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REEL Demo – Romande Energie ELectric network in local balance Demonstrator

Deliverable: 5d1 Development of Future District Scenarios and Definition of Modeling Cases

Demo site: Rolle

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Contents

1 Introduction

1.1 Context

In the optic of a successful energy transition initiated by the Swiss government and approved by the population in May 2017, the extensive integration of renewable energy sources into the evolving electrical infrastructure constitutes an essential milestone. However, matching supply and demand in a stochastic context requires innovative solutions both at the technical and planning levels.

In parallel, the use of a multi-energetic approach, where complex energetic systems interact with heat and electric grids, showed that an insight into more efficient and even autonomous systems is possible. In particular, buildings systems controlled by Smart Energy Management (SEM) strategies developed using Model Predictive Control (MPC) proved to be able to provide flexibility to the grid and thus to increase renewable energy integration [MP1, MP8]. Furthermore, parametric optimization based on multi-parametric mixed-integer linear programming model have proven to be efficient tools for strategic urban planning including multi-energy systems [MP4].

This activity aims at providing guidelines to the multi-energy-systems (MES) planning in order to assess the network flexibility provision as well as integrating renewable energy resources while maintaining safe grid operation.

1.2 Deliverable description

In the optic of providing guidelines for the optimal integration of renewable energy in a connected multi-energy context, this report presents EPFL - IPESE and EPFL - PV-lab's common work on the initial assessment of Romande Energie (RE) demonstration site.

To do so, a building and electrical grid-centered approach was selected, capitalizing on the laboratories research knowledge [MP5, MP6] and on existing databases existing for the built and electrical environment.

In a first phase (section 2), a contextualization of the demonstrator is done by introducing the challenges to be tackled within the Swiss household sector for the energy transition.

The second phase of the deliverable (section 3) focuses on gathering and compiling information on the RE demonstration site from various databases. The data heterogeneity is tackled by the development of a tool allowing to automatize this approach and therefore provide a basis for a generalization of the approach at the Swiss scale.

Based on these informations, the third phase (section 4) provides an assessment of the demonstration site according to various factors, such as: diversity, impact and potential, on three different axis: buildings, thermal energy and electricity. Indicators computed on actual data are defined, such as the diversity indicator, to allow performance quantification.

Based on these indicators, the fourth phase (section 5) aims at selecting subsystems as well as defining scenarios that will serve as basis for the upcoming optimization. Using a weighted decision matrix, a selection of subsystems bounded by the corresponding low-voltage grid are compared, and the most promising technologies identified for these subsystems are chosen in order to generate scenarios.

During the fifth phase (section 6) and for each of these selected subsystems, an optimization combined with an extrapolation is performed in order to assess the potential bottleneck of renewable energy integration.

Finally, the sixth phase (section 7) provides insight into the future developments of the proposed methodology in the optic of providing actual guidelines for the planning of multi-energy systems.

1.3 Achievement of Deliverable

1.3.1 Date

This deliverable is handed, as planned, in December 2017.

1.3.2 Demonstration of the Deliverable

The deliverable is based on published papers presenting the methodology, actual data provided both by the industrial partner and Swiss databases as well as new scientific developments based on previous research works of the participating laboratories.

1.4 Impact

This project has been an opportunity for an extensive knowledge sharing between the various researchers and industrial partners, thus allowing different viewpoints to positively interact in order to provide a coherent vision of the future Swiss multi-energy infrastructure.

Main Publications

[MP1] Araz Ashouri, Paul Stadler, and François Maréchal. Day-ahead promised load as alternative to real-time pricing. In *Smart Grid Communications (SmartGridComm), 2015 IEEE International Conference on*, pages 551–556. IEEE, 2015.

[MP2] Yannick Riesen, Christophe Ballif, and Nicolas Wyrsch. Control algorithm for a residential photovoltaic system with storage. *Applied Energy*, 202, May 2017.

[MP3] Yannick Riesen, Pengcheng Ding, Samuel Monnier, Nicolas Wyrsch, and Christophe Ballif. Peak shaving capability of household grid-connected PV-system with local storage: A case study. In *28th European Photovoltaic Solar Energy Conference, Paris*, 2013.

[MP4] Nils Schüler, Sébastien Cajot, Markus Peter, Jessen Page, and François Maréchal. The optimum is not the goal: Capturing the decision space for the planning of new neighborhoods. *Frontiers in Built Environment - Urban Science*, 2017.

[MP5] Paul Stadler, Araz Ashouri, and François Maréchal. Distributed model predictive control of energy systems in microgrids. In *Systems Conference (SysCon), 2016 Annual IEEE*, pages 1–6. IEEE, 2016.

[MP6] Paul Stadler, Araz Ashouri, and François Maréchal. Model-based optimization of distributed and renewable energy systems in buildings. *Energy and Buildings*, 120:103–113, May 2016.

[MP7] Paul Stadler, Luc Girardin, , Araz Ashouri, and François Marechal. Contribution of model predictive control in the integration of renewable energy sources within the built environment. *In submission*, 2017.

[MP8] Paul Stadler, Luc Girardin, and François Maréchal. The Swiss Potential of Model Predictive Control for Building Energy Systems. In *The 7th IEEE International Conference on Innovative Smart Grid Technologies (ISGT Europe)*, Turin, 2017.

2 Household sector challenges towards Swiss energy transition in a multi-energy context

The Swiss energy transition, initiated by the adoption by the Swiss population of the energy strategy 2050 in May 2017, aims at three different strategic objectives. Indeed, providing measures to increase energy efficiency and renewable energy use as well as to withdraw from nuclear energy are the main objectives. The latter set challenges for various sectors, such as buildings, mobility, industry or appliances [7]. As of 2015, the actual Swiss final energy consumption remains highly based on fossil fuels with a share of 51% for households, industry and mobility sectors [4], as illustrated in Figure 1. Furthermore, in terms of electricity generation, putting aside hydropower which is responsible of 74.9% of the Swiss electricity generation, other renewable energy sources represent only 2.8% of the Swiss electrical mix.

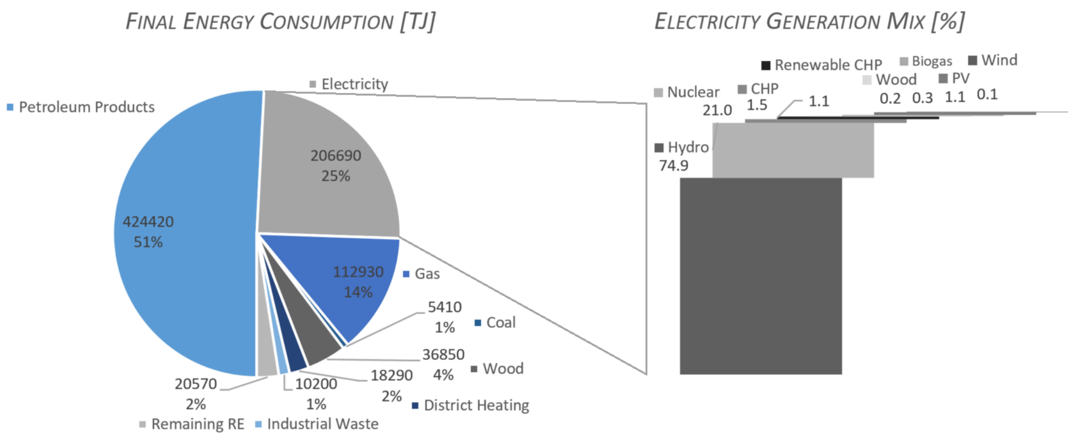


Figure 1: Swiss final energy consumption and electricity generation mix in 2015 [4]

Nevertheless, PV installations have been flourishing over the past years, as illustrated in Figure 2. Indeed, since 2008 in Switzerland, the yearly production has been increased by a factor 30 and PV generation represented 67.6% of the total renewable energy share (hydropower excluded) [4].

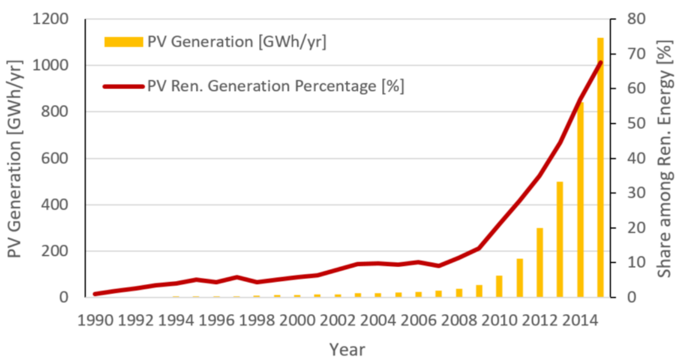


Figure 2: Photovoltaic electricity generation and its share amongst renewable energy [4]

The photovoltaic growth as a part of the energy transition induces a change in the way energy is produced, distributed and stored. Indeed, the lack of flexibility of electricity as a media as well as the shift from a centralized and predictable to decentralized and stochastic renewable-energy-based electricity generation create issues to match supply and demand while requiring efforts for an effective and safe grid operation.

This need for flexibility can be partially met by the introduction of smart systems into the grid or by the design of demand response programs. Among them, MPC-based building EMS have been highlighted as a multi-energy solution to generate an equivalent battery capacity of 0.33 and 8.7 GWh depending on the capital expenses [MP8]. Furthermore, users behavior can be influenced by incentives to provide additional flexibility to the system [8, 6]. These new elements have to be included in the existing Swiss infrastructure by the mean of smart-metering systems [7], considering both fossil-fuel-based systems and renewable energy sources through a multi-energy approach.

In the context of fossil-fuel reduction, smart-systems and extensive stochastic renewable energy sources (RES) integration such as PV generation, buildings, as being one of the selected axis to contribute to the energy transition, will constitute a center of investment for companies, individuals and collectivities through building-centered government incentives [7]. Therefore, an applied methodology of multi-energy systems planning with renewable energy integration is needed. The project aims at combining knowledge of different research institutes and industrial partners in order to provide a methodology and a tool for optimal planning of multi-energy systems while integrating renewable energy, in the optic of the Swiss energy transition.

3 Information Gathering and Compilation

3.1 Collection methodology and Type of Data

In a first phase, data coming from different sources have been collected and compiled in order to provide a solid basis for the planning of multi-energy systems. To guarantee an adaptive and long-lasting methodology/tool, the following criteria have been applied:

- For multi-energy systems planning, the type of data must include electrical and thermal aspects. Furthermore, environmental data is included to serve as a basis for renewable-energy-related computations.
- The need for a real context induces a focus on actual data and not simulated ones. In particular, the Rolle district, i.e. the location of Romande Énergie demonstrator, is considered as the reference case.
- As a matter of scalability, the approach should be applicable to other districts within Switzerland. Therefore, besides Rolle, data available for the entire Swiss territory are preferred.
- In order to generate easily data for another context, data compilation should be automated in a flexible tool.
- Due to the variation rate of building energy systems during the past 10 years (see Figure 2 for the PV case), synchronized and up-to-date data are preferred

According to these highlighted criteria, the following data were selected:

- The *Cadastre*, to obtain actual and clearly defined buildings footprints.
- The *Cantonal Buildings Registry (RCB)*, to obtain buildings data such as construction date, purpose and installed energy systems.
- *SwissBuildings3D*, to have a 3D representation of the buildings considered.
- *Solar roofs*, to have the detailed solar potential for each roof
- The *electrical grid*, to have the actual grid topology for upcoming grid simulation.
- *Linked Objects Group (GOR)*, to have the links between object groups and the corresponding spotloads.
- The *spotloads yearly consumption*, to obtain information on the actual electricity consumption
- *SwissTLM3D*, to obtain information on man-built and natural elements, such as streets, water resources and other natural elements.
- *SwissALTI^{3D}*, to have the elevation model of the district considered.
- *Meteo*, for renewable energy sources and building energy consumption computation.

The selected data and its main parameters are summarized in Table 1:

Category	Designation Name	Supplier	Format	Scope Spatial	Scope Temporal
Buildings	Cadastre	ASIT VD	.shp	Rolle surroundings[1]	April 2017
	Cantonal Buildings Registry (RCB)	ASIT VD	.shp	Rolle surroundings[1]	April 2017
	SwissBuildings3D	SwissTopo	.shp	Rolle surroundings[1]	April 2017
	Solar roofs	SwissTopo/MétéoSuisse	.gdb	Rolle surroundings[1]	April 2017
Grid	Electrical grid	RE[2]	.xlsx	Rolle supply area	Mid-year 2016
	Linked Objects Group (GOR)	RE[2]	.xlsx/.dxf	Rolle supply area	June 2017
	Spotload yearly consumption	RE[2]	.xlsx/.dxf	Rolle supply area	Mid-year 2016
Environment	SwissTLM3D	SwissTopo	.shp	Rolle surroundings[1]	April 2017
	SwissALTI^{3D}	SwissTopo	.tif	Rolle surroundings[1]	April 2017
Meteo	Meteo	MeteoSwiss	.csv	Changins[3]	Year 2016

Table 1: Main parameters of the selected data

[1]Communities of Rolle, Perroy, Mont-sur-Rolle, Bougy-Villars, Essertines-sur-Rolle, Tartegnin, Gilly and Bursinel.
[2]Industrial partner *Romande Énergie*
[3]Nearest MeteoSwiss automated measure station.

3.2 Data Completeness Assessment

> REMARK:
> The main assumption on data for the next computations is their correctness. Indeed, as they are coming from verified and up-to-date databases, they are assumed to be correct and representative of the current situation. On-the-field verification are beyond the scope of this project.

The databases can however present incomplete data due to the inclusion of elements of different time periods. To assess the completeness of the selected data and ensure the consistency of our results, the completeness indicator CI_i for the i^{th} criterion is computed as follow:

$$CI_i = 1 - \frac{N_{i,incomplete}}{N_{i,total}} \tag{1}$$

In equation 1, $N_{i,incomplete}$ is the number of incomplete data points and $N_{i,total}$ the total number of data points for the criterion considered.

The criteria assessed are coherent with the ones selected in the upcoming chapter 4, i.e. : *Age*, *Reference Energetic Surface (SRE)*, *Purpose*, *Heating System*, *Average Thermal Power Consumption* and *Solar Potential*. Their corresponding completeness indicator are detailed in Figure 3:

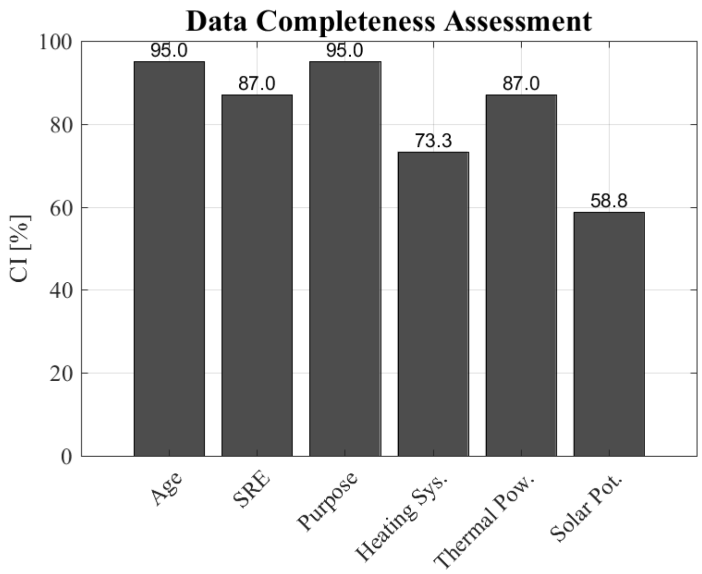


Figure 3: Completeness indicator for the selected criteria

All criteria exhibit a completeness of more than 87.0% except for the heating systems (73.3%) as well as for the solar potential (58.8%). A significant number of roofs from the solarRoof database haven't any building ID (EGID) explaining this low result of the solar potential completeness. Although completeness has been assessed for most criteria, incomplete data has to be taken into account during result interpretation and reference low voltage grids selection, as detailed in section 4.

4 Multi-energy District Assessment

4.1 General Considerations

Having collected the data in section 3, an automated python-based Geographical Information System (GIS) tool was developed that allows to compile the data into one geolocalized database including all the relevant elements for the upcoming optimization. This flexible tool further allows to perform computation directly using the database, and launch other tools previously developed, therefore capitalizing on the previously acquired knowledge.

This GIS and building centered approach, successfully applied to western Switzerland cases by EPFL-IPESE [5], is justified by the extensive databases available, as detailed in section 3. The electrical grid component however, represents an innovation in the field and therefore contributes to the project research objectives. Therefore, buildings are considered as base items connected between themselves by the electrical grid and its medium and low-voltage components.

As optimization of energy systems is highlighted as a computationally demanding task, clustering has been proven to be an accurate and effective way to reduce computation time while maintaining results quality [MP6][3]. Due practical constraints as well as the need for a practical application to a low voltage grid, predefined geographical clusters corresponding to the low-voltage (LV) grids of the Rolle supply area were considered, as illustrated in Figure 4 (limited to the Rolle community limits for display purposes):

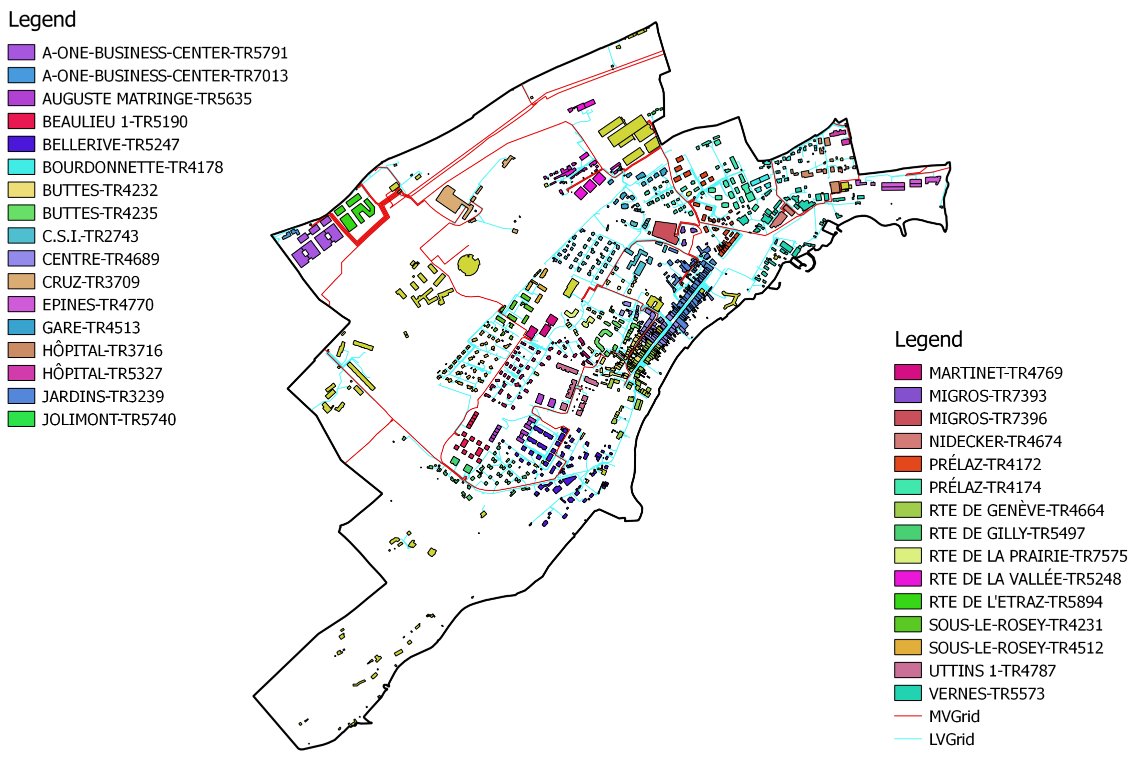


Figure 4: Localization of buildings unit elements according to their LV transformer

Each LV grid was then assessed according to multi-energy criteria applied for each building unit element and then aggregated per LV transformer. The criteria were defined according to the three main axis highlighted in section 1: buildings, thermal energy and electricity. The most relevant criteria were selected both based on EPFL-IPESE knowledge of buildings energy systems assessment [5] as well as EPFL-PV-lab PV potential assessment knowledge. Therefore, the selected criteria were:

- For buildings:
  - *Age*

- *Reference Energetic Surface (SRE)*
- *Purpose*

- For thermal energy:
  - *Heating System*
  - *Average Thermal Power Consumption*
- For electricity
  - *Solar Potential*

4.2 Criterion Definition and Assessment

4.2.1 Building: Age Criterion

The building age is defined as the current date minus the construction date or the last renovation date. As an assumption, renovation date was considered predominant over construction date.

For each LV grid, a boxplot of the building unit elements is drawn, and the diversity criterion is assessed by ranking the various transformers by the inter-quartile range. Outliers, representing isolated values from the main building set, are therefore not taken into account. The resulting ranking is presented in Figure 5:

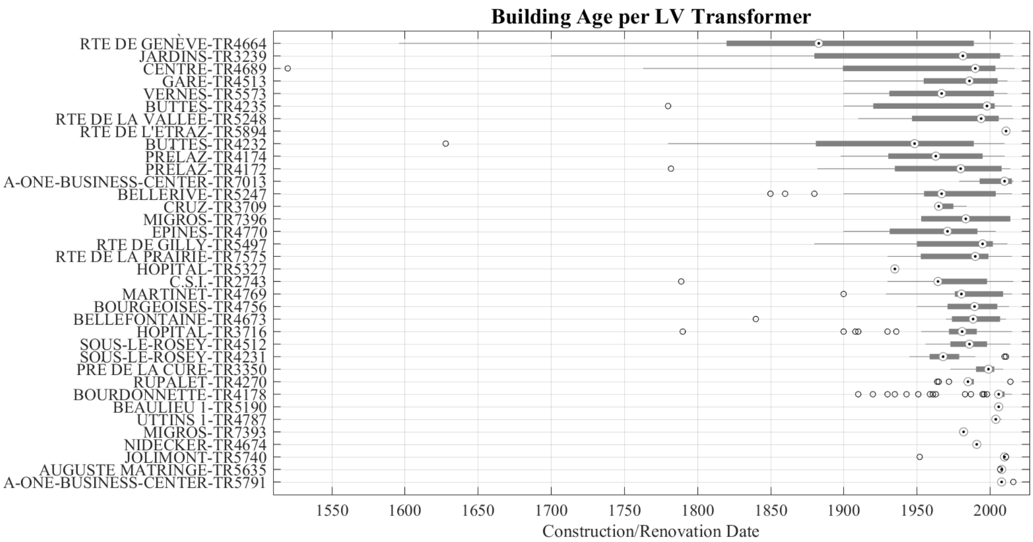


Figure 5: Ranked boxplots of the building age criterion

4.2.2 Building: Reference Energetic Surface (SRE) Criterion

The building reference energetic surface is defined as the surface that characterize the heating and cooling needs. Assuming that the useful area A_{use} or the ground area A_{gnd} as well as the building height h is known, the SRE is computed as:

$$SRE = A_{use} \cdot N_{floor,av} \approx A_{gnd} \cdot \frac{h}{h_{floor,av}} \tag{2}$$

In equation 2, the average number of floor $N_{floor,av}$ (not necessarily an integer) is computed using the average floor height for the considered district $h_{floor,av}$. In special cases, some data might or might not be available. In that case, a complete decision diagram for SRE computation is presented in [5].

Similarly to the age criterion, the SRE criterion is assessed by ranking the interquartile range of the corresponding boxplots, as illustrated in Figure 6:

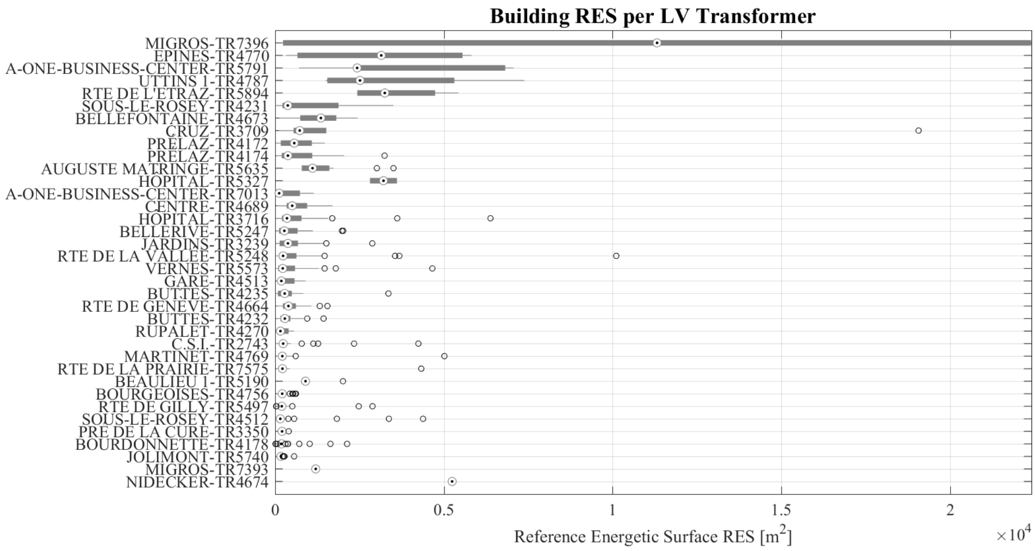


Figure 6: Ranked boxplots of the building SRE criterion

4.2.3 Building: Purpose Criterion

The purpose criterion is linked to the eight building purpose categories identified through EPFL-IPESE previous works [5]: *Residential*, *Administrative*, *Commercial*, *Industrial*, *Education*, *Health-care*, *Tourism* and *Others*.

Due to the enumeration nature of the purpose criterion, the *Mix Indicator (MI)* was developed in order to properly rank the LV grids according to the purpose mix. This indicator is defined as:

$$MI = \frac{n}{n-1}\left[\prod_{i=1}^{n} 1 - \frac{x_i}{\sum_{j=1}^{n} x_j}\right]^{\frac{1}{n}} \tag{3}$$

In equation 3, n is the number of sample categories, x_i the number/weight of samples belonging to the i^{th} category. The mixity indicator is bounded between 0 and 1, and is maximum when all the weights are equal. Indeed, using the inequality of arithmetic and geometric means (AGM) [1], and the fact that the equality is achieved when all numbers/weights are equal, one gets:

$$0 \leq MI \leq \max(MI) = \frac{n}{n-1} \max\left[\prod_{i=1}^{n} 1 - \frac{x_i}{\sum_{j=1}^{n} x_j}\right]^{\frac{1}{n}} \overset{\text{AGM}}{=} \frac{n}{n-1} \cdot \frac{1}{n} \sum_{i=1}^{n} \left(\frac{n-1}{n}\right) = 1 \tag{4}$$

The purpose mix assessment is therefore done using the above-defined indicator, however for display purposes the Figure 7 is ordered according to the total SRE per LV transformer. Detailed mix assessment can be found in section 5.2:

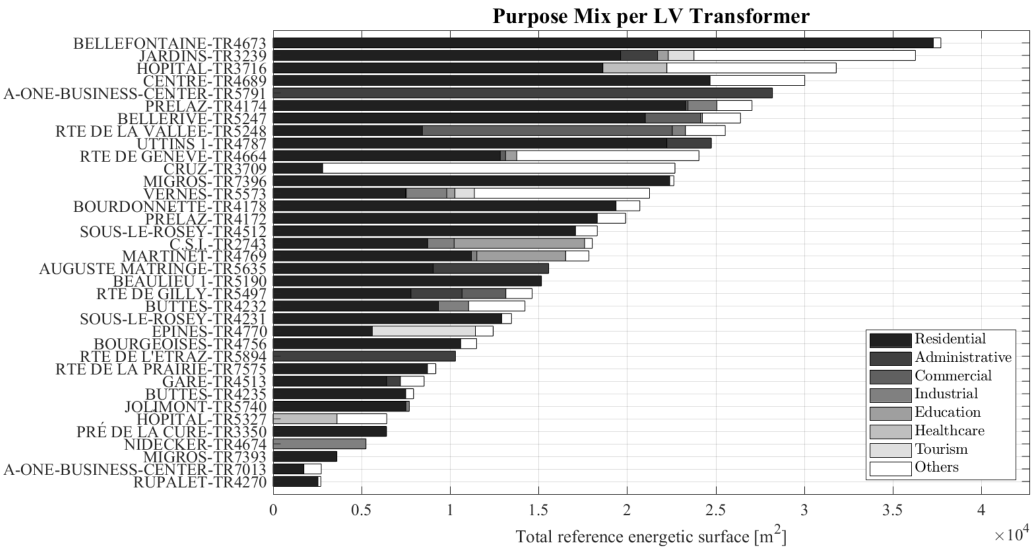


Figure 7: Bar plot of building purposes

4.2.4 Thermal Energy: Heating System Criterion

The heating system mix refers to the variability in a defined LV grid of the installed heating systems. The data collected allows to define a series of 9 heating system types: *Heating Oil*, *Gas*, *Coal*, *Wood*, *Electricity*, *Heat Pump*, *District Heating*, *Other*, *Void*.

The variability within a given LV grid is assessed using the same mix indicator as defined for the purpose criterion. The distribution, ordered by total SRE, is illustrated in Figure 8:

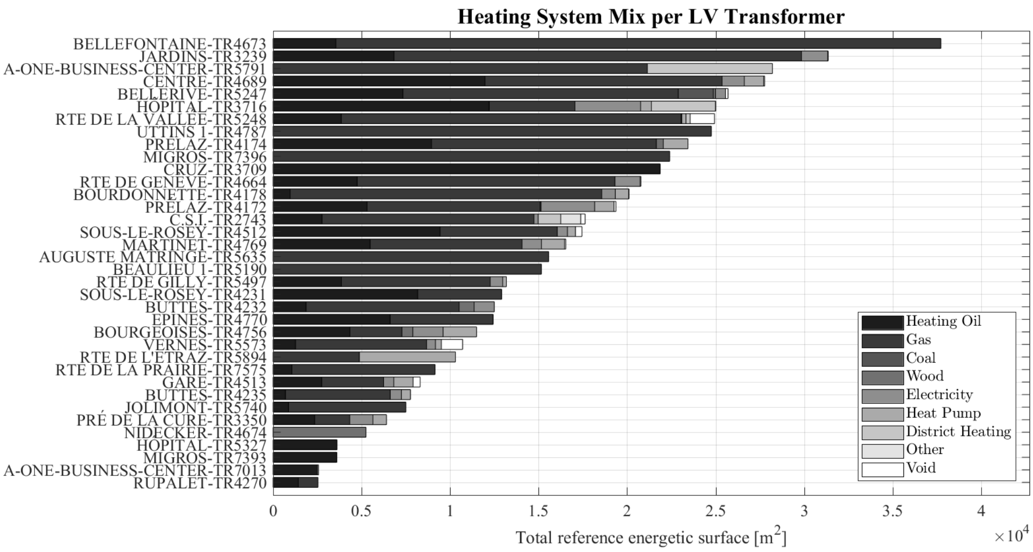


Figure 8: Bar plot of the building heating systems

4.2.5 Thermal Energy: Thermal Power Consumption Criterion

The thermal power demand of building and districts has been previously assessed for parts of western Switzerland in former EPFL-IPESE developments [5]. Capitalizing on these research elements, the average building heating/cooling demand $\dot{q}^s$ is defined as follow:

$$\dot{q}^s\left(T_x\right) = \begin{cases} k_1^s \cdot T_x + k_2^s & \text{If } T_x < T_{tr}^{sh} \text{ and } s := sh \\ k_1^s \cdot T_x + k_2^s & \text{If } T_x > T_{tr}^{sc} \text{ and } s := sc \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

In equation 5, k_1^s is the specific global heat loss coefficient for the considered building, k_2^s is the energy signature model second parameter, T_x is the outside temperature and T_{tr}^{sh} is the threshold temperature at which the heating (sh) or cooling (sc) system is turned on. Due to the lack of data concerning the heat demand of the considered area, those parameters were taken according to the data obtained for the Geneva area under a geographic similarity assumption [5].

The ranking is then assessed for a LV grid by a SRE-weighted sum of all thermal powers and given in section 5.2. For a graphical interpretation, normalized heating power requirements per building for the Rolle community are displayed in Figure 9, where the historical city center and other aged buildings are highlighted by their higher power requirements.

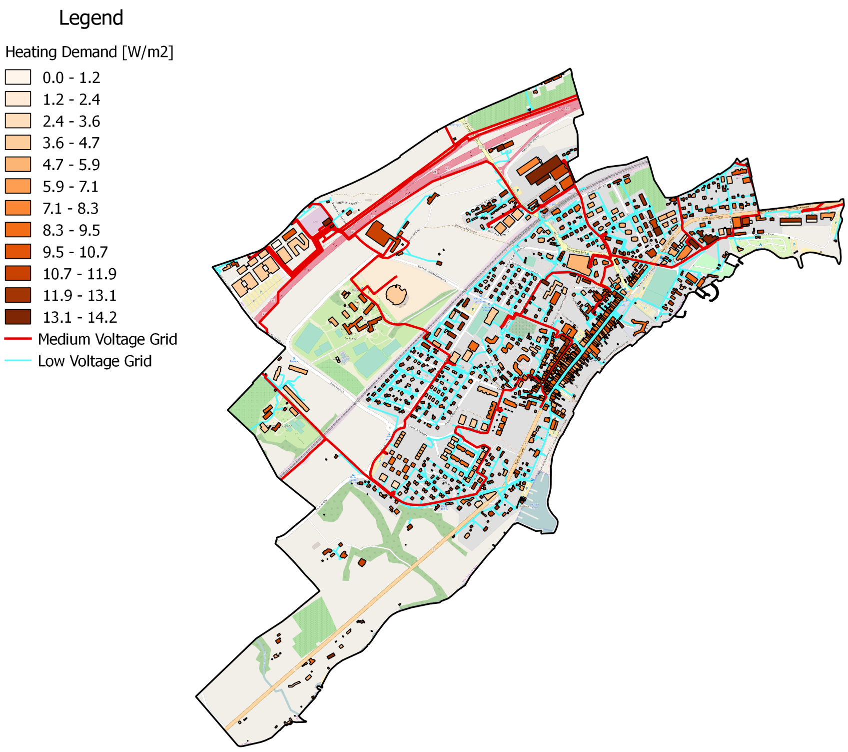


Figure 9: GIS visualization of the buildings normalized heating power requirements

4.2.6 Electricity: Solar Potential Criterion

For each low voltage grid, the solar potential has been calculated as the annual photovoltaic production using all available roofs. In the data used from the solar roof project, the pv production of each roof is defined as the mean annual irradiance taking account shading, times the roof area, module efficiency (17%) and a performance ratio of 80%. The links between roofs, buildings and grid is then used to obtain the solar potential per low voltage grid shown in figure 10. A GIS visualization of the mean annual irradiance per roof for a sample of the Rolle district is shown in figure 11.

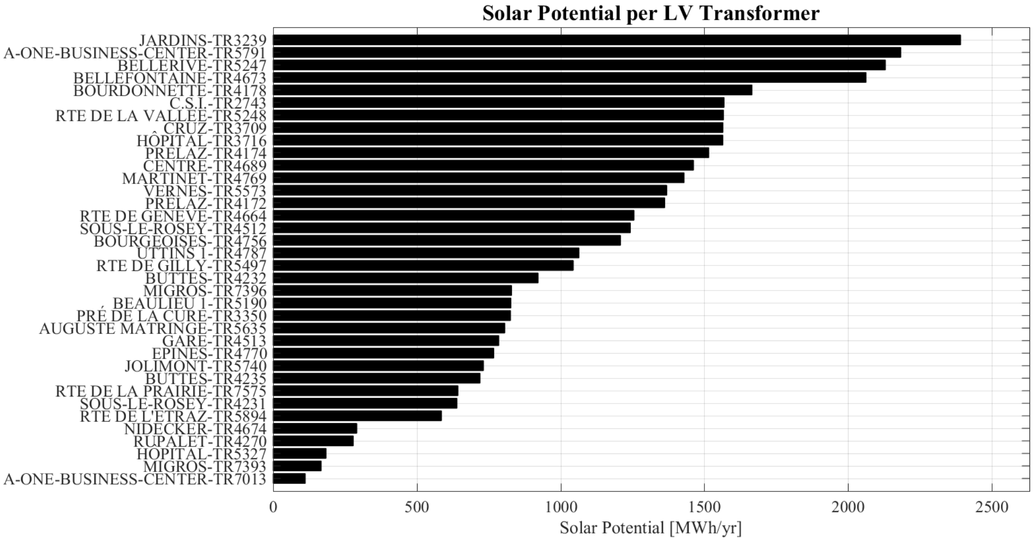


Figure 10: Bar plots of the building solar potentials

Figure 11: GIS visualization of the mean annual irradiance for each roof

5 Subsystems and Scenarios Definition

5.1 General Considerations

In order to provide a framework for the upcoming results and interpretations, scenarios are defined based on two aspects:

1. The subsystem considered (section 5.2), as a detailed optimization for the whole system including the electrical grid is computationally too expensive for the current method.

2. The technologies considered for the distributed energy system optimal design and operation (section 5.3).

Based on these aspects, an optimization is to be carried on for different shares of renewable energy, and its impact on the grid operation as well as the technologies are to be assessed.

5.2 Quantified Subsystem Selection

In order to quantify a selection based on various criteria, a double weighted decision matrix is defined. Indeed, each LV grid i receives a rank-based penalty $P_{i,j}$ according to its performance based on a criterion j:

$$P_{i,j} = r_{i,j} \cdot CI_j \cdot W_j \tag{6}$$

In equation 6, $r_{i,j}$ is the rank awarded, CI_j the completeness indicator and W_j a weight representing the criterion importance with respect to the project's objectives. The sum of all penalties defines a score which is increasing with the final rank of a given LV grid. The resulting double-weighted decision matrix and ranking are presented in Table 2 with the transformers ordered by alphabetic order.

Due to project practical considerations, the main industrial partner preselected 6 LV grids on which the demonstrator will be implemented. Therefore, the selection has been restricted to these subsystems (highlighted in gray in Table 2). Among them, the LV grid presenting the lowest penalty score is the one corresponding to the LV transformer *HÔPITAL-TR3716* with a final score of 118.96. Therefore, this subsystem will be considered as the reference case for the upcoming computations and optimizations.

LV Grid	Buildings			Thermal Energy		Electricity	Penalty
	Age	**SRE**	**Purpose**	**Heating Sys.**	**Thermal Pow.**	**Solar Pot.**	
A-ONE-BUSINESS-CENTER-TR5791	36	3	31	21	24	2	232.63
A-ONE-BUSINESS-CENTER-TR7013	12	13	13	28	36	36	238.87
AUGUSTE MATRINGE-TR5635	35	11	11	32	26	24	252.35
BEAULIEU 1-TR5190	30	28	32	33	21	22	326.63
BELLEFONTAINE-TR4673	23	7	29	27	2	4	206.76
BELLERIVE-TR5247	13	16	15	10	7	3	128.70
BOURDONNETTE-TR4178	29	33	23	24	18	5	255.40
BOURGEOISES-TR4756	22	29	21	1	22	17	203.48
BUTTES-TR4232	9	23	12	18	19	20	182.73
BUTTES-TR4235	6	21	25	22	28	28	241.34
C.S.I.-TR2743	20	25	3	16	15	6	148.90
CENTRE-TR4689	3	14	16	7	4	11	113.96
CRUZ-TR3709	14	8	18	31	8	8	181.10
EPINES-TR4770	16	2	4	12	6	26	122.74
GARE-TR4513	4	20	14	3	27	25	156.50
HÔPITAL-TR3716	24	15	7	4	3	9	118.96
HÔPITAL-TR5327	19	12	9	35	29	34	244.81
JARDINS-TR3239	2	17	5	20	1	1	94.26
JOLIMONT-TR5740	34	34	28	25	31	27	333.19
MARTINET-TR4769	21	26	10	6	16	12	161.96
MIGROS-TR7393	32	35	36	36	33	35	393.98
MIGROS-TR7396	15	1	30	30	17	21	233.58
NIDECKER-TR4674	33	36	35	34	34	32	385.95
PRÉ DE LA CURE-TR3350	27	32	34	2	30	23	275.01
PRÉLAZ-TR4172	11	9	20	5	13	14	140.59
PRÉLAZ-TR4174	10	10	17	9	5	10	126.66
RTE DE GENÈVE-TR4664	1	22	8	19	10	15	139.93
RTE DE GILLY-TR5497	17	30	2	14	23	19	174.53
RTE DE LETRAZ-TR5894	8	5	33	11	32	31	224.69
RTE DE LA PRAIRIE-TR7575	18	27	26	26	25	29	285.40
RTE DE LA VALLÉE-TR5248	7	18	6	23	14	7	136.85
RUPALET-TR4270	28	24	24	13	35	33	280.65
SOUS-LE-ROSEY-TR4231	26	6	27	15	20	30	240.12
SOUS-LE-ROSEY-TR4512	25	31	22	8	12	16	220.44
UTTINS 1-TR4787	31	4	19	29	11	18	225.14
VERNES-TR5573	5	19	1	17	9	13	113.56
Completeness Indicator	0.95	0.87	0.95	0.73	0.87	0.59	
Criteria Weight	2	2	3	3	1	3	

Table 2: Double-weighted decision matrix for the subsystem selection

5.3 Building Multi-Energy Technologies Selection

Based on buildings as unit items of the research approach as well as on previous works in the field of optimal design and operation of smart buildings multi-energy systems [MP1, MP6, MP7], a package of technologies is selected. Considering a building having a surface heating, domestic hot water and electricity demand, the technologies that have proven to satisfy the demand, to provide flexibility as well as to promote renewable energy integration are the following [MP6] (illustrated in Figure 12, taken from [MP6]):

- Heat pump *HP* (water-water and air-water)
- Electric heater *EH* (only for peak demand, limited in size)
- Battery *BAT*
- Hot water tank *DHW Tank*
- Surface heating tank *SH Tank*
- Solar thermal panels *TS* (not included, see below)
- Photovoltaic panels *PV*

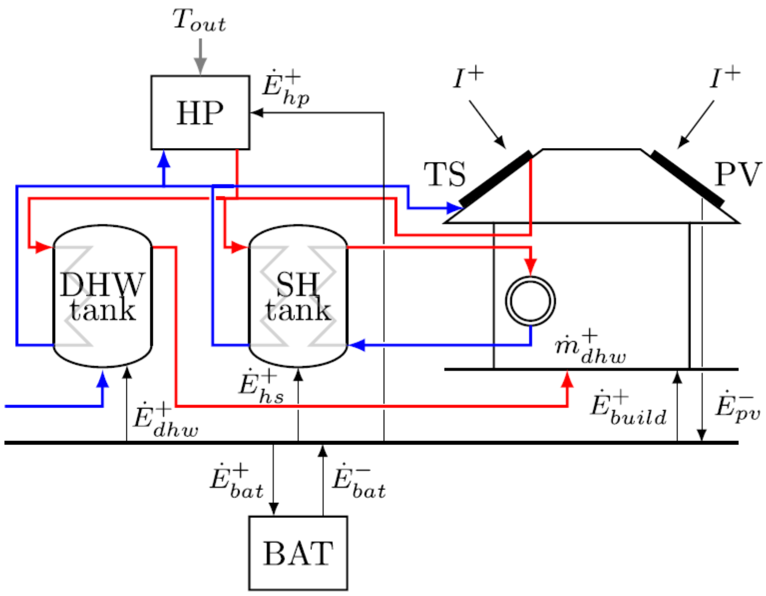


Figure 12: Technologies for the building multi-energy system

Solar thermal panels have been excluded in contrast to [MP6] due to their competition with the PV panels, as well as due to the electricity-centered interest of the main industrial partner.*Solar thermal panels* are also becoming less attractive in terms of costs and energy efficiency compared to a solution including *PV* and *HP*. Furthermore, a non-renewable-energy-based *natural gas boiler has been included* in order to represent an alternative to the fully electricity-centered approach illustrated in Figure 12.

Inside this framework, several scenarios are defined based on the renewable energy integration. Indeed, renewable energy share is introduced as an optimization problem constraint, varied between bounds representing the system capabilities. Three main cases are to be highlighted:

1. *No renewable energy share constraint*: Renewable energy share is not considered, and a cost-based approach is considered, as well as its impact on the grid.
2. *20% renewable energy share*: This is related to the cantonal constraint (Vaud) that states that 20% of the total electricity should be covered by renewable energy (purchased renewable electricity excluded) [2]. Therefore, this scenario is considered as the business-as-usual case, and its impact on the electrical grid is assessed.

3. *Maximal renewable energy share*: The renewable energy share is maximized in order to reach the district renewable energy full potential. Furthermore, the grid operation has to be considered for a successful stochastic RES integration.

The number of scenarios is to be varied according to upcoming developments:

- Research progress in the field of optimal grid design, both thermal and electrical
- Research progress in terms of building technologies
- Research progress in terms of distributed optimization
- Other stakeholders (e.g. WP2) needs and research objectives

Therefore, the scenarios described above might be extended to new variants to fully satisfy both research and industrial partners.

6 Potential Bottleneck Evaluation

6.1 General Consideration

The detailed assessment of the limit of renewable energy integration and thus the potential bottleneck of the considered district constitute a computation based on a distributed optimization of multi-energy systems, and therefore will be the subject of upcoming works (see section 7). However, an extrapolation based on preliminary results is done to assess the renewable energy potential for each LV grid.

6.2 Potential Bottleneck based on Smart Buildings Management

To assess the potential bottleneck based on the capabilities of optimally designed and operated smart buildings, a first optimization for a representative building of the selected LV grid (*HÔPITAL-TR3716*) is performed and then extrapolated for the Rolle supply area.

The single smart building case is done considering a multi-objective optimization based on both capital expenses per square meter of reference energetic surface ($CAPEX$) and renewable energy share of the energy consumption (s_{RES}), generating a Pareto front representing the trade-off between renewable energy integration and investment cost. The modeling, objectives as well as the optimization procedure are not detailled here, as they out of the scope of the current document. Insights into this method are available in [MP6, MP7]. The results are presented in Figure 13:

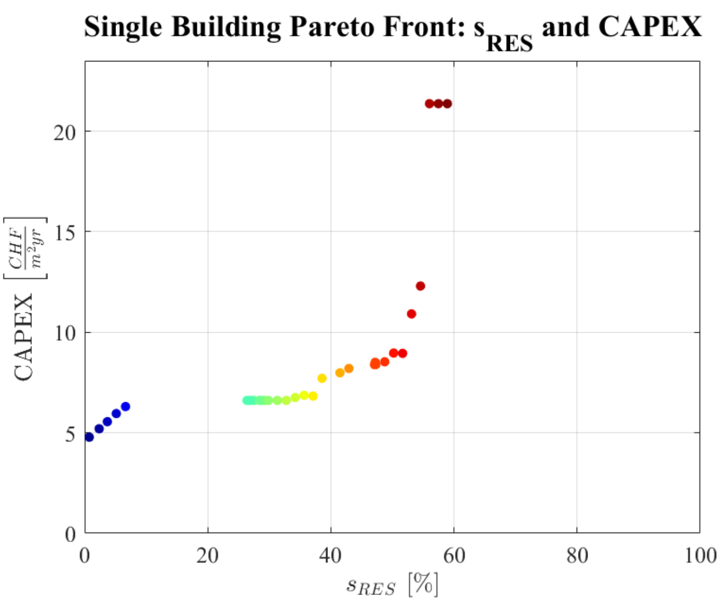


Figure 13: Single building Pareto curve for LV transformer *HÔPITAL-TR3716*

From Figure 13, the following points can be highlighted:

- The curve is clearly divided in three main parts, one for low s_{RES}/low CAPEX, another for medium/high s_{RES}/medium CAPEX and one for high s_{RES} with high CAPEX. These divisions are related to technological choices, and will be fully assessed in the upcoming works.
- The building, due to its geometry, can only reach 58.92% of renewable energy share with a normalized CAPEX of 21.37 CHF/m^2/yr. Therefore, with the technologies chosen and the optimization assumptions, achieving 100% renewable energy is not realistic for this building.
- However, a normalized capital expenditure of 8.95 CHF/m^2/yr already allows to reach a renewable energy share of 51.65 %, representing an interesting trade-off between expenditures and renewable energy integration.

Based on the computation for the considered building, an extrapolation for the preselected LV grids can be performed under the following assumptions:

1. The computation is supposed to be independent from building purpose and age.
2. The capital expenditure is supposed to be linearly related to the building reference energetic surface
3. The renewable energy share is supposed to be similar for all buildings at a given normalized capital expenditure.
4. The computed energy consumption of a given building is similar for all renewable energy integration scenarios.

These assumptions, although restrictive, allow a first assessment of the potential. Indeed, one can compute aggregated values for the total capital expenditure $CAPEX_{tot}$ and total renewable energy consumption $E_{RES,tot}$:

$$CAPEX_{tot} = CAPEX \cdot \frac{\sum_{i=1}^{N_{building}} SRE_i}{CI_{SRE}} \tag{7}$$

$$E_{RES,tot} = s_{RES} \cdot \Delta T \cdot \frac{\sum_{i=1}^{N_{building}} [(\dot{q}_{SH+HW,i} + \dot{q}_{EL,i}) \cdot SRE_i]}{CI_{energy}} \tag{8}$$

In equation 8, ΔT is the year duration, $\dot{q}_{SH+HW,i}$ the thermal power consumption for surface heating and domestic hot water preparation and $\dot{q}_{EL,i}$ the electric power consumption for services of building i. Therefore, aggregated Pareto fronts can be obtained for each LV grid as illustrated in Figure 14:

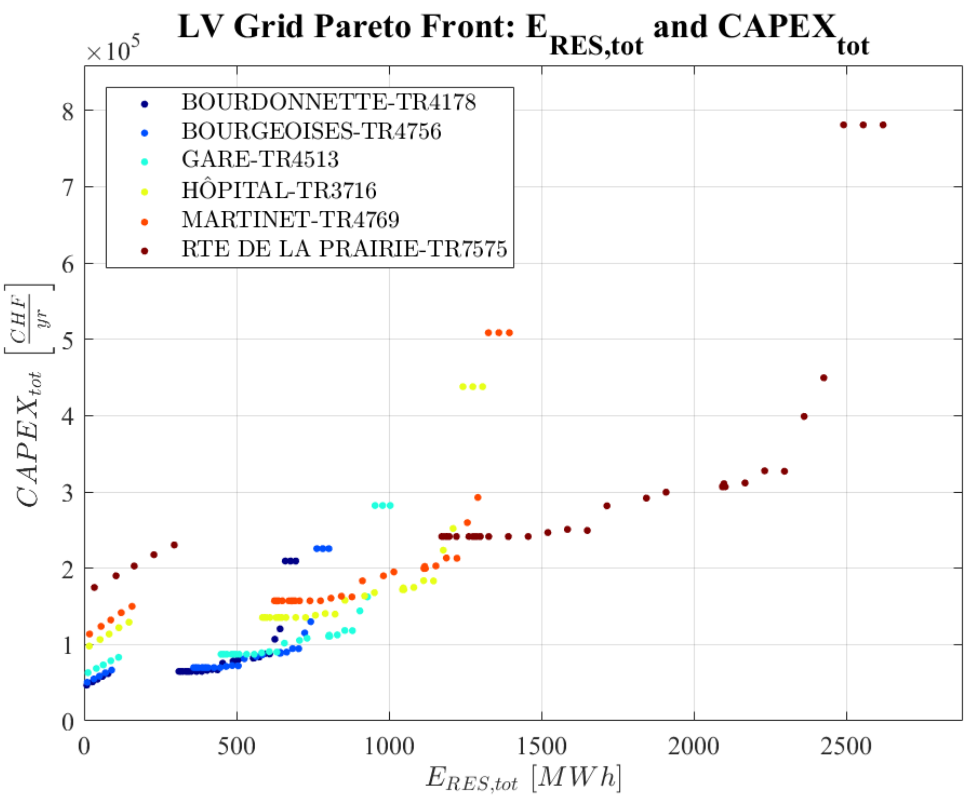


Figure 14: Aggregated Pareto curves for the 6 preselected LV grids

The renewable energy integration bottleneck for the considered LV grid *HÔPITAL-TR3716* can therefore be estimated:

- The renewable energy share reaches at maximum approximatively 58.92 % including the renewable part of the Swiss electrical mix.
- The maximum renewable energy that can be consumed reaches 1306.9 MWh for a total capital expenditure of 437'994.3 CHF/m^2/yr

6.3 Potential Bottleneck based on the Electrical Grid

The complete grid operation bottleneck is going to be assess in the deliverable *D1.2.2: Detailed evaluation of the grid operation bottlenecks and load shifting potential for the reference system* due to December 2018. However, some insight on the electrical grid as a bottleneck to high photovoltaic penetration are given in this section.

In case of high share of distributed generation, the electrical grid can not be considered as a simple copper plate since it very likely becomes the bottleneck of the system. Indeed with a high PV penetration, defined as the ratio of the annual PV production production and electricity consumption at the grid level, the generation peaks could exceed the consumption peaks, possibly leading to overvoltage and line overloading. For this reason the selected low voltage grid *Hôpital-TR3716* represented in figure 15 has been modelled using the grid topology data. Then a load flow solver (OpenDSS) has been used in order to determine the voltage for each bus of this low voltage grid.

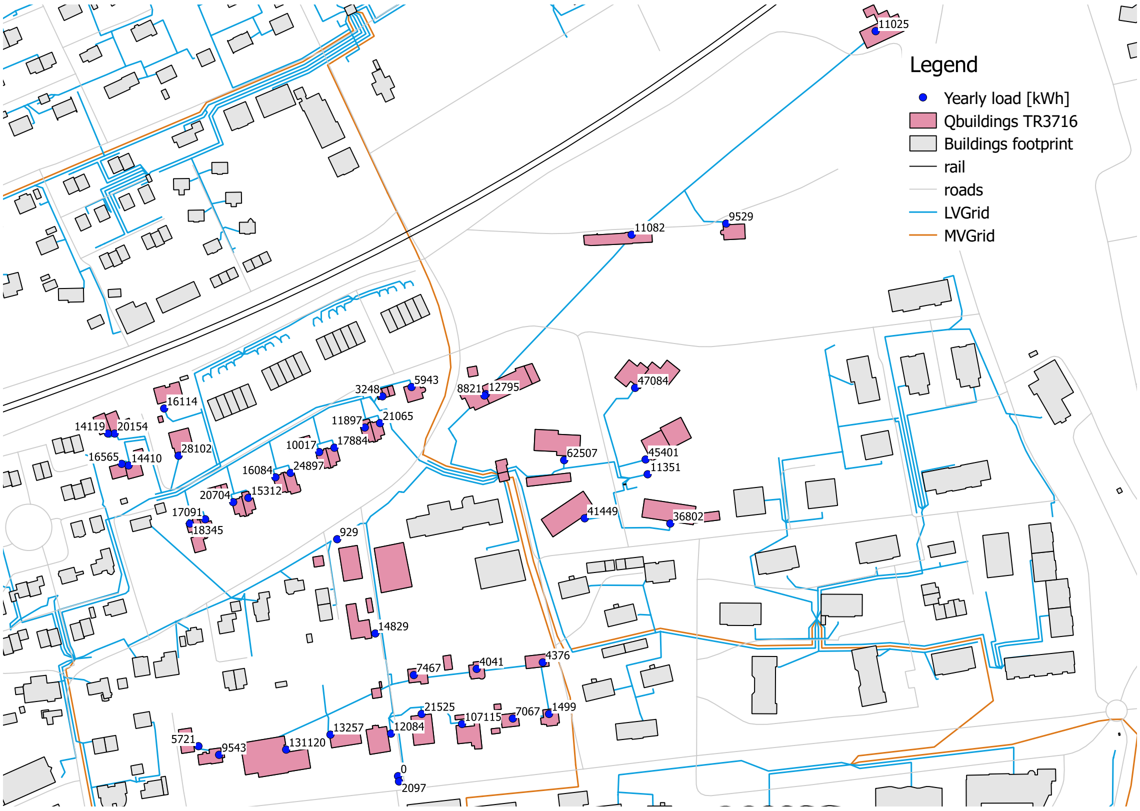


Figure 15: Visualization of the selected low voltage grid (Hôpital-TR3716) with connected building in pink and annual electrical associated loads

The daily electrical load profile of each building is unknown and the generation of such profiles will be part of further work. In the meantime, the load flow problem has been solved using a mean power consumption derived from the annual electricity consumption. The histogram of the bus voltages shown in figure 16 shows that all bus voltage are in the 3% allowed voltage range around the nominal voltage.

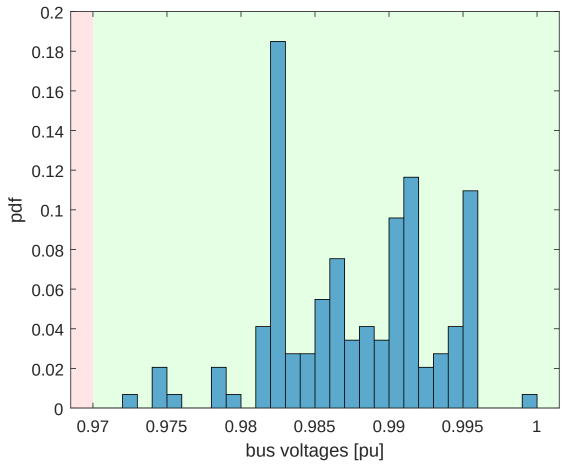
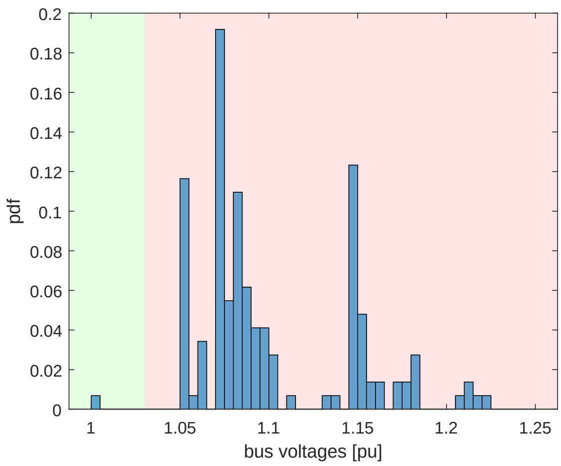


Figure 16: Normalized histogram of the bus voltages without any generation

Each load (SpotLoad) has been linked to a building using the GOR location as intermediate. Then, since each roof belong to defined building, referenced with its EGID, it becomes possible to simulate PV injection at the same point than the load consumption. A worst case scenario has been simulated where all the roofs with an area higher than 20 m^2 are covered with PV modules (figure 17a). Moreover the PV generation of each roof has been simulated using meteoswiss weather data at noon (June 1). In that extreme scenario, figure 17 shows that all bus voltage are above the limit of 3% except at the transformer bus. This very preliminary result indicate an expected bottleneck at the grid that will further investigated.

(a) Scenario where all the roofs with an area higher than $20m^2$ and belonging to buildings connected to the low voltage grid are covered with PV modules



(b) Impact of this scenario of the histogram bus voltages

Figure 17: Maximum PV penetration impact on the grid voltage

7 Conclusion and Future Works

Having assessed the context and collected and compiled data to fully assess the demonstrator area, subsystems and scenarios were successfully selected. Furthermore, an insight into renewable energy integration ultimate limitations for the selected LV grid was presented.

During the following years of the project, further research develop-ments (see Figure 18) will focus on flexibility assessment taking into account smart multi-energy building systems and prosumer activities. Furthermore, optimizations focused on grid impact of multi-energy systems for the preselected scenarios will be carried out. Besides, the planning at different time-scales will be considered, including insights from WP2 stakeholders to take into account market variations and thus enforce the holistic vision of this joined activity.

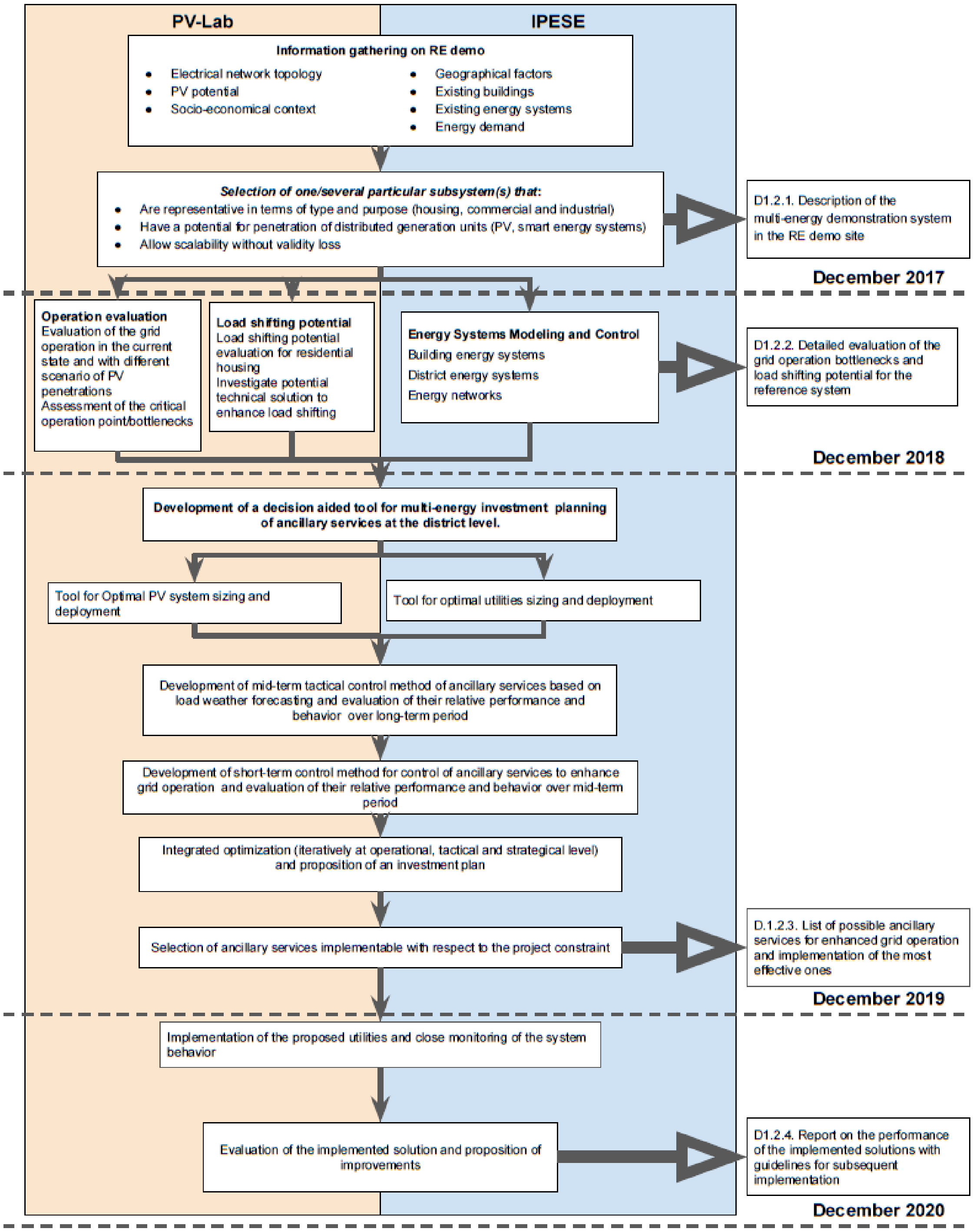


Figure 18: EPFL-IPESE and EPFL-PV-lab common workflow

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