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# D7.1

# FRAMEWORK FOR ENERGY NETWORK IMPROVEMENT

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MULTICARE

# D7.1 FRAMEWORK FOR ENERGY NETWORK IMPROVEMENT

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## PUBLISHED IN THE FRAMEWORK OF

Providing a decision-making framework for assessing responsiveness of districts energy network in case of disruptive events.

## AUTHORS

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## REVISION AND HISTORY CHART

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## DISCLAIMER

Within this report, AI methods have been employed solely for the purposes of language review and enhancing clarity to improve readability for the audience.

# GLOSSARY

| ACRONYM | FULL NAME |
|---|---|
| ASHRAE | American Society of Heating, Refrigerating and Air-Conditioning Engineers |
| BaU | Business as Usual (for scenarios) |
| D | Deliverable |
| DER | Distributed Energy Resources |
| EC | European Commission |
| EU | European Union |
| HVAC | Heating, Ventilation and Air Conditioning |
| IPCC | Intergovernmental Panel on Climate Change |
| iCD | intelligent Communities Design (software) |
| iVN | intelligent Virtual Networks (software) |
| NTE | Norma Tecniche per le Construzioni (Italian regulation) |
| PV | Photovoltaic |
| R&D | Research and Development |
| ROI | Return of Investment |
| S (S1, S2, SN) | Scenario |
| SME | Small and Medium-sized Enterprises |
| T | Task |
| WP | Work Package |

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# Executive summary

This report aims to assess the resilience of the urban energy network and simulate potential strategies to enhance the responsiveness of urban districts to disruptive events that threaten energy supply and security. This analysis involves both risk analysis and cost-benefit estimations.

To ensure the conclusions are applicable to various circumstances and contexts, the network analysis was conducted on two distinct cases with different specificities, climates, and urban configurations: the Multicare pilot sites in Acerra, Italy, and Amsterdam, the Netherlands. Both pilots were modelled using IES software by:

- Gathering data from the local environment through various sources.
- Modelling the geometry of the districts and assigning specific energy data to each building.
- Calculating and calibrating the energy demand of each building and the entire district based on the thermophysical properties embedded in the IES calculation engine.
- Modelling the electrical network according to these energy demands.
- Simulating different resiliency alternatives to improve the responsiveness of the urban district and buildings in case of power outages.

After the analysis of those alternatives, the report concludes that without proactive intervention focused on resiliency, the protection of buildings during disruptive events is very limited. It emphasizes the need for proactive policy, planning, technology, and engagement to create a more resilient energy grid. Decentralized renewable energy production is highlighted as a key resiliency measure to reduce dependency on the main electrical grid, with key factors such as the climate zone, geographic area, roof shapes, and building use influencing its implementation. All in all, the analysis shows that measures depend on context, with examples like Acerra's severe summer disruptions and Amsterdam's economically unviable battery installations.

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# 1. Multicare project

## 1.1 Multicare project

The built environment is ill-prepared for more frequent and increasingly intense climate-related extreme events. The current building stock is particularly vulnerable because it has limited or no capacity to adapt and recover from extreme events thereby leading to building failures that cause severe socio-economic losses and adversely affecting the health and wellbeing of people. Recent scientific and technological advances in the construction industry provide timely solutions for improving the resilience for specific single hazards (e.g. flood hazard or seismic hazard), but they are often not cost effective, rarely eco-friendly and nearly never address the multiple hazards present in many locations. This is hardly surprising because there is neither a clearly defined framework for quantifying the whole-life socio-economic-environmental impacts of extreme natural events nor tools for assessing the holistic climate resilience of buildings. Consequently, it is currently very challenging to develop/select optimal solutions for real-world multi-hazard scenarios.

MULTICARE will address this challenge directly by developing new multi-criteria decision-support frameworks and providing plug & play technological and digital solutions for improving the resilience of the built environment in a cost-effective, reliable and sustainable manner. The technological solutions consist of multi-functional low-carbon resilient technologies embedded in modular and prefabricated construction for the next generation of high performance and smart buildings, characterized by enhanced safety, energy efficiency, environmental-sustainability, improved quality of life, circularity, and scalability for a broad range of natural events and end-user. The plug & play technologies will be applied to either new multi-story buildings or existing structures by means of low-invasive external interventions. The digital solutions consist of a suite of multi-disciplinary digital services and tools for performing multi-hazard resilience assessment, design, operation and management across multiple scales (material, component, building, neighbourhood/city). The new digital tools will enable stakeholders to make informed decisions in the selection of materials/solutions, including for heritage buildings, and support resilient supply chains. The effectiveness of the MULTICARE solutions will be demonstrated through large-scale pilots (3 buildings, 4 neighbourhoods/district) in three different European countries carefully selected for their diverse local environmental, social and economic conditions (Italy, Netherlands, Romania). Banks and institutional investors will be engaged to better understand the financial risk reduction value of resilience and update existing and future "green finance" mechanisms that will help to leverage the project results. A user-centred, inclusive and participatory approach will be consistently implemented throughout the project to engage citizens and extend the durability of MULTICARE impact.

To achieve these ambitious goals, MULTICARE brings together a unique interdisciplinary Consortium of 21 partners (table below) from 6 different EU countries with strong R&D and practical expertise, who are either established leaders in their sector or agile SMEs in emerging fields. Altogether the Consortium members span across the whole technical and

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value chain required for developing and implementing solutions in terms of design, digitization, manufacturing, construction, and monitoring of resilient and sustainable buildings. The Consortium also includes partners with experience in social sciences, user engagement, and training to ensure the success and widespread application of new technologies in local communities. The Consortium will also support clustering activities with other relevant research projects to share knowledge and raise public awareness of building resilience. An international outreach and cooperation strategy will also be implemented to tackle the project challenges.

*Table 1. Multicare project consortium*

| No. | Role | Short Name | Legal Name | Country |
|---|---|---|---|---|
| 1 | CO | TU Delft | TECHNISCHE UNIVERSITEIT DELFT | NL |
| 2 | BEN | PFE | PRIEDEMANN FASSADENBERATUNG GMBH | DE |
| 3 | BEN | IES R&D | IES R&D | IE |
| 4 | BEN | INCDFP | INSTITUTUL NATIONAL DE CERCETARE-DEZVOLTARE PENTRU FIZICA PAMANTULUI | RO |
| 5 | BEN | UNIROMA1 | UNIVERSITA DEGLI STUDI DI ROMA LA SAPIENZA | IT |
| 6 | BEN | XLD | X-LAM DOLOMITI SRL | IT |
| 7 | BEN | STRESS | SVILUPPO TECNOLOGIE E RICERCA PER L'EDILIZIA SISMICAMENTE SICURA ED ECOSOSTENIBILE SCARL | IT |
| 7.1 | AE | UNINA | UNIVERSITA DEGLI STUDI DI NAPOLI FEDERICO II | IT |
| 8 | BEN | AMS Institute | STICHTING AMSTERDAM INSTITUTE FORADVANCED METROPOLITAN SOLUTIONS(AMS) | NL |
| 9 | BEN | PMB | MUNICIPIUL BUCURESTI | RO |
| 10 | BEN | ASM | ASM - CENTRUM BADAN I ANALIZ RYNKUSPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA | PL |
| 11 | BEN | RoGBC | ASOCIATIA ROMANIA GREEN BUILDING COUNCIL | RO |
| 12 | BEN | RINA-C | RINA CONSULTING SPA | IT |
| 13 | BEN | UTBV | UNIVERSITATEA TRANSILVANIA DIN BRASOV | RO |
| 14 | BEN | ACER | AGENZIA CAMPANA PER L EDILIZIA RESIDENZIALE | IT |
| 15 | BEN | Boom | BOOM BUILDS B.V. | NL |
| 16 | BEN | OMRT | OMRT BV | NL |
| 17 | BEN | ROTHO BLAAS SRL | ROTHO BLAAS SRL | IT |
| 18 | BEN | ARUP | ARUP BV | NL |
| 19 | BEN | Tecuci | MUNICIPIUL TECUCI | RO |
| 20 | BEN | Hölscher | DIPL.-ING. HPLSCHER GMBH & CO.KG | DE |

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## 1.2 WP7. Spatial decision-support framework and system for multi hazard resilience analysis at urban level

Within Multicare project, WP7 intends to develop and provide a Spatial Decision Support System for urban planners and municipality managers through several subobjectives:

1. To integrate visualizations of multi-hazards related metrics together to identify zones at risk.
2. To evaluate and predict the resiliency improvement through the installation of the proposed MULTICARE technology packages at building level and potential measures at urban level.
3. To assess the energy network resilience at urban level and simulate potential strategies for improving the responsiveness of the urban district to disruptive events endangering the energy supply and security.

More specifically, this report D7.1 connected to T7.3 intends to address the last point (3), providing a decision-making framework for assessing the responsiveness of districts energy network in case of disruptive events, involving both risk analysis and cost-benefit estimations.

The figure below shows a diagram with the WP7 main outputs and the overall workflow of the WP, providing the context where this report (D7.1) and its task (T7.3) fit and support the WP objectives.

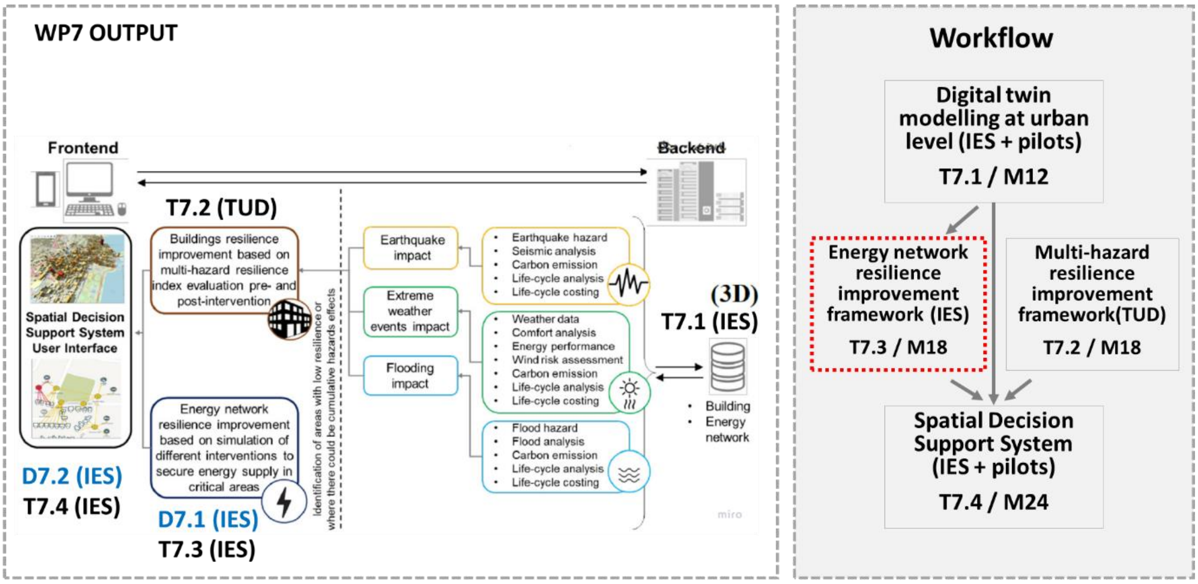

*Figure 1. WP7 outputs and workflow.*

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# 2. Introduction

## 2.1 Climate-related extreme events

The rising frequency and intensity of natural disasters has led to a significant increase in power blackout worldwide. As awareness of these extraordinary events grows, it becomes increasingly urgent to address issues related to resilience and risk mitigation.

Within the Multicare project, diverse hazards are being addressed, like earthquakes, flooding and flush-floods or heatwaves, which impact the project pilots differently due to their diversity in climatic, geographic, and orographic conditions. The figure below shows such difference on the climatic zones (left side; Köppen-Gelger climate map) and the potential impact of those hazards according to a simple traffic-light system (right side; red for severe impact, green for scarce impact).

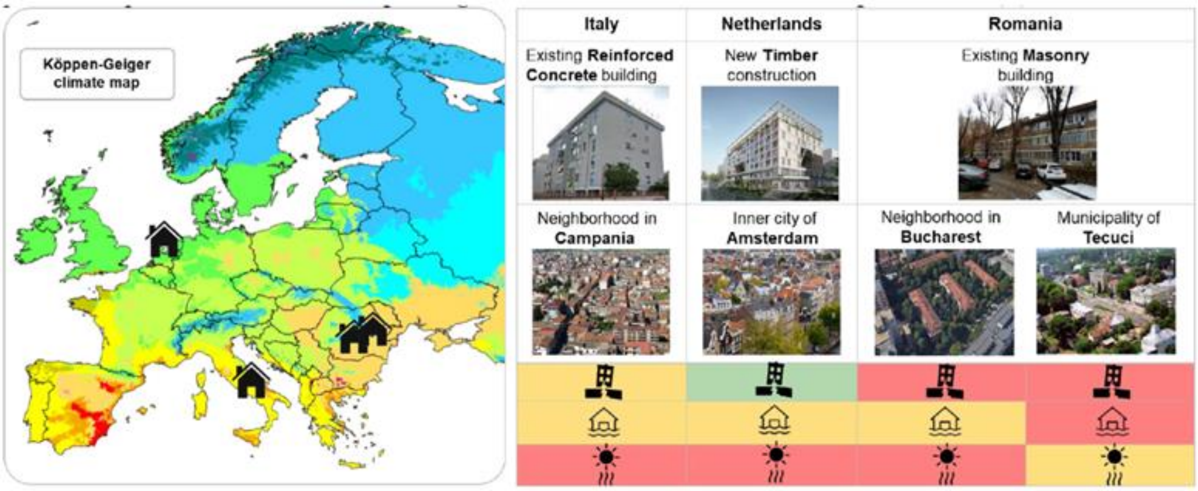

*Figure 2. Climate map and hazards addressed for each Multicare pilot.*

## 2.2 Resiliency of the energy network

These climate-related extreme events as well as the long-term impacts of climate change both significantly affect the energy network, putting their resilience to the test. According to the IPCC[1], *resilience* is defined *as the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a potentially hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions*.
The *resiliency* term is now applied to multiple fields of knowledge, but closely linked to the rising climate emergency and, more specifically, to the field of *disaster risk management*.

---

[1] Lavell, A., M. Oppenheimer, C. Diop, J. Hess, R. Lempert, J. Li, R. Muir-Wood, and S. Myeong, 2012: Climate change: new dimensions in disaster risk, exposure, vulnerability, and resilience. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 25-64.

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The diagram below shows the conceptual framework of resiliency applied to the impacts of climate change, both through long-term impacts and sudden extreme weather events.

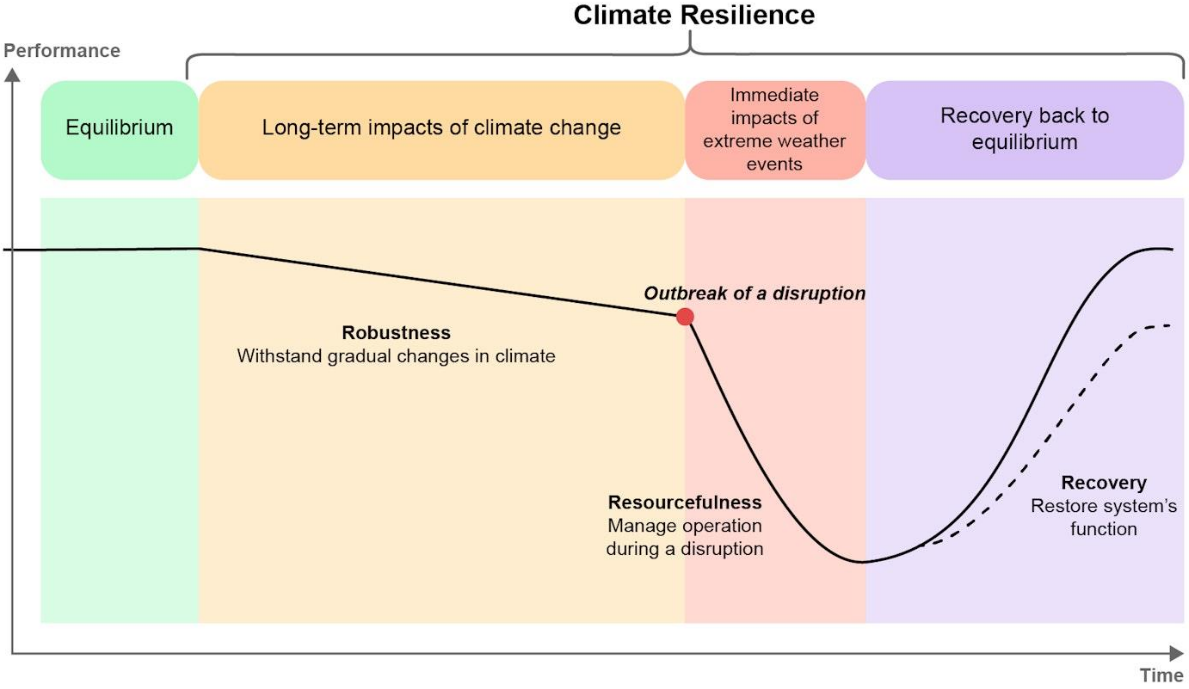

*Figure 3. Conceptual framework for climate resilience*[2]

According to the International Energy Agency's report on *Power Systems in Transition,* this conceptual framework addresses climate resilience through 3 elements of an energy system, which intend to tackle 3 different stages of the energy system lifespan[3]:

- *Robustness;* refers to the capacity of an energy system to endure gradual, long-term changes in climate patterns while maintaining its operations. The robustness of the system will tackle the long-term impact of climate chance (i.e.: gradually increasing temperatures)
- *Resourcefulness;* refers to the capability to sustain operations during sudden disruptions, such as extreme weather events. The resourcefulness of the system will mitigate the sudden impacts of extreme weather events (i.e. flooding)
- *Recovery;* refers to the capacity to restore a system's functionality following a disruption caused by climate-related hazards. A well-designed contingency plan will help in the recovery of the energy system's function.

In this sense, climate resilience and the application of this kind of framework to real energy infrastructure is key by various social, economic, and environmental reasons. For instance, from the economic perspective, a more resilient approach will lead into a reduction of the duration and frequency of power disruption, lowering losses and the cost of reparation, also increasing the lifespan of the infrastructure due to a better withstand of increasing environmental hazards. From the social perspective, the lower the damage, the better the

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[2] Argonne National Laboratory (2012), Resilience: Theory and Applications (ANL/DIS-12-1), as modified by International Energy Agency

[3] IEA (2020), Power Systems in Transition, IEA, Paris https://www.iea.org/reports/power-systems-in-transition, Licence: CC BY 4.0

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community will resist sudden weather events and the quicker it will recover, also keeping essential services functioning during those extreme events. And finally, from the environmental point of view, a more resilient energy system will provide better support to sustainability goals, mainly in climate adaptation terms, but also on the mitigation side.

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# 3. Energy network resiliency framework

With the IEA's energy resiliency framework as a general conceptual standard, the Acerra and Amsterdam pilot sites are taken as case studies, modelling and analyzing their networks through diverse scenarios' simulations to understand their specificities, and accordingly compare their results to gain insights on how to improve the network resiliency in general terms. In the case of this study, the resiliency improvement goal mainly looks at those scenarios analyzing their potential risk and the cost benefit estimations, also taking other factors into consideration to identify the most resilient scenarios as described in the subsections below.

Within the study, both pilots were modelled using IES software by:

- Gathering data from the local environment through various sources.
- Modelling the geometry of the districts and assigning specific energy data to each building.
- Calculating and calibrating the energy demand of each building and the entire district based on the thermophysical properties embedded in the IES calculation engine.
- Modelling the electrical network according to these energy demands.
- Simulating different resiliency alternatives to improve the responsiveness of the urban district and buildings in case of power outages.

The following section presents both Acerra and Amsterdam cases, delving in this analysis.

## 3.1 Acerra's pilot energy network

### Baseline characteristics

Pilot boundary: Acerra pilot site, including twenty-two mostly residential buildings which are delimited by the red line in the *Figure 4*.

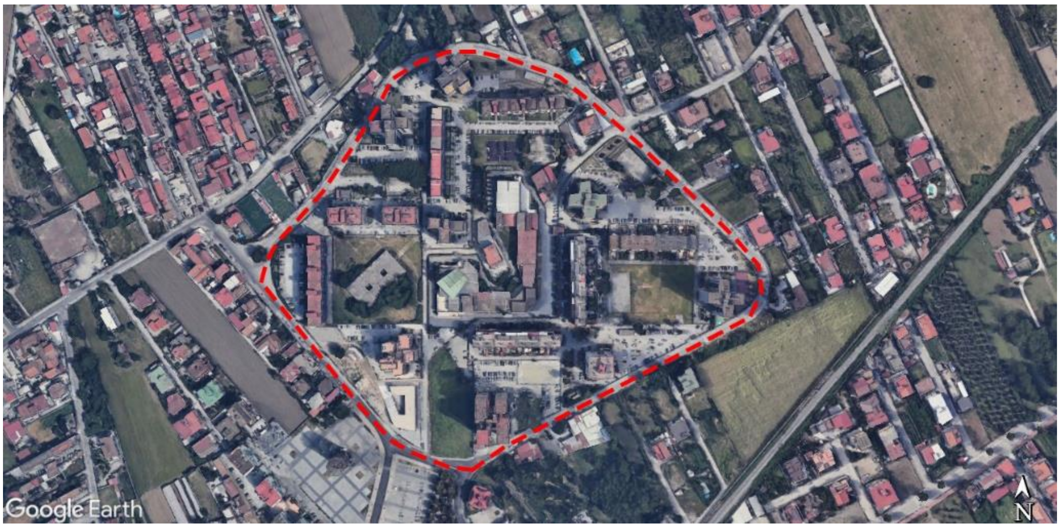

*Figure 4 Acerra Pilot site*

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<u>Main elements of Acerra's Digital Twin / virtual demonstrator</u> generation within IES software:

- Data collection from the pilot representatives at building and electrical network levels (ACER partner)
- Data gaps covered by Tabula database (Tabula webtool[4])
- Energy profiles from the ASHRAE[5] heating, refrigerating and air-conditioning international society
- Buildings geometry definition, data/attributes appointment, and calibration by IES consultants (iCD/iCIM software screenshot in the Figure below)
- Simulations for energy demand/consumption: simulated and divided into 5 categories within IES tool: equipment, lighting, auxiliary energy, cooling, heating and domestic hot water; each of them lead by an energy carrier (considered electricity for equipment, lighting, auxiliary, cooling and, only for a few buildings, heating and domestic hot water). The total electricity simulated is the total electricity demand that the grid must supply to those buildings.

ATTRIBUTES

| | |
|---|---|
| Name | ACER-Demostrator |
| Building storey height | 2.7 m |
| Building type | Multi Family |
| Derived Glazing ratio | 27% |
| External wall area | 1,620.5 m² |
| Footprint area | 498.88 m² |
| Level of Detail - Building | Full Glazing |
| Max bldg height | 21.8 m |
| Number of storeys | 6 |
| Object type | Building |
| Roof angle | 30° |
| Roof overlap | 0 m |
| Roof type | Flat |
| Total floor area | 2,993.28 m² |
| Z axis offset | 5.6 m |

ADVANCED - ENVELOPE

| | |
|---|---|
| Ceiling | 4 In. Light Weight Concrete Deck With False Ceiling (U = 1.04 W/m²·K) |
| Door | Wooden Door (U = 2.19 |

*Figure 5. Digital twin screenshot with the baseline scenario for Acerra pilot*

- Electrical network design from the plans/sketches provided by ACER partner; the electrical considerations have been developed based on the Main Node called "0", assuming the placement of network cabinets at building level too.
- Figure 6 shows the baseline screenshot of the network design into iVN (IES software).

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[4] TABULA WebTool - https://webtool.building-typology.eu/#bm
[5] ASHRAE - https://www.ashrae.org/

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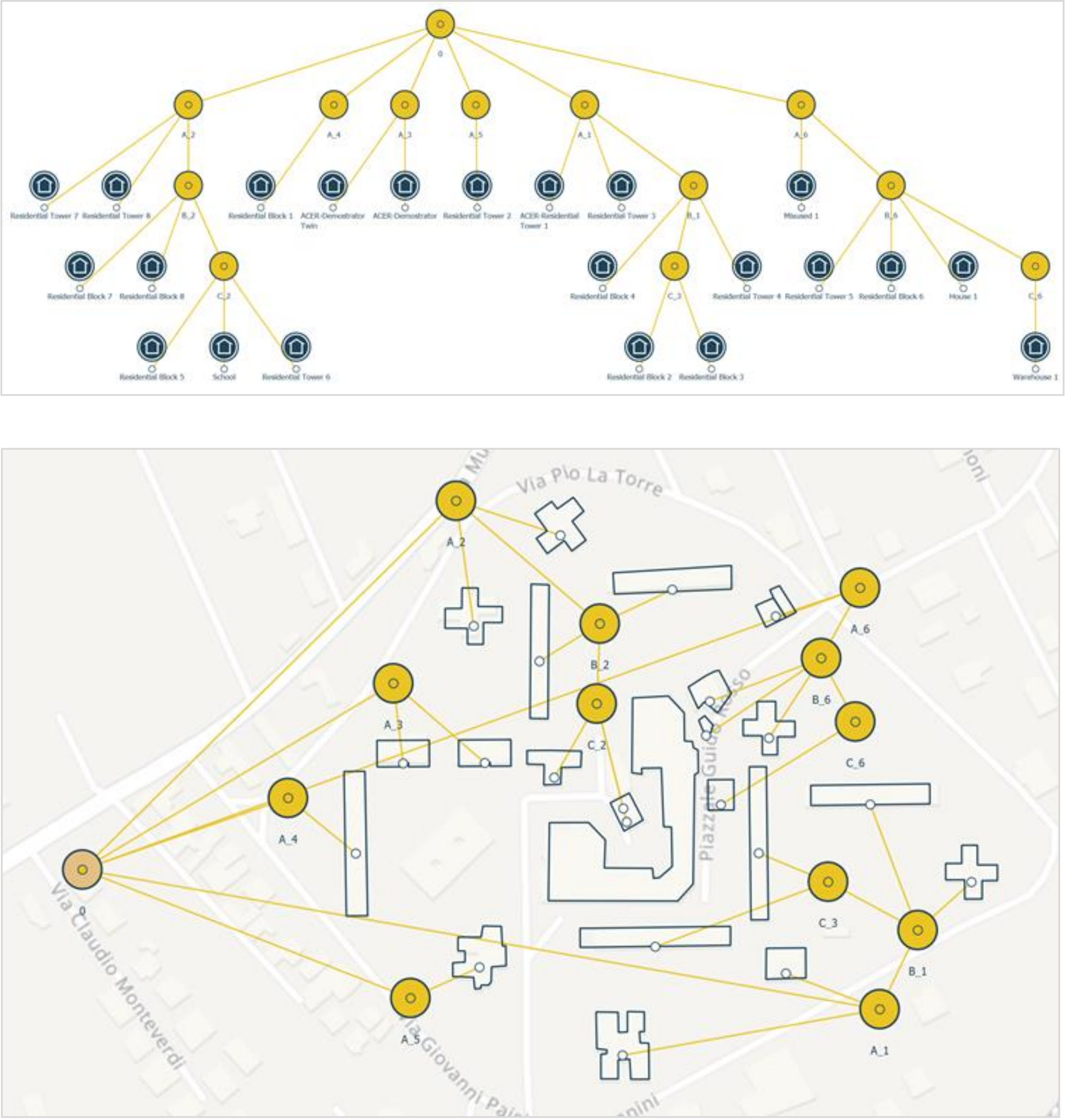

Figure 6 iVN Acerra - Electric Grid; baseline

<u>Vulnerability in regulatory terms</u>: According to Italian legislation (NTC 2018, approved by D.M. 17/01/2018), buildings such as schools, hospitals, and other structures serving public functions or of significant collective interest are classified as 'strategic buildings' or 'relevant buildings' within the regulatory framework. Among such structures, the Ferrajolo-Siani school located at via Mandonella 52$^{nd}$ is the sole building identified within this category, warranting the highest level of protection in the event of disruptive incidents.

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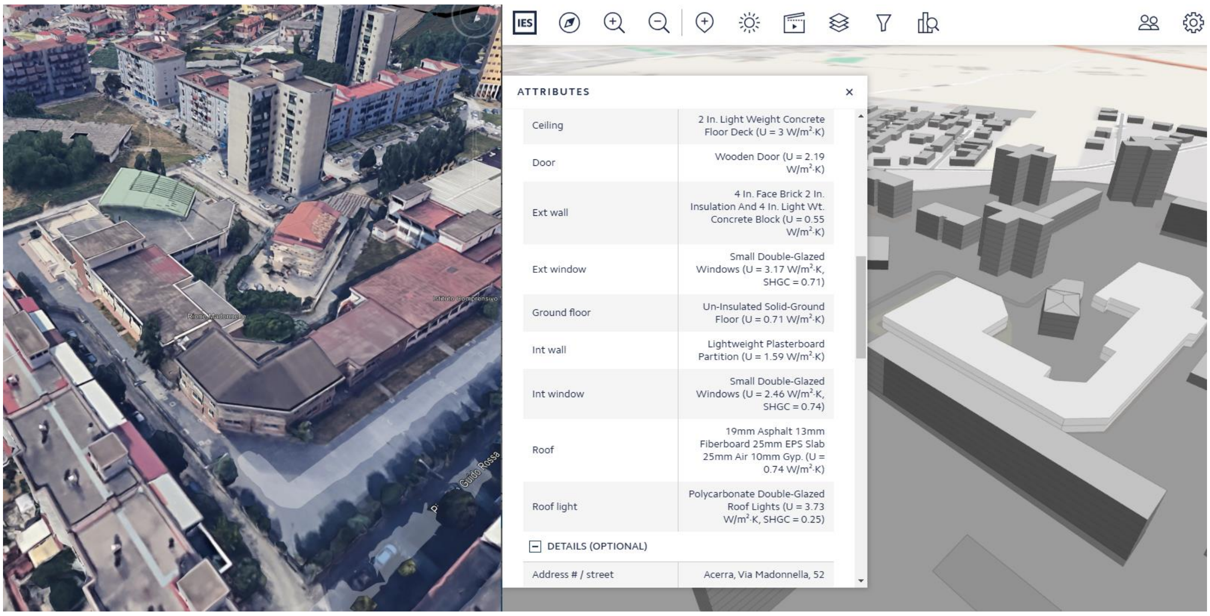

ATTRIBUTES

| | |
|---|---|
| Ceiling | 2 In. Light Weight Concrete Floor Deck (U = 3 $W/m^2 \cdot K$) |
| Door | Wooden Door (U = 2.19 $W/m^2 \cdot K$) |
| Ext wall | 4 In. Face Brick 2 In. Insulation And 4 In. Light Wt. Concrete Block (U = 0.55 $W/m^2 \cdot K$) |
| Ext window | Small Double-Glazed Windows (U = 3.17 $W/m^2 \cdot K$, SHGC = 0.71) |
| Ground floor | Un-Insulated Solid-Ground Floor (U = 0.71 $W/m^2 \cdot K$) |
| Int wall | Lightweight Plasterboard Partition (U = 1.59 $W/m^2 \cdot K$) |
| Int window | Small Double-Glazed Windows (U = 2.46 $W/m^2 \cdot K$, SHGC = 0.74) |
| Roof | 19mm Asphalt 13mm Fiberboard 25mm EPS Slab 25mm Air 10mm Gyp. (U = 0.74 $W/m^2 \cdot K$) |
| Roof light | Polycarbonate Double-Glazed Roof Lights (U = 3.73 $W/m^2 \cdot K$, SHGC = 0.25) |

⊟ DETAILS (OPTIONAL)

| | |
|---|---|
| Address # / street | Acerra, Via Madonnella, 52 |

*Figure 7. "Strategic building" within Acerra pilot site according to Italian legislation (Google Earth and IES software)*

## Resiliency improvement

Once presented the main baseline characteristics for Acerra's virtual demonstrator, some scenarios will be explored to analyze and hence understand how to improve the resiliency of the energy network. To mitigate the impact of disruptive events on the electrical grid, it is crucial to implement a comprehensive blend of technological, physical, and operational enhancements. Those key measures include grid modernization, consisting of i.e.: strengthening the physical infrastructure, enhancing fault detection and isolation capabilities, integrating Distributed Energy Resources (DER), enhancing fault detection and isolation capabilities, and deploying microgrids, as some examples to be explored on how to improve grid's resistance to extreme weather events.

For Acerra's virtual demonstrator, decentralized power generation (DER) was analyzed in detail, primarily due to software limitations and data availability. This analysis focuses on incorporating renewable energy sources into the grid, such as photovoltaic (PV) panels and electric battery storage, across four different scenarios. In the case of wind turbines, those were deemed unsuitable for an urban area, as well as a new small-scale natural gas solution, which are both invasive and require a significant investment. Furthermore, key benchmarks for the resilience improvement of those scenarios were included as critical benefits to be explored, such as enhanced grid stability, flexibility, a smoother energy transition, a stabilized energy supply during peak demand, a faster recovery from outages, and the ability to balance intermittent renewable energy sources while providing backup power during supply disruptions.

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### Scenarios characterization

Four scenarios have been developed and tested based on the previously outlined framework. These scenarios were designed to evaluate the performance, feasibility, and potential impact of decentralized power generation systems under varying conditions and constraints. This approach allowed for a comprehensive assessment of how different configurations and technologies could contribute to enhancing grid stability, resilience, and energy transition goals in Acerra's context:

- Scenario S1 - PV panels on the buildings' roof (covering 65% of the roof's surface if flat; 100% of the south pitch roof if inclined)
- Scenario S2 - PV panels on the buildings' roof (covering 25% of the roof's surface if flat; 100% of the south pitch roof if inclined)
- Scenario S3 – Scenario S1 + Single lithium battery storage for each building
- Scenario S4 – Scenario S1 + One lithium battery storage on the main node

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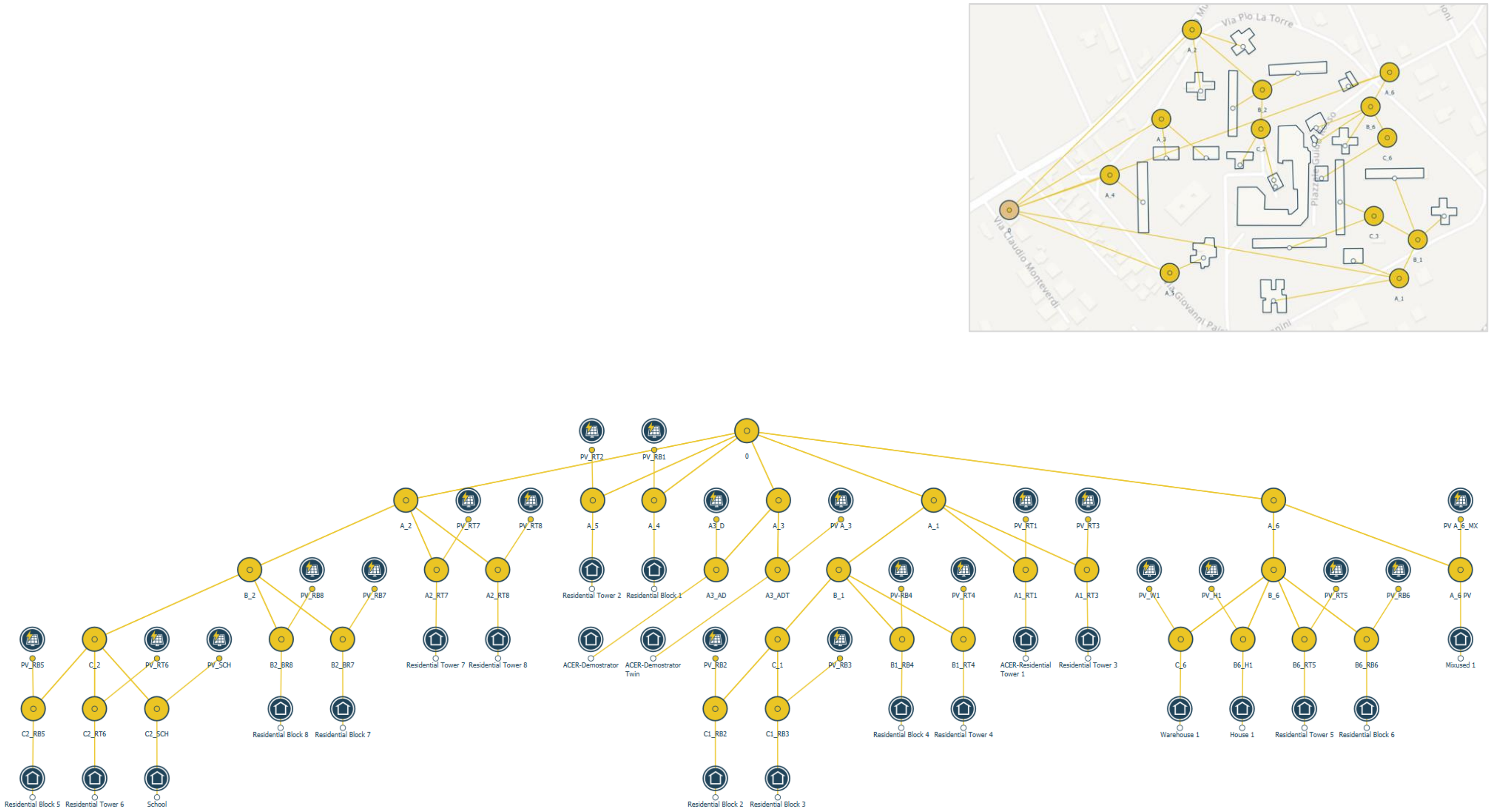

*Figure 8. iVN scenarios S1-S2 in Acerra's virtual demonstrator*

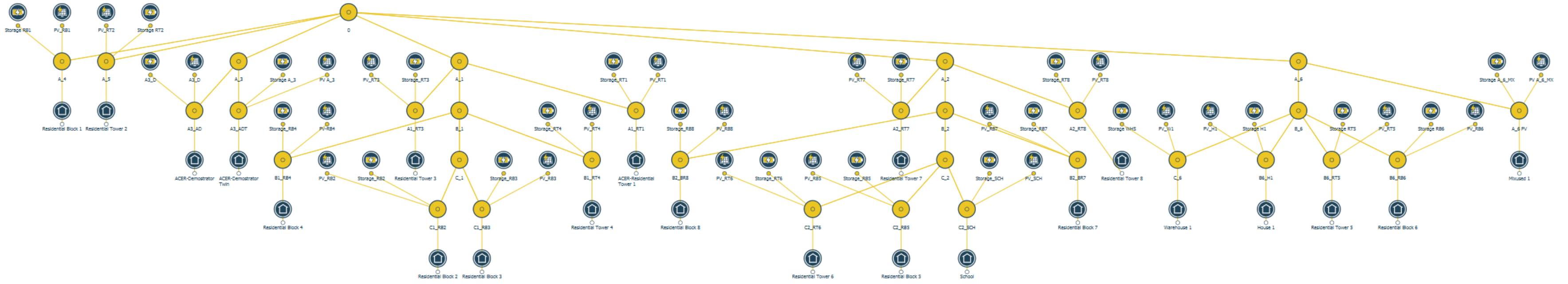

Figure 9. iVN scenario S3 in Acerra's virtual demonstrator

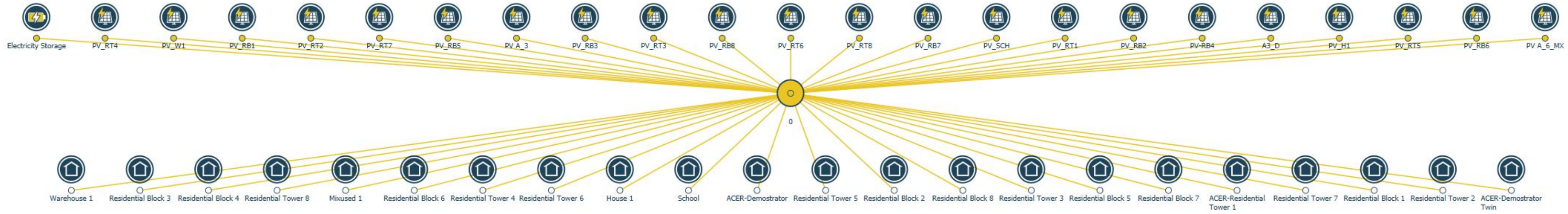

Figure 10. iVN scenario S4 in Acerra's virtual demonstrator

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Regarding the technical information about the PVs and electric storage batteries included in those scenarios, the key specifications are presented below

- The photovoltaic panels (PV_Acerra):
  - 550 Wp
  - Efficiency 0.21
  - Inclination 35 degree
  - Electrical and degradation factor equal to 0.99 (default value)
  - Temperature coefficient equal to 0.0040 1/K (default value)

- The electrical lithium battery storage capacity is calculated based on the average amount of excess electricity generated by each building on a daily basis, and then adjusted/rounded to standardized commercial values available on market batteries:
  - For S3: 10kW, 50kW, 100kW, 200kW, 500kW
  - For S4 5MW.

The table below presents a summary of the total electricity demand, the installed solar PV capacity and the installed battery capacity for each of the four analyzed scenarios.

*Table 2. Acerra Pilot Site – demand, PV capacity and battery capacity for BAU and scenarios*

| NAME OF THE BUILDING | TOTAL ELECTRICITY DEMAND [kWh] | INSTALLED SOLAR PV CAPACITY [kWp] | | | | INSTALLED BATTERY CAPACITY [kWh] | | |
|---|---|---|---|---|---|---|---|---|
| SCENARIO > | **BaU** | **S1** | **S2** | **S3** | **S4** | **S1** | **S2** | **S3** |
| **RESIDENTIAL TOWER 3** | 284,740 | 59.7 | 22.9 | 59.7 | 59.7 | 0.0 | | 100 |
| **RESIDENTIAL BLOCK 2** | 294,567 | 141.0 | 54.3 | 141.0 | 141.0 | 0.0 | | 500 |
| **RESIDENTIAL BLOCK 3** | 287,983 | 131.0 | 50.3 | 131.0 | 131.0 | 0.0 | | 500 |
| **RESIDENTIAL BLOCK 4** | 151,172 | 118.2 | 45.3 | 118.2 | 118.2 | 0.0 | | 500 |
| **RESIDENTIAL TOWER 4** | 406,389 | 71.5 | 27.4 | 71.5 | 71.5 | 0.0 | | 100 |
| **RESIDENTIAL TOWER 5** | 301,974 | 71.5 | 27.4 | 71.5 | 71.5 | 0.0 | | 50 |
| **RESIDENTIAL BLOCK 7** | 161,476 | 118.7 | 45.7 | 118.7 | 118.7 | 0.0 | | 500 |
| **RESIDENTIAL TOWER 6** | 208,000 | 56.6 | 21.8 | 56.6 | 56.6 | 0.0 | | 100 |
| **RESIDENTIAL TOWER 7** | 501,283 | 81.9 | 31.6 | 81.9 | 81.9 | 0.0 | | 100 |
| **RESIDENTIAL BLOCK 1** | 390,170 | 150.5 | 57.8 | 150.5 | 150.5 | 0.0 | | 500 |
| **RESIDENTIAL BLOCK 8** | 269,327 | 130.4 | 50.1 | 130.4 | 130.4 | 0.0 | | 500 |
| **RESIDENTIAL TOWER 8** | 409,080 | 81.9 | 32.4 | 81.9 | 81.9 | 0.0 | | 200 |
| **RESIDENTIAL TOWER 2** | 303,122 | 103.1 | 39.7 | 103.1 | 103.1 | 0.0 | | 200 |
| **ACER-RESIDENTIAL TWR 1** | 583,897 | 135.3 | 52.2 | 135.3 | 135.3 | 0.0 | | 200 |
| **RESIDENTIAL BLOCK 5** | 47,460 | 20.2 | 20.2 | 20.2 | 20.2 | 0.0 | | 50 |
| **HOUSE 1** | 5,897 | 7.7 | 2.9 | 7.7 | 7.7 | 0.0 | | 50 |
| **SCHOOL** | 1,581,442 | 673.6 | 259.0 | 673.6 | 673.6 | 0.0 | | 500 |
| **WAREHOUSE 1** | 38,103 | 39.1 | 15.0 | 39.1 | 39.1 | 0.0 | | 50 |
| **MIXUSED 1** | 41,640 | 9.6 | 9.6 | 9.6 | 9.6 | 0.0 | | 10 |
| **ACER DEMO (TWIN)** | 411,806 | 67.4 | 26.0 | 67.4 | 67.4 | 0.0 | | 200 |
| **ACER DEMO** | 511,718 | 67.4 | 26.0 | 67.4 | 67.4 | 0.0 | | 200 |
| **RESIDENTIAL BLOCK 6** | 48,326 | 52.4 | 20.2 | 52.4 | 52.4 | 0.0 | | 200 |

### Scenarios results: energy performance

Using the iVN IES software with the inputs and scenarios presented, the simulations have obtained the following energy performance results. Accordingly, the tables below provide a performance summary of the renewable energy generation scenarios, evaluated across multiple energy parameters. The results have been calculated for each building in the case study and for each of the four scenarios, which combine different resiliency measures. This detailed breakdown allows for straightforward comparison of values across the study, offering insights into how various measures impact renewable energy performance and system resilience.

- Total Electricity Demand: represents the total building electricity demand met by the grid, considering the contribution from photovoltaic (PV) systems.

- Total Renewable Energy Production: indicates the total electricity generated by the PV panels.

- Total Electricity Self-Consumption: Refers to the portion of renewable energy produced that is consumed entirely within the building.

### Scenarios results: economic performance

The study has also conducted a cost analysis of the various alternatives, based on the following premises outlined here, and with the results presented in the tables below:

- The estimated average electricity prices are 32c€/kWh for households and 21c€/kWh for non-households, based on data from Eurostat_Prices. The selling price of energy is assumed to be 10c€/kWh.

- The payback period (in years) is calculated by dividing the total investment cost (€) by the annual energy cost savings, which is the difference between the baseline operational cost and the scenario operational cost (referenced as PV_price_sell).

- The cost of electric battery installation is derived from a technical specification for a 100kWh battery system. This cost is proportionally scaled based on the actual storage capacity required for the project (referenced as Tec_sheet_Elec_Battery).

- However, cost analysis is excluded for Scenario 4 due to the complexity of estimating costs for each building when considering a centralized electric storage system.

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*Table 3. Energy performance analysis of the scenarios for Acerra*

| Name | Total Renewable energy production [kWh] | | | Total electricity stored [kWh] | Total electricity demand [kWh] | | | Total electricity Self Consumption [kWh] | | | Total Excess [kWh] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S1 | S2 | S3 | S3 | S1 | S2 | S3 | S1 | S2 | S3 | S1 | S2 | S3 |
| Residential Tower 3 | 69,848 | 26,771 | 69,848 | 22,747 | 243,162 | 259,479 | 220,415 | 41,578 | 25,261 | 64,325 | 28,270 | 1,510 | 5,523 |
| Residential Block 2 | 165,006 | 63,520 | 165,006 | 105,610 | 239,103 | 253,700 | 133,494 | 55,463 | 40,867 | 161,073 | 109,543 | 22,653 | 3,933 |
| Residential Block 3 | 153,325 | 58,896 | 153,325 | 98,516 | 235,182 | 250,004 | 136,665 | 52,802 | 37,979 | 151,318 | 100,523 | 20,917 | 2,007 |
| Residential Block 4 | 138,235 | 53,055 | 138,235 | 88,460 | 118,643 | 125,464 | 30,183 | 32,529 | 25,708 | 120,989 | 105,707 | 27,347 | 17,247 |
| Residential Tower 4 | 83,720 | 32,125 | 83,720 | 21,425 | 350,031 | 374,675 | 328,606 | 56,358 | 31,714 | 77,783 | 27,362 | 411 | 5,937 |
| Residential Tower 5 | 83,720 | 32,125 | 83,720 | 14,522 | 257,152 | 273,422 | 242,631 | 44,822 | 28,552 | 59,343 | 38,898 | 3,573 | 24,377 |
| Residential Block 7 | 138,966 | 53,542 | 138,966 | 22,223 | 127,515 | 135,335 | 31,396 | 33,961 | 26,141 | 130,080 | 105,004 | 27,400 | 8,886 |
| Residential Tower 6 | 66,197 | 25,554 | 66,197 | 25,007 | 174,788 | 186,249 | 149,781 | 33,211 | 21,751 | 58,219 | 32,986 | 3,803 | 7,978 |
| Residential Tower 7 | 95,889 | 36,993 | 95,889 | 87,324 | 436,503 | 464,772 | 423,075 | 64,780 | 36,511 | 78,208 | 31,109 | 482 | 17,680 |
| Residential Block 1 | 176,202 | 67,658 | 176,202 | 106,465 | 322,321 | 342,358 | 215,856 | 67,848 | 47,812 | 174,314 | 108,353 | 19,845 | 1,888 |
| Residential Block 8 | 152,594 | 58,653 | 152,594 | 98,470 | 218,060 | 231,547 | 119,590 | 51,268 | 37,781 | 149,738 | 101,327 | 20,872 | 2,857 |
| Residential Tower 8 | 98,809 | 37,966 | 98,809 | 38,649 | 350,258 | 373,294 | 311,609 | 58,822 | 35,785 | 97,471 | 39,988 | 2,181 | 1,338 |
| Residential Tower 2 | 120,713 | 46,484 | 120,713 | 52,273 | 251,474 | 267,741 | 199,201 | 51,648 | 35,381 | 103,920 | 69,065 | 11,103 | 16,792 |
| ACER-Residential Tower 1 | 158,435 | 61,086 | 158,435 | 49,076 | 494,203 | 527,843 | 445,127 | 89,693 | 56,053 | 138,769 | 68,742 | 5,033 | 19,666 |
| Residential Block 5 | 23,607 | 23,607 | 23,607 | 12,857 | 39,069 | 39,069 | 26,212 | 8,390 | 8,390 | 21,247 | 15,217 | 15,217 | 2,360 |
| House 1 | 9,005 | 3,407 | 9,005 | 4,358 | 4,750 | 4,965 | 392 | 1,147 | 932 | 5,505 | 7,858 | 2,475 | 3,500 |
| School | 788,526 | 303,242 | 788,526 | 60,589 | 1,007,183 | 1,333,041 | 946,594 | 574,259 | 248,400 | 634,848 | 214,267 | 54,841 | 153,678 |
| Warehouse 1 | 45,754 | 17,523 | 45,754 | 3,208 | 19,301 | 26,880 | 16,094 | 18,802 | 11,223 | 22,009 | 26,952 | 6,300 | 23,745 |
| Mixused 1 | 11,195 | 11,195 | 11,195 | 520 | 31,329 | 31,329 | 30,809 | 10,311 | 10,311 | 10,831 | 884 | 884 | 364 |
| ACER-Demostrator Twin | 78,853 | 30,422 | 78,853 | 49,237 | 385,889 | 394,333 | 336,651 | 25,917 | 17,472 | 75,154 | 52,936 | 12,949 | 3,698 |
| ACER-Demostrator | 78,853 | 30,422 | 78,853 | 47,225 | 482,541 | 492,137 | 435,316 | 29,178 | 19,581 | 76,403 | 49,675 | 10,840 | 2,450 |
| Residential Block 6 | 61,330 | 23,607 | 61,330 | 33,389 | 37,261 | 39,272 | 3,872 | 11,065 | 9,054 | 44,454 | 50,265 | 14,553 | 16,876 |

*Table 4. Cost analysis of the scenarios for Acerra*

| **Name** | **Total Cost Electricity** | | | | **Total Cost Elecitricity sell** | | | **Total Cost Installation** | | | **Pay back period [year]** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **BaU** | **S1** | **S2** | **S3** | **S1** | **S2** | **S3** | **S1** | **S2** | **S3** | **S1** | **S2** | **S3** |
| Residential Tower 3 | € 93,964 | € 80,243 | € 85,628 | € 72,737 | € 2,827 | € 151 | € 552 | € 89,505 | € 34,305 | € 127,351 | 5.4 | 4.0 | 5.8 |
| Residential Block 2 | € 97,207 | € 78,904 | € 83,721 | € 44,053 | € 10,954 | € 2,265 | € 393 | € 211,440 | € 81,390 | € 400,669 | 7.2 | 5.2 | 7.5 |
| Residential Block 3 | € 95,034 | € 77,610 | € 82,501 | € 45,100 | € 10,052 | € 2,092 | € 201 | € 196,470 | € 75,450 | € 385,699 | 7.2 | 5.2 | 7.7 |
| Residential Block 4 | € 49,887 | € 39,152 | € 41,403 | € 9,960 | € 10,571 | € 2,735 | € 1,725 | € 177,285 | € 67,980 | € 366,514 | 8.3 | 6.1 | 8.8 |
| Residential Tower 4 | € 134,108 | € 115,510 | € 123,643 | € 108,440 | € 2,736 | € 41 | € 594 | € 107,280 | € 41,160 | € 145,126 | 5.0 | 3.9 | 5.5 |
| Residential Tower 5 | € 99,651 | € 84,860 | € 90,229 | € 80,068 | € 3,890 | € 357 | € 2,438 | € 107,280 | € 41,160 | € 126,203 | 5.7 | 4.2 | 5.7 |
| Residential Block 7 | € 53,287 | € 42,080 | € 44,660 | € 10,361 | € 10,500 | € 2,740 | € 889 | € 178,065 | € 68,610 | € 367,294 | 8.2 | 6.0 | 8.4 |
| Residential Tower 6 | € 68,640 | € 57,680 | € 61,462 | € 49,428 | € 3,299 | € 380 | € 798 | € 84,825 | € 32,745 | € 122,671 | 5.9 | 4.3 | 6.1 |
| Residential Tower 7 | € 165,423 | € 144,046 | € 153,375 | € 139,615 | € 3,111 | € 48 | € 1,768 | € 122,865 | € 47,400 | € 160,711 | 5.0 | 3.9 | 5.8 |
| Residential Block 1 | € 128,756 | € 106,366 | € 112,978 | € 71,232 | € 10,835 | € 1,985 | € 189 | € 225,780 | € 86,700 | € 415,009 | 6.8 | 4.9 | 7.2 |
| Residential Block 8 | € 88,878 | € 71,960 | € 76,410 | € 39,465 | € 10,133 | € 2,087 | € 286 | € 195,525 | € 75,150 | € 384,754 | 7.2 | 5.2 | 7.7 |
| Residential Tower 8 | € 134,996 | € 115,585 | € 123,187 | € 102,831 | € 3,999 | € 218 | € 134 | € 122,865 | € 48,645 | € 198,557 | 5.2 | 4.0 | 6.1 |
| Residential Tower 2 | € 100,030 | € 82,986 | € 88,354 | € 65,736 | € 6,906 | € 1,110 | € 1,679 | € 154,680 | € 59,565 | € 230,372 | 6.5 | 4.7 | 6.4 |
| ACER-Residential Tower 1 | € 192,686 | € 163,087 | € 174,188 | € 146,892 | € 6,874 | € 503 | € 1,967 | € 203,010 | € 78,270 | € 278,702 | 5.6 | 4.1 | 5.8 |
| Residential Block 5 | € 15,662 | € 12,893 | € 12,893 | € 8,650 | € 1,522 | € 1,522 | € 236 | € 30,255 | € 30,255 | € 49,178 | 7.1 | 7.1 | 6.8 |
| House 1 | € 1,946 | € 1,568 | € 1,638 | € 129 | € 786 | € 247 | € 350 | € 11,535 | € 4,365 | € 30,458 | 9.9 | 7.9 | 14.1 |
| School | € 332,103 | € 211,508 | € 279,939 | € 198,785 | € 21,427 | € 5,484 | € 15,368 | € 1,010,400 | € 388,500 | € 1,199,629 | 7.1 | 6.7 | 8.1 |
| Warehouse 1 | € 8,002 | € 4,053 | € 5,645 | € 3,380 | € 2,695 | € 630 | € 2,374 | € 58,635 | € 22,455 | € 77,558 | 8.8 | 7.5 | 11.1 |
| Mixused 1 | € 13,741 | € 10,338 | € 10,338 | € 10,167 | € 88 | € 88 | € 36 | € 14,340 | € 14,340 | € 18,125 | 4.1 | 4.1 | 5.0 |
| ACER-Demostrator Twin | € 135,896 | € 127,343 | € 130,130 | € 111,095 | € 5,294 | € 1,295 | € 370 | € 101,040 | € 38,985 | € 176,732 | 7.3 | 5.5 | 7.0 |
| ACER-Demostrator | € 168,867 | € 159,238 | € 162,405 | € 143,654 | € 4,968 | € 1,084 | € 245 | € 101,040 | € 38,985 | € 176,732 | 6.9 | 5.2 | 6.9 |
| Residential Block 6 | € 15,947 | € 12,296 | € 12,960 | € 1,278 | € 5,026 | € 1,455 | € 1,688 | € 78,585 | € 30,255 | € 154,277 | 9.1 | 6.8 | 9.4 |

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Both the energy and economic performance analyses above highlight key trade-offs among the four scenarios:

- **Scenario S2** emerges as the most economically favorable, with the lowest installation costs and minimal electricity excess. Consequently, it achieves the shortest payback period, ranging from 3.9 to 7.9 years. However, this economic advantage comes at the expense of energy resilience, as S2 exhibits the lowest levels of self-consumption and renewable energy production, making it the least robust option. It is also important to note that neither Scenario S1 nor S2 includes batteries or storage systems, further undermining their resilience during disruptive events.

- **Scenario S3** represents the opposite case. While it minimizes electricity excess due to the integration of a storage battery in every building, the system's installation costs are significantly higher. This scenario prioritizes energy storage and resilience over cost-effectiveness.

- **Scenario S4** achieves a stored energy level of 1006 MWh, only slightly lower than the 1042 MWh stored in Scenario S3. The minimal difference is attributed to the limited excess renewable generation in Scenario S3, suggesting that both scenarios offer comparable storage outcomes despite differing system configurations.

These results stress the trade-offs between economic viability and energy resilience, highlighting the importance of aligning scenario selection with project priorities and objectives.

### Seasonal hazard events results

A sample of hazard events were analyzed in iVN software to understand their potential impact on the energy performance of the site. This analysis focused on a limited timeframe during a single day of the year, with the impacts varying significantly between the cold and warm seasons. Specifically, the effects were examined during the hottest week (July 20th to 26th) and the coldest week (February 10th to 16th), as determined by the statistical EnergyPlus[6] weather file. This analysis, conducted for the first scenario (S1), is crucial for understanding the impact of seasonal event hazards (e.g., heatwaves) on energy performance. The insights gained helped to draw conclusions that support selecting the most effective alternatives for enhancing the resilience of the energy system. The table below presents the energy performance results of the study regarding the hottest and coldest weeks of the year.

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[6] EnergyPlus, 2024. Napoli-Capodichino weather file. Accessed online on 6/11/2024: https://energyplus-weather.s3.amazonaws.com/europe_wmo_region_6/ITA/ITA_Napoli-Capodichino.162890_IGDG/ITA_Napoli-Capodichino.162890_IGDG.zip

*Table 5. Energy performance results regarding the hottest and coldest weeks of the year for Acerra*

| | TOTAL ELECTRICITY GENERATION [KWH] | TOTAL ELECTRICITY DEMAND [KWH] | TOTAL ELECTRICITY GENERATION [KWH] | TOTAL ELECTRICITY DEMAND [KWH] | WORST EFFECT WEEK (**H**OT/**C**OLD) |
|---|---|---|---|---|---|
| | **Cold Week** | | **Hot Week** | | |
| **ACER-DEMOSTRATOR TWIN** | 928 | 12,578 | 2,293 | 7,579 | C |
| **ACER-DEMOSTRATOR** | 928 | 15,661 | 2,293 | 9,374 | C |
| **RESIDENTIAL TOWER 3** | 822 | 3,844 | 2,031 | 11,378 | H |
| **RESIDENTIAL BLOCK 2** | 1,943 | 3,992 | 4,798 | 11,747 | H |
| **RESIDENTIAL BLOCK 3** | 1,806 | 3,712 | 4,458 | 12,696 | H |
| **RESIDENTIAL BLOCK 4** | 2,128 | 1,628 | 5,537 | 4,020 | C |
| **RESIDENTIAL TOWER 4** | 986 | 5,701 | 2,434 | 16,823 | H |
| **RESIDENTIAL TOWER 5** | 986 | 3,866 | 2,434 | 13,107 | H |
| **RESIDENTIAL BLOCK 7** | 1,637 | 2,140 | 4,041 | 7,108 | H |
| **RESIDENTIAL TOWER 6** | 780 | 2,769 | 1,925 | 8,945 | H |
| **RESIDENTIAL TOWER 7** | 1,130 | 11,166 | 2,788 | 15,043 | C |
| **RESIDENTIAL BLOCK 1** | 2,076 | 5,039 | 5,124 | 15,108 | H |
| **RESIDENTIAL BLOCK 8** | 1,637 | 1,798 | 4,041 | 4,437 | H |
| **RESIDENTIAL TOWER 8** | 1,164 | 5,431 | 2,873 | 17,232 | H |
| **RESIDENTIAL TOWER 2** | 1,422 | 3,986 | 3,510 | 12,643 | H |
| **ACER-RESIDENTIAL TOWER 1** | 1,866 | 8,021 | 4,607 | 24,278 | H |
| **RESIDENTIAL BLOCK 5** | 278 | 595 | 686 | 2,183 | H |
| **HOUSE 1** | 106 | 59 | 262 | 340 | H |
| **SCHOOL** | 9,289 | 38,820 | 22,929 | 37,615 | C |
| **WAREHOUSE 1** | 539 | 1,434 | 1,330 | 409 | C |
| **MIXUSED 1** | 132 | 511 | 326 | 1,843 | H |
| **RESIDENTIAL BLOCK 6** | 722 | 676 | 1,783 | 1,864 | H |

The results highlight varying situations, with the worst-case scenarios occurring in either the hot or cold weeks depending on several key factors:

- Electricity as a heating fuel: if electricity is used for heating, winter months see significantly higher electricity consumption.
- Solar radiation: reduced solar radiation during winter results in lower renewable energy generation.
- Summer cooling demand: in summer, higher auxiliary and cooling demands are observed, particularly when heating and domestic hot water systems rely on natural gas instead of electricity.

As a result, the performance outcomes vary for each building, influenced by factors such as building properties, the HVAC system in place, and the installed PV capacity. For potential retrofitting purposes, the inclusion of these factors in the decision-making process would impact the energy performance of the site and its resiliency as a whole.

## 3.2 Amsterdam's pilot energy network

### Baseline characteristics

A network resiliency investigation was conducted on 20 buildings located in an urban area of Amsterdam, as illustrated in the figure below. These buildings, constructed near each other and dating back to 1920, represent a diverse mix of uses: 13 are residential, 6 are mixed-use, and 2 serve as commercial units. All the buildings are equipped with gas boilers and radiator heating systems, operating with a setpoint temperature of 20°C.

*Figure 11: Pre-1920 buildings in Amsterdam*

The investigation focused solely on the electrical supply from the network grid to meet the electrical demand of each building. Three types of data—auxiliary, lighting, and equipment consumption—were simulated for each building using IES Intelligent Community Design (iCD) software. The table below shows the estimated annual electrical demand for each building, as simulated by iCD for a typical year without any disruptions.

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*Table 6. Business as usual (BaU) annual electrical demand*

| BUILDING | NAME | TOTAL ELECTRICITY DEMAND [KWH] **BAU SCENARIO** |
|---|---|---|
| **B1** | Eerste Egelantiersdwarsstraat 7 | 6,920 |
| **B2** | Egelantiersstraat 15 | 7,516 |
| **B3** | Egelantiersstraat 13 | 8,113 |
| **B4** | Egelantiersstraat 9 | 9,549 |
| **B5** | Egelantiersstraat 7 | 4,677 |
| **B6** | Egelantiersstraat 5 | 5,357 |
| **B7** | Egelantiersstraat 3 | 3,406 |
| **B8** | Healing People Jordaan - Massage Marin | 4,254 |
| **B9** | L'easeaway | 12,243 |
| **B10** | Prinsengracht 92 | 6,831 |
| **B11** | Eerste Egelantiersdwarsstraat 9 | 1,672 |
| **B12** | Eerste Egelantiersdwarsstraat 11 | 5,697 |
| **B13** | Eerste Egelantiersdwarsstraat 13 | 13,778 |
| **B14** | Egelantiersgracht 8 | 10,536 |
| **B15** | Egelantiersgracht 6 | 43,541 |
| **B16** | Prinsengracht 108 | 11,711 |
| **B17** | Prinsengracht 106 | 2,970 |
| **B18** | Prinsengracht 104 | 3,787 |
| **B19** | Prinsengracht 102 | 5,097 |
| **B20** | Prinsengracht 98 | 4,917 |
| **B21** | Café P96 | 26,831 |

Unlike in the Acerra case, the buildings are interconnected through a single electrical node, as illustrated in the figure below, using again the IES Intelligent Virtual Network (iVN) software. For Amsterdam pilot, in the event of extreme conditions, if the grid connection fails, all the buildings will be impacted.

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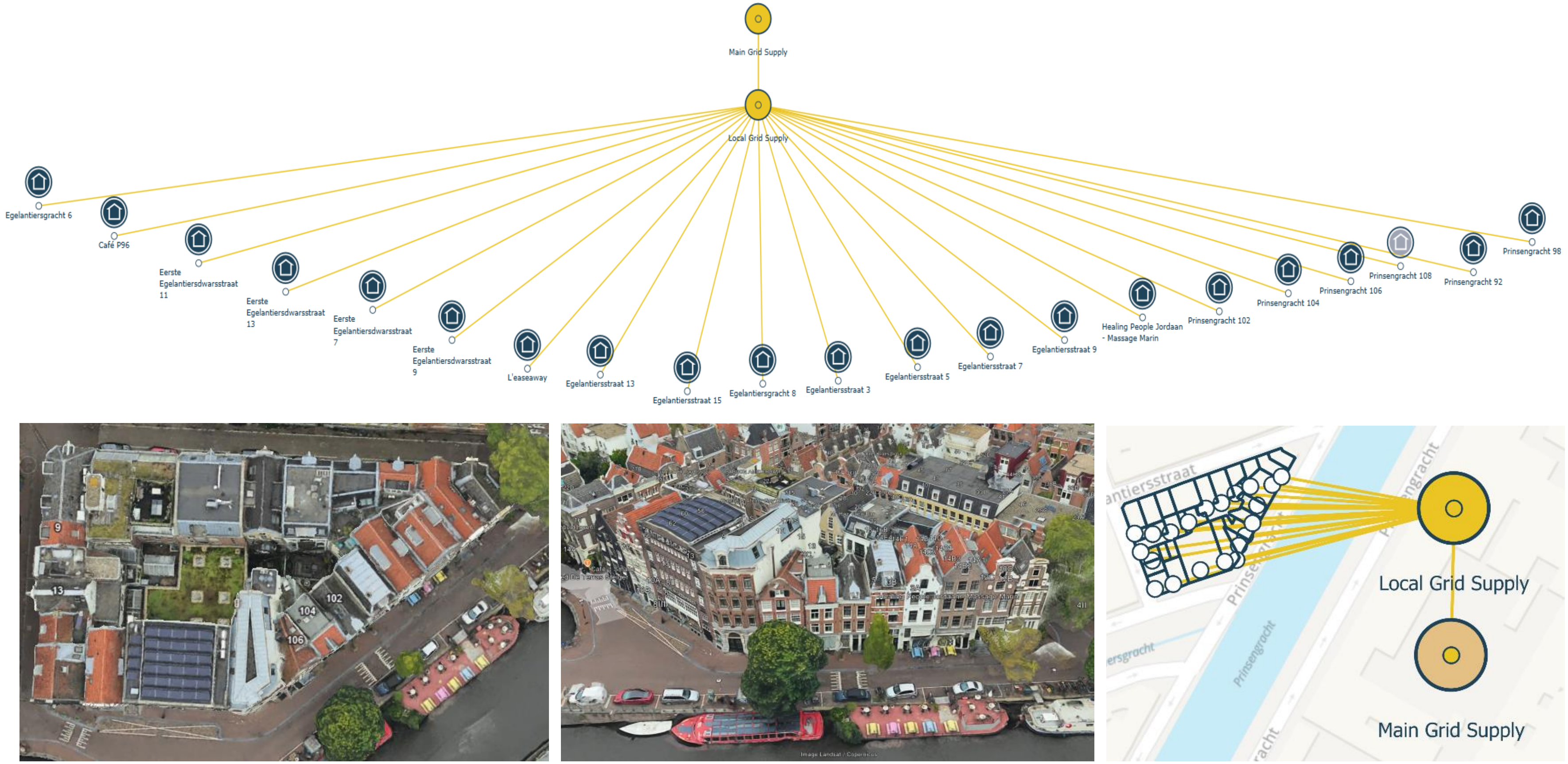

*Figure 12: Grid connection in iVN and Amsterdam virtual demonstrator (GoogleEarth)*

## Resiliency improvement

The buildings in the pilot area are particularly vulnerable during extreme events, such as severe weather or grid failures. To mitigate this risk, energy decentralization strategies were investigated under two different scenarios. One proposed solution is to install PV panels on the rooftops of these buildings. These PV panels would provide an immediate source of electricity to meet daytime demand in the event of a power outage, ensuring that essential functions can continue without interruption. This approach not only enhances the resilience of the buildings but also promotes the use of renewable energy sources.

In this sense, the table below lists the available rooftop areas on each building for installing PV panels for self-generation and consumption. Four buildings -Buildings 3, 5, 16, and 17- are not recommended for PV installation due to their roof geometry. Ideally, PV panels should face south to maximize sunlight conversion to electrical energy. However, many of the buildings have pitched roofs facing east and west. Therefore, the analysis considered a combination of panel orientations and the percentage of roof area that can be utilized for panel installation.

*Table 7. Rooftop area (m$^2$) to install PV panels*

| BUILDING | NAME | AREA(M$^2$) | | | |
|---|---|---|---|---|---|
| | | SOUTH | NORTH | EAST | WEST |
| **B1** | Eerste Egelantiersdwarsstraat 7 | 0 | 0 | 27.16 | 25.92 |
| **B2** | Egelantiersstraat 15 | 55 | 0 | 0 | 0 |
| **B3** | Egelantiersstraat 13 | 0 | 0 | 0 | 0 |
| **B4** | Egelantiersstraat 9 | 79 | 0 | 0 | 0 |
| **B5** | Egelantiersstraat 7 | 0 | 0 | 0 | 0 |
| **B6** | Egelantiersstraat 5 | 59 | 0 | 0 | 0 |
| **B7** | Egelantiersstraat 3 | 10 | 12 | 0 | 0 |
| **B8** | Healing People Jordaan - Massage Marin | | 12 | 0 | 0 |
| **B9** | L'easeaway | 0 | 0 | 20 | 26 |
| **B10** | Prinsengracht 92 | 0 | 0 | 12 | 16 |
| **B11** | Eerste Egelantiersdwarsstraat 9 | 0 | 0 | 6 | 6 |
| **B12** | Eerste Egelantiersdwarsstraat 11 | 15.5 | 0 | 0 | 0 |
| **B13** | Eerste Egelantiersdwarsstraat 13 | 0 | 0 | 30 | 30 |
| **B14** | Egelantiersgracht 8 | 0 | 0 | 30 | 25 |
| **B15** | Egelantiersgracht 6 | 223 | 0 | 0 | 0 |
| **B16** | Prinsengracht 108 | 0 | 0 | 0 | 0 |
| **B17** | Prinsengracht 106 | 0 | 0 | 0 | 0 |
| **B18** | Prinsengracht 104 | 23 | 0 | 0 | 0 |
| **B19** | Prinsengracht 102 | 0 | 0 | 16 | 16 |
| **B20** | Prinsengracht 98 | 40 | 0 | 0 | 0 |
| **B21** | Café P96 | 0 | 0 | 40 | 40 |

Based on the same approach of Acerra's pilot, the two following scenarios are guiding the resiliency analysis for the Amsterdam case:

1. All buildings' roof facing south (flat surface) will have 65% of the area covered with PV panels, while buildings' roofs facing north, east, and west areas will be 100% covered by PVs.
2. All buildings' roof facing south (flat surface) will have 25% of the area covered with PV panels, while buildings' roofs facing north, east and west areas will be 100% covered by PVs.

According to those 2 scenarios, the figure below shows the iVN network with PV installation for the buildings identified in the previous table. The modelling approach has been the same for both scenarios, just variating on the % of flat roof surface covered by PV panels.

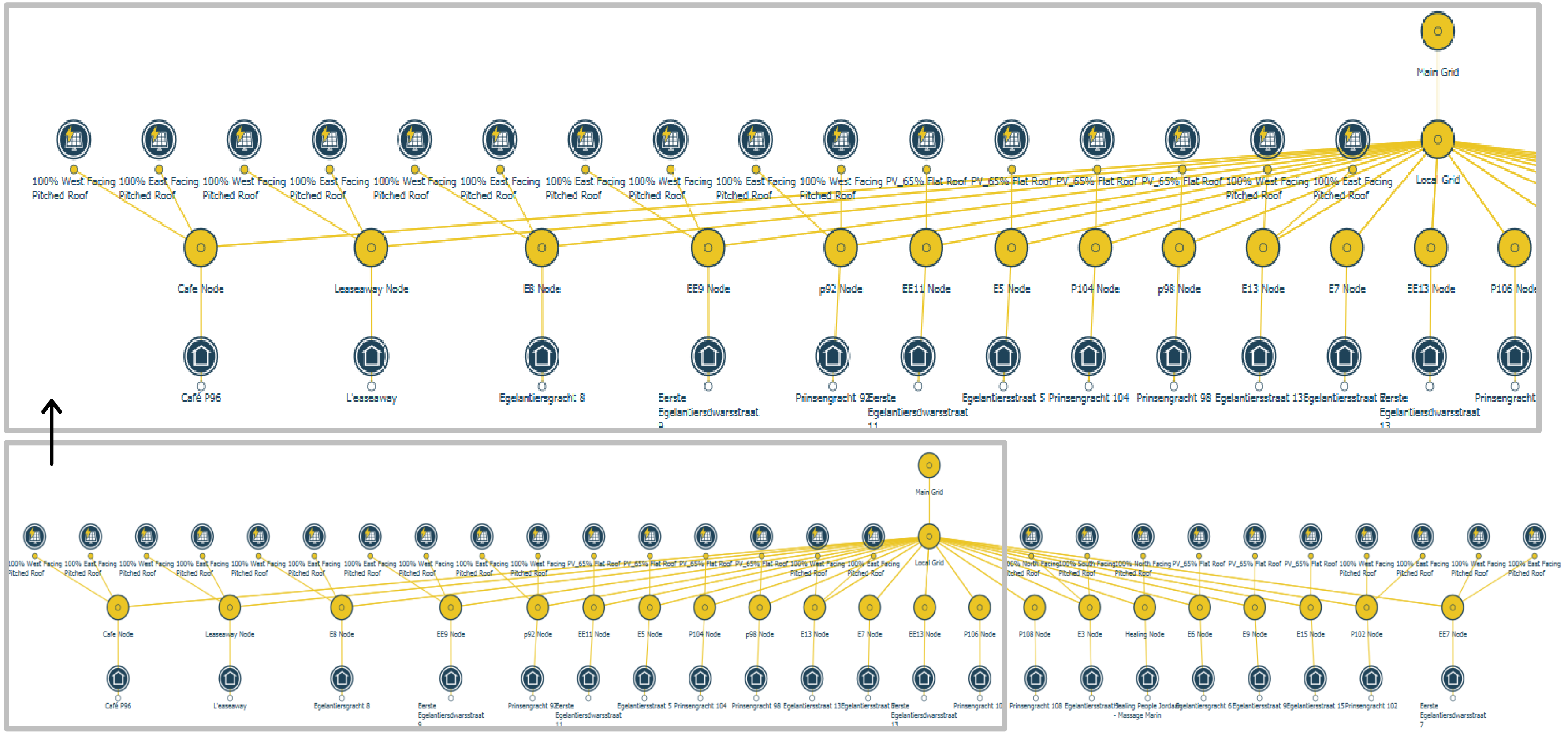

*Figure 13: iVN scenario with PV installation*

### Scenarios results: economic performance

Regarding the economic performance of the scenarios in the Amsterdam case, the results are significantly different to the Acerra case. The table below shows the cost of excess energy that can be sold to the grid, the cost of installation and payback period.

Usually, PV panels have 8 to 13 years of payback period (Strietman, 2023). However, for both scenarios the payback period is over 10 years, reaching up to 20 years for some buildings. Such low return of investment (ROI) is mainly due to the scarce roof area availability, the reduced number of buildings facing south, and the low-excess energy generated through those PVs. Finally, battery storage analysis was not considered as the ROI is very long just by installing PVs. In addition, there is a low excess of electricity produced by the PVs, which makes the electricity storage alternative not viable for the Amsterdam pilot[7].

*Table 8. Excess energy cost, installation cost, and payback period*

| BUILDING | NAME | TOTAL COST ELECTRICITY SOLD | | TOTAL COST OF INSTALLATION | | PAYBACK PERIOD [YEAR] | |
|---|---|---|---|---|---|---|---|
| | | **S1** | **S2** | **S1** | **S2** | **S1** | **S2** |
| **B1** | Eerste Egelantiersdwarsstraat 7 | € 110 | € 110 | € 11,818 | € 11,818 | 20.6 | 20.6 |
| **B2** | Egelantiersstraat 15 | € 65 | € 4 | € 7,598 | € 2,955 | 15.9 | 12.6 |
| **B3** | Egelantiersstraat 13 | € 104 | € 104 | € 12,663 | € 12,663 | 19.5 | 19.5 |
| **B4** | Egelantiersstraat 9 | € 99 | € 7 | € 10,763 | € 4,221 | 16.2 | 12.7 |
| **B5** | Egelantiersstraat 7 | € 0 | € 0 | € 0 | € 0 | - | - |
| **B6** | Egelantiersstraat 5 | € 96 | € 13 | € 8,020 | € 3,166 | 18.1 | 13.7 |
| **B7** | Egelantiersstraat 3 | € 20 | € 20 | € 4,643 | € 4,643 | 17.5 | 17.5 |
| **B8** | Healing People Jordaan - Massage Marin | € 0 | € 0 | € 2,533 | € 2,533 | 18.4 | 18.4 |
| **B9** | L'easeaway | € 15 | € 15 | € 9,708 | € 9,708 | 14.7 | 14.7 |
| **B10** | Prinsengracht 92 | € 11 | € 11 | € 5,909 | € 5,909 | 14.8 | 14.8 |
| **B11** | Eerste Egelantiersdwarsstraat 9 | € 19 | € 19 | € 2,533 | € 2,533 | 19.2 | 19.2 |
| **B12** | Eerste Egelantiersdwarsstraat 11 | € 2 | € 0 | € 2,110 | € 844 | 12.4 | 12.0 |
| **B13** | Eerste Egelantiersdwarsstraat 13 | € 0 | € 0 | € 0 | € 0 | - | - |
| **B14** | Egelantiersgracht 8 | € 59 | € 59 | € 11,607 | € 11,607 | 17.6 | 17.5 |
| **B15** | Egelantiersgracht 6 | € 106 | € 26 | € 30,601 | € 11,818 | 13.4 | 12.9 |
| **B16** | Prinsengracht 108 | € 0 | € 0 | € 0 | € 0 | - | - |
| **B17** | Prinsengracht 106 | € 0 | € 0 | € 0 | € 0 | - | - |
| **B18** | Prinsengracht 104 | € 14 | € 0 | € 3,166 | € 1,266 | 16.2 | 14.0 |
| **B19** | Prinsengracht 102 | € 44 | € 44 | € 6,753 | € 6,753 | 18.5 | 18.5 |
| **B20** | Prinsengracht 98 | € 13 | € 0 | € 5,487 | € 2,110 | 15.1 | 13.9 |
| **B21** | Café P96 | € 2 | € 2 | € 16,883 | € 16,883 | 14.5 | 14.5 |

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[7] Faaij, A. P. (2024, June 03). Driving the energy transition in the Netherlands. Retrieved from Innovation Network: https://www.innovationnewsnetwork.com/driving-the-energy-transition-in-the-netherlands/48160/

### Seasonal hazard events results

Like the analysis developed for Acerra, the table below shows the percentage of energy demand that can be covered by PVs on scenario S1 and scenario S2 during the hottest and coldest times of the year. Based on the weather profile used for the simulation, the week of heatwave falls between 04/06/2022 - 10/06/2022, with a highest temperature of 32°C; while the coldest is -8.4°C, expected to be between 12/02/2022 - 18/02/2022. Unfortunately, the buildings that cannot accommodate PV installations will face challenges, as they will lack self-sufficient power generation to meet their electrical demand during crisis events.

*Table 9. Percentage of energy demand that can be covered by PV production during grid collapse*

| BUILDING | NAME | GRID COLLAPSE DURING HIGHEST **SUMMER** TEMP. (04/06/2022 - 10/06/2022) | GRID COLLAPSE DURING COLDEST **WINTER** TEMP. (12/02/2022 - 18/02/2022) | GRID COLLAPSE DURING HIGHEST **SUMMER** TEMP. (04/06/2022 - 10/06/2022) | GRID COLLAPSE DURING COLDEST **WINTER** TEMP. (12/02/2022 - 18/02/2022) |
|---|---|---|---|---|---|
| | | S1 GRID COLLAPSE | | S2 GRID COLLAPSE | |
| **B1** | Eerste Egelantiersdwarsstraat 7 | 75% | 24% | 75% | 24% |
| **B2** | Egelantiersstraat 15 | 49% | 24% | 19% | 9% |
| **B3** | Egelantiersstraat 13 | 69% | 22% | 69% | 22% |
| **B4** | Egelantiersstraat 9 | 55% | 27% | 21% | 11% |
| **B5** | Egelantiersstraat 7 | 0% | 0% | 0% | 0% |
| **B6** | Egelantiersstraat 5 | 73% | 36% | 29% | 14% |
| **B7** | Egelantiersstraat 3 | 58% | 19% | 58% | 19% |
| **B8** | Healing People Jordaan - Massage Marin | 22% | 3% | 22% | 3% |
| **B9** | L'easeaway | 35% | 13% | 35% | 13% |
| **B10** | Prinsengracht 92 | 38% | 15% | 38% | 15% |
| **B11** | Eerste Egelantiersdwarsstraat 9 | 67% | 21% | 67% | 21% |
| **B12** | Eerste Egelantiersdwarsstraat 11 | 18% | 9% | 7% | 4% |
| **B13** | Eerste Egelantiersdwarsstraat 13 | 0% | 0% | 0% | 0% |
| **B14** | Egelantiersgracht 8 | 48% | 15% | 48% | 15% |
| **B15** | Egelantiersgracht 6 | 34% | 17% | 13% | 7% |
| **B16** | Prinsengracht 108 | 0% | 0% | 0% | 0% |
| **B17** | Prinsengracht 106 | 0% | 0% | 0% | 0% |
| **B18** | Prinsengracht 104 | 37% | 14% | 15% | 6% |
| **B19** | Prinsengracht 102 | 56% | 21% | 56% | 21% |
| **B20** | Prinsengracht 98 | 49% | 19% | 19% | 7% |
| **B21** | Café P96 | 27% | 10% | 27% | 10% |

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# 4. Conclusions

This report has analyzed the resiliency of the energy network from the energy demand perspective, considering potential disruptive events. Using the iVN software, key elements such as energy generation, distribution, and storage were examined.

The main conclusion is that without proactive intervention focused on resiliency, the protection of buildings during disruptive events is very limited. Therefore, it is crucial to be proactive in terms of policy, planning, technology, and engagement to deploy a more resilient energy grid from the energy demand perspective.

The analysis highlighted the importance of decentralized renewable energy production as a resiliency measure to mitigate dependency on the single mainstream flow of the electrical grid, which exposes building operations to blackouts during disruptive events. In this sense, the key factors influencing the introduction of renewable energy options include the climate zone, the geographic area (whether rural or urban), the shape of the building's roof, and the primary use of the building, such as residential, educational, or commercial.

The analysis revealed that the measures to be taken depend heavily on the context and these key factors. For example, a disruption event in Acerra could be more severe during the summer due to significant cooling demand, despite higher photovoltaic production. Additionally, the alignment of resiliency improvement, sustainability, and economic investments can sometimes be challenging, leading to difficult choices. In Amsterdam, for instance, a battery installation would enhance building resiliency but is economically unviable. Conversely, in Acerra, the scenario with fewer implemented photovoltaic panels has a lower payback time, making it economically attractive but riskier and less advisable for disruptive events due to lower self-consumption levels. Furthermore, buildings identified as strategic for the community should be prioritized within the resiliency strategy, as they will be key assets during the recovery stage.

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