged energy $E^{ch}(t)$, and minus the discharged energy $E^{dis}(t)$, both evaluated with their efficiencies of charging η_{ch} and discharging η_{dis}. If the $t = 1$, the initial state of charge should be taken in account:

$$SOC(t) = \begin{cases} b * SOC_{initial} - \dfrac{E^{dis}(t)}{\eta_{dis}} + E^{ch}(t) * \eta_{ch} & if\ t = 1 \\ SOC(t-1) - \dfrac{E^{dis}(t)}{\eta_{dis}} + E^{ch}(t) * \eta_{ch} & if\ t > 1 \end{cases} \tag{4.29}$$

Maximum charge
The state of charge is always equal or less than the size of battery b:

$$SOC \leq b \tag{4.30}$$

Maximum discharge
The state of charge is always above the minimum deep of discharge:

$$SOC \geq b * DoD \tag{4.31}$$

Maximum power in charge and discharge
Maximum power of charge and discharge of the battery depends on the size of the battery:

$$P_{stor}^{max} = \frac{b}{T_{ch/dis}^{max}} \tag{4.32}$$

Maximum energy in charge and discharge
The energy inflow and outflow are always less than the maximum power of charge $E^{ch}(t)$ and discharge $E^{dis}(t)$:

$$E^{ch}(t) \leq P_{stor}^{max} * \Delta t \tag{4.33}$$
$$E^{dis}(t) \leq P_{stor}^{max} * \Delta t \tag{4.34}$$

Battery reposition cost
After a period of usage, it should be considered a reposition cost of the battery evaluated in $\left[\frac{€}{kWh}\right]$, also called wear cost, which depends on the charging and discharging energy and on the unitary cost of battery replacement, which depends on the number of cycles N^{cycles}, on the cost of replaceable parts and on the depth of discharge DoD.

$$C_{batt}^{rep} = \sum_{t} (E^{ch}(t) + E^{dis}(t)) * c_{batt,rep}^{unitary} \tag{4.35}$$

$$c_{batt,rep}^{unitary} = \frac{C_{batt}^{replaceable}}{N^{cycles} * 2 * (1 - DoD)} \tag{4.36}$$

Maximum BESS capacity
It is chosen a maximum capacity b of the BESS depending on the number of the users n_{users} and on a parameter chosen as $5kWh$.

$$b \leq 5kWh * n_{users} \tag{4.37}$$

4.2.4 Objective function

The objective function maximizes the NPV over a period of time l: the NPV considers the costs for the installation of PV panels and of the battery and the actualized cash flow over a period of time l.

The shared energy is valued thanks to the SES_i, while the excess energy is sold at the zonal price to the GSE. ARERA subdivided the Italian territory into six geographical areas, with six different zonal prices. The zonal price NORD is referred to Aosta Valley, Piedmont, Ligury, Lombardy, Trentino, Veneto, Friuli Venice Giulia, Emilia-Romagna: its value is decided on the day ahead market and varies every hour.

$$\max(NPV) = -\sum_k C_k^{fix} * x_k - C_{batt}^{fix} * b + \sum_l \left(\frac{-\sum_k C_k^{var} * x_k - C_{batt}^{var} * b - C_{batt}^{rep} - C_{admin}}{(1+k)^l} + \frac{\left(E^{load}(t) - E^{with}(t)\right) * SES_i + E_t^{inj} * p_{zonal}(t)}{(1+k)^l} \right) \tag{4.38}$$

- C_{batt}^{fix}: investment battery cost expressed in $\left[\frac{€}{kWh}\right]$
- C_{batt}^{var}: variable battery costs $\left[\frac{€}{kWh*year}\right]$
- SES_i shared energy saving index: this index valorises the energy shared between community's members.

4.3 Application and adaptation of the tool

The optimization model was written in Pyomo, which stands for Python Optimization Modeling Objects and is an open-source Python base language [75], useful for describing optimization problems, as MILP. A concrete model is used in this case: concrete models are easy to script and Pyomo construct each component in order at the time it is declared. The optimization problem is solved with Gurobi solver [76].

As written before, the model was created in a previous master's thesis work and then adapted to this specific case. From a modelling capacity of approximately ten users, it was scaled up to treat up to one thousand users also by enabling data input from pre-processed real datasets provided by local authorities. The data processing tool, also designed in Python language, takes the data and a reference profile, then generates the annual hourly load profiles for each user making the data readable for the model. Moreover, it was modified in order to use GIS analysis results on target locations to calculate the features of the roofs, as available areas, azimuth angles, tilt angles, evaluating the best surfaces where to place the PV panels, summarising the outputs and making them readable.

The model is applied in long-term analysis, evaluating the NPV. An economic comparison is done in the same territory between the possibility of creating a single energy community for each secondary substation and the possibility of a unique energy community including all the users. Prices of batteries are varied to see the different economic feasibility. At last, heating loads are added in different percentages to analyses the convenience of heating decarbonization through an energy community.

Chapter 5

The case of Valle d’Aosta: Simulations and Results

5.1 Applicability of Smart Villages approach in Valle d’Aosta

5.1.1 The territory

An overview of the territory of Valle d’Aosta and the context of the collaboration between Poliedra and the Region is presented in this chapter.
The region of Valle d’Aosta has a completely mountainous territory, which includes Italian slopes of the four massifs higher than 4000m: Mont Blanc (4808m), Mount Rosa (4634m), Mount Cervino/Matterhorn (4478m), Gran Paradiso (4061m).
All 74 municipalities in the Region have less than 5 thousand inhabitants, apart from Aosta, and 60% of these has less than 1000 inhabitants [77].
Looking at the Istat data collected before the pandemic of COVID-19, on 1st of January 2019 less than one family out of five (22,6%) in the Region has not an internet access from home, a little less than the Italian average (23,9%). Included in this percentage almost half of the families (24,7% versus 25,5% in Italy) does not know how to use internet, while a quarter of these families considers internet not useful or not interesting (22,6% in the Region, versus 23,9% in Italy).
Despite the fact that the EU set the goal for becoming climate neutral by 2050 [78], the autonomous Italian Region Val d’Aosta is challenging itself to became carbon free and fossil free [1]by 2040 [79]. This objective has made this region looking for new strategies to reach its goal.
The collaboration between Poliedra and Valle d’Aosta Region is focused on creating a system to identify policies and work guidelines to promote actions and measures concerning “Smart Villages” to be included in the 2021-2027 European Programme. Most of the process was done collaborating with the Department of Innovation and Digital Agenda (DIAD).

[1] Carbon free: compensation between CO2 emissions due to energy from fossil fuels and the capacity of the territory to absorb them. Fossil free: abandon or minimize the usage of fossil fuels. [111]

5.1.2 Good practices in rural areas

The work with the Region of Valle d'Aosta started by collecting and analysing good practices involving Alpine, mountain, rural or sparsely populated areas that could be applicable to the Region and by identifying stakeholders that could be involved. During the collecting procedure, it is important to follow the three Design Thinking principles [13], which are:

- Desirability, involving what is desirable and needed by the local population;
- Viability, providing a solution which could be supported economically in a short and long term;
- Feasibility, having technologies, knowledges, and policies to actualise the solution provided.

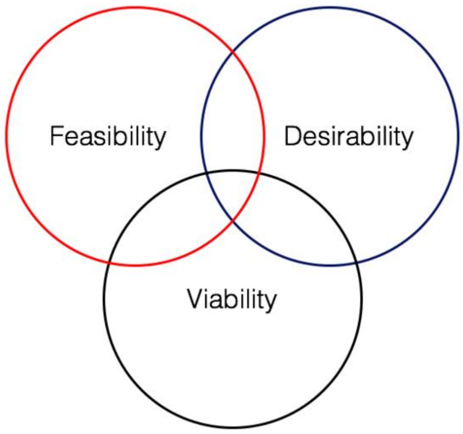


Figure 11 - Design Thinking principles

To bring innovation, so have a smart transition, it is important to select good practices which includes all the three principles, visually explicated by the intersection of the three circles in Figure 11.
Here in the following are listed some of the good practices submitted to the Region, divided into the respective smart dimensions and enumerating the possible stakeholders.

Smart Economy

- SMART SPACE (Alpine Space) [80].

SMART SPACE project has the objective to enhance the technological, economic and social conditions on Alps innovating the societies in the alpine space. Possible stakeholders: Public Administrations, entrepreneurs association.

- Alptracker (Switzerland) [81].

Swiss start-up which designs, creates and sells localization systems for the agricultural and herding sector. Most of the applications are used to localize in a short time the animals which got away from the herd or the cattle. Possible stakeholders: animal husbandry association.

Smart Environment

- Habitech - Distretto Tecnologico Trentino per l'Energia e l'Ambiente (Rovereto, Italy) [82]

Consortium of companies and supply chains specialised in sustainable buildings, energy efficiency and smart technologies, with the goal to transform the energy and the housing market into sustainable ones. Possible stakeholders: Public Administrations, research centres for climate and energy, universities, associations of entrepreneurs.

- Centrales Villageoises des Quatre Montagnes (Vercors, France) [83]

Centrales Villageoises' project includes different areas displaced in France. The goal is to achieve actions favouring the energy transition following a territorial logic. A juridical company is established in each zone, including citizens, authorities, local businesses, which can operate as a web following a common model in the Association. Projects are financed via own funds or bank loans, repaid with electric energy sale. The projects started in October 2016 in a mountain area where 600 m^2 PVs were installed with both economic and environmental benefits for the community. Possible stakeholders: Public Administrations, research centres for climate and energy, associations of entrepreneurs, local actions group, environmental associations.

Smart Mobility

- FLEXIBUS (Valsesia, Piedmont, Italy) [84]

Flexibus is an on-demand bus service which connects all the municipalities in Valsesia. Moreover, if the user booked an exam and/or a medical visit it is possible to reach also the nearest hospital. The service is available from 8am to 7pm every day paying 2.50€. It is necessary to book one day in advance with a phone call to benefit from this service. Possible stakeholders: public administrations, public transport companies, hospitals.

- BUS ALPIN (Switzerland) [85]

Bus Alpin is an association of local and regional authorities that encourage the usage of public transport to reach the main Swiss hiking destinations with buses adapt for mountain driving, promoting the accessibility of tourists. Possible stakeholders: public administrations, public transport companies.

Smart Living

- It happens in Loco (Alto Minho Mountain, Portugal) [86]

Mountainous area of Alto Minho is experiencing youth drain, abandonment and depopulation. The project aims to help local communities to increase their knowledge about how to improve the living and working conditions in their area, according to modern expectations and standards, in order to revitalize the area. Possible stakeholders: public administrations, citizens associations, tourist offices.

- COWOCAT RURAL (Catalonia, Spain) [87]

COWOCAT RURAL is an inter-territorial cooperation project developed between 2014 and 2016 about creating a network of coworking spaces in the rural Catalan areas. The main goal was to stop the youth drain, creating a place to develop and share new ideas. Optical fiber in coworking spaces was essential to have a good and stable connection. The project created 14 coworking spaces, with more than 130 professionals linked to the network. Possible stakeholders: professionals associations, telecommunications societies.

Smart People

- Jemlokalno – Eat Local (Murska Sobota, Pomurje, Slovenija) [88]

Public Administration along with SmartIS, an IT society, created a platform during lockdown to connect local food producers with consumers. Jemlokalno, which means "eat local", enabled the population to know opening hours, availability of food products and possibility to connect with the producers. Ministry for agriculture of Slovenia has planned to develop a business case to cooperate in further development of the platform, to have a long-term success story. Possible stakeholders: Public Administrations, local business, IT societies, breeders' associations, farmers' associations, local action groups.

- Le Parlement de Montagne (Occitanie, France) [89]

The Parliament of the Mountain was established in 2018 at the citizens' requests, following an idea coming from the Sea Parliament. It is composed by an online forum with about 700 active users and by online and in presence meetings between local mountain communities and public administrations, which topics are deepened by working groups. In 2019 with online vote people participated to participatory budgeting, allocating resources of more than 70 initiatives, encouraging people to be part of the community and increasing trust in public administrations. Possible stakeholders: local action groups, mountain associations, public administrations, citizens associations, IT societies.

Smart Governance

- Megaphone (Fieschertal, Canton Vallese, Switzerland) [90]

Introduced before local lockdown in 2020, Megaphone's app was useful especially during the emergency, enabling fast communications between public administration of Fieschertal and citizens, also thanks to push notifications and the possibility to give back feedbacks. Moreover, citizens used it to interconnect and organize neighbourhood assistance, especially for elderly people. Local restaurants could also promote their delivery service through the app, with benefits for both the community and the business. Possible stakeholders: Public Administrations, citizens associations, tech companies.

- SALUTILE Pronto Soccorso (Lombardia) [91]

SALUTILE is an app by Lombardy Region which enables citizens to see on a map the public and private hospital's emergency rooms, knowing how many patients are already there, divided into their triage code, giving an approximation of waiting time. Possible stakeholders: Public Administrations, tech companies, hospitals.

Alongside this collecting work, Poliedra collected data and needs of the Region itself, including good practices from the Region itself.
By analysing the pre-existent documents and listening to the different stakeholders, main needs of the Region emerged. During these meetings recurring themes got out and were noted, understanding if those could be included in Smart Village's politics.
It is important to highlight that most of the documents given by the Region to Poliedra were drafted before the pandemic and that the decision support system needed to be long time

oriented: this condition made also more interesting the meetings with the Departments, in order to understand if the pandemic had caused a shift in needs of the population.
On the 23rd of June 2020, kick-off meeting takes place online, sharing to the Region what has been analysed by Poliedra. Main requirements are found as:

- Rethink regional transport systems, adding alternatives and including intermodality, in particular looking at remote areas;
- Consider the increased vulnerability of the territory due to climate change;
- Increase the digital literacy of the population and the level of digital innovation;
- Improve digitalization in PA;
- Create spaces dedicated to proximity services;
- Increase the sharing of renewables in energy production and pursue energy independency, both at local and regional level.

All these requirements are taken in account when thinking about Smart Villages' approach in the Valle d'Aosta Region.

5.1.3 Main stakeholders involved in the Smartness Assessment process

Having a complete picture of main needs, it is possible to formulate indicators to be included in a questionnaire to measure the smartness of the Region. The questionnaire is focused on the six smart dimensions previously discussed: Smart Mobility, Smart Governance, Smart Economy, Smart Environment, Smart Living, Smart People.
The main stakeholders are the fourteen Departments of the Region and the Regional General Secretary. Every department had to compile the part of the questionnaire referred to the Smart Dimensions assigned to them on the basis of their different competences and areas of interest, plus the dimension of the Smart Governance, which was compulsory for every department. Moreover, it was asked to the DM how many common points are present between his work and the other smart dimensions. If the DM considered that there was something in common, it was possible to fill out that part of the questionnaire too. Questionnaire structure and its results are discussed in detail in the next chapter.
Before submitting the test to all the stakeholders, on the 2nd of October 2020 seven members of DIAD tried the test in an online meeting, in which they had to discuss to give a single answer, bringing the completion of the test in three hours. Thanks to this experiment some changes were made, as the decision to use a website instead of online or in person meetings with each department and the decision to ask to the departments which Smart Dimensions are related to their work.
The questionnaire had to be taken in person in Aosta by Poliedra with the departments but, considering the spreading of the SARS-CoV-2 pandemic and the decrees issued by the Italian Prime Minister, the relative link was sent to each department and the Smartness Assessment was compiled using the platform LimeSurvey version 2.62, which is present on the Val d'Aosta Regional servers. On the platform it was also present an introductory tutorial made by Poliedra explaining the goals of the analysis and the usage of the tool.

The questionnaire was submitted in December 2020 to the main stakeholders, which were 14 departments, plus the General Secretary:

1. Dipartimento Innovazione e Agenda Digitale (DIAD)
2. Dipartimento Turismo, Sport e Commercio
3. Dipartimento Politiche del lavoro e della formazione
4. Dipartimento Sovraintendenza agli studi
5. Segretario Generale
6. Dipartimento Sanità e Salute
7. Dipartimento Trasporti
8. Dipartimento Agricoltura
9. Dipartimento Industria, Artigianato ed Energia
10. Dipartimento Ambiente
11. Dipartimento Personale e Organizzazione
12. Dipartimento Politiche Sociali
13. Dipartimento Protezione Civile e Vigili del Fuoco
14. Dipartimento Soprintendenza per i beni e le attività culturali
15. Dipartimento Programmazione, risorse Idriche e territorio.

Currently, departments are being subdivided differently, consequently to rearrangement after the regional elections held in September 2020.

5.1.4 Structure of the Regional Smartness Assessment

The Smartness Assessment is divided into the six Smart Dimensions. For each dimension the relative work guidelines are listed, then the relative seven indicators, called statements, are enumerated. The forty-two statements are attached at the end of this document (Attachment A), divided into the seven smart dimensions.
The DM must declare his closeness of agreement with each statement on a Likert's scale with five options:

- I strongly disagree (-2)
- I disagree (-1)
- I don't disagree nor agree (0)
- I agree (+1)
- I strongly agree (+2)

The DM was also expected to self-assess its competences in that field in a Likert's scale from one to three:

- Low competences (0)
- Medium competences (1)

- High competences (2)

Numerical evaluations of the different answers are report and they will be useful in the numerical analysis.
In this chapter some images from Smartness Assessment are attached, mainly from the Smart Governance dimension which is common for every department.

Figure 12 - Work Guidelines

Figure 13 – Smart Governance's statements

Then, for every smart dimension compiled, the DM should sort the seven statements from what they considered the most to the least important. The priority order stated by the DM has been converted numerically into the following numerical values:

- First position: +7
- Second position: +6
- Third position: +5
- Fourth position: +4
- Fifth position: +3
- Sixth position: +2
- Seventh position: +1

Figure 14 – Smart Governance's prioritization

Afterwards, three open questions for every compiled dimension were asked: the first one was about integrating or changing some statements or some work guidelines for the considered dimension.

SMART GOVERNANCE

Integrazioni e modifiche

Avete qualche **commento o integrazione** alle affermazioni dello smartness assessment relative alla dimensione **Smart Governance**? Qualche ulteriore direttrice di intervento nella logica «Smart Villages» non ricompresa dall'attuale formulazione dello smartness assessment per la dimensione Smart Governance?

Figure 15 – Open question about integrations and changes

The second question was about essential measures related to the smart dimension considered as necessary in an envisioned Valle d'Aosta in the future in a Smart Village logic, considering both what was and what was not mentioned in the Smartness Assessment.

SMART GOVERNANCE

Vision

Qual è l'aspetto imprescindibile che **secondo voi non potrà mancare**, facendo riferimento alla logica Smart Villages per la dimensione Smart Governance, nella vostra visione della Valle d'Aosta del futuro? Questa visione può tenere conto delle affermazioni dell'assessment, ma anche proporre altro.

Figure 16 – Open question about vision in Smart Governance

The last question was about explaining how far from realizing the essential measures listed in the precedent point the DM considers the Region to be and about listing what DM thinks could be a way to realize those points.

Figure 17 – Open question about next steps in governance

5.1.5 Parameters used in the Smartness Assessment

In this chapter, the parameters used to analyze the answer of every DM to each statement are listed and explained.

- *Judgements* are evaluated for each statement and for each DM by multiplying the points given to the statement by the declared competence.
- *Essential factors* depend on judgements and on the answers to the open questions at the end of the questionnaire: if a statement stated as essential by the DM has a judgment with a positive value, the essential factor is $4{,}5$. Instead, if the judgement is zero or negative, the essential factor is $1{,}5$. If the DM did not state that statement as essential, the essential factor is 0.
- *Weights* are important parameters that could be evaluated quickly: the priority order declared by every DM is normalized diving by the maximum value given, which is 7. Then, for every statement the arithmetic mean between the different answers is calculated.
- *Utilities* are defined for each statement as:

$$Utility = (Judgement + Essential\ Factor) * Weight \tag{5.1}$$

The average between the utilities of a department is calculated. These values are used to calculate *Euclidean distances* between the utilities of different departments with the following formula:

$$Euclidean\ Distance_{dep\ A,\ \ dep\ B} = \sqrt{\sum_{i=1}^{7\ statements} \left(Utility_{\ dep\ A_i} - Utility_{\ dep\ B_i}\right)^2} \tag{5.2}$$

5.1.6 Comparing the results between different Smart Dimensions

A possible extension of this work is to determine the relative importance of each dimension, hence the different weights of the dimensions. Determine which dimension is more important than another could be done by neutral experts, or it could give a strong political message, if the DM is part of the Region.

It could be used a Comparison Matrix, following the procedure used in Analytic Hierarchy Processes (AHP) by Thomas Saaty [92]. The AHP is a compensatory optimization approach, based on the idea that humans are more able in doing relative judgments than absolute ones [93].

A pairwise comparison between different dimensions (n) is done in the Comparison Matrix (nxn), in which the DM should express his preference between two alternatives. It is a reasonable assumption to compile just the upper triangle of the matrix and to report the reciprocal ones in the bottom part, such that for $i \neq j$, $a_{ij} = 1/a_{ji}$. In the diagonal of the matrix, only ones are present, since each dimension is compared with itself, such that $a_{ii} = 1\ \nabla i$.

Also, this matrix is referred by Saaty to be reciprocal: weights are consistent if transitive, such that $a_{ik} = a_{ij} * a_{jk}\ \nabla i, j, k$. Considering that the matrix is compiled by human judgement, this condition does not always hold. Because of this, it will be calculated -at the end of the procedure- a consistency index, to see if the data collected are consistent: if not, it could be asked to recollect the data [94].

The values used in the pair wise comparison matrix by Saaty are positive, such that we have a positive matrix, composed of positive elements $a_{ij} > 0$, and these goes from 1 (equal importance) to 9 (extreme importance) [92], while here, to simplify the Smart Assessment, values are from 1 to 3.

Intensity of importance
1 Equal importance
2 Little importance
3 Strong importance

Table 3 - Parameters to be used in the comparison matrix, representing the intensity of importance between two dimensions

In the incomplete matrix proposed below, the number reported in red as an example indicates that the "Smart Environment" has a stronger importance than "Smart Mobility". It is also possible to notice that reciprocity is automatically respected, considering that its reciprocal value is reported in the opposite part of the matrix, so between “Smart Mobility” and “Smart Environment”.

	Smart Economy	Smart Environment	Smart Governance	Smart Living	Smart Mobility	Smart People
Smart Economy	1					
Smart Environment		1			3	
Smart Governance			1			
Smart Living				1		
Smart Mobility		1/3			1	
Smart People						1

Table 4 - Example of how to compile a comparison matrix

After completing the matrix, it is possible to do some evaluations. The eigenvector given by the column which contains the maximum eigenvalue called λ_{max} , is used to find the relative weights: dividing every element in the matrix by the sum of its column, it is possible to find the priority vector.

$$w_i = \frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}} \tag{5.3}$$

To measure the consistency of answer, the Consistency Index (CI) is used:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{5.4}$$

Consistency Ratio (CR) is given by the ratio between the Consistency Index (CI) and the Random Index (RI).

$$CR = \frac{CI}{RI} \tag{5.5}$$

The Random Index depends on the matrix order: it was computed by Saaty and it is reported in the table below.

Random Index (RI)										
Matrix order	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Values	0	0	0,58	0,9	1,12	1,24	1,32	1,41	1,45	1,49

Table 5 - Saaty's values for Random Index (RI)

Matrices with $CR \leq 0{,}1$ are accepted as a rule of thumb, otherwise values are recollected [93].

Geometrical mean, and not the arithmetic mean, is recommended by Saaty to combine judgments of individuals into a single representative judgement for the entire group. He also suggests combining only the final outcomes in case the individuals are experts that do not wish to combine their judgements and priorities [92].

5.1.7 Results of the Regional Smartness Assessment

Results are here listed. Tables for weights and utilities are reported, while tables for Euclidean distances are reported at the end of the document for simplicity. (Attachment B)

Smart Economy

WEIGHTS SMART ECONOMY							
	1	2	3	4	5	6	7
1. Dipartimento Innovazione e Agenda Digitale	0.714	0.429	0.571	0.286	0.857	1.000	0.143
2. Dipartimento Turismo, Sport e Commercio	0.286	0.143	0.857	1.000	0.714	0.571	0.429
3. Dipartimento Politiche del lavoro e della formazione	0.429	0.143	0.571	0.286	0.714	1.000	0.857
4. Dipartimento Sovraintendenza agli studi							
5. Segretario Generale							
6. Dipartimento Sanità e Salute							
7. Dipartimento Trasporti							
8. Dipartimento Agricoltura	1.000	0.714	0.429	0.571	0.857	0.286	0.143
9. Dipartimento Industria, Artigianato ed Energia	1.000	0.857	0.714	0.571	0.429	0.286	0.143
10. Dipartimento Ambiente	0.714	0.429	0.571	0.143	0.286	1.000	0.857
11. Dipartimento Personale e Organizzazione	0.857	1.000	0.714	0.143	0.286	0.429	0.571
12. Dipartimento Politiche Sociali	0.571	0.286	0.714	0.143	0.857	0.429	1.000
13. Dipartimento Protezione Civile e Vigili del Fuoco							
14. Dipartimento Soprintendenza per i beni e le attività culturali	0.857	0.286	1.000	0.714	0.571	0.429	0.143
15. Dipartimento Programmazione, risorse Idriche e territorio	0.571	0.429	0.714	0.286	1.000	0.857	0.143
Average	***0.700***	*0.471*	*0.686*	*0.414*	*0.657*	*0.629*	*0.443*

Table 6 - Results of the Regional SA: weights Smart Economy

UTILITIES SMART ECONOMY							
	1	2	3	4	5	6	7
1. Dipartimento Innovazione e Agenda Digitale	4.643	0.857	3.714	0.286	1.714	1.000	0.143
2. Dipartimento Turismo, Sport e Commercio	0.286	0.000	5.571	2.000	0.714	0.571	2.357
3. Dipartimento Politiche del lavoro e della formazione	0.857	0.000	3.714	0.571	4.643	0.000	5.571
4. Dipartimento Sovraintendenza agli studi							
5. Segretario Generale							
6. Dipartimento Sanità e Salute							
7. Dipartimento Trasporti							
8. Dipartimento Agricoltura	6.500	0.714	0.643	2.286	5.571	0.571	0.786
9. Dipartimento Industria, Artigianato ed Energia	0.000	3.429	4.643	0.571	0.000	0.000	0.214
10. Dipartimento Ambiente	0.000	0.857	0.000	0.000	0.000	0.000	0.000
11. Dipartimento Personale e Organizzazione	3.429	4.000	2.857	0.571	1.143	3.643	2.286
12. Dipartimento Politiche Sociali	0.000	0.000	1.071	0.000	0.000	0.000	0.000
13. Dipartimento Protezione Civile e Vigili del Fuoco							
14. Dipartimento Soprintendenza per i beni e le attività culturali	1.286	0.286	0.000	2.857	2.286	0.429	0.286
15. Dipartimento Programmazione, risorse Idriche e territorio	0.000	0.000	1.071	0.000	0.000	0.000	0.000
Average	*1.700*	*1.014*	***2.329***	*0.914*	*1.607*	*0.621*	*1.164*

Table 7 - Results of the Regional SA: utilities Smart Economy

Smart Environment

WEIGHTS SMART ENVIRONMENT							
	1	2	3	4	5	6	7
1. Dipartimento Innovazione e Agenda Digitale	0.714	0.286	0.571	0.429	1.000	0.857	0.143
2. Dipartimento Turismo, Sport e Commercio	0.286	0.857	0.571	0.429	0.143	1.000	0.714
3. Dipartimento Politiche del lavoro e della formazione							
4. Dipartimento Sovraintendenza agli studi							
5. Segretario Generale							
6. Dipartimento Sanità e Salute							
7. Dipartimento Trasporti							
8. Dipartimento Agricoltura	0.857	0.286	0.143	0.429	0.714	0.571	1.000
9. Dipartimento Industria, Artigianato ed Energia	0.714	1.000	0.857	0.429	0.143	0.286	0.571
10. Dipartimento Ambiente	0.429	0.714	0.143	0.857	0.286	0.571	1.000
11. Dipartimento Personale e Organizzazione	1.000	0.571	0.857	0.286	0.143	0.429	0.714
12. Dipartimento Politiche Sociali	0.571	0.286	0.857	0.143	0.429	1.000	0.714
13. Dipartimento Protezione Civile e Vigili del Fuoco	0.714	0.429	0.286	0.571	0.857	1.000	0.143
14. Dipartimento Soprintendenza per i beni e le attività culturali	1.000	0.143	0.857	0.714	0.571	0.429	0.286
15. Dipartimento Programmazione, risorse Idriche e territorio	0.429	0.571	1.000	0.286	0.714	0.857	0.143
Average	*0.671*	*0.514*	*0.614*	*0.457*	*0.500*	***0.700***	*0.543*

Table 8 - Results of the Regional SA: weights Smart Environment

UTILITIES SMART ENVIRONMENT							
	1	2	3	4	5	6	7
1. Dipartimento Innovazione e Agenda Digitale	0.000	0.000	0.000	0.857	4.000	7.286	0.143
2. Dipartimento Turismo, Sport e Commercio	0.000	0.000	0.000	0.000	0.000	6.500	0.000
3. Dipartimento Politiche del lavoro e della formazione							
4. Dipartimento Sovraintendenza agli studi							
5. Segretario Generale							
6. Dipartimento Sanità e Salute							
7. Dipartimento Trasporti							
8. Dipartimento Agricoltura	0.857	0.000	0.000	0.000	4.643	1.143	2.000
9. Dipartimento Industria, Artigianato ed Energia	6.071	8.500	5.571	0.429	0.571	0.571	1.143
10. Dipartimento Ambiente	2.786	1.429	0.000	7.286	2.429	3.143	4.000
11. Dipartimento Personale e Organizzazione	4.000	2.286	3.429	1.143	0.571	1.714	2.857
12. Dipartimento Politiche Sociali	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13. Dipartimento Protezione Civile e Vigili del Fuoco	0.000	0.000	0.000	0.000	3.429	-0.500	0.000
14. Dipartimento Soprintendenza per i beni e le attività culturali	0.000	0.571	0.000	0.000	0.000	0.000	0.286
15. Dipartimento Programmazione, risorse Idriche e territorio	0.429	1.143	0.000	0.000	2.857	1.714	0.000
Average	*1.414*	*1.393*	*0.900*	*0.971*	*1.850*	***2.157***	*1.043*

Table 9 - Results of the Regional SA: utilities Smart Environment

Smart Mobility

WEIGHTS SMART MOBILITY							
	1	2	3	4	5	6	7
1. Dipartimento Innovazione e Agenda Digitale	0.857	0.571	0.429	0.143	0.714	1.000	0.286
2. Dipartimento Turismo, Sport e Commercio	0.286	0.571	0.429	0.143	1.000	0.714	0.857
3. Dipartimento Politiche del lavoro e della formazione	0.571	0.714	0.857	0.143	0.286	1.000	0.429
4. Dipartimento Sovraintendenza agli studi							
5. Segretario Generale							
6. Dipartimento Sanità e Salute	0.714	0.143	0.286	1.000	0.429	0.571	0.857
7. Dipartimento Trasporti	1.000	0.857	0.143	0.714	0.571	0.286	0.429
8. Dipartimento Agricoltura							
9. Dipartimento Industria, Artigianato ed Energia	0.714	0.571	1.000	0.143	0.857	0.286	0.429
10. Dipartimento Ambiente	0.857	0.286	0.571	0.714	0.143	0.429	1.000
11. Dipartimento Personale e Organizzazione	0.857	0.571	0.714	0.429	0.286	0.143	1.000
12. Dipartimento Politiche Sociali	0.571	0.857	0.143	1.000	0.286	0.714	0.429
13. Dipartimento Protezione Civile e Vigili del Fuoco							
14. Dipartimento Soprintendenza per i beni e le attività culturali	0.571	0.429	0.286	0.714	0.857	1.000	0.143
15. Dipartimento Programmazione, risorse Idriche e territorio	0.571	0.286	0.429	0.714	0.857	1.000	0.143
Average	***0.688***	*0.532*	*0.481*	*0.532*	*0.571*	*0.649*	*0.545*

Table 10 - Results of the Regional SA: weights Smart Mobilty

UTILITIES SMART MOBILITY							
	1	2	3	4	5	6	7
1. Dipartimento Innovazione e Agenda Digitale	1.286	3.143	2.357	0.143	0.714	4.000	0.000
2. Dipartimento Turismo, Sport e Commercio	0.286	1.143	0.000	0.000	6.500	1.429	1.714
3. Dipartimento Politiche del lavoro e della formazione	0.000	0.000	0.000	0.000	0.000	0.000	0.857
4. Dipartimento Sovraintendenza agli studi							
5. Segretario Generale							
6. Dipartimento Sanità e Salute	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7. Dipartimento Trasporti	4.000	0.857	0.143	0.000	1.143	0.571	0.857
8. Dipartimento Agricoltura							
9. Dipartimento Industria, Artigianato ed Energia	2.857	0.571	4.000	0.143	0.857	0.571	3.643
10. Dipartimento Ambiente	1.286	0.429	0.000	0.000	0.000	0.000	0.000
11. Dipartimento Personale e Organizzazione	3.429	1.143	1.429	0.857	-0.571	-0.286	4.000
12. Dipartimento Politiche Sociali	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13. Dipartimento Protezione Civile e Vigili del Fuoco							
14. Dipartimento Soprintendenza per i beni e le attività culturali	0.000	0.000	0.000	0.000	0.000	0.000	0.214
15. Dipartimento Programmazione, risorse Idriche e territorio	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Average	***1.195***	*0.662*	*0.721*	*0.104*	*0.786*	*0.571*	*1.026*

Table 11 - Results of the Regional SA: utilities Smart Mobility

Smart Living

WEIGHTS SMART LIVING							
	1	2	3	4	5	6	7
1. Dipartimento Innovazione e Agenda Digitale	1.000	0.429	0.286	0.857	0.143	0.714	0.571
2. Dipartimento Turismo, Sport e Commercio	0.571	0.143	0.857	0.429	1.000	0.286	0.714
3. Dipartimento Politiche del lavoro e della formazione	0.714	0.571	0.429	1.000	0.286	0.143	0.857
4. Dipartimento Sovraintendenza agli studi	0.571	1.000	0.714	0.429	0.143	0.286	0.857
5. Segretario Generale							
6. Dipartimento Sanità e Salute	1.000	0.857	0.143	0.286	0.714	0.429	0.571
7. Dipartimento Trasporti	0.857	0.571	0.714	0.429	0.143	0.286	1.000
8. Dipartimento Agricoltura							
9. Dipartimento Industria, Artigianato ed Energia	1.000	0.857	0.714	0.429	0.286	0.571	0.143
10. Dipartimento Ambiente							
11. Dipartimento Personale e Organizzazione	0.286	0.143	0.714	0.571	0.857	0.429	1.000
12. Dipartimento Politiche Sociali	1.000	0.857	0.286	0.714	0.143	0.571	0.429
13. Dipartimento Protezione Civile e Vigili del Fuoco	0.286	1.000	0.143	0.429	0.571	0.857	0.714
14. Dipartimento Soprintendenza per i beni e le attività culturali	0.857	0.429	0.714	0.571	0.143	0.286	1.000
15. Dipartimento Programmazione, risorse Idriche e territorio	0.571	0.714	0.857	0.429	0.286	1.000	0.143
Average	***0.726***	*0.631*	*0.548*	*0.548*	*0.393*	*0.488*	*0.667*

Table 12- Results of the Regional SA: weights Smart Living

UTILITIES SMART LIVING							
	1	2	3	4	5	6	7
1. Dipartimento Innovazione e Agenda Digitale	2.000	0.429	0.000	1.714	0.000	1.429	3.143
2. Dipartimento Turismo, Sport e Commercio	0.857	0.000	1.286	0.000	0.000	0.000	0.000
3. Dipartimento Politiche del lavoro e della formazione	0.714	0.571	0.429	2.000	0.000	0.000	0.857
4. Dipartimento Sovraintendenza agli studi	0.000	4.000	0.000	0.000	0.000	0.000	0.000
5. Segretario Generale							
6. Dipartimento Sanità e Salute	2.000	1.714	0.143	0.286	1.071	0.000	0.000
7. Dipartimento Trasporti	0.000	0.000	1.071	0.000	0.000	0.000	0.000
8. Dipartimento Agricoltura							
9. Dipartimento Industria, Artigianato ed Energia	0.000	5.571	0.000	0.000	0.000	0.000	0.000
10. Dipartimento Ambiente							
11. Dipartimento Personale e Organizzazione	0.571	-0.571	6.071	2.286	5.571	0.857	2.000
12. Dipartimento Politiche Sociali	1.000	0.857	0.286	0.714	0.143	0.571	0.429
13. Dipartimento Protezione Civile e Vigili del Fuoco	0.000	6.500	0.000	0.000	0.000	0.000	1.071
14. Dipartimento Soprintendenza per i beni e le attività culturali	0.000	0.429	0.000	0.000	0.000	0.286	1.000
15. Dipartimento Programmazione, risorse Idriche e territorio	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Average	*0.595*	***1.625***	*0.774*	*0.583*	*0.565*	*0.262*	*0.708*

Table 13 - Results of the Regional SA: utilities Smart Living

Smart People

WEIGHTS SMART PEOPLE	1	2	3	4	5	6	7
1. Dipartimento Innovazione e Agenda Digitale	0.571	0.286	0.143	0.857	0.714	1.000	0.429
2. Dipartimento Turismo, Sport e Commercio							
3. Dipartimento Politiche del lavoro e della formazione	0.429	0.857	1.000	0.286	0.571	0.714	0.143
4. Dipartimento Sovraintendenza agli studi	0.857	0.429	0.571	0.143	0.286	0.714	1.000
5. Segretario Generale							
6. Dipartimento Sanità e Salute	1.000	0.571	0.857	0.714	0.429	0.286	0.143
7. Dipartimento Trasporti							
8. Dipartimento Agricoltura	1.000	0.714	0.143	0.571	0.429	0.857	0.286
9. Dipartimento Industria, Artigianato ed Energia	0.286	0.571	1.000	0.429	0.714	0.857	0.143
10. Dipartimento Ambiente							
11. Dipartimento Personale e Organizzazione	0.286	0.143	0.714	1.000	0.429	0.571	0.857
12. Dipartimento Politiche Sociali	0.714	0.286	0.143	1.000	0.429	0.857	0.571
13. Dipartimento Protezione Civile e Vigili del Fuoco							
14. Dipartimento Soprintendenza per i beni e le attività culturali	0.857	0.714	0.429	0.143	0.286	1.000	0.571
15. Dipartimento Programmazione, risorse Idriche e territorio	0.286	1.000	0.143	0.429	0.571	0.714	0.857
Average	*0.629*	*0.557*	*0.514*	*0.557*	*0.486*	***0.757***	*0.500*

Table 14 - Results of the Regional SA: weights Smart People

UTILITIES SMART PEOPLE	1	2	3	4	5	6	7
1. Dipartimento Innovazione e Agenda Digitale	1.143	1.571	0.143	3.429	1.429	6.500	0.429
2. Dipartimento Turismo, Sport e Commercio							
3. Dipartimento Politiche del lavoro e della formazione	0.857	1.714	0.000	0.571	1.143	1.429	0.000
4. Dipartimento Sovraintendenza agli studi	7.286	0.000	0.000	0.000	0.000	0.714	8.500
5. Segretario Generale							
6. Dipartimento Sanità e Salute	1.000	0.000	0.000	0.000	0.000	0.000	0.000
7. Dipartimento Trasporti							
8. Dipartimento Agricoltura	1.500	1.071	0.000	0.571	0.000	0.857	0.000
9. Dipartimento Industria, Artigianato ed Energia	0.286	3.143	2.000	0.000	3.929	1.714	0.000
10. Dipartimento Ambiente							
11. Dipartimento Personale e Organizzazione	0.571	0.571	2.857	2.000	3.643	1.143	3.429
12. Dipartimento Politiche Sociali	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13. Dipartimento Protezione Civile e Vigili del Fuoco							
14. Dipartimento Soprintendenza per i beni e le attività culturali	0.000	0.000	0.429	0.143	0.000	1.000	2.286
15. Dipartimento Programmazione, risorse Idriche e territorio	0.000	0.000	0.000	0.857	1.143	0.000	0.000
Average	*1.264*	*0.807*	*0.543*	*0.757*	*1.129*	*1.336*	***1.464***

Table 15 - Results of the Regional SA: utilities Smart People

Smart Governance

WEIGHTS SMART GOVERNANCE	1	2	3	4	5	6	7
1. Dipartimento Innovazione e Agenda Digitale	0.143	0.857	1.000	0.714	0.571	0.429	0.286
2. Dipartimento Turismo, Sport e Commercio	0.429	0.143	0.286	0.857	0.714	1.000	0.571
3. Dipartimento Politiche del lavoro e della formazione	0.714	0.571	0.429	0.286	0.143	0.857	1.000
4. Dipartimento Sovraintendenza agli studi	0.571	0.429	0.286	0.857	0.714	0.143	1.000
5. Segretario Generale	0.429	0.571	0.714	1.000	0.857	0.143	0.286
6. Dipartimento Sanità e Salute	0.429	1.000	0.857	0.571	0.143	0.286	0.714
7. Dipartimento Trasporti	0.714	0.571	0.857	0.429	0.286	0.143	1.000
8. Dipartimento Agricoltura	0.571	0.857	1.000	0.714	0.429	0.143	0.286
9. Dipartimento Industria, Artigianato ed Energia	0.286	0.429	0.571	1.000	0.857	0.714	0.143
10. Dipartimento Ambiente	0.429	0.571	0.714	0.286	0.143	1.000	0.857
11. Dipartimento Personale e Organizzazione	0.286	0.714	0.857	0.571	1.000	0.143	0.429
12. Dipartimento Politiche Sociali	0.286	1.000	0.571	0.143	0.429	0.714	0.857
13. Dipartimento Protezione Civile e Vigili del Fuoco	1.000	0.714	0.429	0.286	0.143	0.571	0.857
14. Dipartimento Soprintendenza per i beni e le attività culturali	1.000	0.429	0.286	0.857	0.714	0.143	0.571
15. Dipartimento Programmazione, risorse Idriche e territorio	0.429	0.714	0.286	0.571	0.857	0.143	1.000
Average	*0.514*	*0.638*	*0.610*	*0.610*	*0.533*	*0.438*	***0.657***

Table 16 - Results of the Regional SA: weights Smart Governance

UTILITIES SMART GOVERNANCE	1	2	3	4	5	6	7
1. Dipartimento Innovazione e Agenda Digitale	0.143	7.286	4.000	2.857	2.286	0.857	0.286
2. Dipartimento Turismo, Sport e Commercio	0.000	0.000	0.000	0.000	0.000	6.500	0.000
3. Dipartimento Politiche del lavoro e della formazione	1.429	1.143	0.857	0.000	0.000	0.000	0.000
4. Dipartimento Sovraintendenza agli studi	0.000	0.000	0.000	0.000	0.000	0.000	1.000
5. Segretario Generale	3.643	2.286	2.857	6.500	1.714	0.286	1.143
6. Dipartimento Sanità e Salute	0.000	2.000	1.714	0.000	0.000	0.286	0.000
7. Dipartimento Trasporti	0.000	0.571	4.714	0.000	0.000	0.000	0.000
8. Dipartimento Agricoltura	0.000	1.286	8.500	0.714	0.429	0.000	0.000
9. Dipartimento Industria, Artigianato ed Energia	0.429	2.357	3.143	1.500	0.000	0.000	0.000
10. Dipartimento Ambiente	0.000	0.000	0.000	0.429	0.000	0.000	0.000
11. Dipartimento Personale e Organizzazione	1.143	6.071	3.429	2.286	4.000	0.571	1.714
12. Dipartimento Politiche Sociali	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13. Dipartimento Protezione Civile e Vigili del Fuoco	2.000	1.429	0.000	0.000	0.000	0.000	1.286
14. Dipartimento Soprintendenza per i beni e le attività culturali	0.000	2.357	0.286	0.000	0.000	0.000	0.000
15. Dipartimento Programmazione, risorse Idriche e territorio	0.857	1.429	1.857	3.714	1.714	0.286	2.000
Average	*0.643*	*1.881*	***2.090***	*1.200*	*0.676*	*0.586*	*0.495*

Table 17 - Results of the Regional SA: utilities Smart Governance

Considering the average of the utilities of the seven statements of each dimension, it is possible to summarize the sum of the obtained points by the dimension:

Smart Environment	9.73
Smart Economy	9.35
Smart Governance	7.57
Smart People	7.30
Smart Living	5.11
Smart Mobility	5.06

Table 18 - Results of the Regional SA: sum of utilities for each dimension

This high total score in Smart Environment shows that all the Departments are in agreement in moving together to reach the ambitious objectives of the Region for 2040 with a great interest for sustainability, addressing this challenge from different sides.
Smart Economy captured a great interest having a high score.
The only Smart Dimension in which all the fifteen DMs answered is Smart Governance: this Dimension is crucial to help PA in digitalizing, with advantages both for the citizens and for the different offices. A lot of talks have been made about digitalization of the PA and this topic is also included in the first mission of Italy's Piano Nazionale di Ripresa e Resilienza.
Smart Mobility in the last place was penalized especially by a strong difference in approaching the questionnaire by some Departments.
Here are listed the two statements with the maximum score for the six Smart Dimensions and the five statements with the maximum score:

First two maximum values for each dimension		
Smart Economy		
3	Support digital literacy and digital soft skills spreading. Facilitate the usage of web services to industries.	2.33
1	Develop actions and strategies supporting digital innovation of productive processes, in particular conserning small companies	1.70
Smart Environment		
6	Invest in citizens education, promoting the territory preservation and the active participation through digital platforms	2.16
5	Increase economic attractiveness and the delevopment of new entrepreneurships in marginal areas through innovation and digitalization	1.85
Smart Mobility		
1	Encourage sustenaible intermodality in transport	1.19
7	Invest in sustainable mobility, in particular cycling, by creating new routes or reinforcing pre-existent ones	1.03
Smart Living		
2	Promote actions and strategies to have digital educative and formative services	1.63
3	Promote actions/strategies to provide in proximity services, in particular for rural areas	0.77
Smart People		
7	Promote in population Valdostan identity and cultural heritage through digital means of communication	1.46
6	Invest in initiatives supporting young enterpreneurs, in particular concerning digital innovation	1.34
Smart Governance		
3	Invest to digitalise practices for citizens and companies	2.09
2	Promote digitalization of practices and processes of PA at every level	1.88

Table 19 - Result of the Regional SA: for each Smart Dimension two first statements

First five statements		
Smart Dimension	*Number of statement*	*Utilities*
Smart Economy	3	2.33
Smart Environment	6	2.16
Smart Governance	3	2.09
Smart Governance	2	1.88
Smart Environment	5	1.85

Table 20 - Result of the Regional SA: first five statements

Highest score is reached by the third statement of Smart Economy: in PNRR almost double the amount of funds Digitalization in PA are allocated to Digitalization, Innovation and competitivity in the productive system are allocated for Digitalization in PA. This is reflected in these results.

In a Smart Village approach the territory should be considered as central, as it could be seen by the score of the sixth statement of Smart Environment, taking care of the territory is essential in a mountain region to prevent problems: making citizens aware of digital risks

and involve the community in prevention measures, also through digital platform, could help in controlling the regional area.
Third highest score is related to digitalization of practices between the PA and citizens or private societies: this could speed up bureaucracy and help those citizens who live in remote places.
Results are proposed to the Valle d'Aosta Region as guidelines to define principles for actions to be included in the new Regional Programme 2021-2027.

5.1.8 Local Smartness Assessment

After the ending of my internship, the Smartness Assessment was transposed to a local level by Poliedra. The Test Area selected is the Grand-Paradis Unité des Communes. The main goal was to compare if what has emerged from a regional point of view, could be found also from a local one. Even if I did not take part in this part of the work, it is interesting to list some of the results to bring conclusions.
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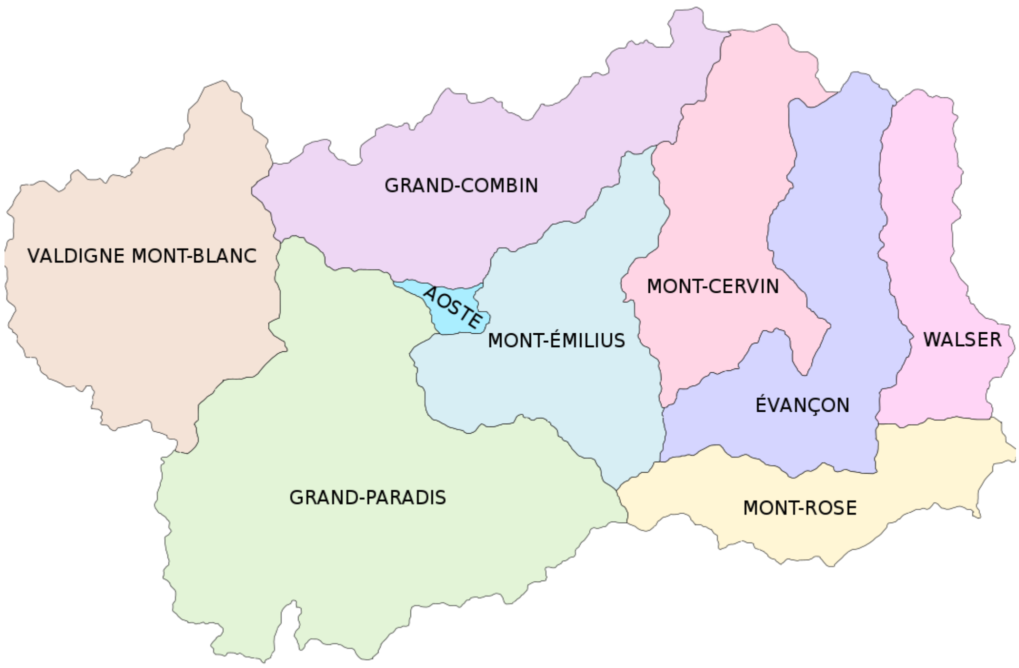

Figure 18 - UdCs of Valle d'Aosta Region from [95]

This area includes 15.547 inhabitants in 2020 distributed between thirteen municipalities: Arvier, Avise, Aymavilles, Cogne, Introd, Rhemes-Notres-Dame, Rhemes-Saint-Georges, Saint-Nicolas, Saint-Pierre, Sarre, Valgrisenche, Valsavarenche, Villeneuve [96]. The majors of all these municipalities answered to the local Smartness Assessment.
A comparison matrix was performed between the different smart dimension, highlighting a strong interest for Smart Mobility (29%) and Smart Environment (27%), which together carry on more than half of the interest of the Unité des Communes. Moving from regional to local perspective in a mountain area as this one, the mobility has a crucial value for the mayors: the absence of shared mobility, the inadequate offer for electric mobility and of

intermodal infrastructures for transport is seen as a strong problem for the communities. The dimension of Smart Environment is important too, aligned with the regional view.
From the results it is possible to see that one of the main goals of the Unité des Communes is to increase the renewable energy production, taking in consideration mainly hydro and photovoltaic power plants. Moreover, although energy communities are a new topic that still is not well known by public administrations, all the involved municipalities showed interest in this theme. For these reasons, the next subchapter is based on a real case study on energy communities in the territory of the Grand Paradis Unité des Communes.

5.2 Energy community in Grand Paradis Unité des Communes Valdotaines

This part of the work aims to discuss current and future regulations on energy communities: it is made a comparison between the possibility to set up different energy communities, each one referred to the relative secondary substation, and a unique energy community, composed by users referred to different secondary substation. Then, heating demand profiles of the two municipalities are added to the loads' profiles, evaluating a long-term analysis of the possibility of decarbonization of the heating systems.
This work is referred to the area of Arvier and Avise, two little neighbouring municipalities with respectively 860 and 300 inhabitants, included in the Grand Paradis Unitè de Communes Valdotaines. As previously seen by the Local Smartness Assessment, this area is strongly interested in developing energy communities: this evaluation should be intended as a first analysis to understand the possibilities in the territory to create an energy community.

Figure 19 - Arvier and Avise municipalities on Open Street Map

Valle d'Aosta Region has shared for this work confidential grid data about the positions of the secondary substations and about the monthly aggregated consumes of the users for one year, referring each user to its substation.

5.2.1 Evaluating PV distributed generation

Considering the users as prosumers and in a distributed energy generation optic, it is evaluated the potential generation in the presented territory for building integrated photovoltaic technology, hence it is necessary to analyse the territory estimating buildings' rooftops, to evaluate available roof areas.
This part of the work is conducted on a free and open Geographic Information System software: it is used QGIS 3.18.2 with GRASS 7.8.5 on a Windows computer.
Through the tool QuickOSM, all the buildings in the two municipalities are found and visualized on OpenStreetMap, as in Figure 20. Buildings are filtered, excluding historical and religious buildings, churches and ruins, some through the open data already present on QGIS, some through comparison with satellite images from Google Maps.

Figure 20- Some buildings in Avise, represented on OpenStreetMap

The positions of the secondary substations are known from confidential grid data and represented on the GIS software.
Generally detailed distribution grid information is not available, inspiring scientists in estimating grid topologies and characteristics from public data sets. In this case it is not possible to couple users and buildings, and to couple buildings and secondary substations. For this latter problem the geographical area served by each secondary substation is inferred by partitioning the municipalities with Voronoi Polygons, using the algorithm already present on QGIS, with a buffer of 150%, reasonably assuming that each building is referred to the closest MT/BT substation, as found in literature [14].

Details about roofs are not available: Avise's building regulations states that gable and pavilion roofs are admitted, with a slope between 35% and 45% [97]. Arvier gives less restrictive building regulations: the municipality does not admit roofs that are not considered characteristic of the place or flat roofs, excluding terraces and other exceptions [98]. Based on these regulations and on Google Maps validation, as a simplifying assumption in this analysis all the roofs are considered two pitches, reasonably divided in half on the shortest side. Hence, only the longest sides of the buildings are considered for placing PV panels.
Tilt angles, which are the angles of inclination from the horizontal, where 0° are horizontal, 90° are vertical, are not known for the buildings: usually these parameters depend on the snow load and on the location of the buildings. In this case, tilt angles are randomly chosen between 19° and 24° for each roof, following building regulations.
For each building depending on the exposition, both the pitches or one only could be taken in account for installing rooftop PV panels. Considering that not all the buildings have regular shapes, it could be a high time-consuming task to consider manually the best exposed pitches. To overcome this problem, the "Oriented minimum bounding box" tool in QGIS is used. It creates oriented rectangles that cover the buildings following the orientation of the original edifices, obtaining buildings' azimuth angles. Considering fixed mounted, integrated PV systems, azimuth angles of the PV panels are the same as the azimuth of the pitch. It is necessary to notice that in this case azimuth angles could not be the optimized ones for the panels.
Therefore, azimuth angles are calculated for all the four sides respect to the North and the data are exported in Python. The azimuth angles are evaluated for both sides considering 0° as South, 90° as West, -90° as East and 180°as North: if a side is North oriented, it is not chosen, while it is the opposite if it is South oriented. Moreover, if a side is oriented East or West, it is taken, unless it is North-East or North-West.

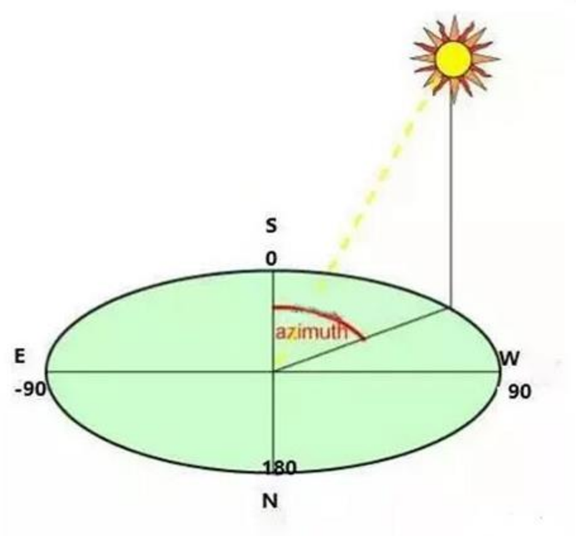

Figure 21 - Azimuth angle representation from [99]

For each building the area of the roof is calculated by QGIS: it is equally divided between the two pitches and corrected with the cosine of the tilt angle. Moreover, correction coefficients are adopted to better estimate the area.

Considering the presence of chimneys, aerials, windows, security cables, the available roof area is considered as 70% of the total by the usage of a corrective feature coefficient $C_F = 0{,}7$. Another corrective factor is given by the shadowing between different buildings. Digital Terrain Model (DTM) and the Digital Surface Model (DSM) for Arvier and Avise are available as open data on the regional website [100]: considering the time-intensive and computer-resource intensive methods to evaluate shadowing with GIS methods and considering that these data are referred to more than ten years ago, it is instead chosen to estimate the corrective shadowing coefficient from literature of pitched roofs, as $C_{SH} = 0{,}6$ [101].

$$roof\ area_i = \frac{calculated\ area_i\ from\ QGIS}{2 * \cos(tilt\ angle_i)} * C_F * C_{SH} \qquad (5.6)$$

Smallest pitches are excluded from the analysis by dividing the obtained value by a standard measure for a panel, here taken as $2.5\ m^2$ by analysing technical catalogues of various vendors; if the result is less than two panels, the roof is discarded.
Considering that about 8 to 10 square meters are needed for each installed kW in crystalline silicon in modulus oriented as roofs, while a major space is needed if panels are divided on different rows to prevent reciprocal shadowing [15], the previously calculated roof area is divided by $8\ sqm/kW$ to find the power produced by the PV.
Investment cost of the PV panels is taken from a 2019 report by the GSE as $1{,}55\ €/W$ [16]. A smaller value is reported in the National Survey Report of PV Power Applications in Italy by GSE and RSE for residential BAPV (Building Applied Photovoltaics), roof mounted, as $1{,}41€/W$ in 2018 [102].
From literature about 144€/kWh are considered as investment in 2018 for storage with Lithium-ion batteries [17].
All the data about the buildings are exported into an Excel file, which is then recalled on Python, importing the data in PVGIS to evaluate PV production.
The Photovoltaic Geographical Information System, also called PVGIS, is a free web application by JRC used to collect data about solar radiation and PV generation depending on the data inserted by the user [103]. In this case we are analysing performances of a grid connected PV to estimate energy potential from a one-kilowatt peak system.

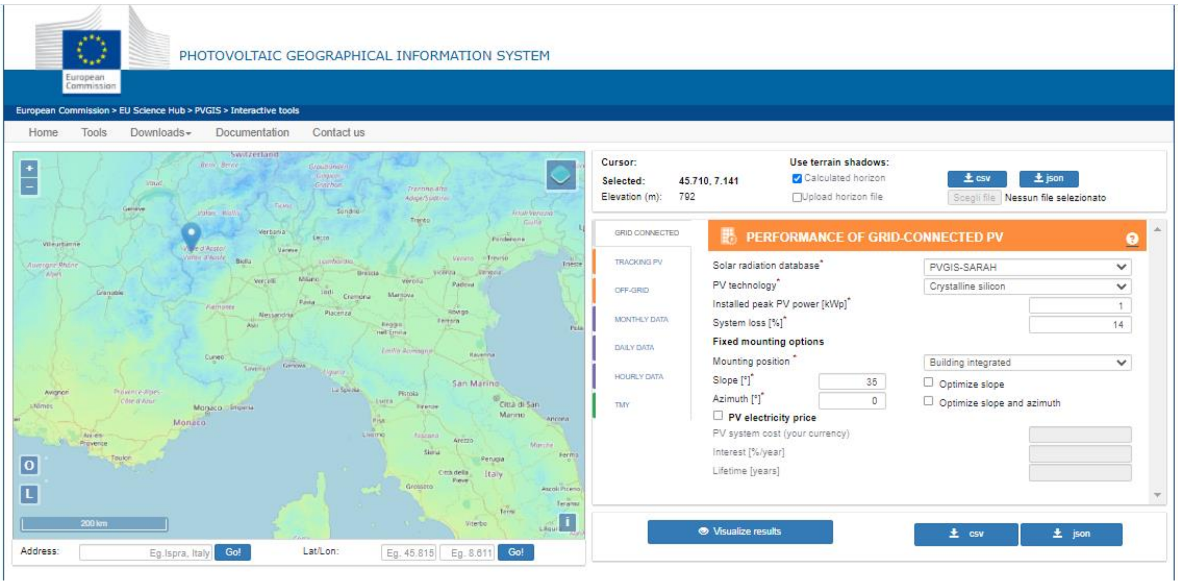

Figure 22 - PV GIS web interface

PV-GIS SARAH is chosen as database: it is the standard database for Europe, Africa, most of Asia, and parts of South America. Crystalline silicon is the selected PV technology. System losses are 14%, the default value. The PV panels are building integrated and the geographical coordinates, the slopes and the azimuth angles of every building are evaluated as previously explained and given as an input in every simulation, recalling from MongoDB Database.

5.2.2 Evaluating load profiles

Electric demand

To properly monitor the exchanges of energy inside the energy community, it is important to know the number of users, their consumptions at least with an hourly resolution, the present power plants and their production profiles.

Consumptions profiles of the users are estimated starting from the aggregated month data given by the Valle d'Aosta Region, which are subdivided into the three time slots set by ARERA, the Italian Regulatory Authority for Energy, Networks and Environment.

The time slots define the price of energy in that hour, which is lower when the request is lower and higher during the peak hours. The three time slots, in Italian called "*fasce orarie*" are:

- F1: Monday, Tuesday, Thursday, Friday from 8 to 19
- F2: Monday, Tuesday, Thursday, Friday from 7 to 8 and from 19 to 23, Saturday from 7 to 23
- F3: Sunday all day, Monday, Tuesday, Thursday, Friday, Saturday from 0 to 7 and from 23 to 24.

Profiles LV labelled as residential, in Italian *Domestico,* and for other usage, *Altri usi,* are selected to participate in the energy community, while public lighting, *Illuminazione pubblica*, is not considered as it is negligible compared to other loads. Following the

EUROSTAT's definition reported in previous chapter [18], here are reported the different types of users present in the two municipalities of Avise and Arvier:

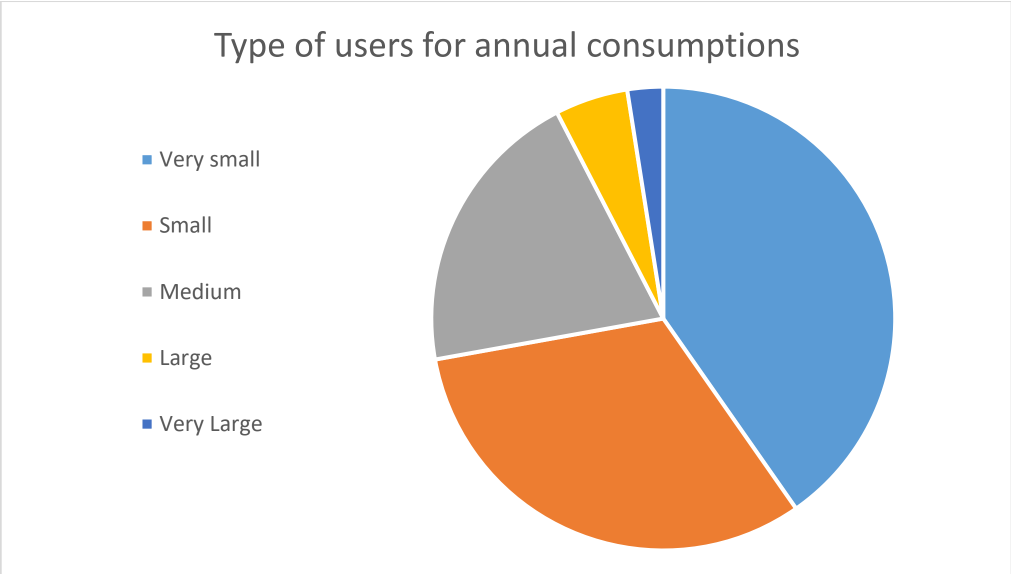

Table 21 - Type of users for annual consumptions

A reference hourly profile is chosen, which represents the medium profile of the secondary substations present in Valle d'Aosta region. MV/LV substations are not directly monitored: this profile was evaluated from an energy balance involving the HV/MV substations and all the users in MV.
For each user and for every month three coefficients, one for every time window given by ARERA, are calculated to fit the available data with the reference data: consumes are scaled maintaining a reasonable profile.
As an example, the coefficient for the time window $F1$ is calculated as follows for a user k, in a month i:

$$Coeff\ F1_{k,i} = \frac{Monthly\ consumptions\ in\ F1_{k,\ i}}{\sum_{j=1}^{last\ day\ of\ month\ i} consumes\ of\ reference\ profile\ in\ F1} \quad (5.7)$$

Some users do not have all the monthly data consumes available: in this case the numerator is obtained by averaging the available consumption data for the relative time windows.
The hourly profiles for the energy communities are evaluated by multiplying the hourly reference profile by the relative coefficients, depending on the month and on the time window.
Representations of the annual energy consumptions in 2019 of some users are reported in the following figures: it is possible to notice a trend for which consumes in colder months are higher than in hotter ones.

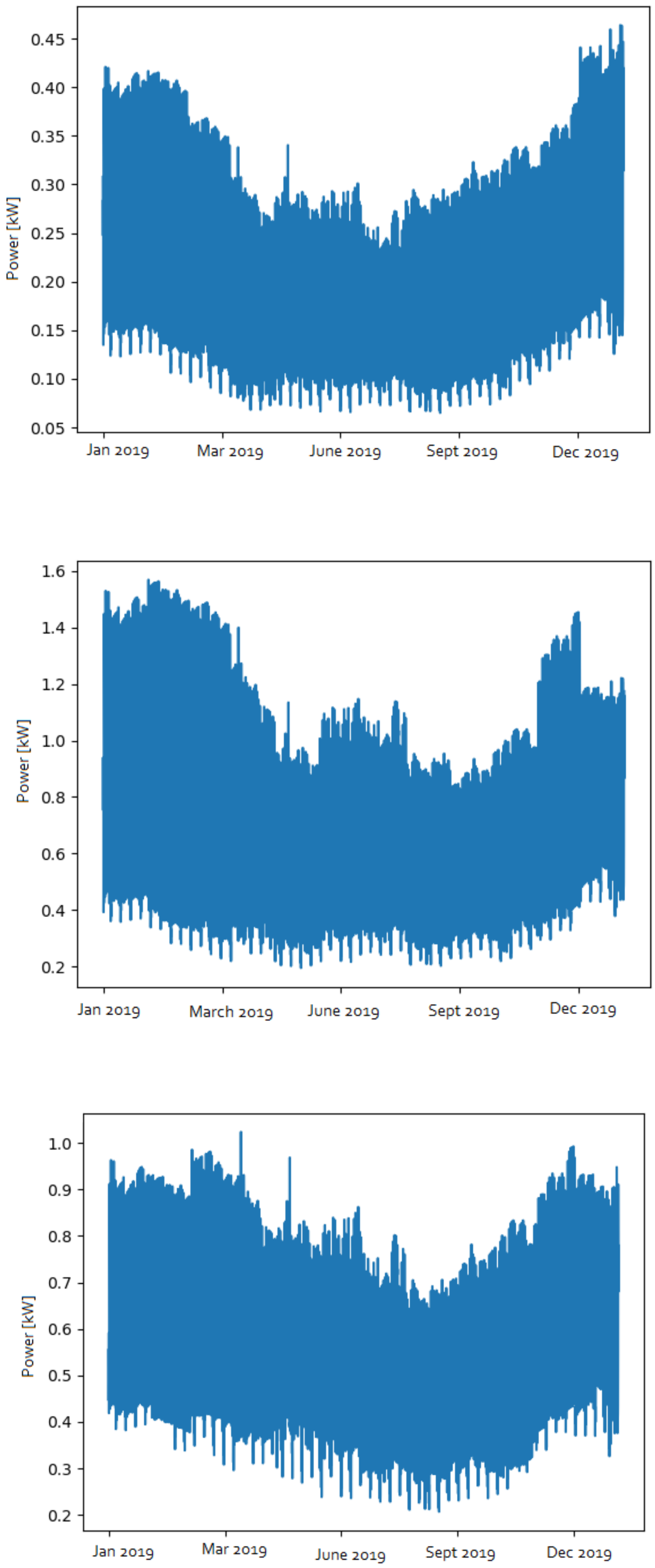

Figure 23 - Representations of hourly load profiles by different users of Arvier and Avise in 2019

Heating demand

The energy community could be shaped differently adding other loads, considering the possibility of electrification of the heating demand.
In 2019 only 11% of heat was supplied by renewable energies [104]. Self-consumption of the energy produced by PV could increase by using heat pumps, especially with a thermal or electrical, as it could be seen in [105]. The most efficient technology to electrify and decarbonize heat are heat pumps: most used heat pumps in Italy are air source heat pumps (ASHPs), which operate with air that could be exhaust, outdoor or indoor air.
The heating profiles are taken from a previous thesis, in which a model reconstructed with a 15-minute resolution the heating demand profiles of the 74 municipalities of Valle d'Aosta [19]. These heating profile consider only non-electrified sources of heating, in order to model a case in which it is possible to electrify them. The electrification case is done by considering all the loads, electric and heating, together for the two municipalities, variating the percentage of electrification of the profiles.

5.2.3 Results of the long-term analysis

In this subchapter, two evaluations are conducted: the first one includes the possibility of having for each secondary substation an energy community, as it is stated in the current regulatory framework, while the second one considers all users as referred to a single energy community, which could be a possible future transposition of the CEP in Italy. In both simulations three cases are considered, in which battery costs varying as follows:

	Case A	Case B	Case C
Storage investment cost [€/kWh]	300	150	75
Storage reposition cost [€/kWh]	200	100	50

Table 22 - Costs of batteries storage systems

Case A reflects the actual costs of lithium-ion storage systems. Case B reflects prices that research estimates feasible in a short-term view, as less than five years, while the third one estimated battery's prices in a long-term view [17]. Prices are considered for a storage system "turnkey".
It is supposed that all the inhabitants of the two municipalities are members of the energy communities and that all the present roofs which could be suitable for PVs installation are available. These strong assumptions are supported by the intentions of this work, which has the goal to highlight advantages and disadvantages of various configurations in ECs.
First results presented include the value maximised by the objective function of tool, which is the net present value (NPV): the following graphs represent the evolution of NPV in 20 years in the three cases A, B and C, also by comparing the two selected configurations, the one with an EC for each secondary substation and the one with all the users in the same energy community. After NPV considerations, results of the two configurations are listed.

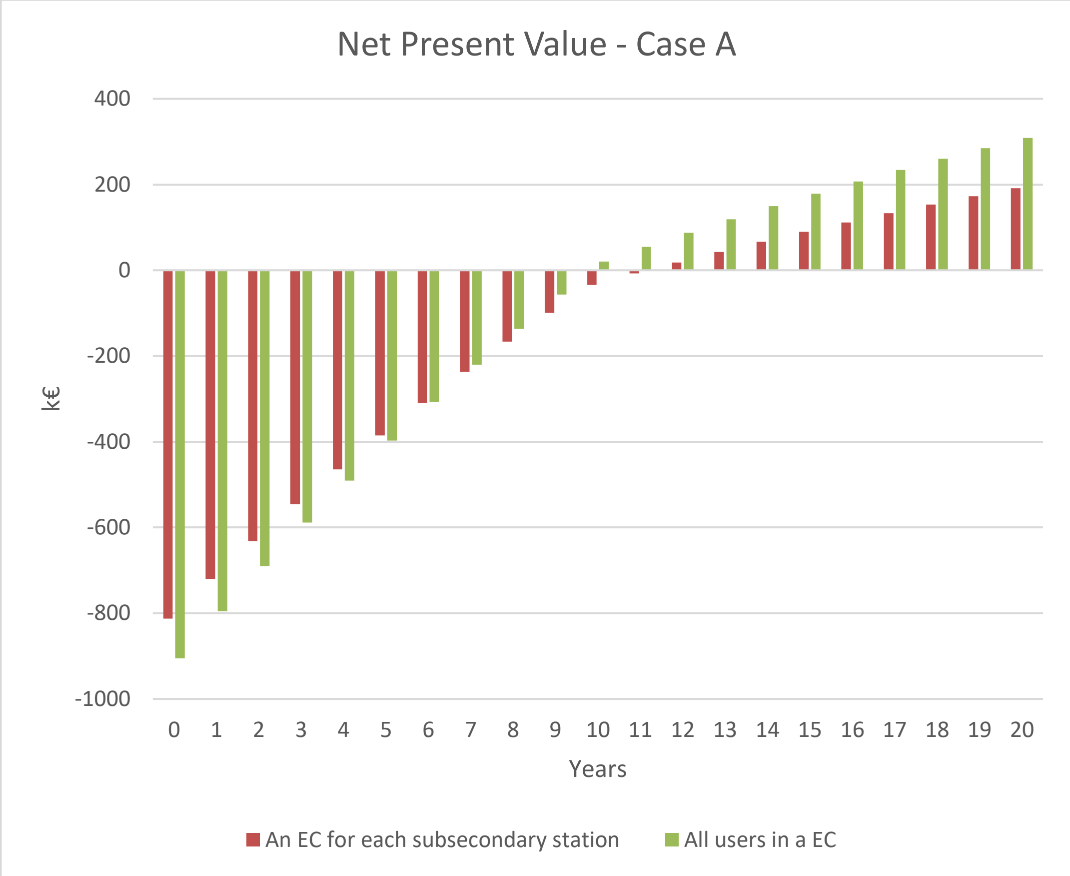

Figure 24- Net Present Value, Case A

The highest NPV, which is 308,9 $k€$, is reached by the configuration including all the users in a single energy community, with a significantly higher value compared to the NPV of the second configuration, which is 191,6 $k€$. Moreover, as it could be seen in Figure 24, the configuration with the highest NPV also reaches sooner a positive NPV despite the lowest NPV at year 0.

With a decrease in battery costs, as it happens case B, the highest NPV after 20 years is still reached by the configuration including all the users in a single energy community, but it has not a significant increase compared to case A, since it counts about 14 $k€$ more. The configuration of an EC for each secondary substation shows an increase of about 27 $k€$ in NPV respect to the same configuration in case A.

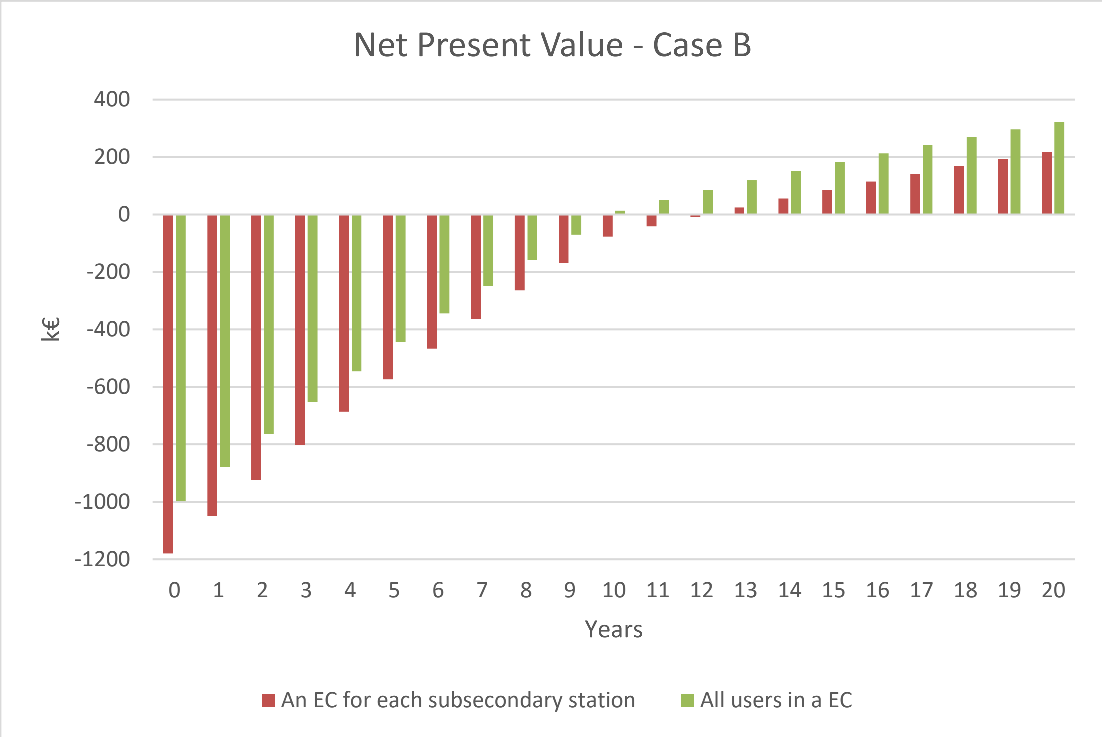

Figure 25 -Net Present Value, Case B

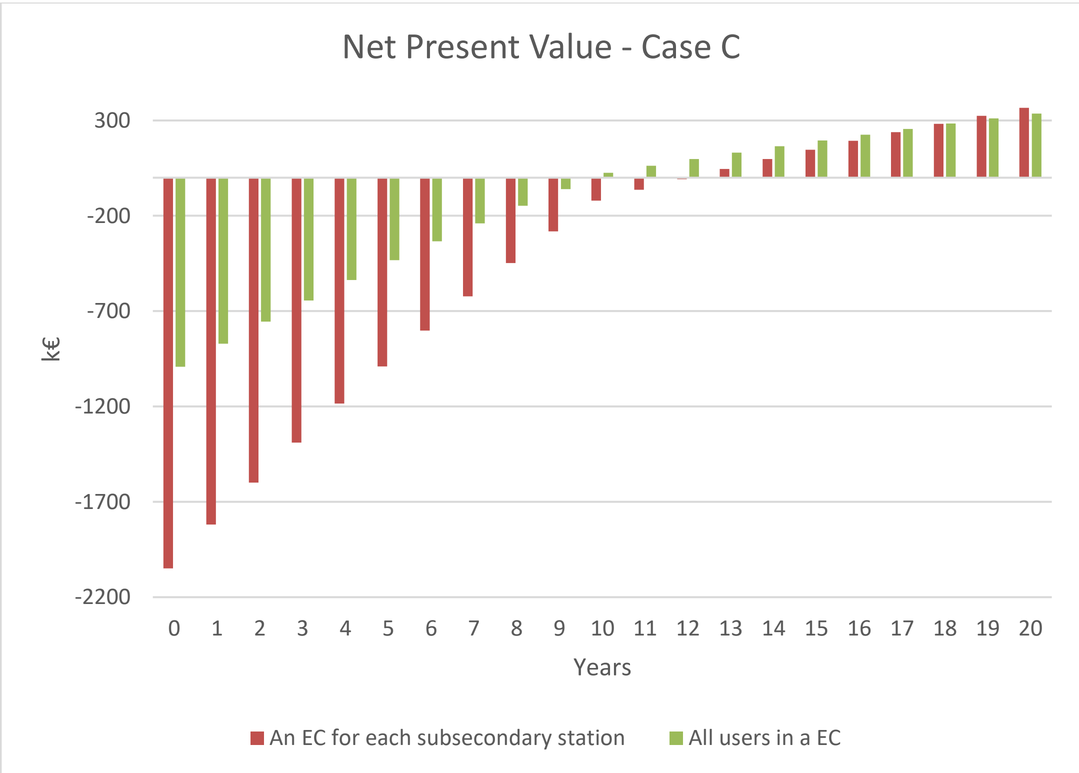

Figure 26 - Net Present Value, Case C

In case C, at year 20 two configurations reached almost equal NPVs, with less than $1k€$ of advantage for the configuration that considers an energy community for each secondary station. Anyway, looking at Figure 26, it is possible to see that this configuration has also the higher investments at year 0, which is more than doubled compared to the other case, and that it reached a positive NPV 3 years later than the other case: these two aspects are important for an energy community, considering that the investors are usually private citizens or municipalities, which prefers to have a lower investment and to see sooner a return on their expenses. Moreover, the little difference in NPV at year 20 does not justify the request of a double investment at year 0.
In next pages the two configurations are deeply compared considering other parameters.

For each secondary substation an energy community

As it could be seen in Figure 27, in case A the storage system is not chosen by the optimizer, while for B and C are respectively selected storage systems of about $0{,}9MWh$ and, about four times bigger, $3{,}7\ MWh$: it seems that the different costs significantly impact on the battery's sizes in this configuration, remaining anyway far away from the maximum storage represented by the red baseline. Battery sizing impact also on the PV capacity installed, as in Figure 28: bigger the battery, bigger is also the PV capacity that could be installed. In Figure 28, it is also represented the maximum possible installation, which is calculated by considering the installation of PV panels in each suitable roof and which remains far away from the actual kW installed in the three cases.

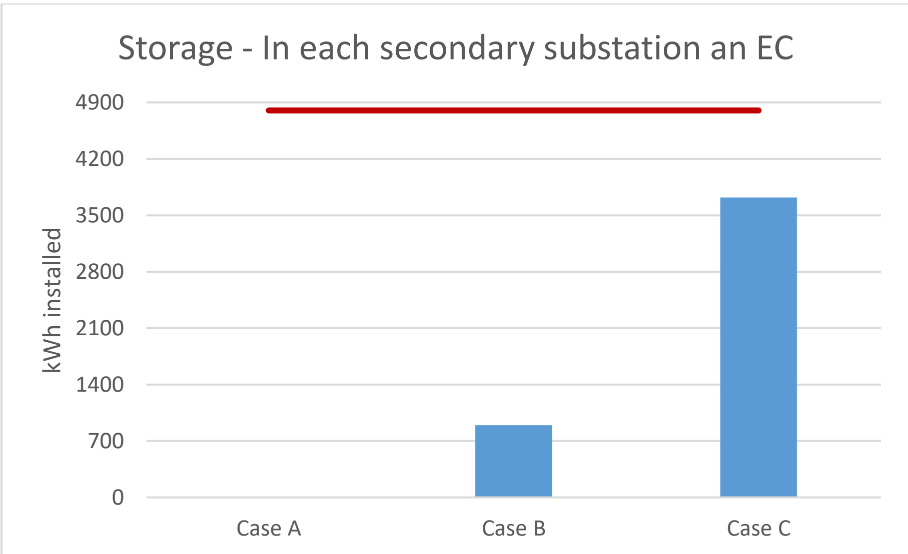

Figure 27 - Storage installed in the configuration including an EC for each secondary substation, distinguishing between cases A, B and C

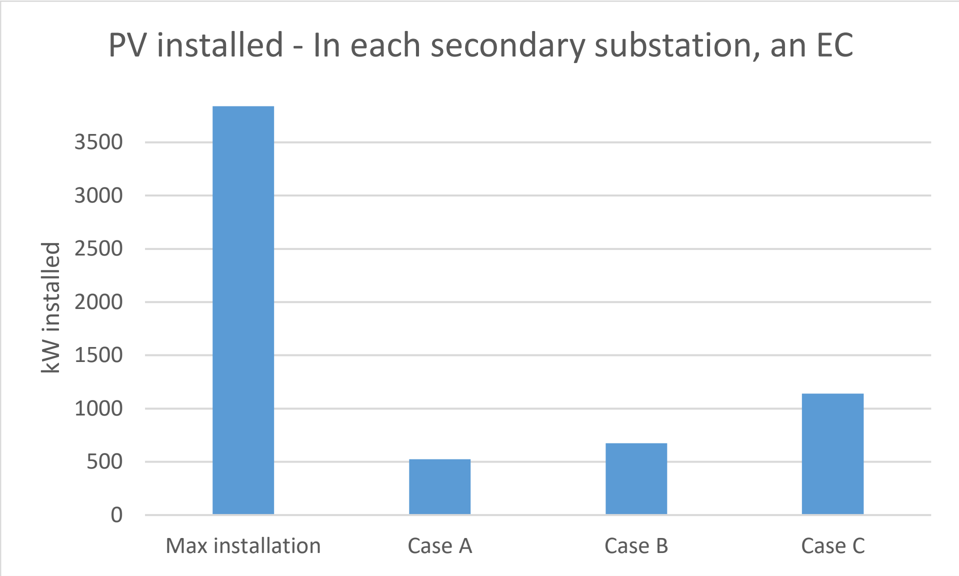

Figure 28 - PV panels installed in the configuration including an EC for each secondary substation, distinguishing between cases A, B, C and the possible maximum installation.

The following graph accounts for the energy shared, comparing it with other quantities and evaluating the three cases A, B and C: as definitions, the energy shared in real time $E^{shared\ RT}(t)$ depends on the produced energy by PVs, while the energy shared $E^{shared}(t)$ takes into account both the $E^{shared\ RT}(t)$ and the energy shared thanks to the discharging of the storage system. In case of no storage $E^{shared}(t) = E^{shared\ RT}(t)$.
The energy generated by the PV panels is E_{gen}, the consumed energy by the users is E_{load} and the withdrawn energy from the grid is $E^{with}(t)$. The maximum produced energy $E^{\max production}(t)$ is the energy produced by the maximum possible installation of PVs. These definitions are used also in the subsequent graphs.

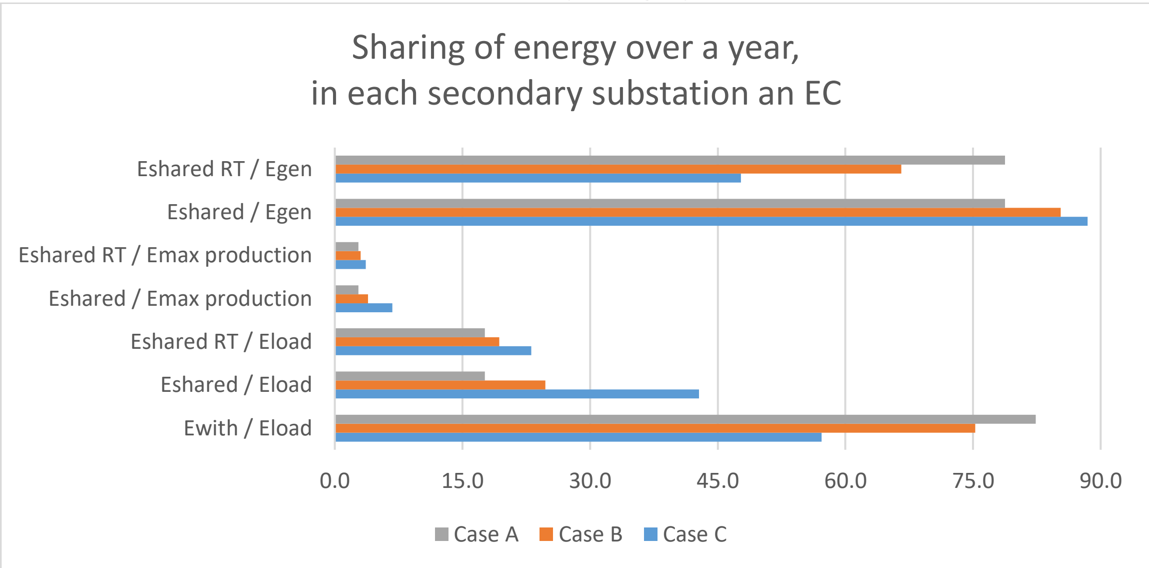

Figure 29 - Sharing of energy over a year in the configuration including an EC for each secondary substation, distinguishing between cases A, B, C

Looking at case C, it could be seen how much the storage system helps in increasing the sharing of energy respect to the real time PV production and in reducing the withdrawn energy from the grid. Although the presence of the storage battery, withdrawn energy covers more than half of the load in the three cases, with a peak of 82,4% in the case with no storage, case A.
Respect to the maximum possible production, the energy shared is low, remaining between 3% and 7%, in fact it is possible to see in Figure 30 that the number of roof exploited is low, but it increases by decreasing the cost of batteries, as previously seen in Figure 28.

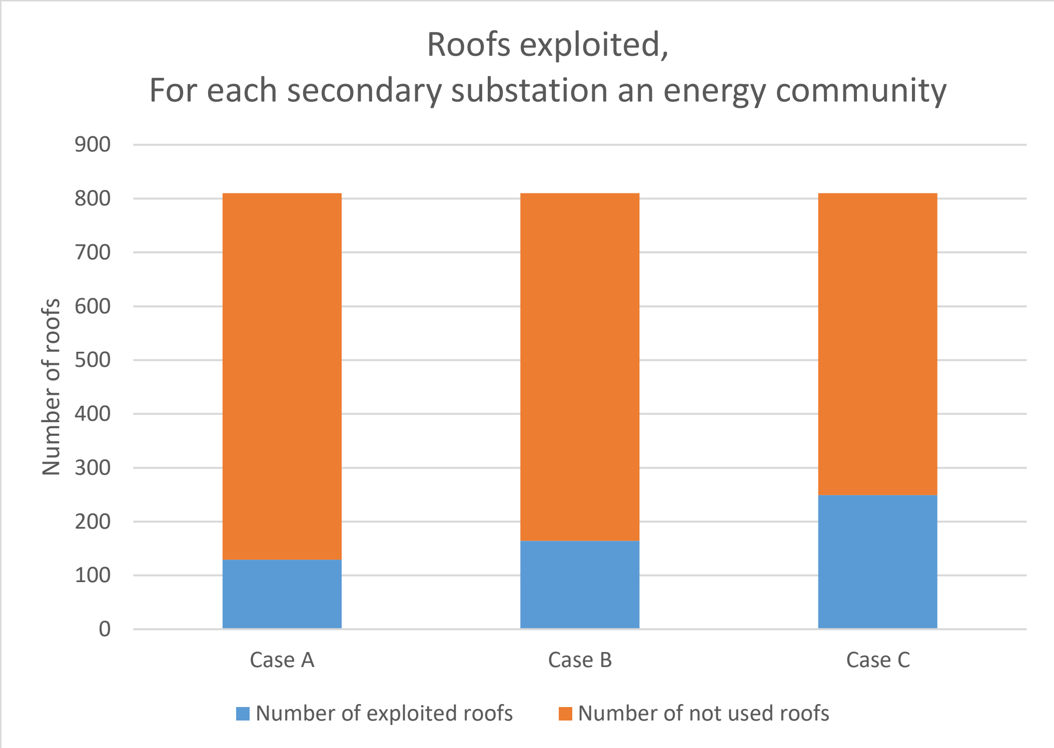

Figure 30 - Roofs exploited, in the configuration with an energy community for each secondary substation.

A single energy community including all the users

As it could be seen in Figure 31, in this configuration the storage installed is only 200 kWh for both case B and case C, much less than the previous configuration in which values were respectively 0,9MWh and 3,7 MWh, while case A in both configurations requires no storage. Moreover, comparing the PVs installed in this configuration with the previous one, also these values result smaller and significantly smaller for case B and C, while in case A it is possible to see a little increase.

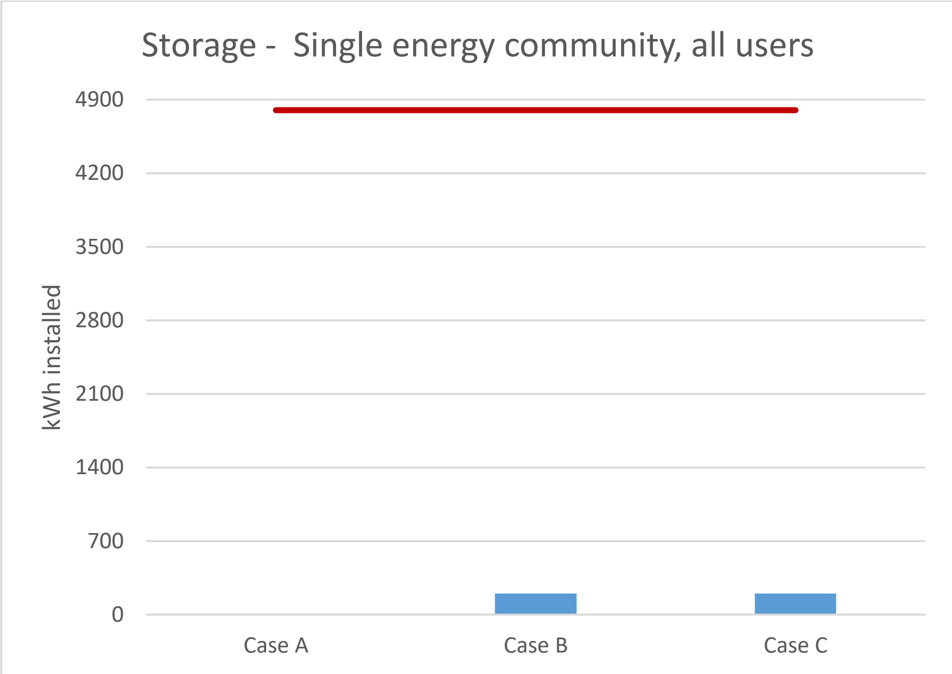

Figure 31 - Storage installed in the configuration including a single energy community with all members, distinguishing between cases A, B and C

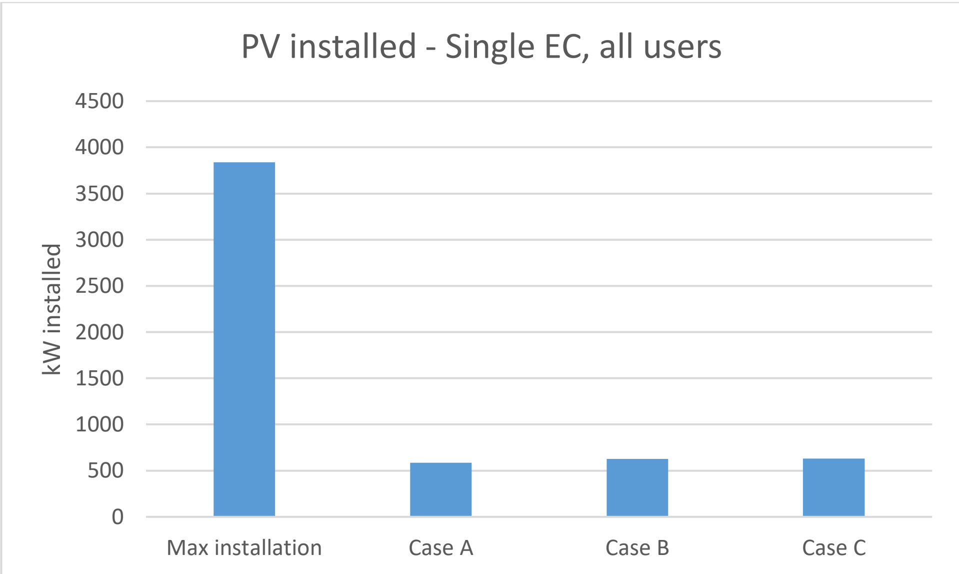

Figure 32 - PV panels installed in the configuration including a single energy community with all members, distinguishing between cases A, B, C and the possible maximum installation.

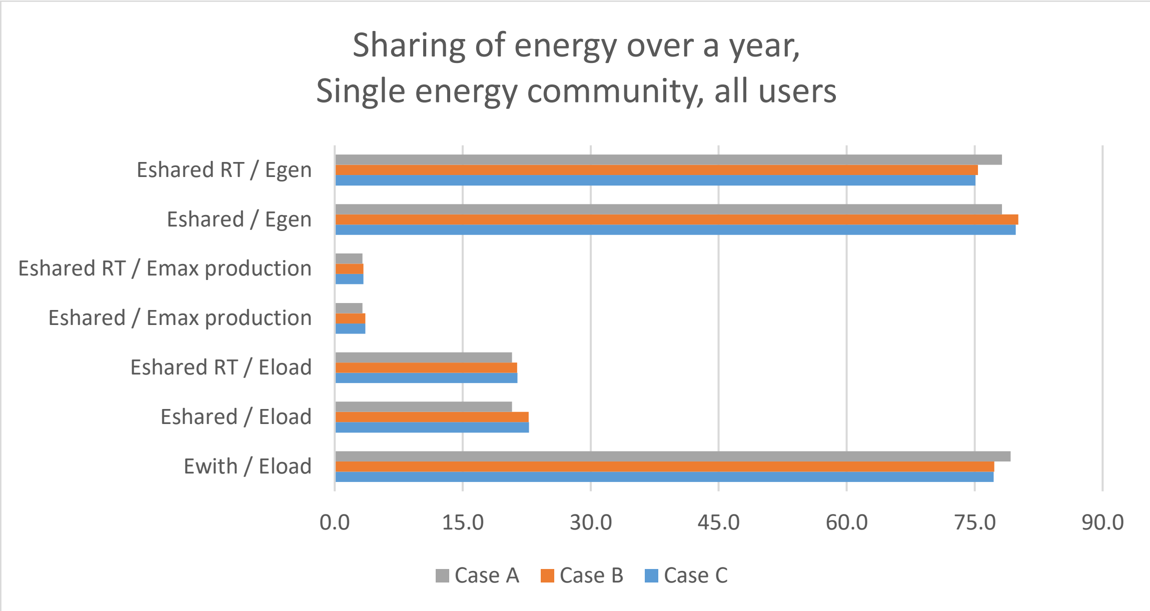

Figure 33 Sharing of energy over a year in the configuration including a single energy community with all members, distinguishing between cases A, B, C

Sharing of energy in real time respect to the energy generated is significantly higher than in the previous configuration, while the energy shared respect to the energy generated is the same or a little lower than the previous configuration: it is possible to see that in this configuration the possibility of optimizing the exchanges of energy between members increases comparing to the previous one, in which exchanges of energy were optimized by a higher investment to have bigger batteries and bigger PV panels, distributed between the different energy communities. Anyway, in this configuration the energy shared respect to the energy load does not overcome 23%, while in the previous one for case B and C respectively values of 24,8% and 42,8% are reached.

It is reported in Figure 34in the production of PV panels in the cases A, B, C for two days in summer: the different peaks in production could be attributed to the different orientation of the panels, that receive energy in different times, and to the different tilt angles of the roofs.

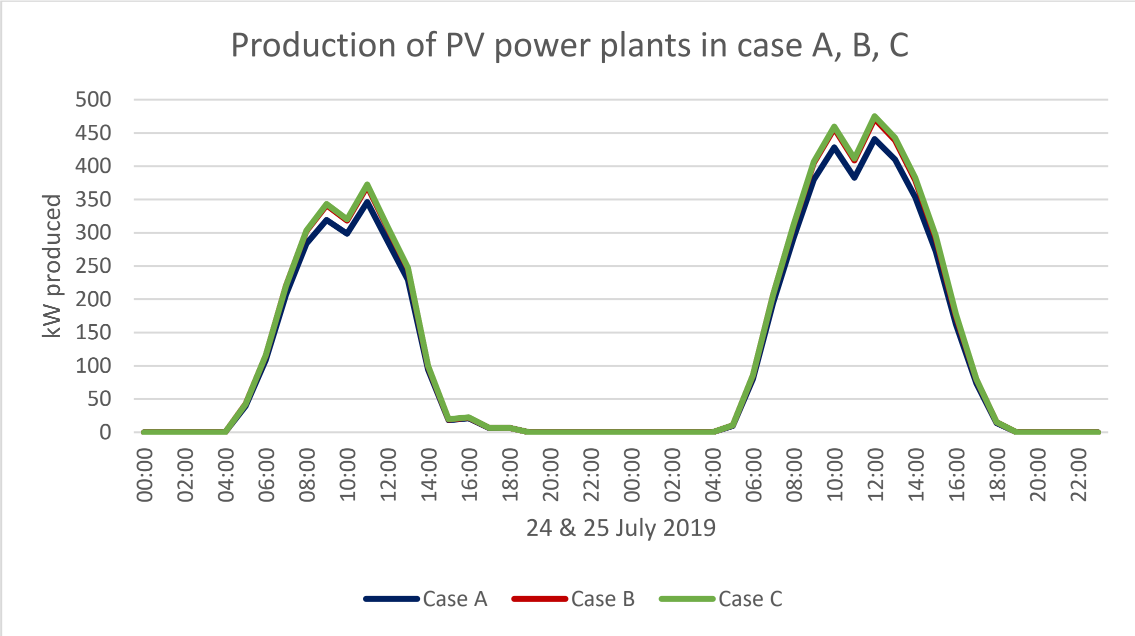

Figure 34 - Production of PV power plants in the configuration including a single energy community with all members, distinguishing between cases A, B, C for two days in 2019, 24 and 25 of July.

5.2.4 Results of a long-term analysis considering the decarbonization of heating

In this subchapter, it is considered a single energy community including all the users of Avise and Arvier municipalities, evaluating economic results in a long-term analysis, adding to the loads the possibility of electrifying partially or totally the heating system. In this configuration, it is distinguished between case A and case B, varying the costs of batteries as before:

	Case A	Case B
Storage investment cost [€/kWh]	300	150
Storage reposition cost [€/kWh]	200	100

Table 23 - Costs of batteries storage systems

Starting from evaluating the Net Present Value (NPV), which is the parameter maximized by the tool, it is possible to see that both in case A and in case B at year 20 the NPV increases with the increase of the percentage of heating decarbonized and with the decrease in the cost of storage systems. In addition to this, at year 20 in both cases the NPV is higher than in cases without heating. Moreover, in both cases the NPV becomes positive at the same year for all the heating percentages, which is the year 10 for case A and year 11 in case B.

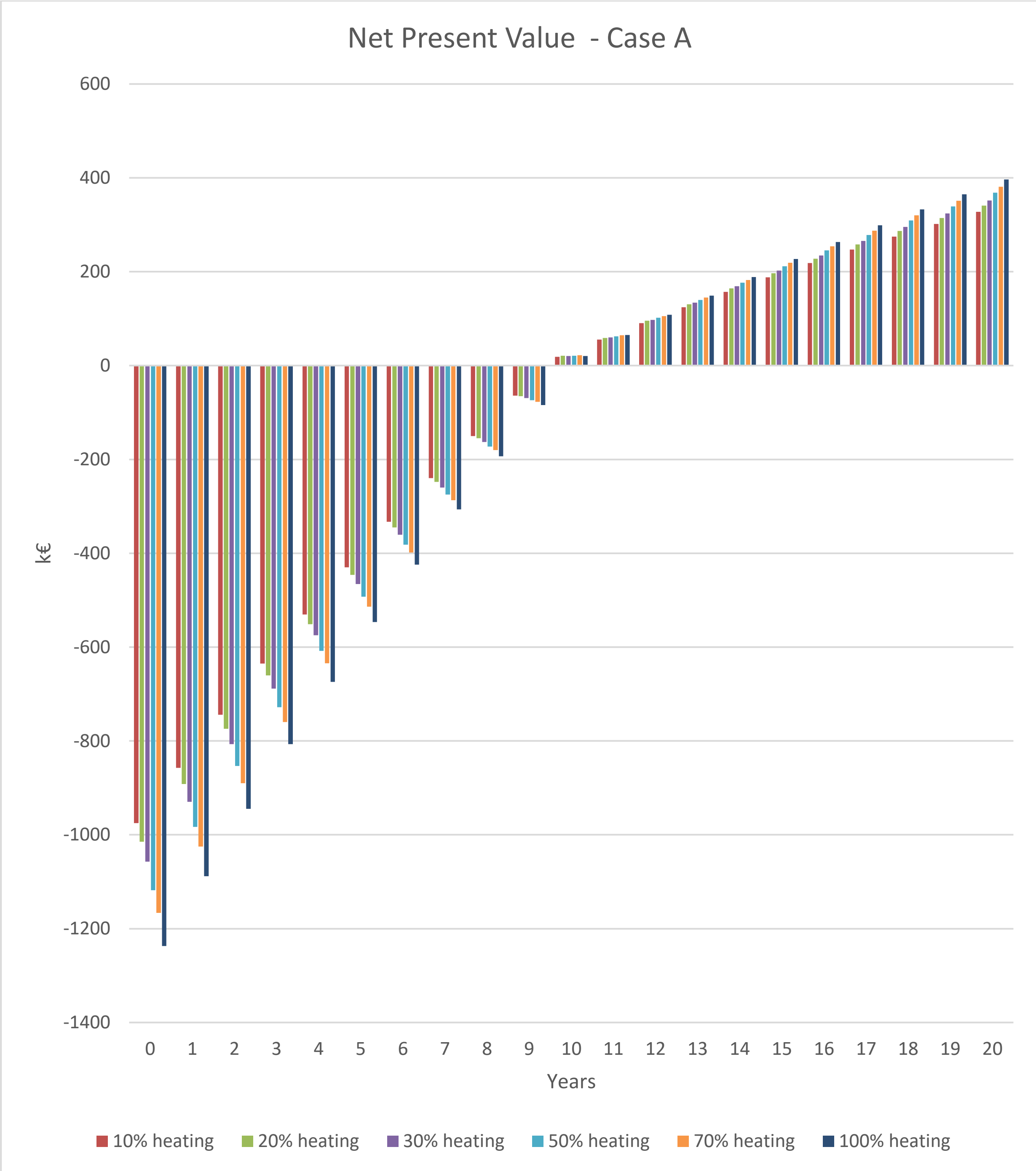

Figure 35 - Net Present Value in case A, with different percentages of heating

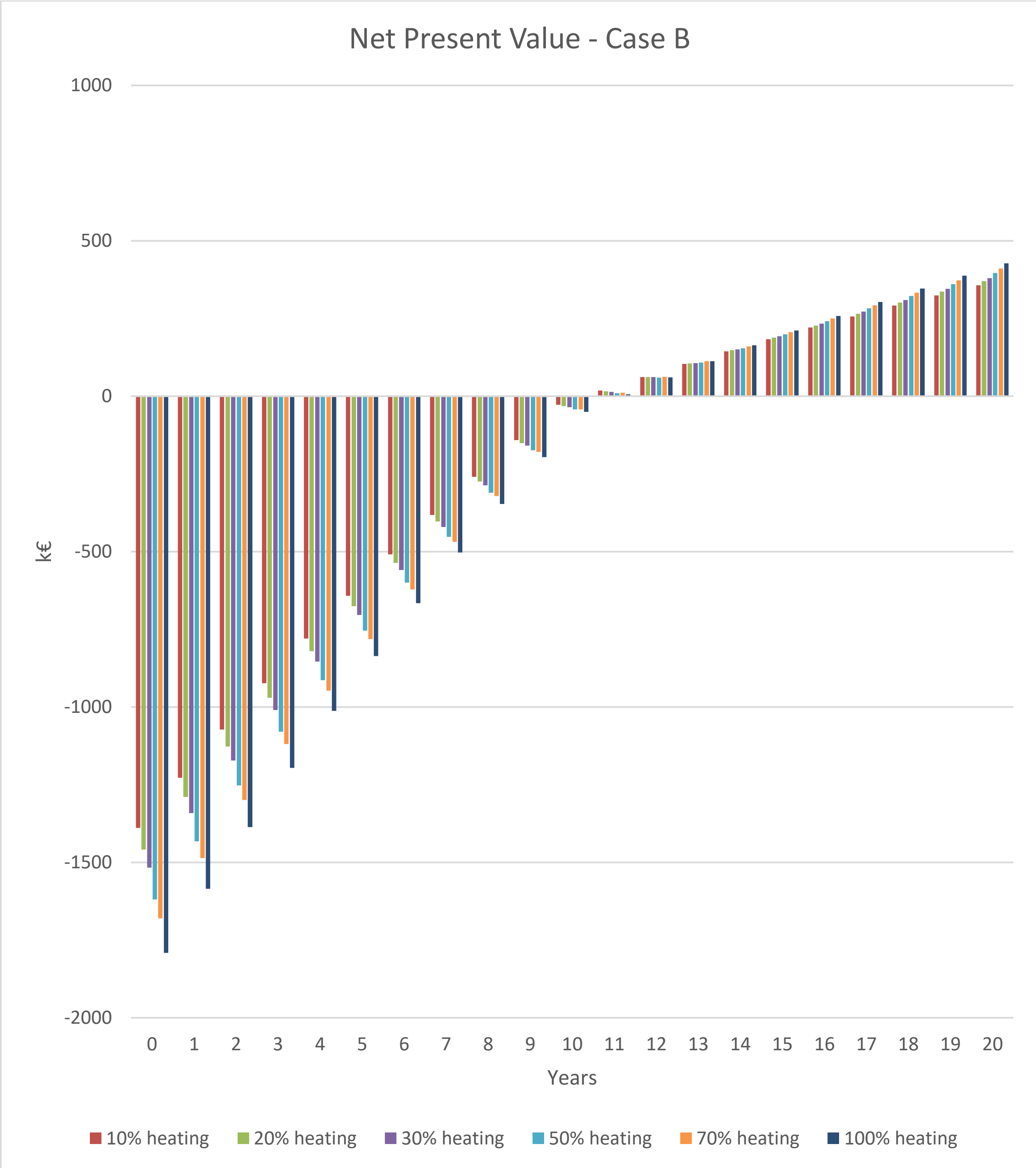

Figure 36- Net Present Value in case B, with different percentages of heating

Storage in case A is not chosen by the tool, so it is not represented in graphs. Instead for case B, as it is possible to see in Figure 37, storage systems are chosen between $1MWh$ and 1,4 MWh, increasing with the increase of the percentage of heating to be decarbonized. PV installed for case A goes from $630kW$ to about 800 kW and from 800 kW to 1030 kW in case B, which are higher values than configuration without heating.

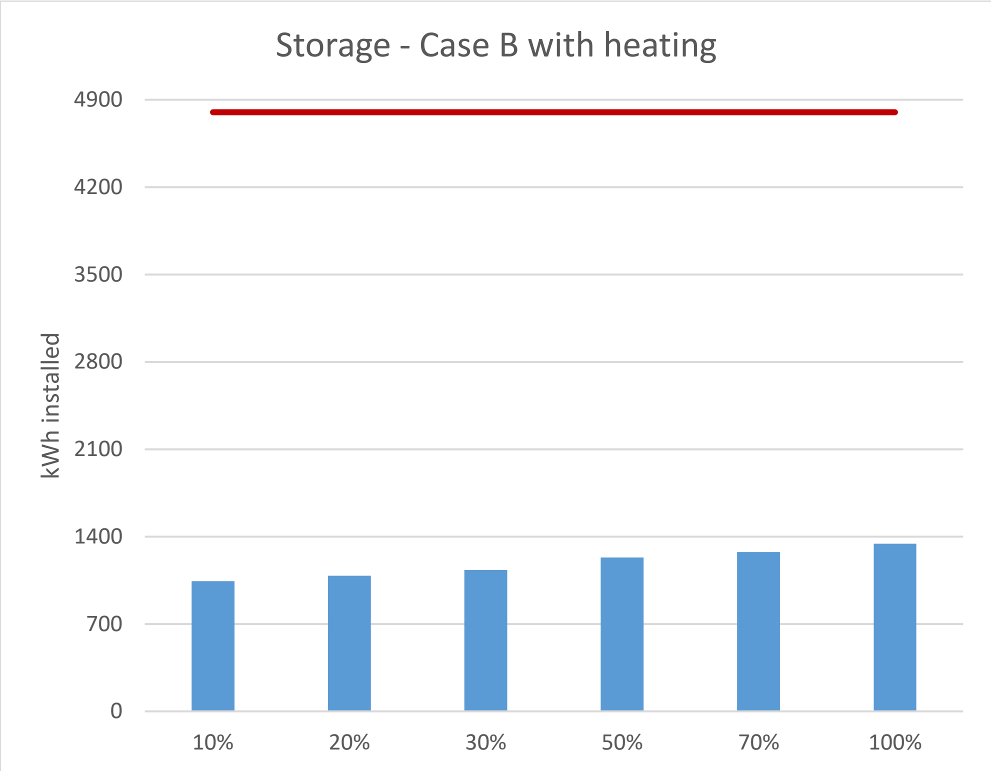

Figure 37 - Storage installed in the configuration including heating in different percentages. The red baseline is the maximum for the installation.

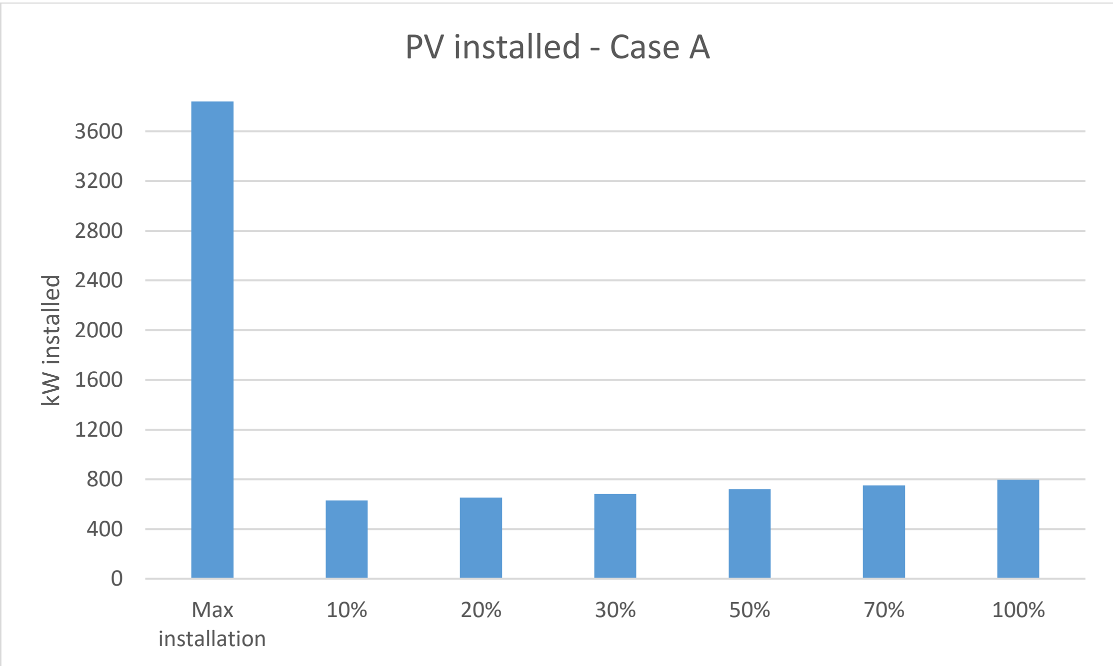

Figure 38 - PV panels installed in the configuration including heating in different percentages, 10%, 20%, 30%. 50%, 70%, 100%, in case A, compared to the maximum possible installation

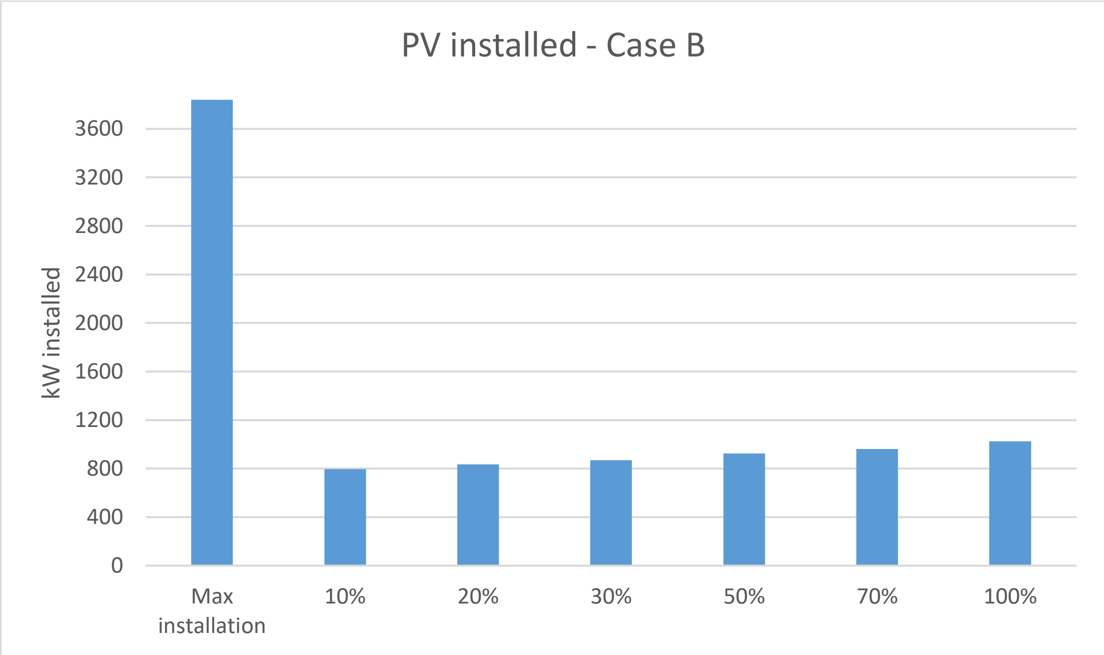

Figure 39 - PV panels installed in the configuration including heating in different percentages, 10%, 20%, 30%. 50%, 70%, 100%, in case B, compared to the maximum possible installation

Sharing of energy respect to energy generated over a year in case A is about 78% and 85% in case B, which are values almost equal to cases A and B in configurations without heating. The shared energy respect to the load decreases increasing the percentage of heating, both for case A and case B, while it increases the withdrawn energy.

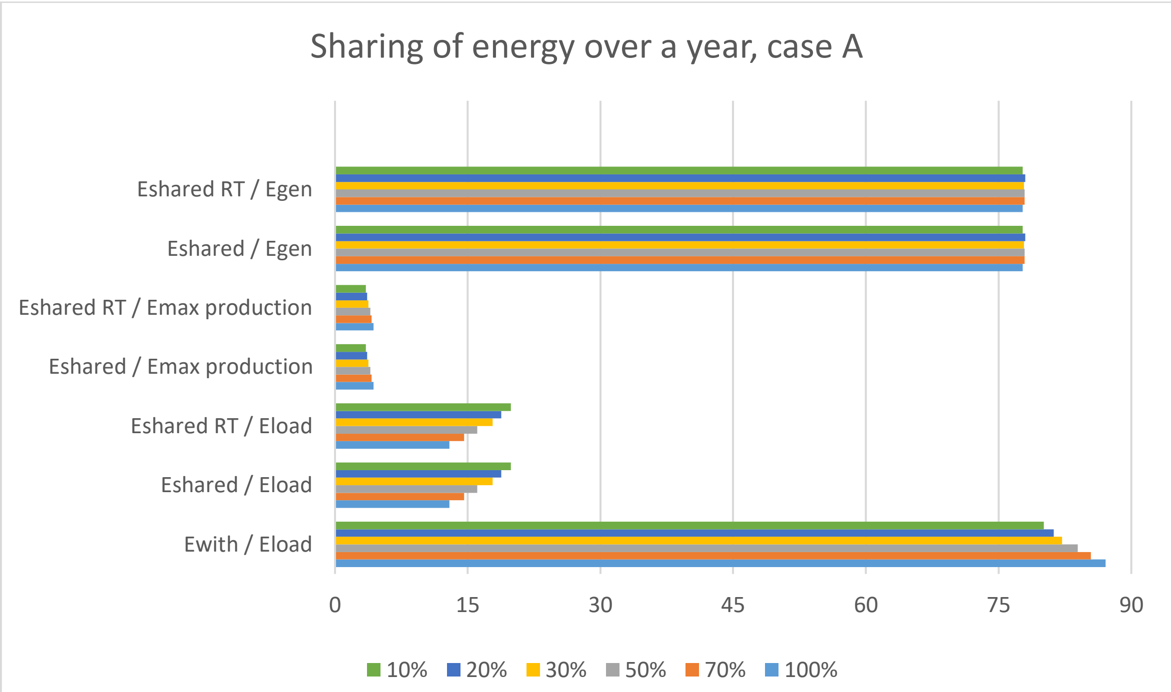

Figure 40 Sharing of energy over a year in the configuration with heating in different percentages, 10%, 20%, 30%. 50%, 70%, 100% in case A

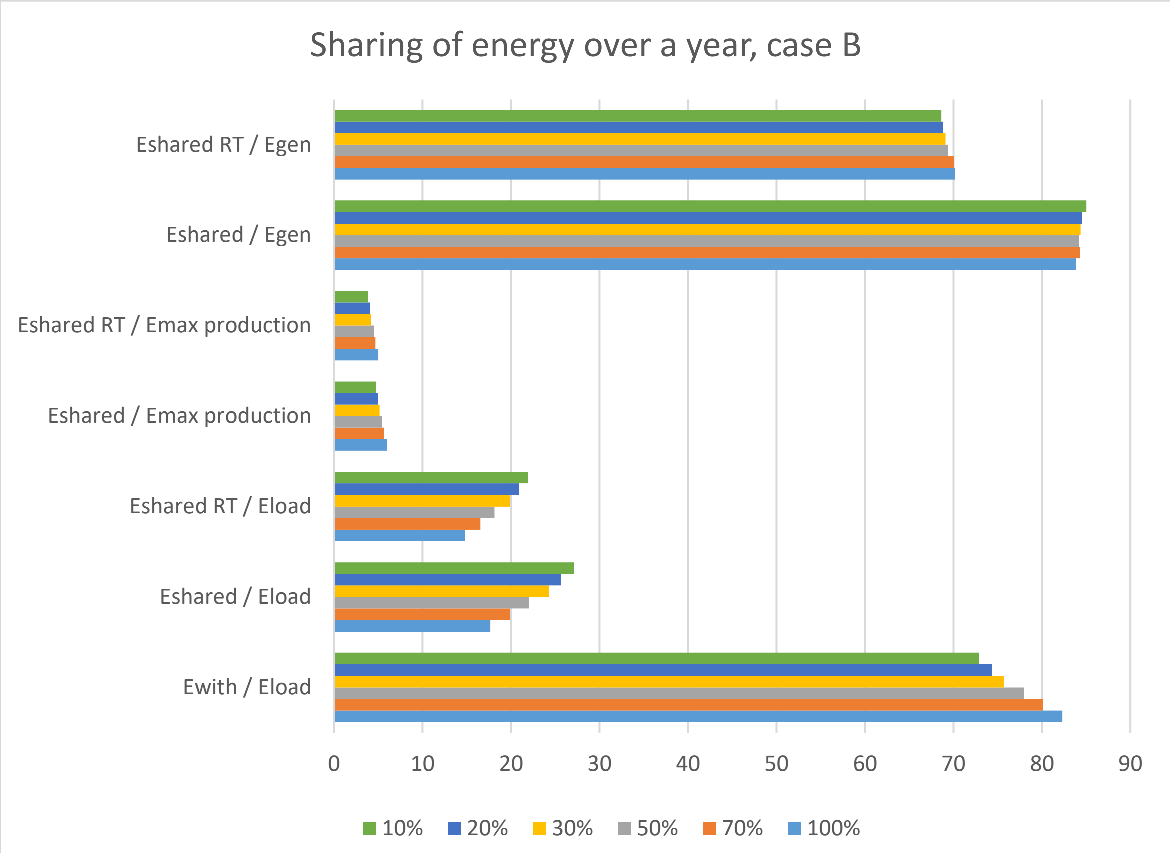

Figure 41 - Sharing of energy over a year in the configuration with heating in different percentages, 10%, 20%, 30%. 50%, 70%, 100% in case B

It is interesting to compare the energy consumed by all the users with and without heating in the first year of operation.

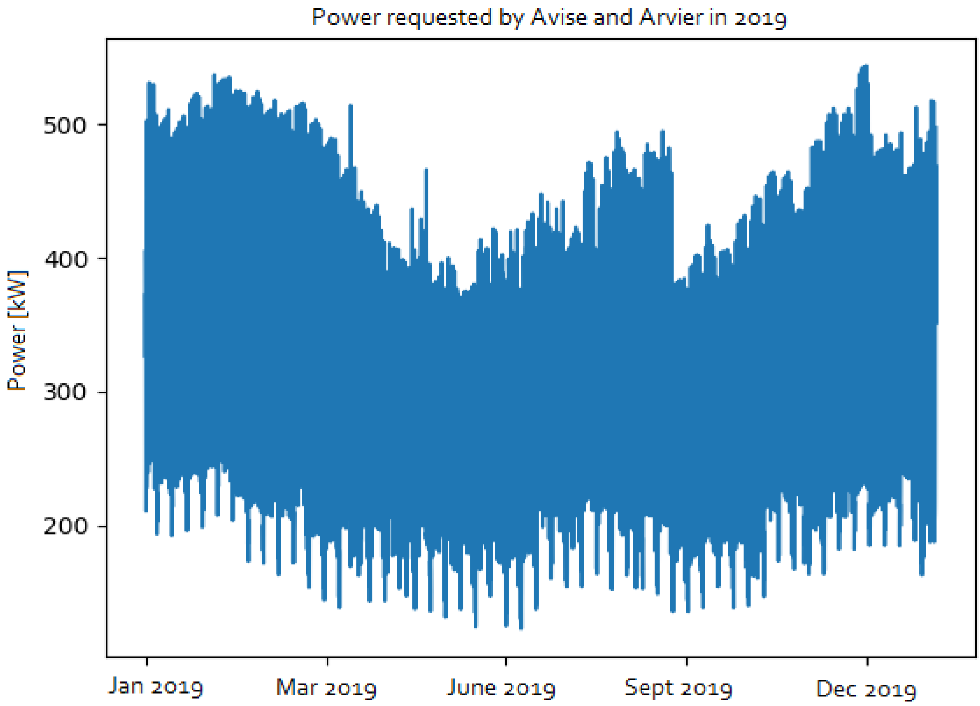

Figure 42 - Power requested by Avise and Arvier in 2019

With the hypothesis of adding 10% of the energy needed to decarbonize the heating in the two municipalities:

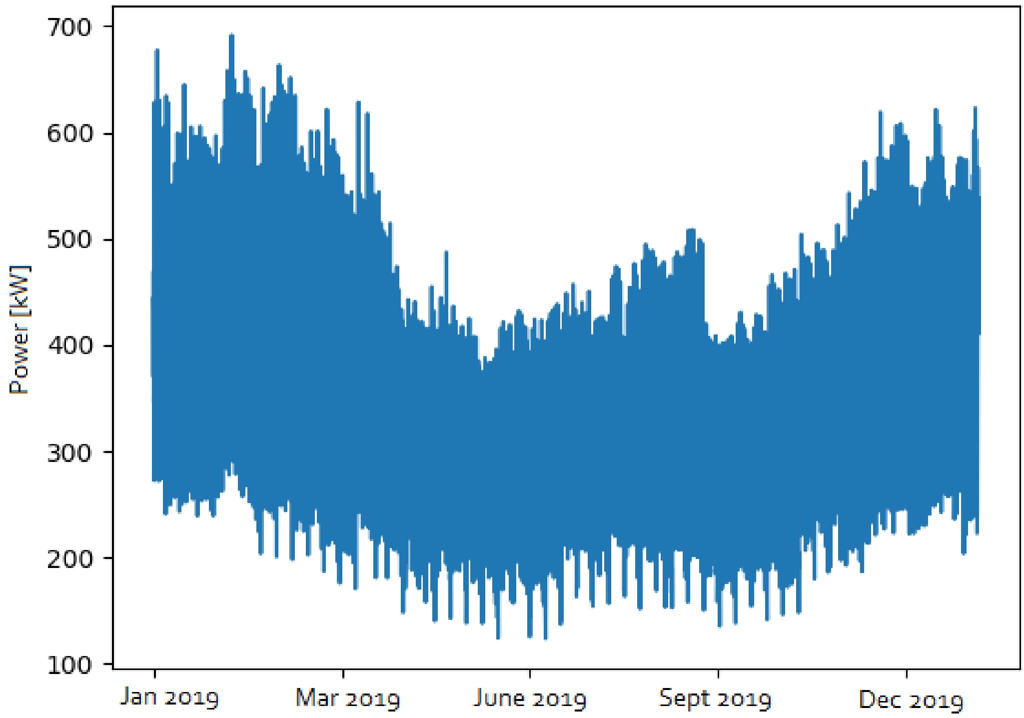

Figure 43 - Power requested by Avise and Arvier in 2019, adding 10% of heating to be decarbonized

Adding the 50% of the energy needed to decarbonize the heating in the two municipalities, it is possible to find numerous peaks in the colder months, with values that could arrive up to three times the maximum power requested:

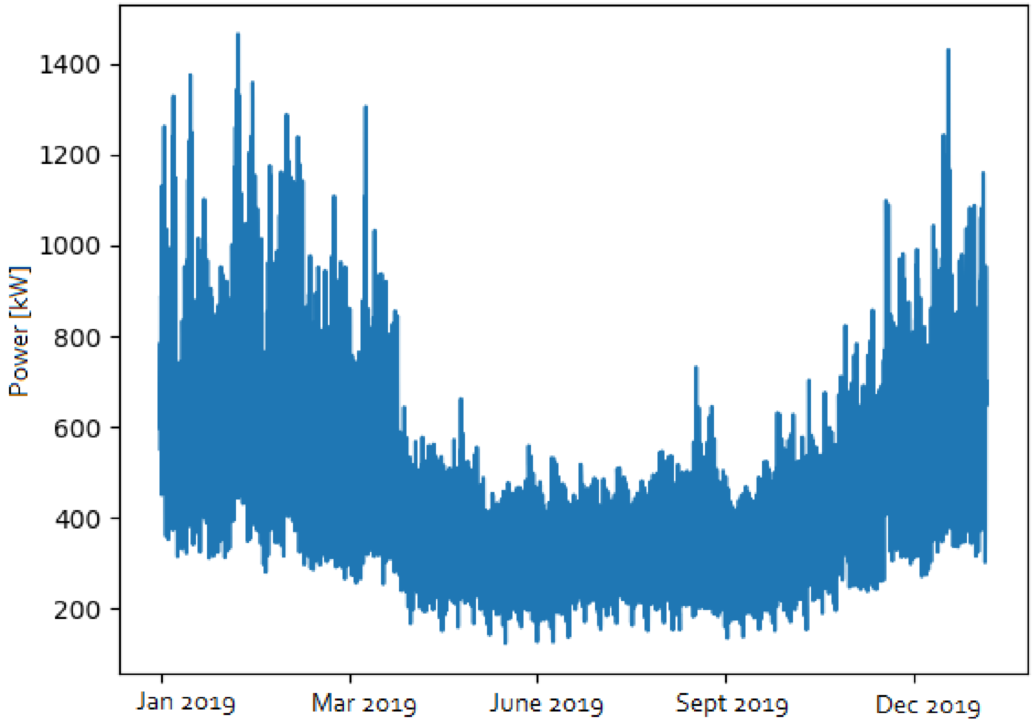

Figure 44 - Power requested by Avise and Arvier in 2019, adding 50% of heating to be decarbonized

Adding 100% of the energy needed to decarbonize the heating in the two municipalities, the peaks become higher.

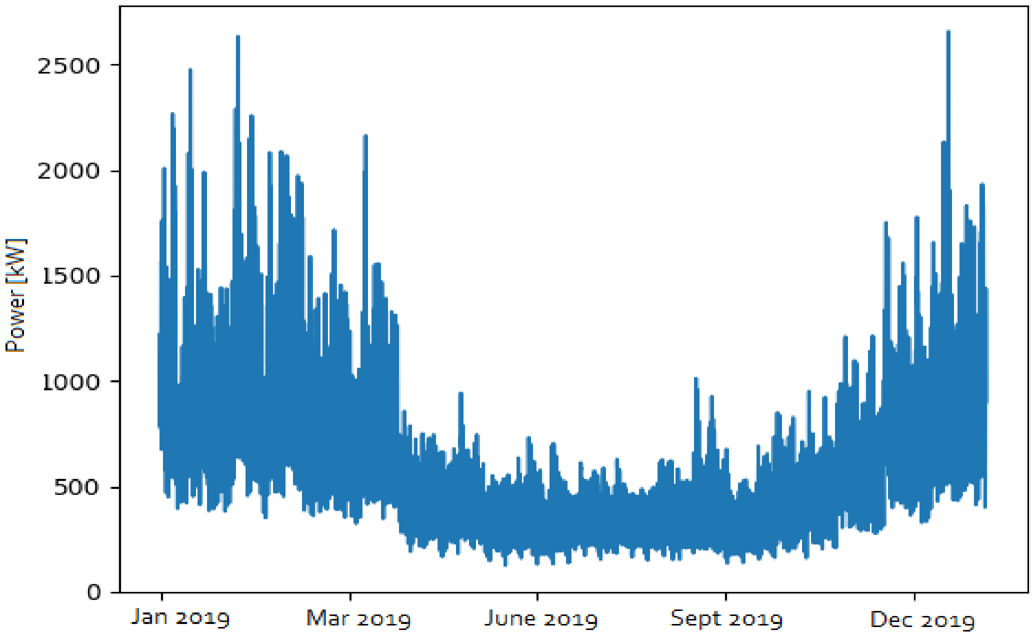

Figure 45 - Power requested by Avise and Arvier in 2019, adding 100% of heating to be decarbonized

Chapter 6

Conclusions

This thesis conducted an analysis in the Valle d'Aosta territory. In the first part of the work a regional and the local Smartness Assessment is submitted to the selected stakeholders, then in the second part of the work the feasibility of an energy community in the territory of the Grand Paradis Unitè de Communes Valdotaines is evaluated.
From the regional Smartness Assessment, the smart dimensions of Environment and Economy are the ones with the highest total scores: the environment and its protection are crucial in mountain territories, as it is the fact that the citizens take care of it. In a territory with many localities tourist-oriented Smart Economy and Smart Environment are both fundamentals and inseparable. Moreover, this result confirms the regional effort in reaching ambitious objectives as becoming carbon free and fossil free in 2040, addressing these challenges from different sides.
Statements regarding soft skills spreading, facilitating the usage of web services for private societies, digitalization, especially referred to practices between private citizens or private societies and public administrations, are also seen as important by the Region, as they reached high scores: the topic of digitalization and innovation is one of the three areas of PNRR, which especially after the COVID-19 pandemic is important to consider for Italian recovery.
Then, from the local Smartness Assessment it is possible to see the commitment of the Grand Paradis Unité des Communes in increasing renewable energy production, considering mainly hydro and photovoltaic power plants, also expressing interest in knowing more about energy communities.
Next steps for this work could include to submit a questionnaire, obtained from the results of the regional and the local Smartness Assessment, to other stakeholders as citizens, students, workers in the tourism sector or others, to compare the different answers and evaluate the distance between the PA and the inhabitants, understanding which measures could bring closer these two entities.
Then, a real case of an energy community formation is evaluated in the same UdC of the local Smartness Assessment, in particular in the two little mountainous municipalities of Avise and Arvier which count altogether less than 1200 inhabitants.
In this area, the possibility of overcoming current Italian regulations in energy community's formation is evaluated: Italy transposed the proximity condition stated in RED II directive into the possibility of creating energy communities only between users connected to the same LV/MV stations, while in this work it is proposed to form energy communities including users of all the secondary substations in the two municipalities.
Comparing this new configuration to the other one, it is seen a higher Net Present Value at year 20 and a NPV which becomes positive sooner, an element that could be important for

small investors as private citizens or little municipalities. In a configuration with a single energy community, it is possible to optimize energy exchanges between the users, to do not oversize batteries and PV panels and to install PV panels in different roofs optimizing the production in different hours of the day, following the hourly request of the community.
Moreover, it could be advantageous to have a single energy community in the territory for many social reasons. First of all, creating and managing an energy community are time-intensive activities: it could be difficult to find conspicuous group of citizens in each secondary substation willing to put a great effort in the project, while with a single energy community a little group of inhabitants could take care of the main activities. In addition to this, to take decisions about the different energy communities it should be organized more than twenty meetings in the same two little municipalities: it would be more economical and less time consuming to have a single meeting.
Adding the heating loads of the two municipalities in different percentages and varying batteries costs, the outcomes give back higher Net Present Values after 20 years, making it a feasible possibility to support the partial or total decarbonization of the heating system.
It would be interesting for next steps to conduct an analysis in Avise and Arvier to understand in which percentage the participation of the population is necessary to have an economically feasible energy community. This analysis requires coupled data of users and their relative roofs, or it could be simulated, for example with a Montecarlo's analysis. Moreover, a more precise estimate of the available spaces for the PV panels could be done by using the regional Digital Surface Model (DSM) and the Digital Terrain Model (DTM) relative 2005 and 2008, checking these data with a more recent satellite photography, evaluating also the shadowing between buildings. A more detailed model to allocate costs for the users could be developed.

Appendix A: Smartness Assessment

Smart Economy

1) È importante per la nostra Regione sviluppare azioni/strategie a supporto dell'innovazione tecnologica digitale dei processi produttivi e dei servizi dei diversi settori economici, con particolare riferimento alle filiere corte e ai piccoli operatori economici.
2) È importante per la nostra Regione sviluppare azioni/strategie a supporto dell'innovazione green (a basse emissioni) dei processi produttivi e dei servizi nei diversi settori economici del territorio.
3) È importante per la nostra Regione supportare l'alfabetizzazione digitale e la diffusione di skill digitali nei diversi settori economici e facilitare l'accesso ai servizi digitali per le imprese.
4) È importante per la nostra Regione supportare l'alfabetizzazione digitale e la diffusione di skill digitali nei diversi settori economici e facilitare l'accesso ai servizi digitali per le imprese.
5) È importante per la nostra Regione incrementare l'attrattività economica e lo sviluppo di nuove imprenditorialità nelle aree marginali attraverso l'innovazione e la digitalizzazione.
6) È importante per la nostra Regione supportare la creazione di servizi digitali collaborativi tra gli operatori economici, in particolare quelli dislocati in aree marginali del territorio, facilitando lo sviluppo di «reti nella rete».
7) È importante per la nostra Regione supportare la creazione di spazi comuni di interscambio («hub») e/o laboratori per la formazione e la facilitazione della transizione digitale delle imprese dei vari settori economici, in particolare nelle aree marginali del territorio.

Smart Environment

1) È importante per la nostra Regione sviluppare azioni/strategie a livello locale a supporto della transizione verso la produzione e l'uso di energie rinnovabili.
2) È importante per la nostra Regione sviluppare azioni/strategie a supporto dell'efficientamento energetico degli edifici e la bio-edilizia, sia per gli edifici pubblici, sia per quelli privati.

3) È importante per la nostra Regione supportare lo sviluppo di iniziative e soluzioni locali per la sostenibilità e l'indipendenza energetica del territorio, come ad esempio attraverso la formazione di Comunità Energetiche, con particolare riferimento alle aree marginali del territorio.
4) È importante per la nostra Regione agire per un'economia circolare e a zero sprechi, con particolare riferimento alle aree marginali del territorio.
5) È importante per la nostra Regione investire in sistemi di monitoraggio distribuiti sul territorio per la raccolta, la condivisione e la comunicazione agli attori rilevanti del territorio dei dati ambientali (dati idrologici, dati energetici, dati meteorologici, dati geomorfologici, dati d'inquinamento, …).
6) È importante per la nostra Regione investire nella formazione di una cittadinanza consapevole che si senta custode del territorio e partecipi attivamente al suo monitoraggio attraverso piattaforme digitali.
7) È importante per la nostra Regione porsi obiettivi di sviluppo sostenibile, anche in un quadro di possibile ripopolamento della montagna, e di mitigazione delle emissioni in tutte le realtà territoriali, con particolare riferimento a quelle marginali.

Smart Governance

1) È importante per la nostra Regione sviluppare azioni/strategie a supporto dell'alfabetizzazione digitale e dei digital skills del personale della Pubblica Amministrazione, sia regionale sia locale.
2) È importante per la nostra Regione promuovere la digitalizzazione delle pratiche e dei processi della Pubblica Amministrazione a tutti i suoi livelli.
3) È importante per la nostra Regione investire per poter erogare in modalità digitale le pratiche verso il cittadino e le imprese (accesso a contributi, comunicazioni obbligatorie, ecc…).
4) È importante per la nostra Regione investire nell'infrastrutturazione in Banda Ultra Larga e nella diffusione delle reti di nuova generazione (5G) che coprano sia le aree più popolate sia quelle marginali.
5) È importante per la nostra Regione investire nell'infrastrutturazione e nella diffusione dell'Internet of Things (IoT) anche nelle aree remote della Regione.
6) È importante per la nostra Regione investire in portali Open Data per dati di interesse pubblico per cittadini e imprese e in ecosistemi digitali che abilitino, ad esempio l'interscambio di informazioni tra pubblico e privato e modelli innovativi di servizio («Open innovation»).
7) È importante per la nostra Regione investire in iniziative per lo sviluppo di logiche di «cittadinanza digitale» accessibili anche nelle aree marginali del territorio per permettere l'inclusione e la partecipazione attiva delle comunità locali.

Smart Living

1) È importante per la nostra Regione incentivare azioni/strategie per l'erogazione di servizi socio-sanitariaggiuntivi alla persona in forma digitale, in particolare per le fasce più fragili della popolazione.
2) È importante per la nostra Regione incentivare azioni/strategie per l'erogazione di servizi educativi e formativi alla persona in forma digitale.
3) È importante per la nostra Regione incentivare azioni/strategie volte all'erogazione in prossimità di servizi (formativi, educativi, sociali, sanitari, …) alla persona, in particolare nelle aree marginali del territorio.
4) È importante per la nostra Regione incentivare azioni/strategie per la creazione di spazi di erogazione dei servizi condivisi e connessi volti all'aggregazione in singoli luoghi di più servizi alla persona, specialmente nelle aree marginali.
5) È importante per la nostra Regione investire in iniziative per creare reti di cittadini (autorganizzazione) per l'aggregazione nella richiesta di servizi.
6) È importante per la nostra Regione incentivare l'adozione di soluzioni tecnologiche atte a rafforzare la sicurezza sul territorio (sicurezza pubblica, merci pericolose, presenze sul territorio, etc.).
7) È importante per la nostra Regione facilitare l'adozione di soluzioni tecnologiche per la raccolta e condivisione delle informazioni sui servizi alla persona, anche allo scopo di aumentare la partecipazione attiva delle persone (in un'ottica, ad esempio, di social innovation).

Smart Mobility

1) È importante per la nostra Regione incentivare l'intermodalità sostenibile nel trasporto, ad esempio creando interscambi bici-treno, bici-autobus, velostazioni, stazioni di mobilità condivisa-stazioni di trasporti pubblici, …
2) È importante per la nostra Regione incentivare azioni/strategie per la mobilità condivisa (car-sharing, car-pooling, bike-sharing, …) anche in forma compartecipata pubblico-privata, con particolare attenzione alle aree marginali.
3) È importante per la nostra Regione incentivare azioni/strategie per la mobilità elettrica privata o condivisa (auto, bici, scooter elettrici) e la relativa infrastrutturazione (colonnine, parcheggi dedicati).
4) È importante per la nostra Regione investire sulla mobilità sostenibile delle merci e sulla logistica smart nelle aree marginali.
5) È importante per la nostra Regione investire in iniziative per i servizi di mobilità personalizzati e a chiamata (Mobility as a Service), specialmente per le aree meno densamente abitate.

6) È importante per la nostra Regione facilitare la raccolta e la condivisione delle informazioni sui trasporti (trasporto interno e attraverso la Regione, trasporto pubblico, trasporto privato, trasporto condiviso, …) per la pianificazione e la gestione smart della mobilità nelle aree marginali.
7) È importante per la nostra Regione investire nella mobilità dolce, in particolare quella ciclabile (anche elettrica), rafforzando itinerari esistenti o creandone nuovi.

Smart People

1) È importante per la nostra Regione incentivare la formazione all'utilizzo delle nuove tecnologie per l'innovazione nella popolazione (studenti, lavoratori, pensionati, …).
2) È importante per la nostra Regione incentivare la formazione all'utilizzo delle nuove tecnologie per l'innovazione nella popolazione (studenti, lavoratori, pensionati, …).
3) È importante per la nostra Regione investire sulla propria attrattività in termini di innovazione digitale per attrarre e ri-attrarre talenti da fuori Regione.
4) È importante per la nostra Regione investire sulla propria attrattività in termini di innovazione digitale per attrarre e ri-attrarre talenti da fuori Regione.
5) È importante per la nostra Regione incentivare azioni/strategie per la creazione di spazi di comunità infrastrutturati e connessi.
6) È importante per la nostra Regione investire in iniziative per supportare l'imprenditorialità giovanile, specialmente quella caratterizzata da innovazione digitale.
7) È importante per la nostra Regione incentivare, nella popolazione, la veicolazione digitale dell'identità e del patrimonio culturale valdostano e del multilinguismo.

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