NOVEMBER 22, 2025 | 9TH AIEE ENERGY SYMPOSIUM - CURRENT AND FUTURE CHALLENGES TO ENERGY SECURITY

Efficiency and decarbonization through electrification in non-residential civil sector: challenges, potential and main obstacles

Francesco Castellani

SAPIENZA UNIVERSITÀ DI ROMA

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Summary

- Technical and Legislative framework
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    - Electrification of large non-residential civil users
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- Case Studies
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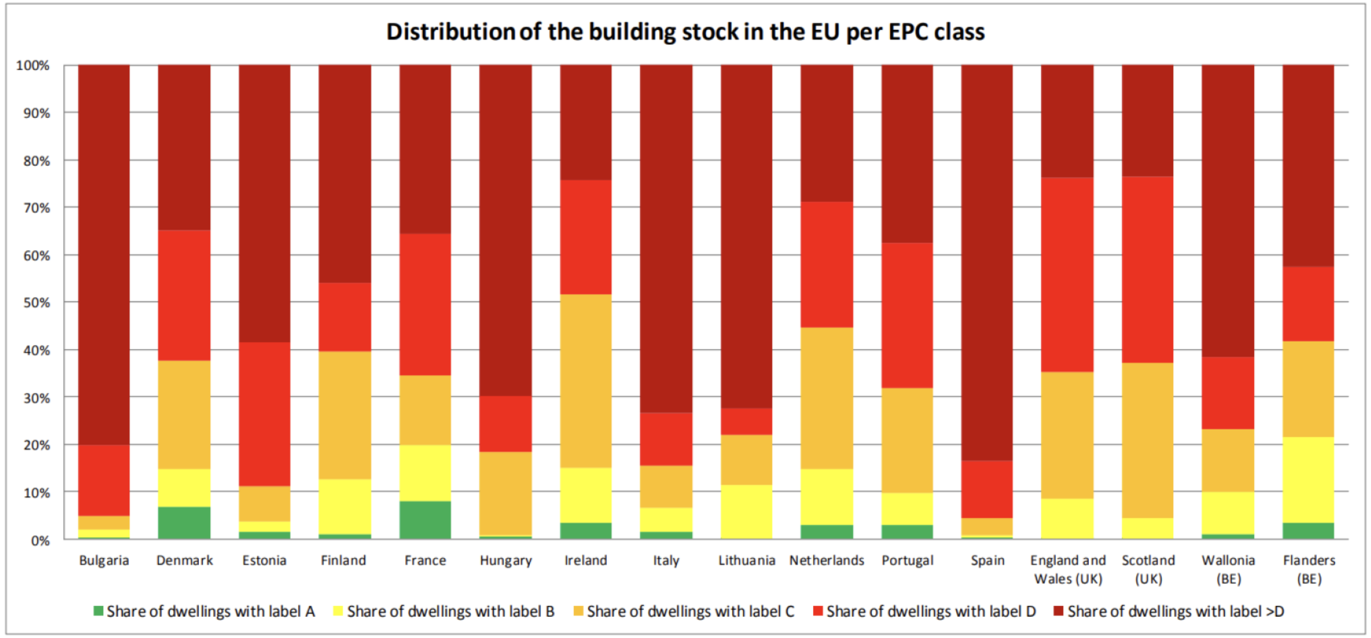
- Conclusions and future developments

Decarbonization of the civil sector

The impact of the construction sector

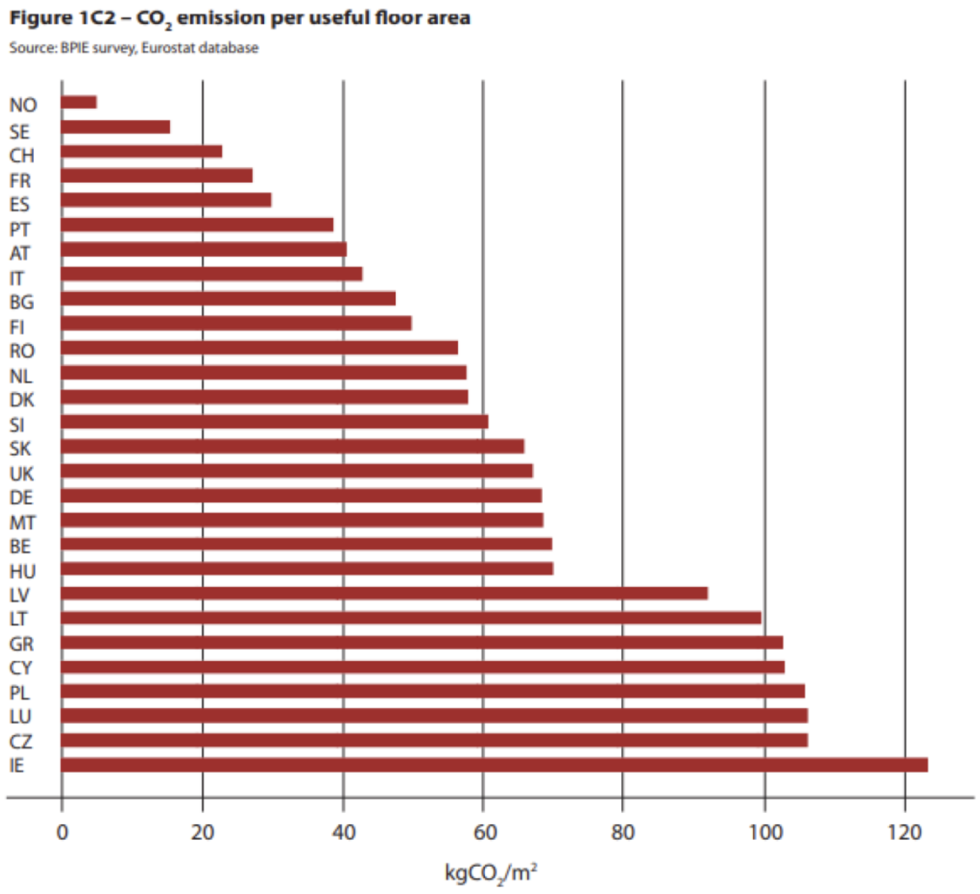


Distribution of the building stock in the EU per EPC class (BPIE, Buildings Performance Institute Europe, 2017)

- The **construction sector** is responsible for approximately 11% of global CO2 emissions and 36% of the European Union’s energy consumption.
- **International agreements** (e.g. Paris Agreement, European Green Deal) set ambitious targets to limit global warming to 1,5°C and achieve climate neutrality by 2050. These goals demand important action across industries, particularly in high-emission sectors such as construction.
- The **regulatory landscape is rapidly evolving to enforce decarbonization**. The EU’s Fit-for-55 package mandates a 55% reduction in net GHG emissions by 2030, while the Renewable Energy Directive (RED II) raises renewable energy targets to 45% by 2030 under the RePowerEU Plan.

Decarbonization of the civil sector

EU targets require a strong effort in renovation and decarbonization of buildings

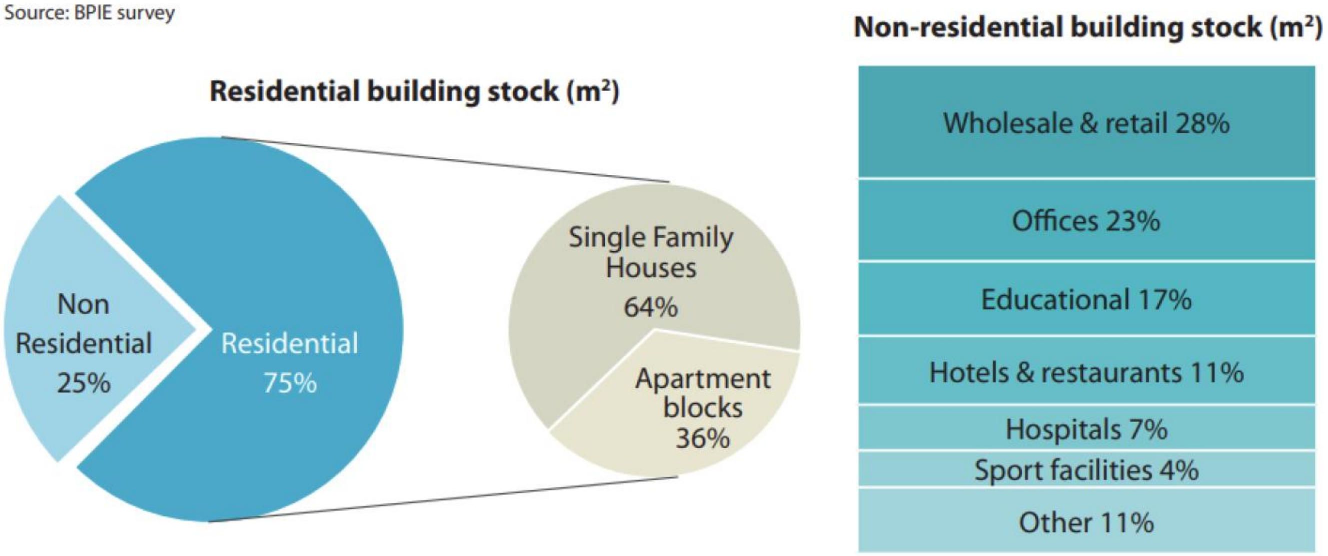


CO2 emission per useful floor area (BPIE, Building Performance Institute Europe, 2015)

- Both the **REPowerEU** - focused on saving energy, producing clean energy and diversifying energy supplies - and the **Renovation Wave** - focused on at least doubling the annual energy renovation rate by 2030, bringing also the reduction of emissions and creation of green jobs in the construction sector – push to decarbonize the civil sector.
- According to Buildings Performance Institute Europe, the **97% of buildings in the EU need to be upgraded and a share from 35% to 42% of the EU buildings were built before 1960**. These data can help to understand how aged the European building stock is; furthermore, old buildings are affected by historic constraints because they are part of the cultural heritage of the countries, so the renovation, efficiency and decarbonization works – in order to achieve the EU targets – are often very difficult and far to be cost-effective.

Electrification of large non-residential civil users

Non-residential buildings are important players in the decarbonization challenge

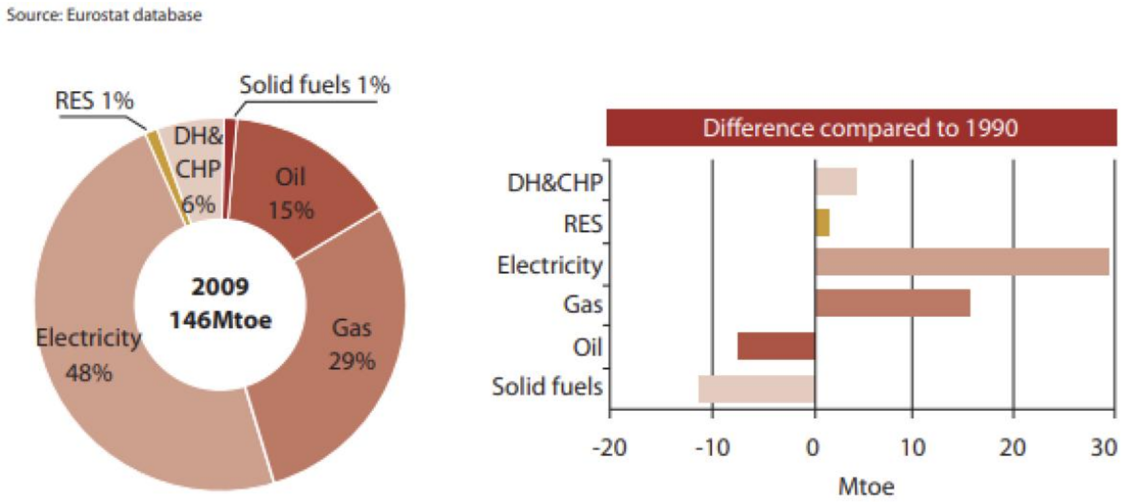


Details on European buildings stock (BPIE, Building Performance Institute Europe, 2015)

- **Electricity is, generally, a reliable energy source** to achieve decarbonization of the civil sector since it is provided by the grid and it benefits from the effort that countries are undertaking to decarbonize the electricity mix.
- The other benefit of electricity is that it **can be produced from renewables onsite**, directly on the building (e.g. rooftop photovoltaic) or nearby (e.g. ground-mounted photovoltaic directly/indirectly connected to the building).
- The focus of this study is on **non-residential buildings** (25% of the total buildings stock: wholesale and retail, offices, educational, hotels and restaurants, hospitals, sport facilities and others). They are, very often, organized in large complexes, owned by private or public entities, with centralized energy systems. For this reasons to work on non-residential buildings is more cost-effective and to reach the goal is more feasible.

Electrification of large non-residential civil users

Electrification of fossil-fueled services is the key



Energy mix in the non-residential sector in the EU 27 together with Switzerland and Norway and corresponding difference compared to 1990 profile (BPIE, Building Performance Institute Europe, 2015)

- Since **fossil fuels**, in non-residential buildings, are mostly used for **Heating, DHW (Domestic Hot Water), Cooling (e.g. absorption chiller)** the main strategy to electrify these complexes is to transfer those services from fossils to renewable energy. To electrify these services, the easiest and common way - by using well developed technologies available on the market – is to **replace the fossil-fueled equipment with electric equipment**, maintaining the same quality of the services (e.g. water temperature). Electric heat pumps are the key to achieve this target.
- Cooling and DHW are easily transferrable; **Heating can be difficult**, since traditional HPs don't reach **high temperature of water** to substitute boilers and HPs with new refrigerants (R290, CO_2) are not yet mature and efficient enough.
- **Adjustment of the electric infrastructure and grid connection of the building** can also be requested if there is no electric cooling that already demands high power during summer: electrification brings a sensitive winter power increase.

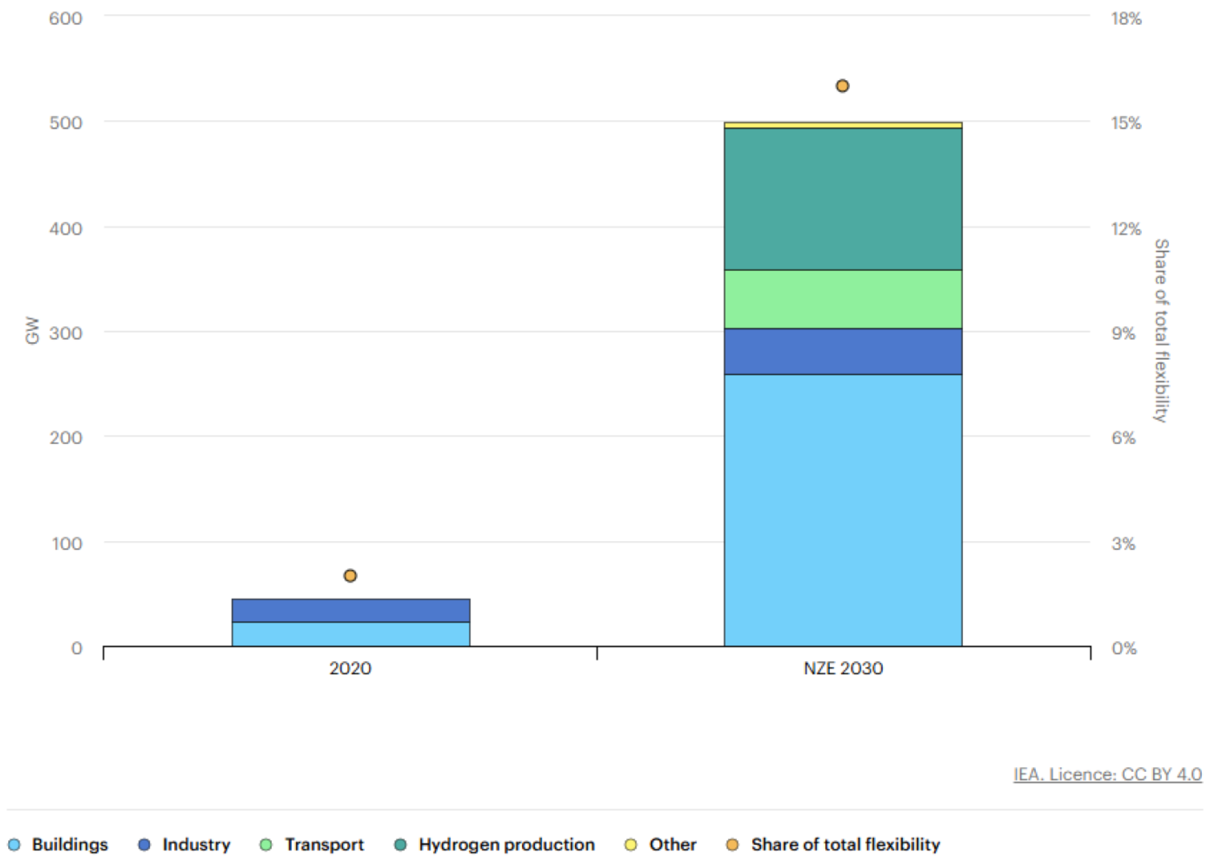
Access to the electricity market

Demand response from electrified buildings is an important source of flexibility for the grid

- Electrification of the services can lead the building to provide to the electrical grid capacity services such as the absorbed power regulation according to the requests of the grid, so called **“demand response”**. It refers to balancing the demand on power grids by encouraging customers to shift electricity demand to times when electricity is more plentiful or other demand is lower, typically through prices or incentives. Along with smart grids and energy storage, **demand response is an important source of flexibility** for managing the impact of variable renewables and growing electricity demand on the stability and reliability of electricity grids.
- In the **Net Zero Emissions by 2050 Scenario**, large increases in electricity demand from the electrification of end uses (like transport and home heating) and the widespread rollout of unstable solar PV and wind place increasing demands on the power grid. Technologies like **demand response can help to accommodate these impacts** and reduce the need for costly new transmission and distribution infrastructure.
- New digital technologies can help to **automate demand response through connected devices** and harness the growing potential of distributed energy resources, but the pace of policy implementation and technology deployment needs to accelerate.
- The European Union approved an action plan for the digitalization of the energy system, which includes establishing **requirements to facilitate data access for demand response**, as well as to support the adoption of smart appliances. In parallel, the **EU electricity market design proposed reform** is under discussion with an aim to introduce measures to support low-carbon flexibility solutions in the market, including demand response.
- In Italy there are 3 pilot projects from the major DSOs: **ENEL, ARETI, A2A**.

Access to the electricity market

A clear environment for demand response services and renewable self-consumption of buildings is needed

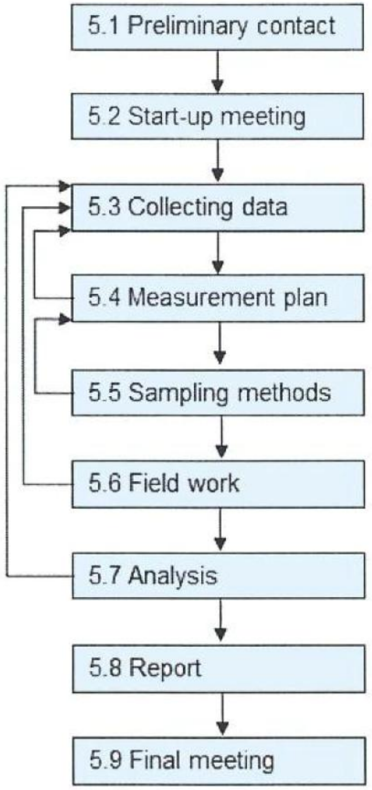


Demand response availability at times of greatest flexibility need and share of total flexibility under the Net Zero Scenario, 2020 and 2030 (IEA, 2025)

- From the **renewables point of view**, the electricity market already exists and it is accessible to electrified non-residential civil complexes. In Italy, the so called "remote self-consumption" is already operative after the Regulator published the "Testo integrato Autoconsumo Diffuso" (ARERA, 2022) in order to create a clear environment where energy producers, consumer and "prosumer" (combination between producer and consumer) can **cooperate – and receive incentives - to optimize the energy flows into the transmission and distribution grid**.
- The decarbonisation of civil complexes through electrification and installation of renewables can habilitate non-residential buildings to participate in this electricity market once it will be fully developed.

Simulation models: Energy audit EN16247, pre-feasibility evaluation

A deep energy audit is needed to evaluate the decarbonization through electrification potential



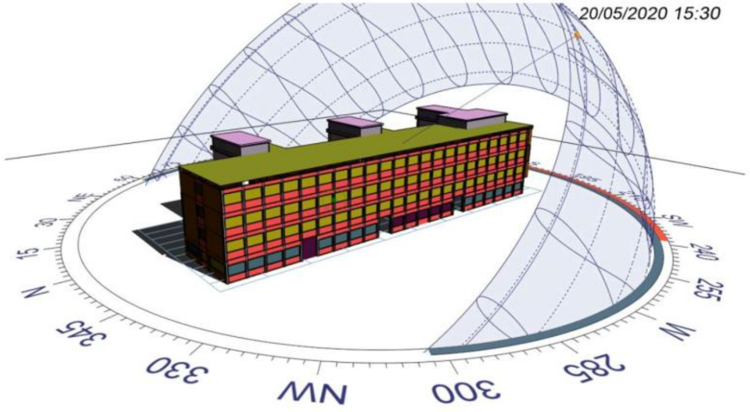
Flowchart of the energy audit
(EN 16247-1)

Screenshots of the MS Excel EN 16247 model

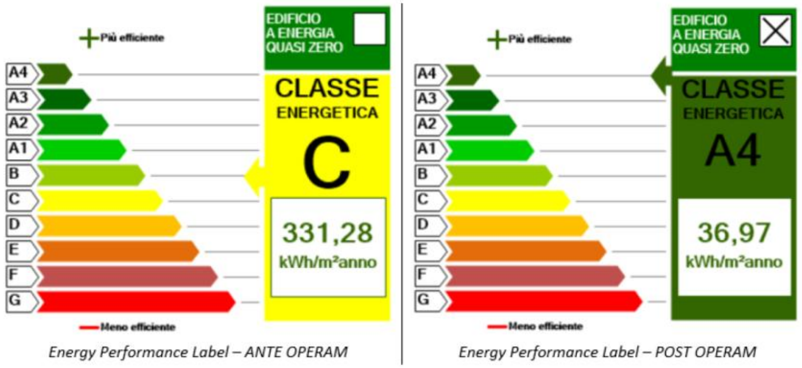
- The decarbonization through electrification potential can be evaluated only through a **deep energy audit** of the non-residential civil complex.
- The simulation methodology used the **European EN 16247 series**, a suite of European standards specifically designed to facilitate energy audits across various sectors.
- The specific standards used, since the research concerns the civil sector, is **EN 16247-1**: General Requirements and **EN 16247-2**: Energy Audits in Buildings.
- The standard flowchart to perform an Energy audit, following EN 16247-1, is made by nine phases. The simulation models were built in MS Excel, following these standards, generating tables, graphs and calculations. The standard structure of the Excel model is the following: Energy consumption analysis; List of significative energy users; Energy model with acceptance check; Energy performance indicators; Pre-feasibility study of efficiency opportunities; Final summary.

Simulation models: Detailed modelling UNI/TS 11300

The findings of the energy audit should be confirmed by a detailed energy model



Solar analysis of the building through Edilclima



Energy performance labelling comparison, baseline and decarbonized building

- Once the detailed audit has been performed, and the impact of the energy efficiency opportunities has been estimated through the EN 16247 methodology, **those assumptions should be confirmed by a detailed energy model of the civil complex** (envelope + systems) both in the actual and decarbonized stage.
- This modelling is performed through the **Italian UNI/TS 11300 Technical Specification**, created with the aim of defining a unified calculation methodology for determining the energy performance of buildings in Italy.
- The simulation models were made by using the software **Edilclima EC700, EC705, EC706** compliant to the UNI/TS 11300 standard. The standard workflow of the energy modelling is the following: Characterization of the building envelope, shadings, greenhouses; Drawing of the building, Rooms and areas characterizations; Characterization of systems (heating, cooling, DHW, ventilation, lighting, transport, renewables); Simulation results: thermal and primary energy needs of the building; Energy performance labelling of the building.

Case studies: Italian museum in historic building

Full decarbonization through electrification is feasibile, even in historic buildings

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- The **National Gallery of Modern and Contemporary Art in Rome** started in 2017 its sustainability path, following the Efficiency First principle. This path started with the design and implementation of a new air-to-water heat pumps heating and cooling system, powered by renewable electricity and renewable aerothermal energy, in substitution of the old gas-powered system, to become a **net-zero museum hosted in a historic building**.

- **2022 was the first year of the new efficient system**, and the measured data proof the achievement of the aimed results. If compared with the 2017 data, 2022 registered -9% electricity consumption, -100% natural gas consumption, -62% primary energy consumption, -83% carbon emissions (that could have been -100% if the purchase of renewable electricity from the market started from January and not from July).

- These measured results show that **it is possible to transform historic buildings in net-zero buildings through electrification**, leading to full decarbonization if the electricity purchased from the grid is produced by renewable sources.

- One of the most important findings of this study is that, in an electrification process, **the new electric consumption of the electrified scenario can be even smaller than the previous one of the fossil scenario** in cases like the National Gallery – very frequent, especially in Western countries – because the starting point was very un-efficient, totally natural gas-powered and also the new systems are very efficient.

Case studies: Italian museum in historic building

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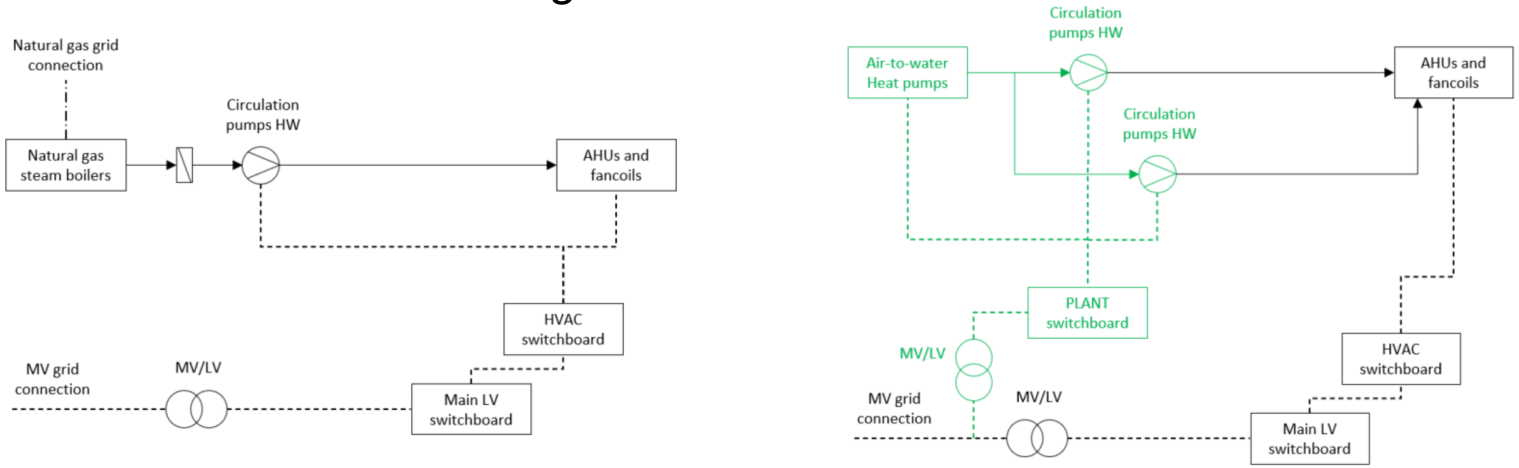
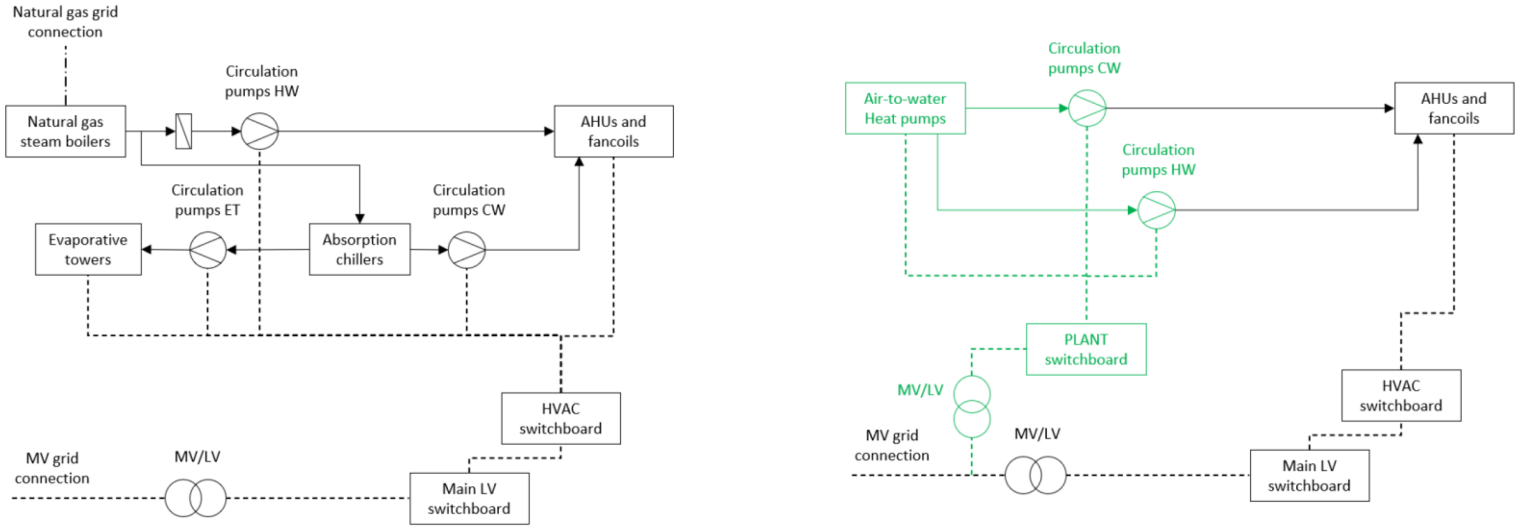


Winter heating: previous fossil and actual renewable HVAC system



Summer cooling: previous fossil and actual renewable HVAC system

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Case studies: Italian museum in historic building

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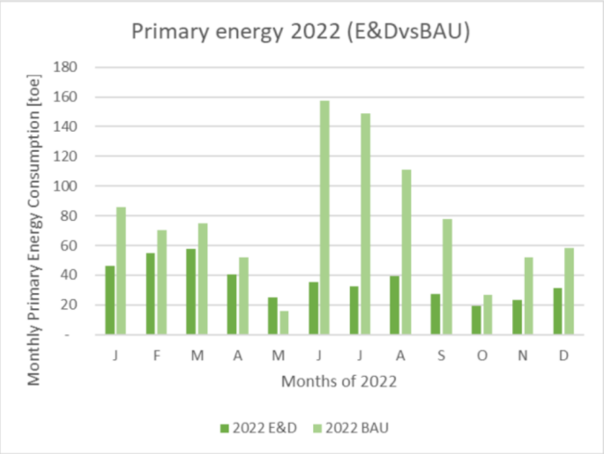
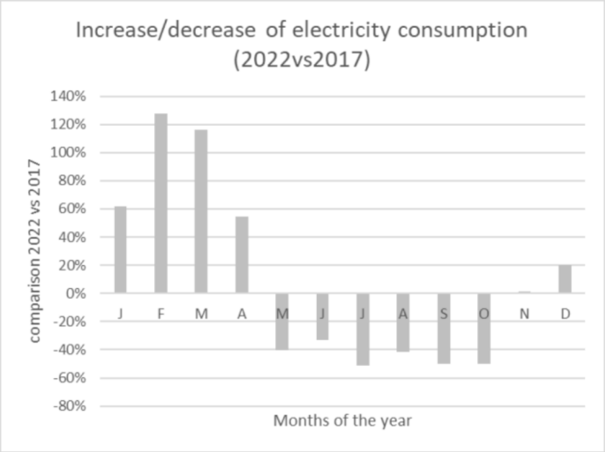
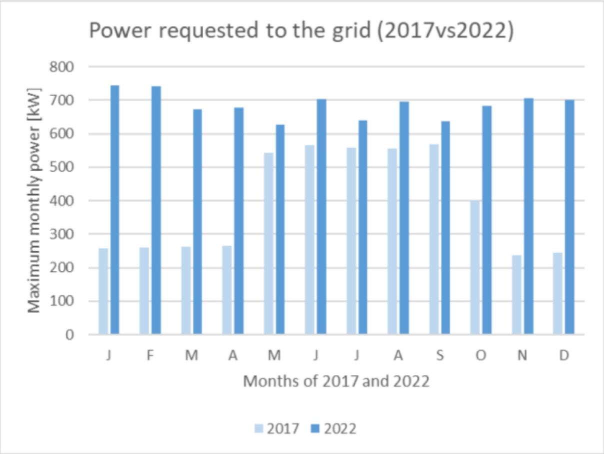
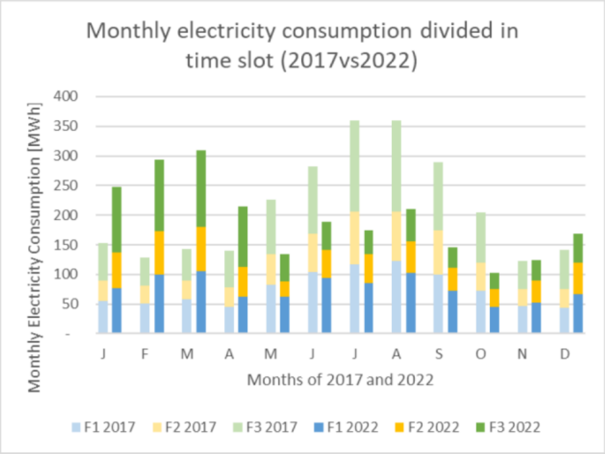








Comparisons between old fossil system and new renewable system

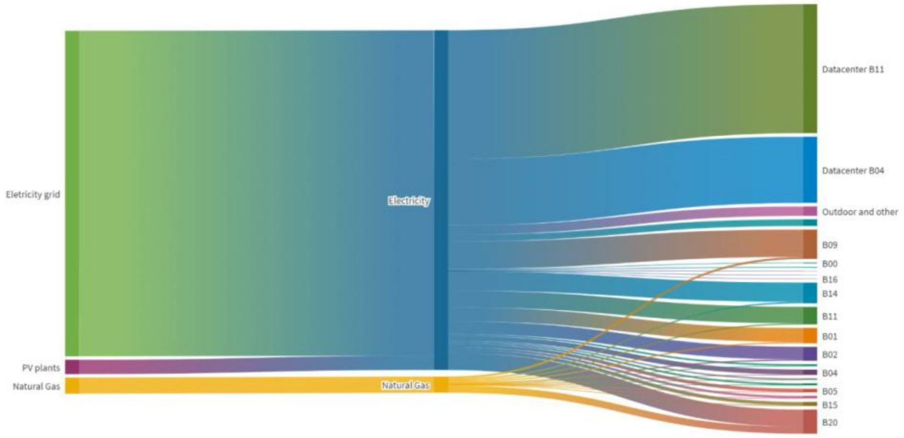
Case studies: European research centre

Research centers with large datacenter are easy to decarbonize

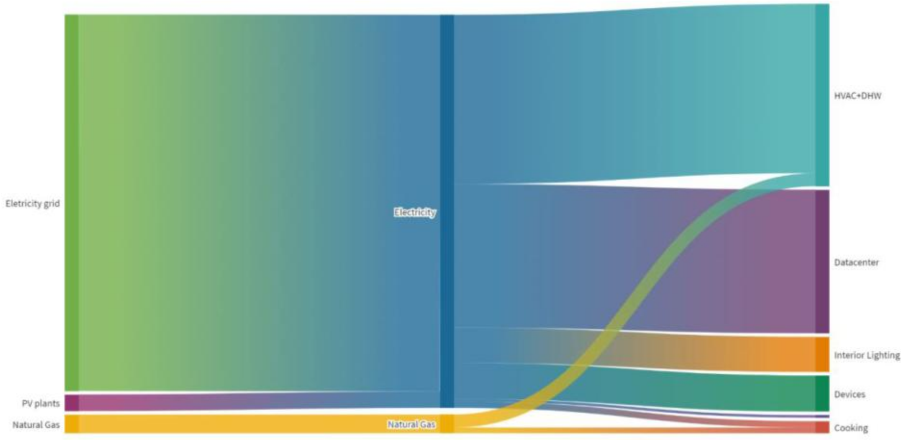
- The **ESA ESRIN (Rome)** case study, a European research centre, demonstrates the potential of energy efficiency, electrification and decarbonisation plan in this kind of civil complexes. Through an organic combination of projects, the centre can achieve 28% both of emission and primary energy savings.
- The electrification process is undertaken through the **replacement of natural gas boilers with heat pumps**, since winter heating was the only fossil-fuelled process. Due to the fact that those boilers were not so often used (heat recovery from datacentre, air-to-water heat pumps), the decarbonisation potential is very low (-1,53% in carbon emissions) and **no any issue in the electric infrastructure is expected** (power increase during the winter is fully covered by the local grid, that is sized for the electric summer loads of chillers). It is possible to get a full decarbonization, without using gas boilers anymore, since the HVAC system is already sized for medium temperature fluids that fit with the operational temperatures of electric air-to-water high efficiency heat pumps.
- **The electrification leads, of course, to an increasing of electricity consumption** (around 100 MWh/y more than the baseline): in the efficiency plan this is compensated by the efficiency works on other areas of the centre (e.g. UPS, lighting, BACS, etc.) and by the strong use of local generation of electric energy by photovoltaic plants (rooftop and carports, 700 kWp in total). The overall electricity consumption, at the end of the efficiency plan, is lower than the current one (- 1.500 MWh/y).
- In terms of **power requested to the grid**, during the winter season an increase is expected due to the electric heating through heat pumps and to the lower energy production by photovoltaic during the winter season.

Case studies: European research centre

Research centers with large datacenter are easy to decarbonize



Sankey diagram of primary energy flows, Functional Areas



Sankey diagram of primary energy flows, End Uses

Energy vector and source		MWhp	%
Electricity from the grid	5.383.479 kWhe	11.708,04	91,3%
Natural gas	61.862 Scm	580,70	4,5%
Electricity from PV	235.859 kWhe	512,95	4,0%
Heat from solar thermal	26.952 kWht	27,08	0,2%
	TOTAL	**12.828,78**	**100,0%**

Primary energy consumption summary (2019)

Intervention	Emissions reduction		Primary energy consumption reduction		Electricity consumption reduction/increase
	tCO_2	%	MWhp	%	kWhe
PVS	365	- 14,23	1.858	- 14,28	- 854.490
LED	150	- 5,86	765	- 5,88	- 351.780
PVR	145	- 5,67	740	- 5,68	- 340.200
HP	45	- 1,72	199	- 1,53	+ 94.175
UPS	31	- 1,17	157	- 1,20	- 72.030
TOTAL	**736**	**- 28,65**	**3.719**	**- 28,57**	**- 1.524.325**

Summary of the proposed efficiency and decarbonization interventions

Case studies: Italian research centre

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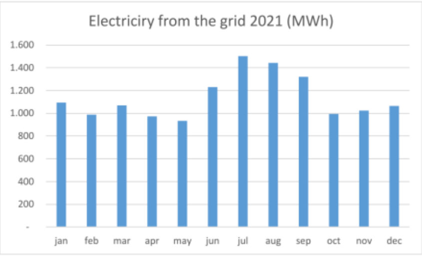
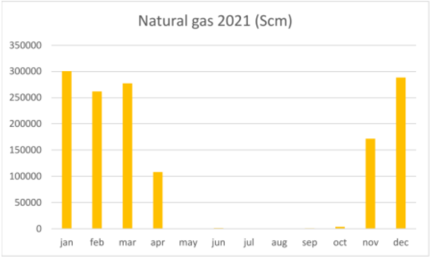
Research center with buildings connected to fossil-fueled district heating can be electrified

- Efficiency, electrification and decarbonization in research center can be **very challenging for technical, managerial and politic issues**. The most cost-effective approach (money, time and results) should be found.
- Instead of proposing light interventions in many different buildings, occupied by a few people, the technical and managerial proposal was to concentrate the employees on a few renovated full-electric and efficient buildings, shutting down the inefficient ones, and providing energy for those buildings through photovoltaic, both rooftop and ground-mounted. This proposal was accepted by the administration and led to the design of the feasibility plan.
- The **renovation of 5 buildings**, hosting **800 employees in more than 16.000 m2**, leads to the reduction of natural gas consumption (and related emissions) by 27%: the buildings will be disconnected by the internal district heating grid and they will provide to their heating (and cooling) through air-to-water electric heat pumps. Through the energy modeling of each building, it is demonstrated that no increase of electricity consumption is expected: the extra-consumption of the electric heat pumps is compensated by savings in other services (e.g. cooling, lighting, ventilation). This electrification leads to a reduction of the carbon emissions of the site but this intervention is not enough to get an important result in terms of decarbonization: local production of renewable energy is needed.
- The other leg of the intervention is the introduction of a huge quantity of photovoltaic (822 kWp rooftop and 7,8 MWp ground-mounted) to provide to the whole site (both renovated and old buildings and existing activities) renewable energy. Thanks to this intervention, capable of generating 12,9 GWh/y of clean electricity, the carbon emissions of the site decrease of -33%. Electrification is strongly bonded with onsite production of clean electricity.

Case studies: Italian research centre

Research center with buildings connected to fossil-fueled district heating can be electrified



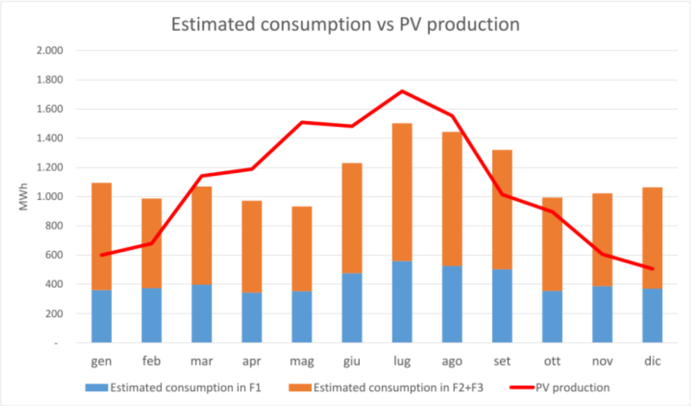


Electricity and natural gas consumption before the energy efficiency works (2021)

Aggregate (5 buildings)			
Energy vector	**ANTE OPERAM**	**POST OPERAM**	**Results**
Electricity consumption	1.091,56 MWh	950,03 MWh	-141,52 MWh
Electricity production (822 kWp)	0 MWh	1.051,50 MWh	-1.051,50 MWh
Natural gas	385.033 Scm	0 Scm	-385.033 Scm

New solar farm		
Energy vector	**ANTE OPERAM**	**POST OPERAM**
Electricity production	-	11.849 MWh

Summary of the energy efficiency and renewables works impact



Estimated electricity consumption vs Photovoltaic production, monthly details

Energy consumption 2021		Primary energy [toe]	Carbon emission [tCO_2]
Electricity	13.636.909 kWh	2.550	3.477
Natural gas	1.413.343 Scm	1.166	2.807
		3.716	**6.284**

Estimated energy consumption		Primary energy [toe]	Carbon emission [tCO2]
Electricity	8.484.200 kWh	1.587	2.163
Natural gas	1.028.310 Scm	848	2.042
		2.435	**4.206**

Energy consumption and carbon emissions before (measured, 2021) and after (estimated) the efficiency works

Case studies: Italian public administration

Historic complex in the city center of Rome, owned by public administration, can reduce its carbon impact

- Even historic buildings that host the **headquarters of an important and critical public administration** can be electrified and decarbonized. An aggregate of 4 civil historic buildings in the city centre of Rome (65.200 m2) was deeply analysed to estimate the efficiency and decarbonization potential, especially through electrification interventions.
- The complex uses **natural gas boilers for winter heating**. Due to the system constraints, the proposal does not concern a full electrification but a hybridization of the heating system: air-to-water heat pumps have the priority but the natural gas boilers are maintained just to cover the peak (very few working hours).
- The new winter electric power is expected to be lower than the electric power requested by the chillers during the summer: for this reason, **important adjustments on the electric systems or delivery are not planned**. This goal is reached because a partial electrification was planned, so the requested electric power is similar to the power of the chillers.
- This intervention causes an increase in electricity consumption and the decrease of the natural gas usage, leading to savings both on primary energy (-2,0%) and carbon emissions (-6,4%). **Other interventions are planned**, bringing large savings in terms of electricity, for a final value of -37% carbon emissions: the extra-consumption of the electrification of heating through decarbonization can be compensated through other efficiency interventions.
- The combination between electrification of heating and production of electricity through local renewables is proposed also in this case, even if the installation of **renewables (photovoltaic) in historic buildings is very difficult and not cost-effective** (low efficiency and high costs due to constraints on material to be used).

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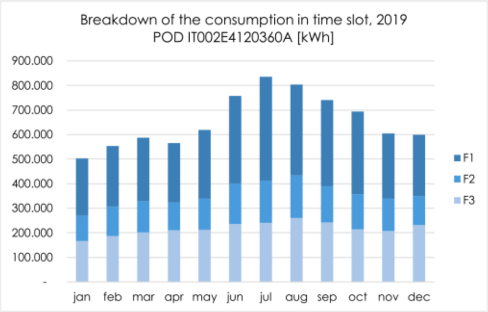
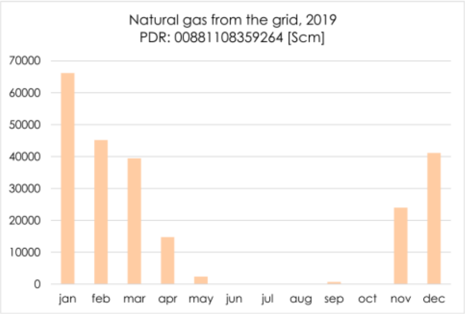
Case studies: Italian public administration

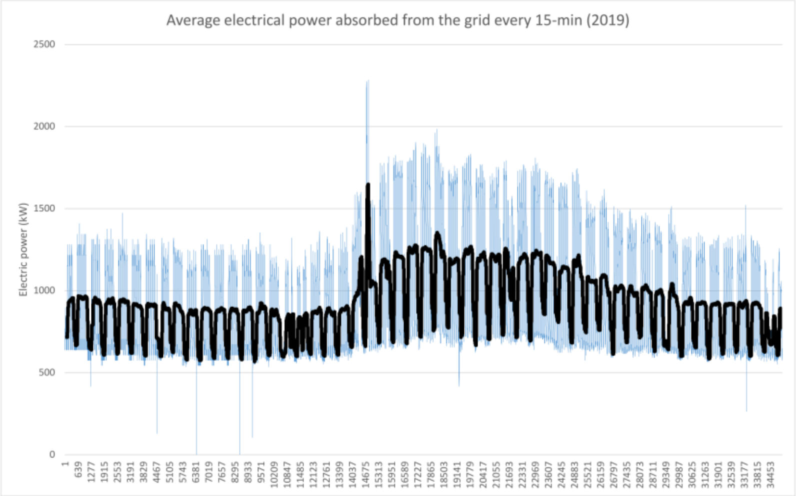
Historic complex in the city center of Rome, owned by public administration, can reduce its carbon impact





Energy vector and source of supply (2019)		toe	%
Electricity from the grid	7.864.082 kWh	1.471	88,3%
Natural gas	233.637 Scm	195	11,7%
	TOTAL	**1.666**	**100,0%**

Electricity and natural gas consumption, 2019, monthly detail and aggregated



Average electrical power from the grid, every 15-min (2019)

Intervention	Emissions reduction (w/o GO)		Primary energy consumption reduction		Electricity consumption reduction/increase
	tCO_2	%	toe	%	kWhe
BACS	211	-8,2	129	-7,7	- 531.531
HP	165	-6,4	34	-2,0	+ 288.554
BIPV best	142	-5,5	99	-5,9	- 528.600
LED+AUT	136	-5,3	95	-5,7	- 505.195
WIN	125	-4,8	79	-4,7	- 348.977
UPS	116	-4,5	81	-4,8	- 430.704
INV	59	-3,3	85	-3,5	- 315.389
TOTAL	**954**	**-37,0**	**602**	**-36,0**	**- 2.371.842**

Summary of the energy efficiency and decarbonization proposals

Conclusion and future development

- This research explored **the potential of electrification of large non-residential civil users for the decarbonization**, by developing simulation models of aggregates of active and passive users for the access to the electricity market.
- The **policy framework** was analysed, then the work focused on electrification of large non-residential civil users, demonstrating that this process is undergoing in some EU countries. The **access to the electricity market** of decarbonized and electrified buildings was studied: demand response services are strongly requested by the Net Zero Emission 2050 scenario but both the regulatory framework and the available technologies are **still not ready** (just pilot projects, in Italy managed by the DSOs).
- A **specific methodology** was studied and simulation models were developed to analyze the case studies. These models were built on current standard such as EN 16247 and UNI/TS 11300.
- The case studies were four real decarbonization through electrification projects:
  - **Italian museum in historic building** (National Gallery of Modern and Contemporary Art in Rome), already electrified in 2022.
  - **uropean research centre** (ESA ESRIN Rome), **Italian research centre** and **Italian public administration**, ongoing projects, demonstrating the potential of energy efficiency, electrification and decarbonisation through renewables in this kind of civil complexes.
- Non-residential buildings can have an important role in the decarbonization of the energy system, especially through the electrification process that can also habilitate active and passive users to access to the electricity market.
- The **future development** should be focused on the regulatory framework and on the production of common technologies to allow these buildings to **provide services to the grid, especially demand response**, to improve the reliability of the electric system itself.

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