Project Acronym/ Acronimo del progetto:

INTEGRIDS

Project title:

Electric and thermal grids integration with energy flexible building

Titolo del progetto:

Studio dell'integrazione di reti elettriche e termiche con la flessibilità energetica degli edifici

Deliverable name	Descrizione della metodologia per valutare il best energy mix di una data area geografica e degli algoritmi utilizzati per l'ottimizzazione
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Foreword

The increasing penetration of distributed renewable thermal and electrical energy generation and the need of decarbonizing the existing energy infrastructure (both thermal and electrical) has led to a new set of challenges. These will have to be tackled in the next 10 years to make sure that the full potential of renewables can be exploited within electric grids and thermal networks. In the INTEGRIDS projects the concept of integrated energy grids defined as the synergy between thermal and electrical grids to enable high renewable energy penetration in efficient energy buildings and districts is explored.

This is relevant to the local energy landscape of the Province of Bolzano as the energy strategy KlimaLand "Energy South Tyrol 2050" in 2011 set ambitious targets for 2020 and 2050 in terms of CO_2 reduction (4 t/year/person in 2020 and 1.5 t/year/person in 2050) and energy demand covered by renewables (75% in 2020, 90% in 2050). These targets can only be met with a complex mix of energy demand reduction and i) solutions which enable integration of an increasing amount of local and centralized renewable sources in combination with appropriate deployment of active loads (e.g. electric vehicles), electrical and thermal storage, flexible back up generation and virtual power plants and ii) solutions which enable the full exploitation of the flexibility potential provided by a wider range of ancillary services (electricity market frameworks, demand and generation forecasting, balancing or demand side management). Further integration of clean generation entails increasing levels of complexity. It is hence important that cost-effectiveness is also considered together with the security and high quality of supply for customers.

A reduction of the demand of not-renewable energy (and of CO_2 emissions) is thus possible thanks to a better match between energy generation from renewables and loads, exploiting synergies between buildings and the energy grids.

In the INTEGRIDS project the validity of the concept is proven in an innovative laboratory environment.

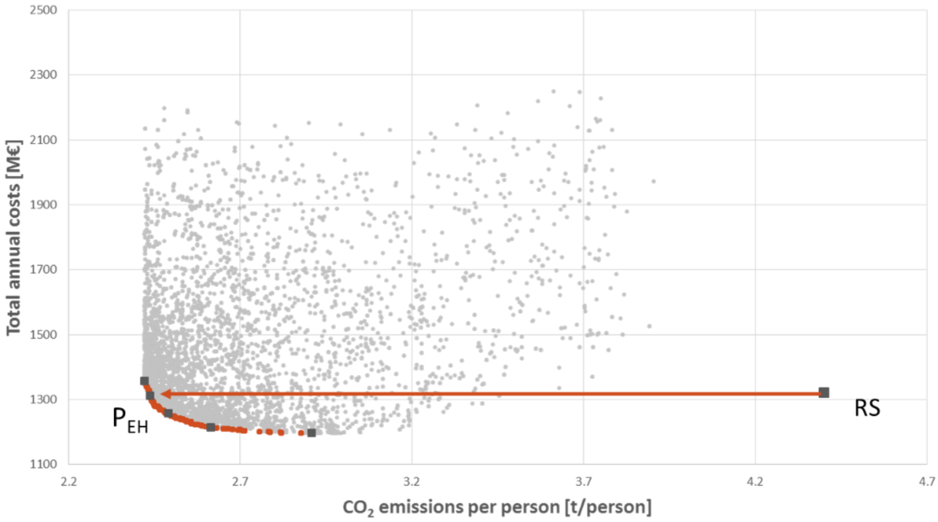
Challenges covered by this deliverable: Integration of thermal networks and electricity grids.

Looking at the electricity grid, it is essential to enable effective and efficient integration of growing shares of PV into the grids (7.5% share of the electricity demand already reached in Italy) along with other renewable energy sources (RES) and new types of electricity demand. Thermal grids have to react fast to changes in energy supply and demand rate and temperature and should enable the interaction of the end user with the heating and cooling system creating possibilities for the prosumers to participate and developing new business models. The integration in the whole urban energy system is also a critical aspect from a spatial point of view and from an energy system point of view. Thermal energy storage (TES), both centralized and local at building level, is a central component for enhancing the flexibility of district and heating systems, matching variable renewable energy sources with a fluctuating thermal demand and as an option to store excess electricity. Advanced DHC systems must be developed that are able to deal with both centralized and decentralized hybrid sources (e.g. solar thermal, biomass, geothermal, heat pumps, waste heat, waste-to-energy, excess renewable electricity, storage).

Executive summary

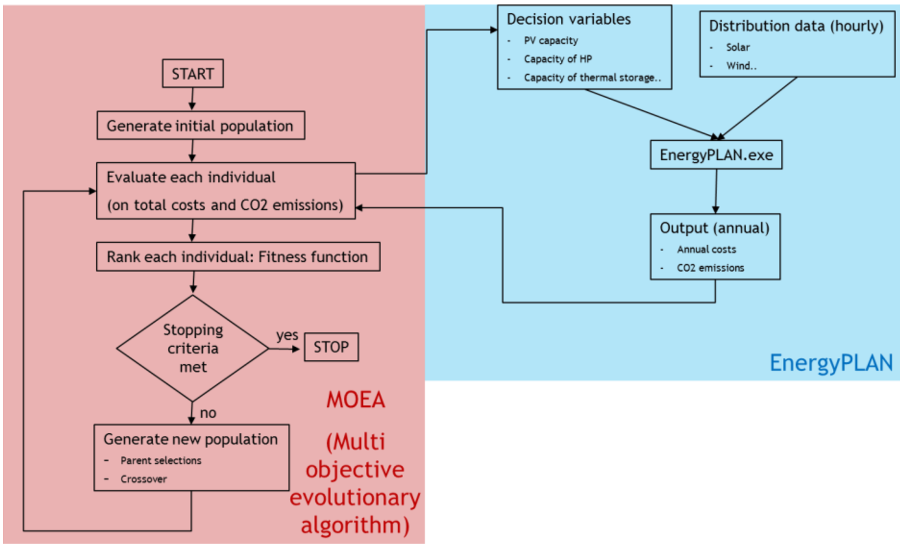
Una delle maggiori sfide della comunità internazionale è la riduzione delle emissioni di gas serra (GHG) per mitigare i cambiamenti climatici. I settori elettrico, termico e dei trasporti insieme a quello industriale rappresentano il 60% della produzione mondiale di gas serra. Per rispondere a questa sfida e insieme migliorare la sicurezza del sistema energetico, un numero crescente di paesi ha fissato obiettivi energetici con l'obiettivo di ampliare la propria quota di energie rinnovabili. L'Unione europea nel 2007 ha adottato il "Pacchetto per il clima e l'energia 2020" e il "Quadro per il clima e l'energia 2030" nel 2014. La pianificazione energetica sta assumendo quindi un ruolo centrale nella valutazione del sistema energetico futuro e nel supportare i decisori politici a fissare gli obiettivi e a scegliere i migliori percorsi e configurazioni del sistema energetico che permettano di raggiungerli.

Il seguente deliverable relativo al task 4.1 si concentra sulla metodologia di modellazione del mix energetico ottimale di una data area geografica. Una prima fase fondamentale riguarda il reperimento dei dati energetici di input del modello che riguardano lo stato attuale del sistema energetico. In questa fase è quindi necessario reperire dati che riguardano i tre principali settori del sistema energetico: settore elettrico, termico e dei trasporti. Una seconda fase è collegata alla stima del potenziale reale di energia producibile da fonti rinnovabili. Per far questo è necessaria un analisi spaziale del territorio ad esempio attraverso l'ambiente GIS. È inoltre necessario valutare l'andamento dei costi futuri delle tecnologie e dei combustibili. Questo viene fatto attraverso l'uso di learning curves che esprimono l'andamento dei prezzi delle tecnologie in funzione della capacità installata e da cui è possibile ricavare una stima dell'andamento futuro dei prezzi.

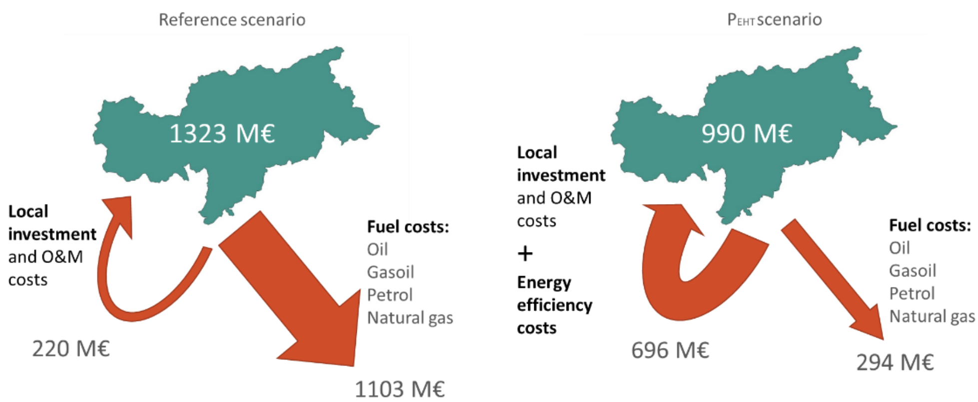


Una volta raccolti tutti questi dati e informazioni è necessario un modello di ottimizzazione che indaghi diverse possibili configurazioni del sistema energetico e scelga le migliori sulla base di una serie di obiettivi che sono in genere collegati ai costi, alle emissioni di CO_2 e alla percentuale di rinnovabili nel sistema. L'ottimizzazione di diverse tecnologie all'interno di un sistema energetico è infatti un problema multi-obiettivo perché riguarda aspetti economici, tecnici e ambientali. L'ottimizzazione di questi obiettivi in competizione tra loro produce un fronte di Pareto di soluzioni Pareto-ottimali, cioè che dominano tutte le altre configurazioni del sistema energetico (figura sovrastante). Con l'obiettivo finale di trovare le migliori alternative per il futuro sistema energetico di una regione o nazione, Eurac Research ha sviluppato un

codice open source sotto licenza LGPL chiamato EPLANopt. Questo modello accoppia il software di simulazione EnergyPLAN, sviluppato dall'università di Aalborg, con un algoritmo genetico multi obiettivo che permette di valutare un alto numero di configurazioni diverse del sistema energetico selezionandone le migliori.
Il modello EPLANopt, sviluppato precedentemente all'interno di un progetto interno da EURAC research, è stato applicato al caso studio del sistema energetico dell'Alto Adige.



L'Alto Adige è una regione situata nelle Alpi italiane ed è caratterizzata da un'elevata disponibilità di risorse rinnovabili: energia idroelettrica e biomassa (proveniente prevalentemente da manutenzione boschiva) sono utilizzate intensamente per la produzione di elettricità e calore. L'importazione di energia riguarda prevalentemente il gas naturale per l'industria, i servizi e il riscaldamento residenziale e i combustibili fossili più in generale per il settore dei trasporti.
I risultati del modello di ottimizzazione presentano le configurazioni ottimali per il sistema energetico dell'Alto Adige al 2050. Sono stati indagati diversi livelli di penetrazione di veicoli a zero emissioni. Uno scenario in particolare è stato scelto per essere confrontato con il caso iniziale. Lo scenario caratterizzato da una percentuale di penetrazione di veicoli a zero emissioni del 60% ha dimostrato che un sistema energetico con minori emissioni di CO_2 e una maggiore percentuale di energie rinnovabili è possibile senza aumentare i costi totali annui.



Si è inoltre dimostrato che, analizzando le caratteristiche dei costi totali annui, la natura dei costi varia in modo positivo per l'economia dell'Alto Adige. Infatti mentre nello scenario di riferimento, relativo al caso attuale proiettato al 2050, i costi totali annui sono caratterizzati da elevati costi esterni per i combustibili fossili nello scenario individuato sul fronte di Pareto e caratterizzato da un penetrazione di veicoli a zero emissioni pari al 60% i costi sono per lo più legati a efficientamento energetico e a costi che possono essere definiti interni e che vanno a potenziare e sostenere l'economia interna dell'Alto Adige.

I risultati di questo deliverable derivano in parte da risultati del progetto Integrids e di un progetto interno di EURAC, RegEnMod dove parte della metodologia è stata sviluppata. Si ringraziano pertanto i seguenti collaboratori: Marco Cozzini, Giulia Garegnani, Ulrich Filippi Oberegger, Roberto Vaccaro, Wolfram Sparber.

1 Why a dynamic energy model?

Many cities and regions in Europe and around the world have established long and medium term climate targets. Usually the objective of these strategies are formulated in CO_2 emissions per capita or renewable energy percentage (%) within the energy supply to be reached.

In most cases it is not clear if the energy targets can be reached and how the energy system would look like in order to achieve the targets. An additional interesting point is: if there are several energy system scenarios which allow to reach the set target, which of the possible solutions is the most cost effective? Dynamic energy modelling allow us to find answer to exactly this question.

2 Introduction

The deliverable of task 4.1 focuses on the modeling methodology of the optimum energy mix. One first step is connected to the estimation of the real potential from renewables in the grid that has been calculated using spatial analysis (e.g. GRASS GIS environment). Once the potential is known, it is possible to analyze the best energy mix scenarios using analytical modelling (e.g. EnergyPLAN) and multi objective optimization algorithms. The simulation also includes the use of electrical and thermal storage and demand side management through load profile variation. The methodology is applied to the South Tyrol energy system.

3 Energy system modelling

The main purpose of energy system modeling is to assist policy makers by developing potential scenarios for the energy system development by evaluating different alternatives with high penetration of renewable sources.

It is possible to classify the modeling of energy systems into two main approaches [1]:

- a techno-economic model-based approach that simulates the energy system and relative cost variations of each new technology with a high degree of technological detail (Bottom-up model)
- a top-down approach that can simulate future energy consumption and production, including impacts on socio-economic growth, employment and foreign trade.

3.1 Bottom-up approach

The Bottom-up approach is mainly used by engineers, researchers and power generation/dispatch companies. The main objective of these models is to identify the best technology options for the future energy system. There are two main models that use this type of approach: simulation and optimization model. The former reproduces the behavior of the energy system under certain values of input variables. The latter does not simply depict potential snapshots of the energy system in a hypothetical future, but develops an optimization analysis to select the best options from the point of view of certain indicators.

The most used indicators in the optimization analysis are economical as the total costs of the energy or environmental such as CO_2 emissions or the percentage of the integration of renewable sources. A model of this type that performs an optimization analysis on different competing objectives is called multi-objective optimization model. The objectives, in conflict between each other, lead to the identification of a Pareto front made up of all non-dominated solutions. This type of models uses an hourly time-step that allows the description of the interaction between the various sources of energy generation with a high degree of detail. The advantage of this approach is therefore the high degree of technological detail. A weakness is the high dependence on the goodness, availability and credibility of the input data. It does not consider the macroeconomic impacts of the energy sector, energy policies or related investments. Examples of software that use this approach are: EnergyPLAN developed by Aalborg university [2], MARKAL / TIMES developed by the International Energy Agency (IEA) [3], REMod developed by Fraunhofer Ise [4], Osemosys by KTH Royal Institute of Technology [5], Oemof framework by Reiner Lemoine [6] Institute and Calliope by ETH Zürich [7].

3.2 Top-down approach

The top-down approach aims to analyze and convert the aggregate effects of energy policies and those relating to climate change in monetary terms in order to quantify and compare them. Contrary to bottom-up modeling, these models lead to an aggregate view of the energy system considering its effects on other sectors such as employment, economic development, gross domestic product (GDP), welfare and social growth. These macroeconomic models are used to assess the economic costs and environmental impacts of energy and climate policies. Thus to evaluate policy measures such as carbon taxes, emission trading schemes (ETS) and feed-in tariffs for renewable energies. Model users of this type of approach are more economists and public administrations. The benefits of these types of models regards the possibility to inspect the interactions of the energy system with other related sectors. The disadvantage is the lack of technological detail if compared to bottom-up models. There are currently four different types of top-down models: input-output models, econometric models, global models of overall computational equilibrium and system dynamics models. Some examples of software based on this approach are Primes, Enpep-balance, MARKAL / TIMES (partially) and LEAP.

3.3 Hybrid models

To overcome the weaknesses and limitations of the two approaches, a third type of approach has recently developed which tries to combine a macroeconomic model with a bottom-up modeling. The simplest form of hybrid models is to connect top-down and bottom-up models through the so-called soft linking, which involves manual data transfer. If the connection evolves into automatic routines, a hard link is established between the two models. The main challenge of this type of models is to keep them from a theoretical and empirically valid point of view without having to build enormous size models that can hardly be executed by a computer in a short time.

4 Methodology used in the case study

4.1 EnergyPLAN

The EnergyPLAN software developed by Aalborg University and based on the bottom-up approach has resulted at the moment of the present study in one of the most complete tools to describe future energy system [8 - 11] in a very short computational time. EnergyPLAN is a deterministic input/output model that permits to integrate the three primary sectors of any national energy system, (electricity, heat and transport sectors) thanks to predefined priorities. This characteristic allows for a complete simulation of the interactions between different energy system sectors. The energy system integrated modelling shows advantages compared to the software characterized by sector modelling [12 - 25]. The program is a descriptive and analytically programmed computer model for hourly base simulation of a regional or national energy system. This characteristic allows to catch the variability of non-programmable renewable energy sources. In addition, an hourly time-step modelling of energy system with the presence of variable renewable energy sources (VRES) shows advantages over the approach in which the simulation of the year is created through characteristic days [26].

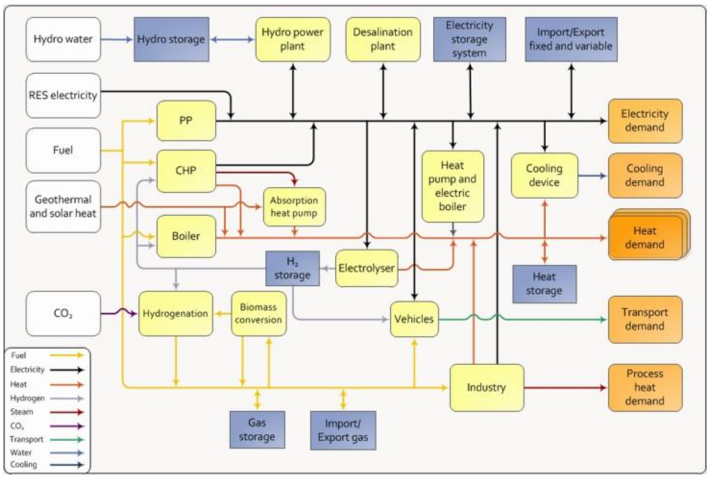


Figure 1 - Diagram of the EnergyPLAN's structure.

4.2 EPLANopt

With the final goal to find the best alternatives for the future energy system of a region or nation Eurac Research developed an open-source code under LGPL license called EPLANopt [27, 28]. Within the Integrids project this model is applied at the territory of the province of South Tyrol.

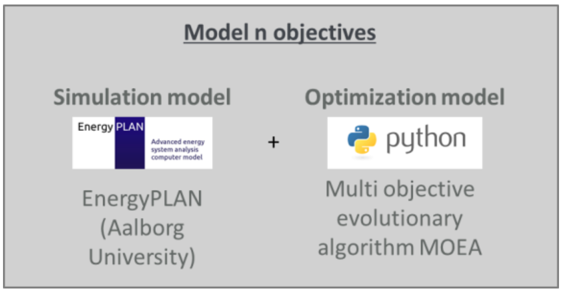


Figure 2 - Structure of the PLANopt's code

The EPLANopt model is characterized by the following features: it is a Multi-Objective Evolutionary Algorithm developed in Python based on the DEAP python library [29]. This optimization model is designed to work with the deterministic model EnergyPLAN by being linked to it, Figure 3.

EnergyPLAN [9 - 11] is a deterministic model because there is no effect of randomness or probability profile in the calculation of a given output. It is a simulation model that assesses the behavior of an energy system configuration, as opposed to an optimization model where the objective is to find the best technology mix for the configuration of the energy system. EnergyPLAN is analytically programmed because there is not a solver in the model that calculates the optimal hourly dispatch based on a set of constraints and an objective function. A set of priorities drives the energy balances resulting in a very short computational time. The main purpose of the model is to support the design of national energy planning strategies through the technical and economic analyses of different configurations of the energy system. The model has been applied at different scales: at European level [30], at national level [31-36] as well as at local level for energy system planning of towns and municipalities [24, 37]. In present case, the EnergyPLAN model is applied to a region in Northern-Italy with a single node approach. Thus, transmission constraints are not considered in the model. A comparison of single-node and multi-node approach is given by Prina et al. [38] in this study.

The Multi-Objective evolutionary algorithm in the EPLANopt model [27] is a meta-heuristic optimization algorithm that is inspired by the principle of natural selection [39]. A heuristic optimization algorithms is particularly suited for finding solutions in a fast and easy way [40]. Multi-objective evolutionary algorithms (MOEA) [41] are a version of EAs for multi-objective optimization (MOO) problems. The optimization starts with a population of solutions generated with random values of the decision variables from their respective range. Each solution is then evaluated by the simulation model, all required distributions and relevant cost are fixed inputs parameters of EnergyPLAN as they do not change during the algorithm evolution. In this model learning effects in terms of investment cost reduction are not endogenously modelled, the effects of this economic transition are accounted considering expected costs for the technology at the time of investment. Each individual is then ranked considering the multiple objectives of the optimization. At each step, the MOEA generates a new population of individuals applying the typical operators of genetic algorithms: parent selection, crossover and mutation. After completion of all the generations, a Pareto front is generated by the MOEA (see Figure 3).

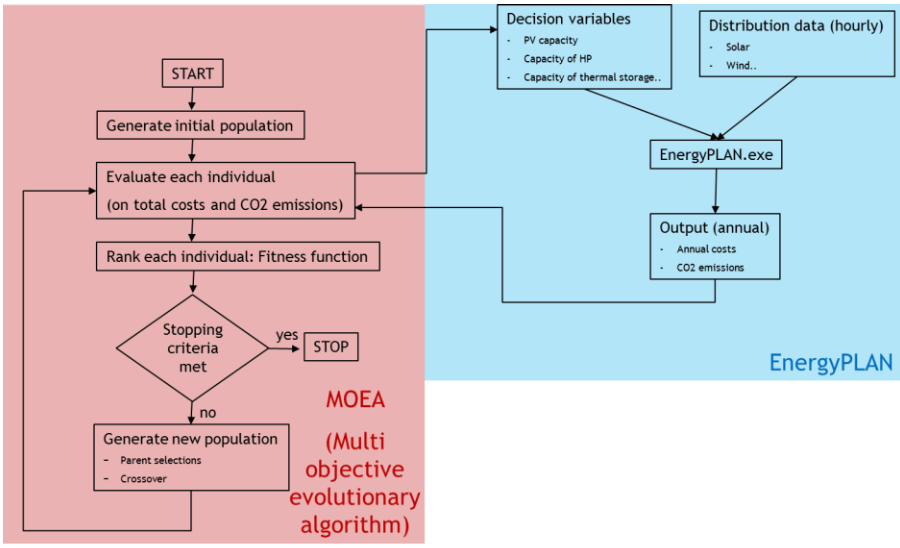


Figure 3 Diagram of the EPLANopt model.

The code leaves the possibility to set a number *n* of objectives within the multi-objective optimization, to easily change operators and parameters of the genetic algorithm and to initialize part of the population with known solutions (seeding the population). The parameters and data are setting through a Json file. The possibility to run EnergyPLAN in parallel is adopted saving computational time. Moreover the documentation and a simple example are provided [27].

The evolutionary algorithm has the following characteristics:

I. Parent selection is the stage of an evolutionary algorithm at which individuals are chosen to be later mutated or crossed. This stage in EPLANopt is based on the NGSA-II algorithm [42].
II. Uniform crossover with a probability of crossover equal to 90% and a probability to exchange each single attribute equal to 50%. Uniform crossover modifies two sequence individuals. The attributes are swapped according to the probability exchange each attribute [29].
III. Uniform mutation mutate an individual by replacing attributes with probability equal to 5% by a integer chosen between a low and up bound [29].

Figure 4 shows the progresses of the Multi-Objective evolutionary algorithm during its processing for the case study of South Tyrol. It shows the progress in terms of new Pareto front every 125 iterations or new evaluated configuration of the energy system. It is possible to see how this temporary Pareto front evolves up to a stable curve.

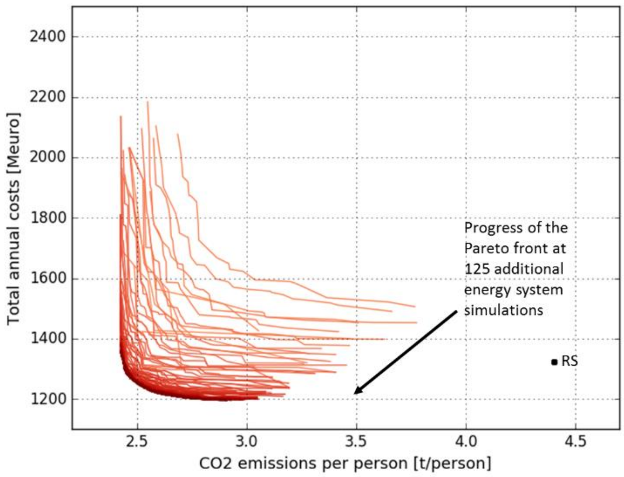


Figure 4 Progresses of the Pareto front during the optimization analysis.

5 Results – exemplary application on the region of South Tyrol located in Northern Italy

The creation of the energy system baseline is the first step needed for the analysis of an energy system. The created energy system model is based on a single node approach. Thus, a perfect distribution grid without bottlenecks and losses is assumed. The second phase of this process regards the identification of the input optimization variables and the evaluation of their potentials for the province area. The final step deals with the running of the optimization analysis itself and analysis of the results.

5.1 South Tyrol reference scenario 2014

South Tyrol is a region located in the Italian alps. With an extension of 7400 km² and a population of around 520 thousand inhabitants [43], it has a very low population density but is extensively visited region by tourists. Energetically rich renewable energy resources characterize it. Hydropower and biomass (forest wood) are used intensively for electricity and heat production and further expansion of utilization has been considered to be very limited in the present scenario. Energy import is mainly based on natural gas for industry, services and residential heating and fossil liquid fuels for the transportation sector.

The reference scenario has been created from data available within Eurac research, energy development plan from single municipalities of the territory and from data provided by the province of Bolzano. The reference year taken into consideration is 2014. Figure 5 shows the electric and thermal energy balance for the baseline of South Tyrol energy system.

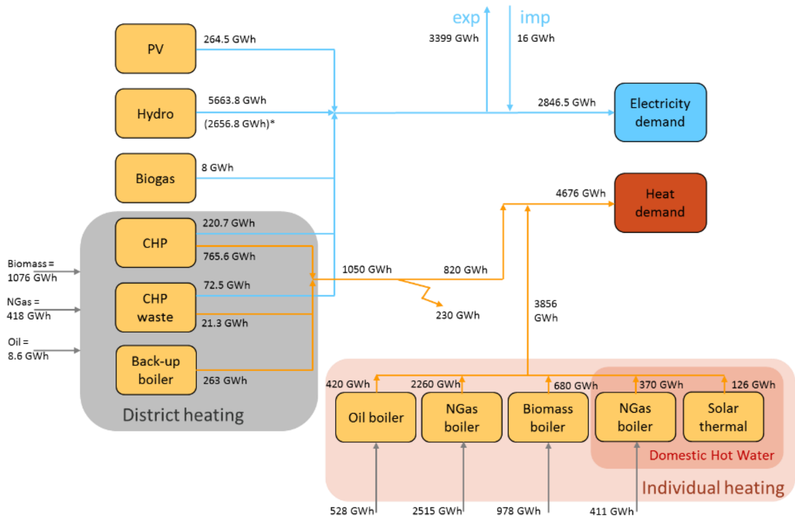
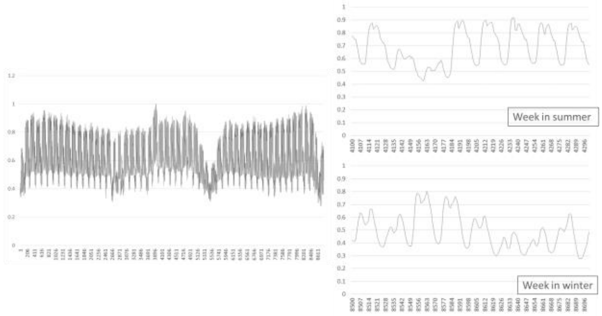


Figure 5 Diagram of the electricity and thermal sector of the South Tyrol energy system.

EnergyPLAN software in order to simulate one configuration of the energy system requires three different types of input data:

i) the distribution for the fixed sources such as electricity, heat demand and not-programmable renewable energies,
ii) costs data for fuels and technologies,
iii) absolute value data regarding capacities and efficiencies for each source.

Figure 6 and 7 shows the hourly profile of the electricity and heat demand [44, 45]. Figure 8 shows the production profile of photovoltaics as result of a hourly average on 13 different areas of South Tyrol.



Sizing of the best battery capacity coupled to a rooftop residential 3 kWp PV system

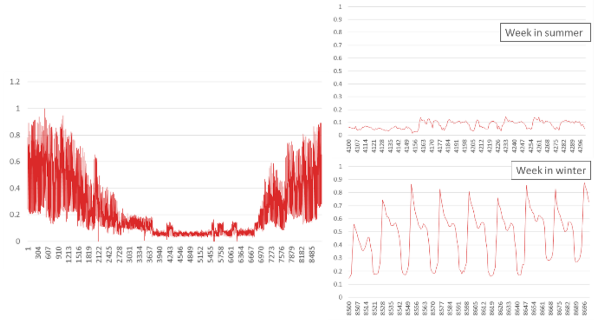


Figure 7 Hourly distribution of the heat demand [45].

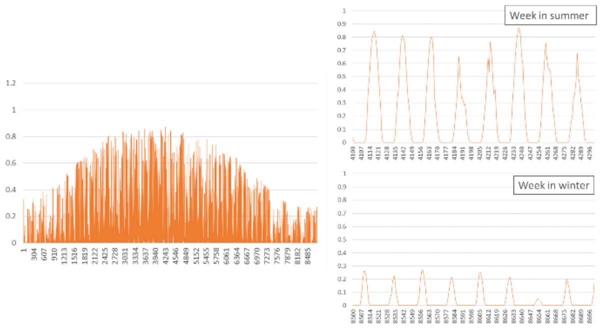


Figure 8 Hourly distribution of photovoltaics electricity production.

Figure 9 shows how the energy consumption is subdivided in the three sectors of the energy system in the province of South Tyrol. Clearly visible is the dominance by the heating sector, followed by the transportation sector and finally followed by the electricity sector. The absolute values are the following: Electricity consumption is equal to 2846.5 GWh, the heat consumption 6166.5 GWh and the transport energy consumption equal to 3400 GWh.

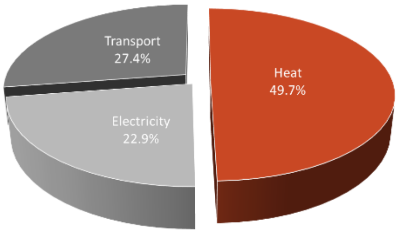


Figure 9 Energy demand: comparison between electricity, heat and transport.

Figure 10 shows the annual electricity balance and the total annual cost balance. Within the cost balance there have been considered:

- the annual fuel costs
- the operating and maintenance cost of the single energy technologies
- the investment cost divided by the useful life time of the single investment

It is possible to see how the total annual costs are mainly due to the costs of the various fossil fuels.

Within the electricity balance is clearly visible the overproduction of electricity based on hydropower with regard to the local energy consumption.

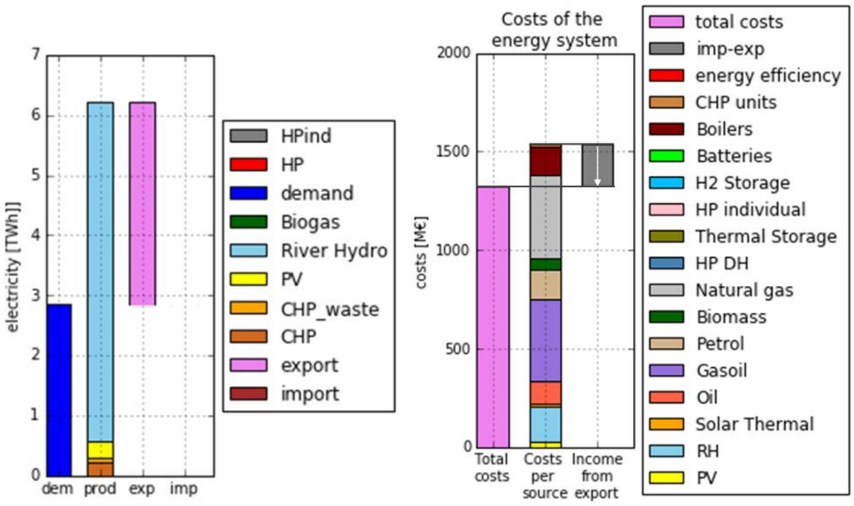


Figure 10 Annual electricity balance, on the left, and total annual costs balance for the energy system baseline.

Figure 11 shows the hourly electricity production in two weeks of the year, in summer and in winter. It can be noticed that both in summer and in winter the electricity generation is higher than the electric demand and the share of export is considerable. This is due to the peculiar situation of South Tyrol characterized by a high generation from hydro power plants. There are only few hours during the year in which the production is not able to fully cover the demand. The share of import within this framework is consequently limited and lower than 1 % of the total annual demand of electricity.

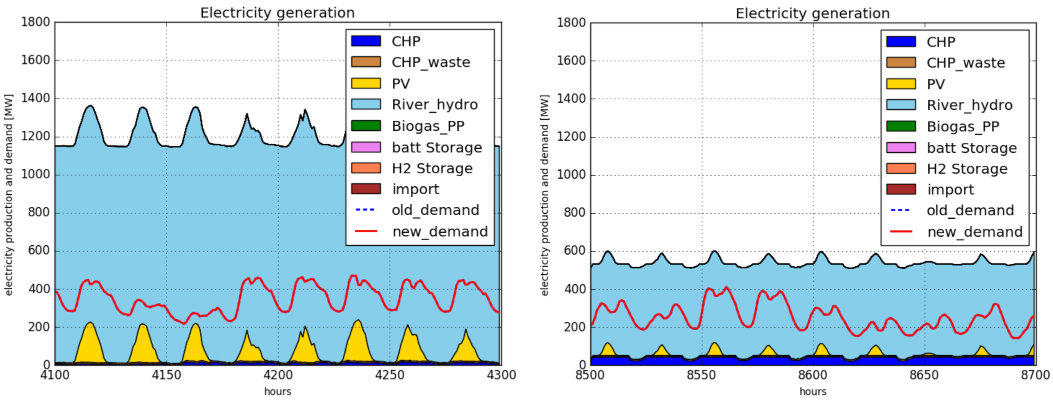


Figure 11 Reference scenario 2014 South Tyrol. Hourly electricity production of a week in June (from 4100 to 4300) and of a week in December (from 8500 to 8700).

Figure 12 shows the hourly heat production within the district heating network in two weeks, in summer and in winter. It is possible to notice that in summer the demand is very low and fully satisfied by the cogeneration plants. In winter the installed power of the cogeneration plants cannot cover all the demand and back-up boilers must intervene to cover the peaks.

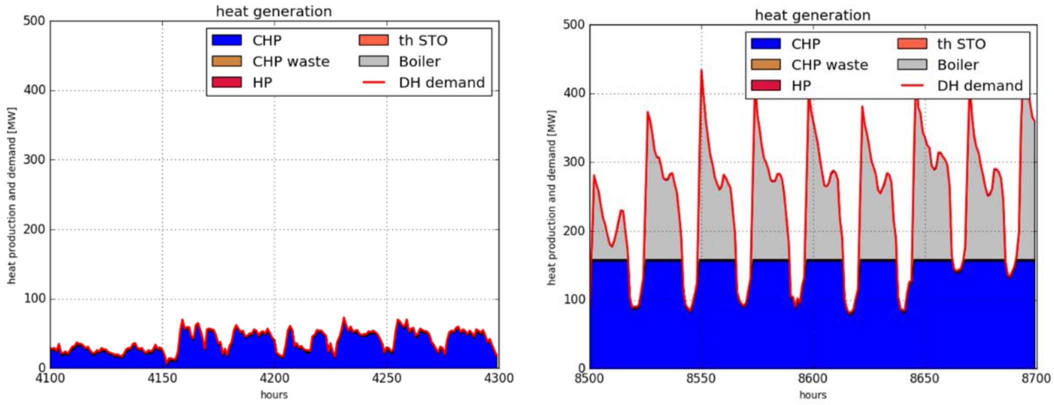


Figure 12 Reference scenario 2014 South Tyrol. Hourly heat production in the district heating network of a week in June (from 4100 to 4300) and of a week in December (from 8500 to 8700).

5.2 Objective – Targets of the regional energy and climate strategy

Objective is to reach the targets set in the regional energy strategy plan, called Klimaplan [46]. The climate plan, Energy-South Tyrol-2050 published by the province in 2012, indicates the path that South Tyrol intends to follow regarding the energy strategy of the Province. The objectives and measures contained in this document allow for the evaluation of the 2050 targets and underline the importance of specific mid-term evaluations to be carried out every five years in order to allow a possible redefinition of the measures. The main objectives include: a share of renewable energy needs up to 75% by 2020 and up to 90% by 2050 and the reduction of CO_2 emissions to less than 4 t per year per capita by 2020 and less than 1.5 ton per year per capita by 2050.

5.2.1 Optimization variables and potentials

The variables contemplated into the optimization analysis have been identified following the Klimaland direction. These variables are listed in table 1 and can be subdivided in additional capacity for electricity generation, such as photovoltaics and biogas, two different types of electric storage, heat generation capacity and storage connected to the district heating network, such as large heat pumps and seasonal thermal storage and heat generation capacity connected to individual heating.

	Simulation range (step)
PV [MW]	250 – 1250 (25)
Biogas power plants [MW]	0- 10 (10)
Electric storage Batteries [GWh]	0 – 10 (1)
Electric storage Hydrogen [GWh]	0 – 500 (10)
Electrolyser [MW]	0 – 1500 (100)
Fuel cell [MW]	0 – 1500 (100)
Large heat pumps [MW]	0 – 30 (5)
Seasonal thermal storage [GWh]	0 – 100 (10)
Solar thermal [GWh_th]	126 -500 (50)
Heat pumps individuals [%]	0 – %Energy Eff.
Energy efficiency [%]	0 – 75 (5)

Table 1 optimization variables and potentials.

The main assumption on these variables are the following:

- *Photovoltaic (PV) capacity*

The rooftop PV potential for the province of South Tyrol has been evaluated by Eurac Research through two different studies [47, 48]. Thus, the rooftop PV potential has been estimated equal to 1.25 GW of capacity that correspond to 5 times the current installed power. The Solar Tyrol project web GIS, in figure 13, permitted to verify this value through a different methodology and better accuracy.

Figure 13 PV potential estimated through the Solar Tyrol project webGIS [49].

- *Heat pumps and energy efficiency potential*

The potential of individual heat pumps is directly related to the level of energy efficiency refurbishment. In fact application of heat pumps in the building stock has been allowed in the model only after deep energy refurbishment of the building.

At first, an analysis of the provincial residential building stock has been carried out. In order to quantify the energy savings resulting from the implementation of energy efficiency measures it is important to know the current specific heat consumption (thermal consumption per square meter of heated surface), the building type, the construction technologies applied, the technical possibilities and cost of refurbishment measures.

This requires the classification of the South Tyrol building stock according to the construction period, the types of buildings and the heating degree days (HDD). The next step regarded the evaluation of the specific heat consumption for each municipality, construction period, and type of buildings. It was thus possible to estimate the heat energy consumed by all residential buildings in South Tyrol. The total thermal energy consumption for residential buildings in South Tyrol in 2013 has been estimated through Istat data [50] and internal calculations to be equal to about 2.8 TWh. Further a typical domestic hot water (DHW) consumption of 25 kWh/m²y is assumed based on monitoring data of one city quarter in Bolzano. The total heat consumption thus excluding DHW amounts to 2.3 TWh. The total heated residential surface of South Tyrol in 2013 has been estimated to be 18,845,637 m^2. The next step regarded the assessment of the cost of retrofit and the actual energy savings associated to retrofit measures. Passive House Planning Package (PHPP) simulations have been carried out for the following four types of housing: single family house (SFH) 250 m², multi family house (MFH) 904 m², detached 1363 m² and block 2308 m². An investment cost was allocated to each retrofit measure for each type of building and PHPP simulations were launched to evaluate the thermal energy consumption in post-retrofit conditions with the aim of quantifying actual energy savings. At this point, it was assumed that the energy saving percentage is the same regardless of the municipality and the construction period of the buildings. This could be considered as a strong assumption, but energy efficiency interventions on an old, inefficient building compared to a more efficient one produce higher thermal energy savings and therefore the percentage remains similar. With this assumption it is possible to calculate the annual thermal energy savings for each construction period and type of building and also the value of the euro per kWh saved. It is important to note that heat consumption is calculated according to the HDD after setting construction period and type of building. The results obtained show therefore higher values of energy savings for municipalities with colder climates. The assumption is that retrofit costs do not depend on HDD or construction period. For this reason, retrofit interventions tend to be cheaper in colder climatic zones (or at least in terms of cost of retrofitting per annual saved kWh). The main result of this analysis is the curve represented in Figure 14, which expresses the investment costs of each retrofit intervention in relation to the annual total energy savings.

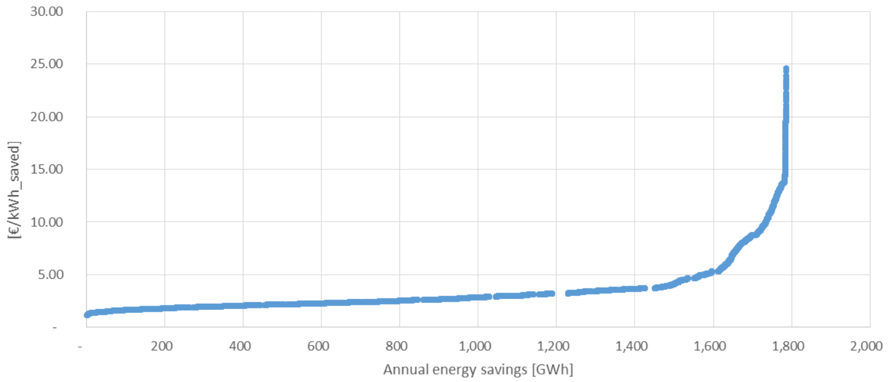


Figure 14 Specific costs of retrofit interventions depending on annual energy savings generated by these interventions.

The final assumption is therefore the following: the average existing residential building in South Tyrol is characterized by a thermal consumption of 149 kWh / m²y of which 25 kWh / m²y for the request of DHW. It is assumed a maximum reduction in the thermal demand due to energy efficiency measures of 75%. The installation of heat pumps is strictly connected to energy efficiency measures. In fact, within the optimization analysis the possibility to install heat pumps is linked to individual users only where energy efficiency interventions have reduced thermal demand enough to make the installation of heat pumps effective without having to change the heating system.

- *Imported electricity*

For the imported electricity, an emission factor of 0.483 t CO_2/MWh was considered [51]. For the calculation of the percentage of renewables in the system, the percentage of renewables in the system at the Italian level was considered equal to 37.04%, 2014 data [52].

6 Results of the optimization analysis

After collecting the reference scenario input data and filling in the data in the energyPLAN spreadsheet, the optimization algorithm was launched. Figure 15 shows the results of all the simulations and the Pareto front of non-dominated solutions. The objectives on which the optimization analysis is based are three: total annual costs, CO_2 emissions and renewable energy integration percentage. For the sake of simplicity and a better representation of the results, it has been decided to use the reverse of the penetration of renewables and to minimize all three objectives. In this way, the 100% RES objective is the reverse of the percentage of renewables within the system or more simply the percentage of energy still covered by fossil sources. In figure 15 only two objectives are represented for an easier understanding of the results.

The following paragraph is dedicated to the analysis of the results. It is possible to see how compared to the reference scenario (RS) the Pareto front leads to a significant improvement in CO_2 emissions without a significant increase in costs. The scenario P_{EH} has been chosen for a deeper analysis because it allows for a consistent decrease of the CO_2 emissions per person at the same costs of the reference scenario.

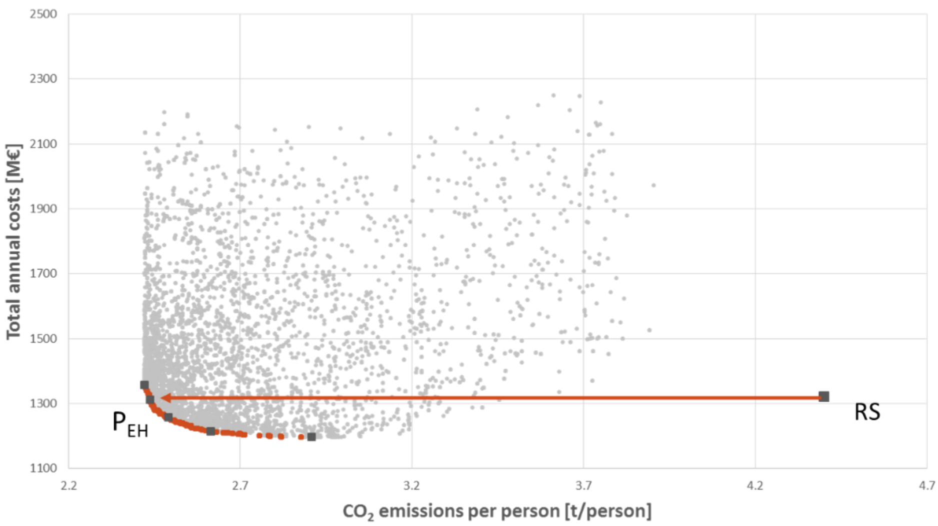


Figure 15 Pareto front of best configuration of the energy system of the South Tyrol province.

Figure 16 shows the hourly electricity production in winter and summer. In winter, it is possible to notice the increase of the electricity demand due to heat pumps. The conclusion from these graphs is that without a consistent increase of electric vehicles the electricity generation from renewable energy sources is still enough to cover the demand almost during the whole year. Figure 17 shows the annual electricity balance and the increase of electricity demand equal to 7.7% of the overall demand.

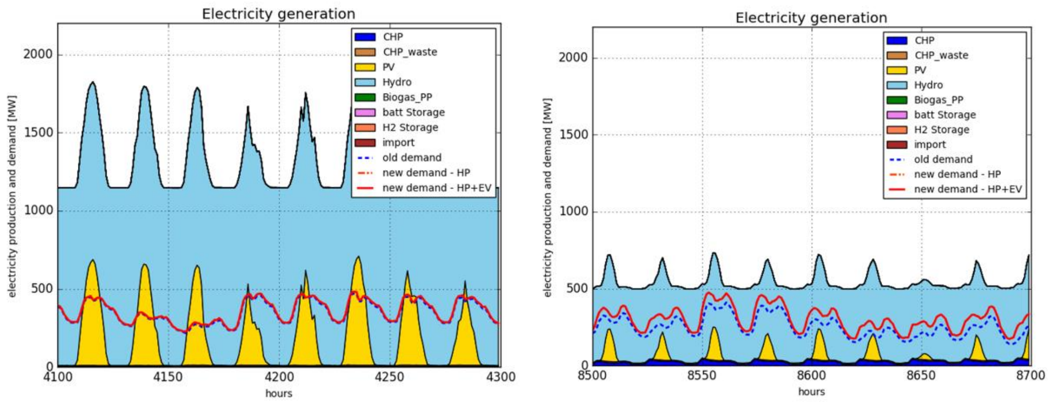


Figure 16 P_{EH} scenario. Hourly electricity production of a week in June (from 4100 to 4300) and of a week in December (from 8500 to 8700).

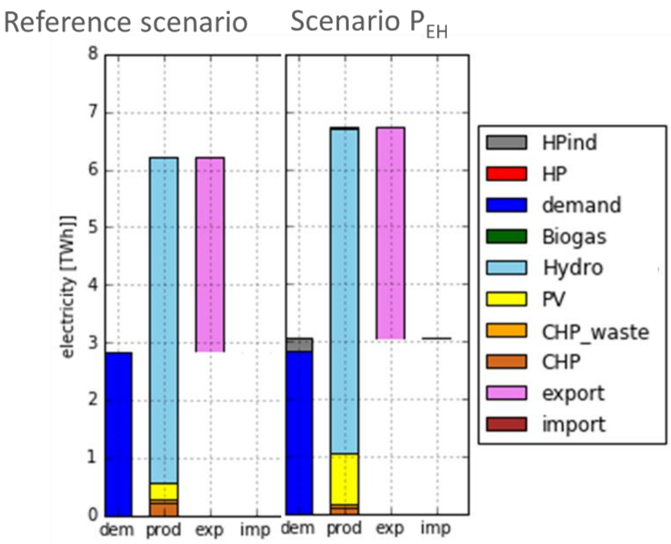
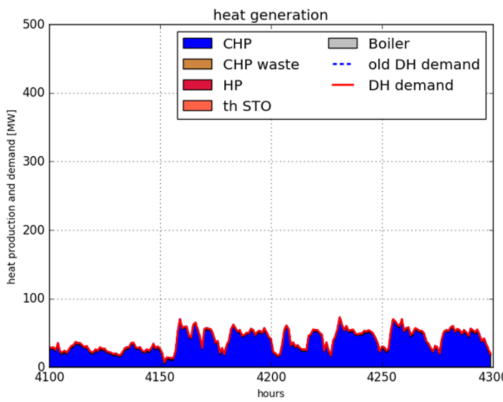


Figure 17 Annual electricity balance, comparison between the reference scenario and the P_{EH} scenario.

Figure 18 shows the hourly heat production within the district heating network in the two weeks taken as reference. The P_{EH} scenario, compared to the reference scenario, is characterized by a remarkable 75% energy efficiency that drastically reduces the load. The use of heat storage connected to the district heating network allows cogeneration plants to operate more flexibly with greater production at times when electrical production is limited and a shutdown of plants at hours when there is excess production electricity from renewable sources.



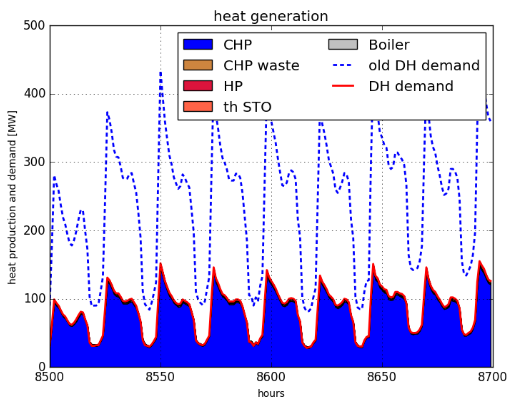


Figure 18 P_{EH} scenario. Hourly heat production in the district heating network of a week in June (from 4100 to 4300) and of a week in December (from 8500 to 8700).

Figure 19 shows the comparison between the overall energy demand and distribution among the three sectors of the energy system. While the transport sector remains the same of the reference scenario, the overall energy demand of the heat sector decreases drastically. The electricity demand increase slightly, mainly due to increased application of heat pumps.

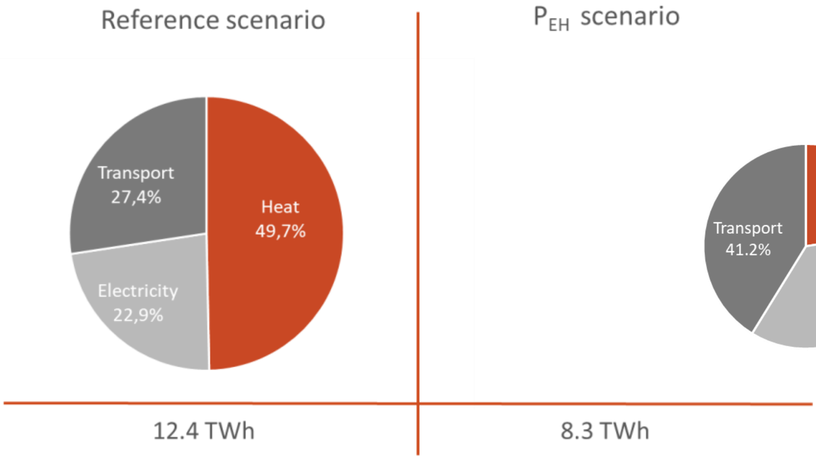


Figure 19 Comparison of the overall energy consumption between the reference scenario and the P_{EH} scenario.

Figure 20 shows the comparison between the total annual costs of the reference scenario and the P_{EH} scenario. The overall costs are almost the same but in the P_{EH} scenario costs connected to the fuels such as natural gas and oil are replaced by the costs in energy efficiency. One might argue: Well than were is my advantage. It should be highlighted here, that next to the environmental advantage, such a scenario has an important impact on regional economy. In fact the investment in the regional energy systems and construction sector through building refurbishment is drastically enhanced while the cost for fossil fuel decreases. So in simple words, similar cost, much higher local added value.

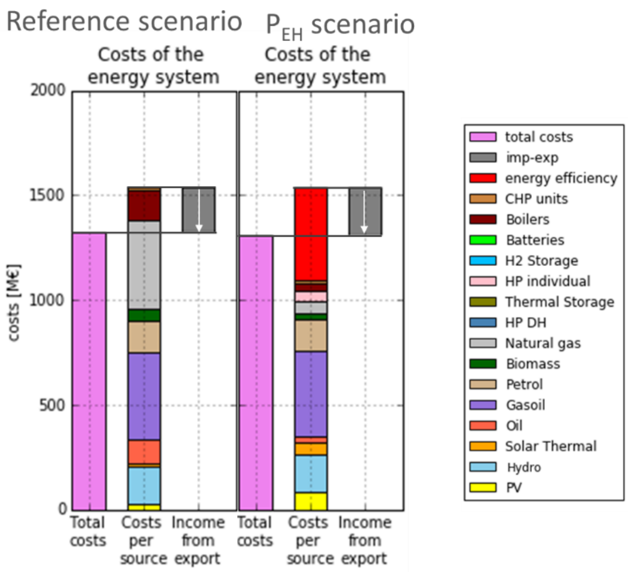


Figure 20 Comparison between the total annual costs of the reference scenario and the P_{EH} scenario.

Another optimization analysis has been implemented in order to include into the analysis also the transport sector. Different levels of penetration of percentage of zero emission transport on the overall kilometers covered in the transportation sector have been analyzed. In the study, no cost has been allocated for switching to an electric car. This based on the assumption that in the decades to come the costs of electric vehicles will stepwise decrease and finally equalize the costs of conventional cars. As the present scenario is located in 2050, there are several car generations included in the remaining period. In figure 21 it is possible to observe that at the increasing of penetration percentage of zero emission transport produces a decrease of both CO_2 emissions and total annual costs. At the increasing of the penetration percentage of zero emission transport is also possible to observe that the Pareto front become longer with an increase of the steep section. This is mainly due to the fact that at the increasing of the electric demand the electricity generation from RES is not enough anymore to cover the demand in each hour of the year and investments in electric storage become necessary. The electric storage is therefore expensive and increase the steep section of the Pareto front. In order to reach the Klimaland target of 1.5 t CO_2/person following the present calculations it is necessary to reach a penetration of zero emission transport equal to 60 %. The P_{EHT} scenario is further analyzed and compared to the reference scenario to better understand how the configuration of the energy system has changed.

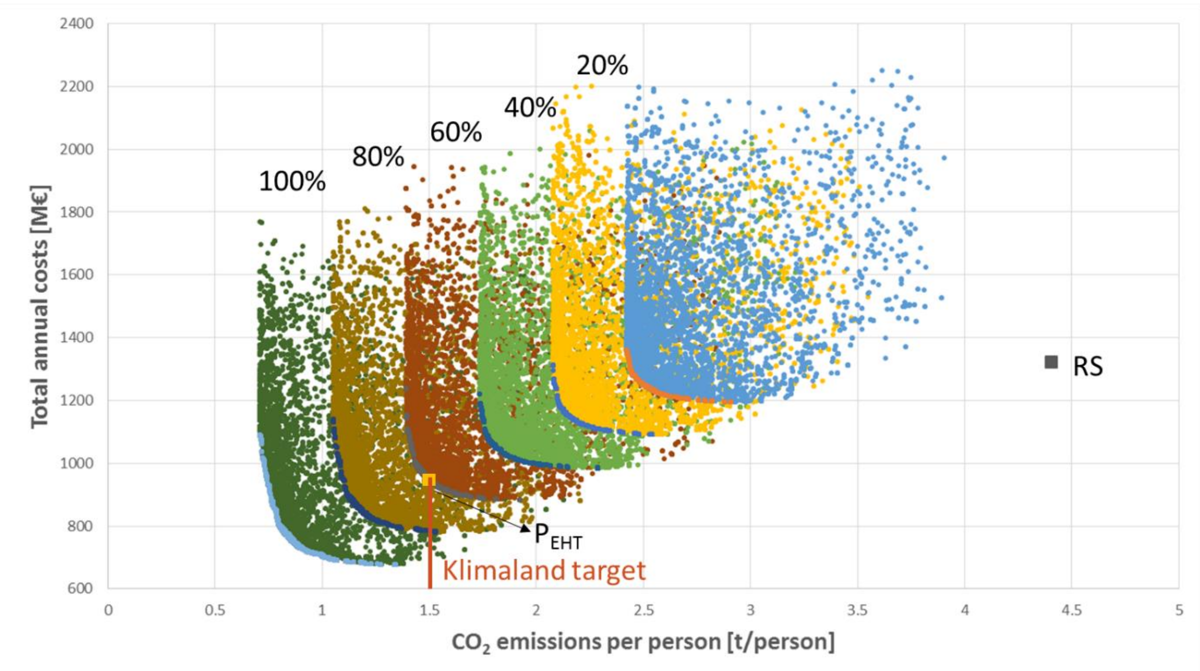


Figure 21 Pareto fronts with different levels of penetration percentage of zero emission transport on the overall kilometers covered in the transportation sector.

Figure 22 shows the hourly electricity production in winter and summer for P_{EHT} scenario. It is possible to notice the increase of the electricity demand due to electric transport in summer is mostly during the night. This is because a night-charge curve has been chosen for the electric transports. In winter this effect coupled to heat pumps which usually have to cover the peaks during the day produce an higher and constant increase of the electricity demand. Figure 23 shows the annual electricity balance and the increase of electricity demand due to heat pumps and electric vehicles. It has to be noticed that although more than 50% of overall transport km is shifted to electric transport and a substantial application of electrical driven heat pumps are present in the scenario, the increase o the electricity consumption is limited to 26.7% of the overall demand.

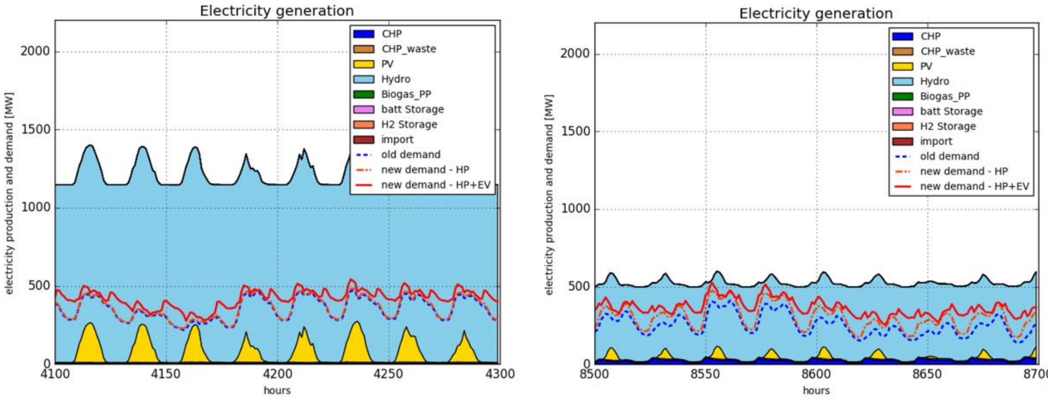


Figure 22 P_{EHT} scenario. Hourly electricity production of a week in June (from 4100 to 4300) and of a week in December (from 8500 to 8700).

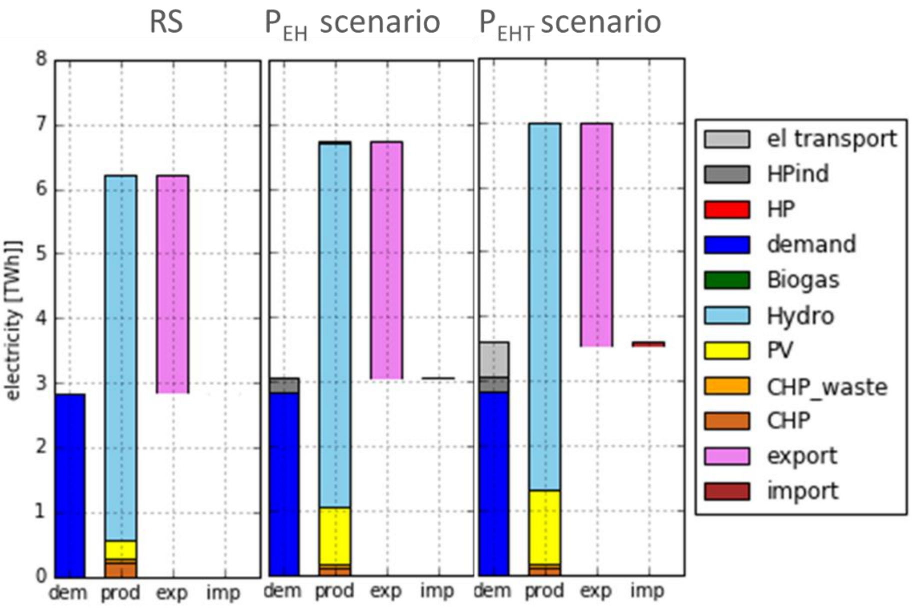


Figure 23 Annual electricity balance, comparison between the reference scenario and the P_{EHT} scenario.

Figure 24 shows the hourly heat production within the district heating network in the two weeks taken as reference for the P_{EHT} scenario.

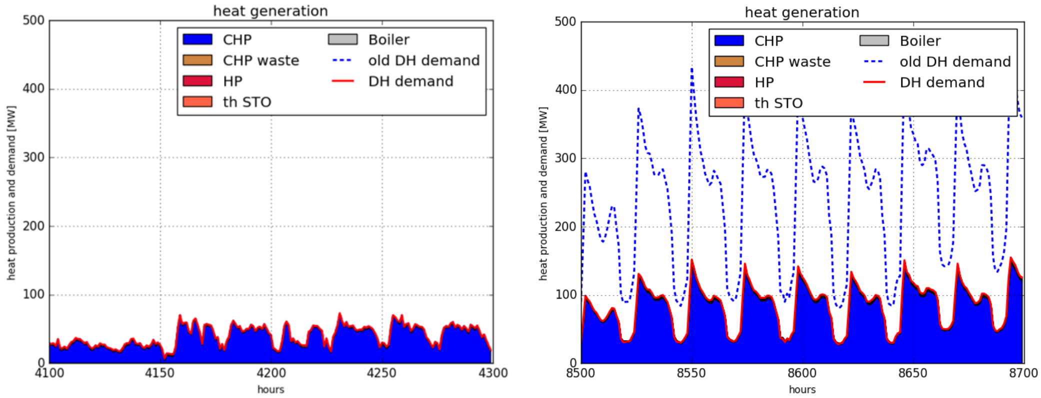


Figure 24 P_{EHT} scenario. Hourly heat production in the district heating network of a week in June (from 4100 to 4300) and of a week in December (from 8500 to 8700).

Figure 25 shows the comparison between the overall energy demand and distribution among the three sectors of the energy system between the reference scenario, the P_{EH} and the P_{EHT} scenario. In this case also the transport sector fuel consumption decrease and the demand shift on the electricity sector. The result is a larger share of electricity consumption and a lower overall energy consumption. The decrease in the overall energy demand is mainly due to deep energy efficiency and higher efficiency of electric vehicles.

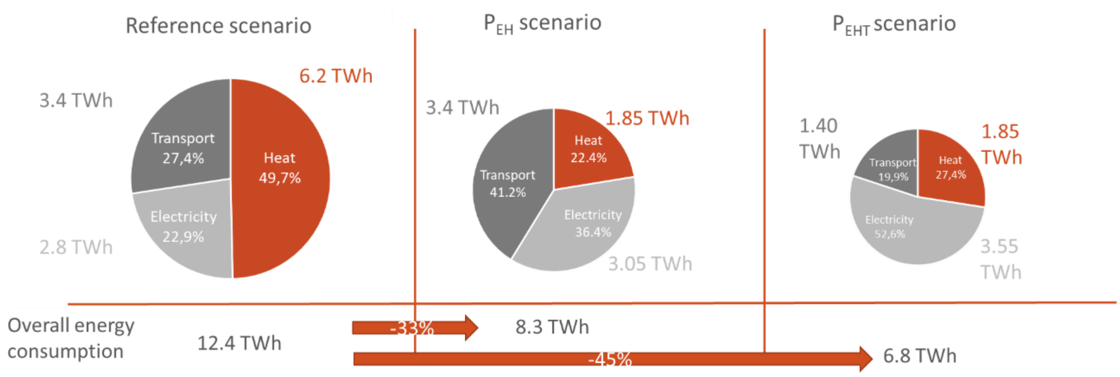


Figure 25 Comparison of the overall energy consumption between the reference scenario, the P_{EH} and the P_{EHT} scenario.

Figure 26 shows the comparison between the total annual costs of the reference scenario and the P_{EHT} scenario. The overall costs decrease for P_{EHT} scenario mainly due to the decrease of the costs connected to fuel consumption.

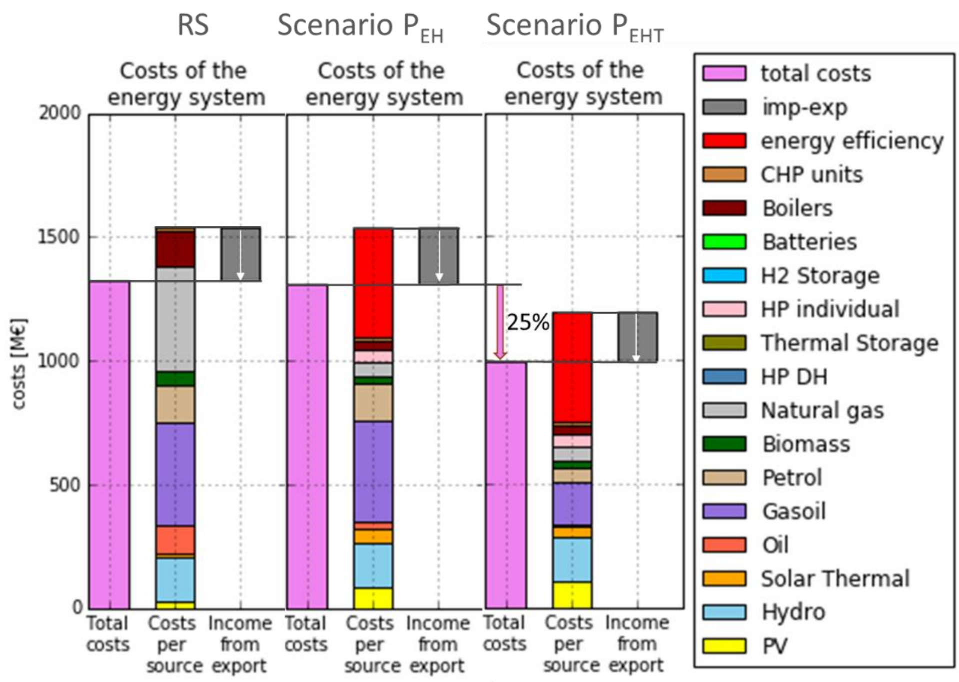


Figure 26 Comparison between the total annual costs of the reference scenario and the optimized scenarios.

Regarding financial results, it is important to underline how the nature of the total annual costs changes from the reference scenario to the P_{EHT} scenario. While in the reference scenario the majority of the costs regards fuel costs, in the P_{EHT} scenario the share of fuel costs decreases and increase the investments on the territory such as local investment, operation and maintenance interventions and costs due to energy efficiency measures, see figure 27.

As can be seen, following this simplified calculation approach, the annual share of financial resources spend in the territory increase from around 220 million €/year nearly 700 million €/year. There are out of question many details to argue and discuss about in the presented financial figures. But even if imprecise it gives a feeling of how important the impact of such a development can be for a regional economic development.

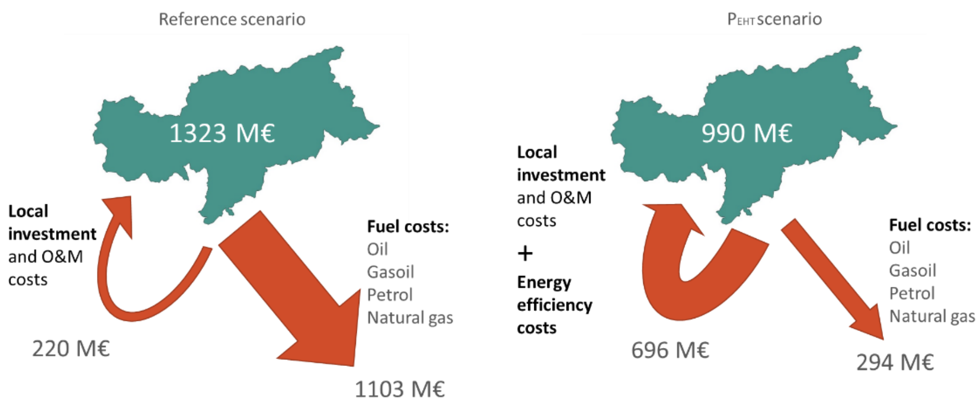


Figure 27 Comparison between typology of total annual costs of the reference scenario and the P_{EHT} scenario.

7 The use of distributed storage systems and the role of prosumers

EnergyPLAN philosophy is to model the energy system from an aggregated perspective from the point of view of an omniscient decision maker. The electric storage installed capacity is then considered as storage in support of the grid. This approach does not catch the prosumers behavior and the distributed generation benefits. The installation of photovoltaics system coupled to batteries, under certain regulation of the electricity market, could be an advantage for the prosumers and the owner of single family house. The installation of the package PV and battery produce a benefit also at regional level with a PV production flattened by the use of distributed storage. In this case also the need for electric storage of the grid is reduced with a consequent reduction of the total annual costs of the energy system. Figure 29 shows the production profile of photovoltaics when coupled to a battery for residential applications. At first, the best size of battery capacity coupled to a rooftop residential 3 kWp PV system has been inspected (Figure 28). A 4 kWh lithium-ion battery has resulted as the best size in order to maximize the self-consumption and minimize the pay back time of the whole system, PV and battery.

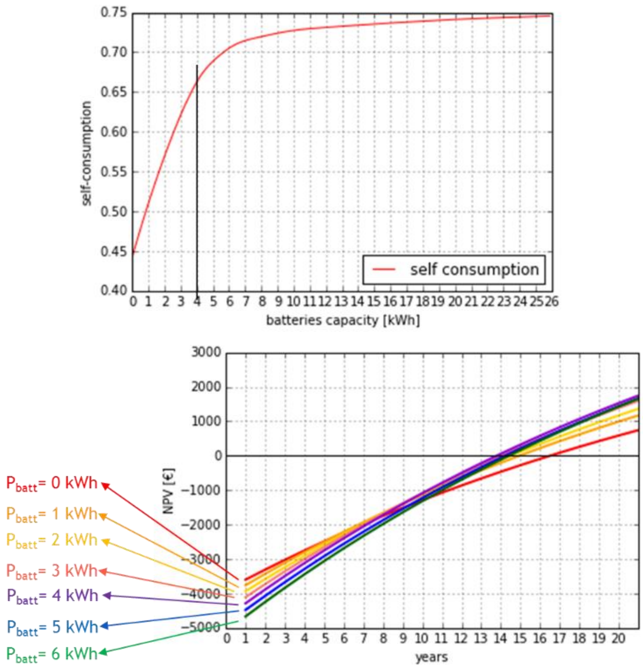


Figure 28 Sizing of the best battery capacity coupled to a rooftop residential 3 kWp PV system.

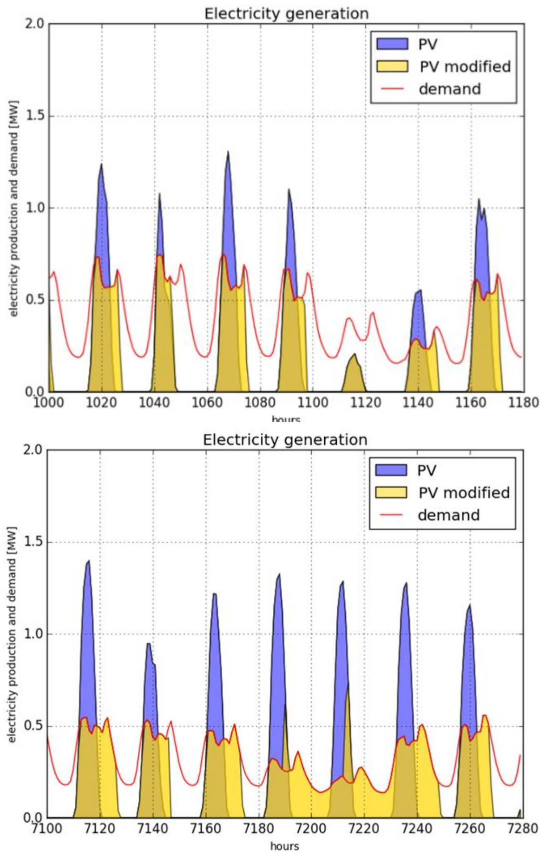


Figure 29 Sizing of the best battery capacity coupled to a rooftop residential 3 kWp PV system and the final production profile.

8 Conclusions

A methodology coupling multi-objective optimization and the energy system simulation software energyPLAN has been developed through the creation of the EPLANopt model. The final scope of this methodology is to find the best configurations of the energy system according to n different objectives. The indicators that are usually chosen as optimization objectives are: total annual costs, CO_2 emissions and percentage of renewables in the system. The EPLANopt model has been applied on the South Tyrol energy system in order to analyze the best option for the energy system following the klimaland guidelines. The South Tyrol energy system is characterized by a large electricity production from hydroelectric plants that at the current stage is exported. Thus the main options for the future energy system regards the shift of part of the heat and transport demand on the electricity sector. The final scenario, characterized by 60% penetration percentage of zero emission transport, has shown that an energy system with lower CO_2 emissions and higher percentage of renewables is possible without increasing the total annual costs. It has also shown that, analyzing the features of the total annual costs, the nature of the costs changes from high external expenses for fossil fuels to very relevant investments on the territory year over year.

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