



Consumer and Neighbourhood demand flexibility profiling Module

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D7.4 Consumer and Neighbourhood demand flexibility profiling Module

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Nomenclature

Abbreviation	Explanation
AI	Artificial Intelligence
API	Application Programming Interface
BDT	Building Digital Twin
CDT	Consumer Digital Twin
CIBSE	Chartered Institution of Building Services Engineers
CommDT	Community Digital Twin
DoA	Description of Action
DSM	Dynamic Simulation Modelling
DT	Digital Twin
iCD	Intelligent Community Design
iCIM	Intelligent City Information Model
iCL	Intelligent Community Lifecycle
iCL-DT	Intelligent Community Lifecycle – Digital Twin
iSCAN	Intelligent Control and Analysis
iPIM	Intelligent Portfolio Information Model
iVN	Intelligent Virtual Network Model
OSM	Open Street Map

Abbreviation	Explanation
RES	Renewable Energy Systems
TSOs	Transmission System Operators
VE	Virtual Environment

Summary

This present document is D7.3 “Consumer and Neighborhood demand flexibility profiling Module” of the TwinERGY project, funded by the European Commission’s Innovation and Networks Executive Agency (CINEA) under its Horizon 2020 Research and Innovation programme (H2020). The main objective of this deliverable is to use the capabilities of the consumer and communities Digital Twins methodology for calculating and profiling the potential flexibility and micro and macro level. The particular module is based both on physics-driven and data-driven modelling and simulation. Depending on the type of flexibility the appropriate modelling tool was deployed to calculate the amount of flexibility and its controllability aspects.

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1. Introduction

The flexibility model developed as a part of D6.2 TwinERGY Digital Twin framework will be used to optimize demand response with no disruption to consumers' comfort or daily routines. This is achieved using the Digital Twins that was developed in the D6.4 Digital Twin Interconnected Platform.

The demand profiles were optimised in line with the objective functions defined for all four pilot sites. This work uses the IES ICL platform for modelling the BDTs of each pilot site within the VE and using them then to create the CommDTs within the iVN and/or iCD, depending on the level of information available during the development time.

The next steps will be to connect the algorithm to the sensors and wearables real data from the Consumer DT once the modelling work has been completed.

2. Networking modelling

The Intelligent Virtual Network Model (iVN) project consists in the layout of the electricity network, where the interconnections between the electricity sources (the grid and the renewables) and the buildings are schematically presented. The logic behind the creation of the network is simple and follows the flow of the electricity, from the sources on top to the receiver on the bottom, as shown below.

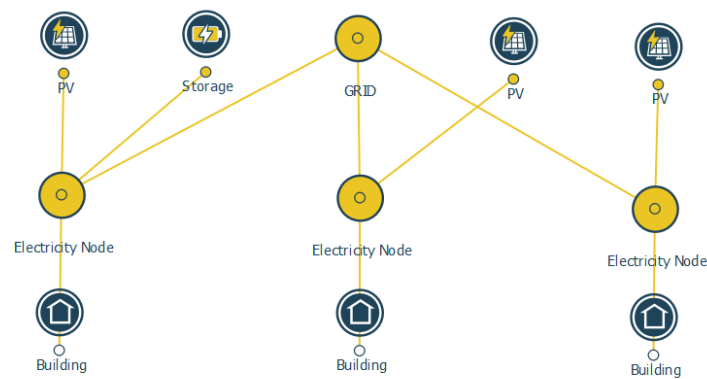


Figure 1: Example of a network

The first step to create the iVN project was to import the iCIM 3D model. This allowed not have only the entire terrain available in 3D with the specific geolocation of the buildings in the site, but also all data of the iCIM directly assigned to buildings.

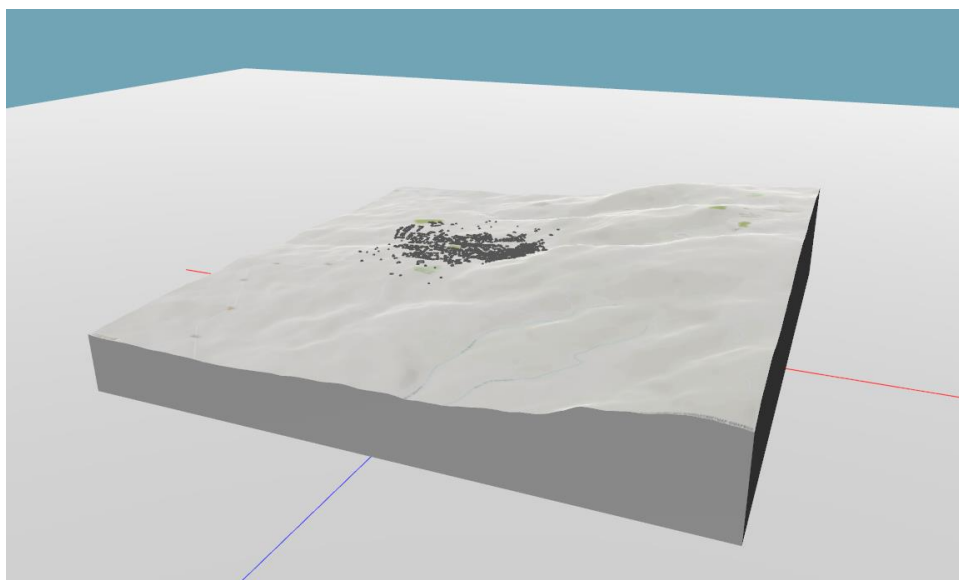


Figure 2: Example of an iCIM terrain imported in iVN

In addition, all buildings linked to iSCAN were also automatically populated with the iSCAN channels. These channels contain the electricity usage of each appliance in two different scenarios:

1. 'Baseline', which correspond to the timeseries of the energy simulation results for year 2021; such results were directly imported from VE models;
2. 'Measured data' or 'Default', which will contain the data extracted from utility bills.

Both sets of channels are imported in iVN.

Thanks to the instantaneous synchronisation between the ICL tools, any update in one tool will appear also in the others.

The second step consisted in the creation of the Network in 2D version, simply placing and connecting the buildings, the renewable sources, and the electricity nodes.

Finally, the renewables were populated with the data from datasheets, documentation, and calculations. The missing information was filled with reasonable or average values.

Benetutti

The terrain created in iCD was imported in iCIM and iVN.



Figure 3: iCD and iCIM terrains

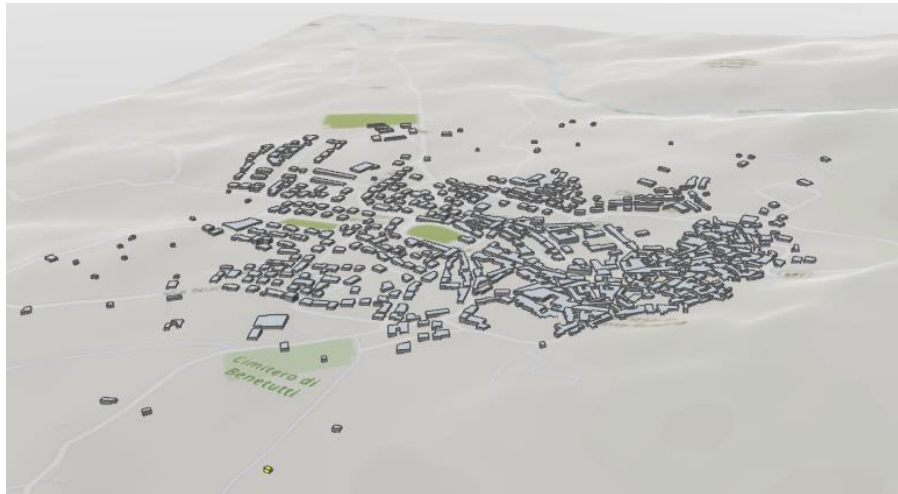
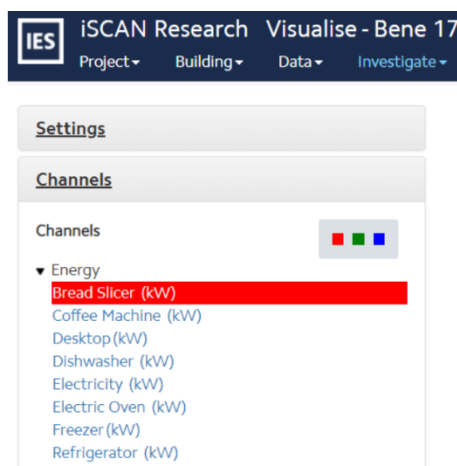


Figure 4: iVN terrain

The iSCAN channels of all appliances are automatically assigned to the iVN buildings. Here an example for Building 17 (Figure 5) . For each appliance in iVN there are 2 profiles, baseline and default, corresponding to simulation results and utility bills data respectively.



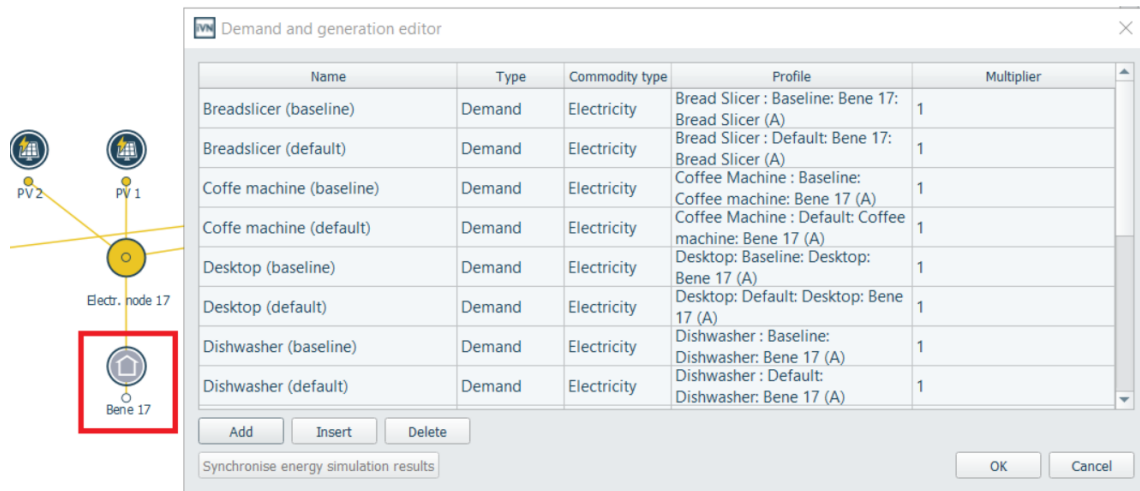


Figure 5: Appliances channels in iSCAN (first image on top) and in iVN (second image on the bottom).

Once the iCIM was imported, it was possible to create the Electricity Network, shown in the image below. The buildings are directly connected with the Grid and the renewable sources.

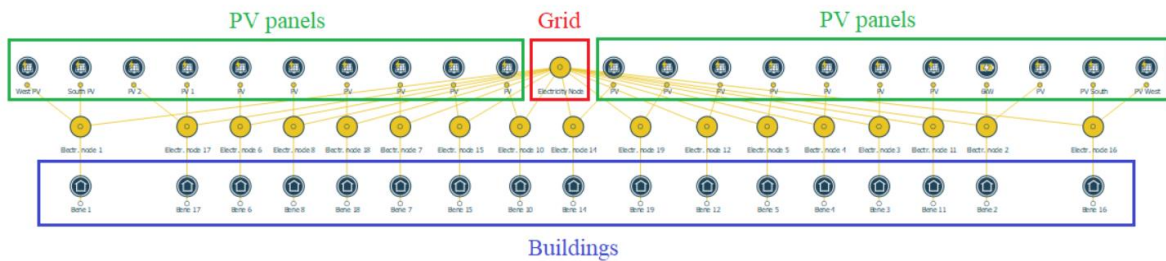


Figure 6: Electricity Network of Benetutti.

All buildings of the site are supported by photovoltaic generation. Only in Building 2 there is also a battery of 6kW to store the electricity produced by PV panels.

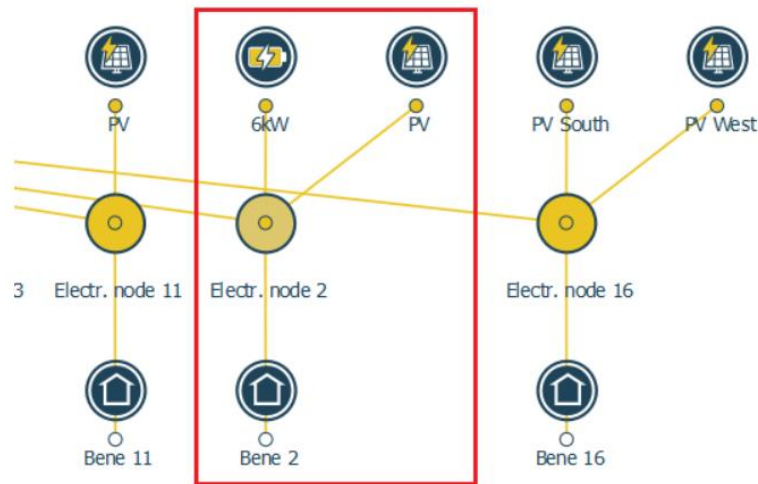


Figure 7: Detail of the Electricity Network: Building 2.

Finally, renewable sources were manually characterised.

Specifically:

- Area, inclination, and Azimut for PV panels and Solar heating panels were extracted from google maps;
- The efficiency was either directly extracted from the datasheet of the PV panels (if their model was known) or calculated considering the peak load and the area occupied;
- The battery storage of BENE-2 was populated with data from the technical sheet.

The following tables showcase the renewables settings for each building. Some of the buildings (BENE-1, BENE-16, BENE-17) have PV panels facing two different sides, so they have been separated and assigned a different Azimut.

The two tables of BENE-2 describe the PV panels and battery storage data respectively.

BENE-1		BENE-1	
Data Inspector		Data Inspector	
Property	Benetutti, Italy	Property	Benetutti, Italy
Name	South PV	Name	West PV
ID	e3e0f30b-5101-4021-1	ID	0fc4508a-e630-4675-2
Object Type	PV Array	Object Type	PV Array
▼ iVN PV array		▼ iVN PV array	
Category	Custom	Category	Custom
Area (m ²)	11.00	Area (m ²)	12.00
Available provision profile	On continuously	Available provision profile	On continuously
Azimuth (°)	180.00	Azimuth (°)	270.00
Degradation factor	1.00	Degradation factor	1.00
Electrical conversion	1.00	Electrical conversion	1.00
Inclination (°)	15.00	Inclination (°)	15.00
Nominal cell temperature (°C)	45.00	Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.20	PV Module nominal efficiency	0.20
Reference irradiance for NOCT (W/m ²)	800.00	Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00	Shading factor	1.00
Temperature coefficient (/K)	0.0001	Temperature coefficient (/K)	0.0001

BENE-2		BENE-2	
Data Inspector		Data Inspector	
Property	Benetutti, Italy	Property	Benetutti, Italy
Name	PV	Name	6kW
ID	96703227-f771-4d06-1	ID	f473ea6c-0009-4f52-8d
Object Type	PV Array	Object Type	Electricity Storage
▼ iVN PV array		▼ iVN electricity storage	
Category	Custom	Category	Custom
Area (m ²)	23.20	Available charging flux profile	On continuously
Available provision profile	On continuously	Available discharging flux profile	On continuously
Azimuth (°)	195.00	Charge loss factor	0.05
Degradation factor	1.00	Control type	Passive
Electrical conversion	1.00	Discharge loss factor	0.05
Inclination (°)	10.00	Initial stored energy (kWh)	0.00
Nominal cell temperature (°C)	45.00	Leakage loss factor (/30d)	0.02
PV Module nominal efficiency	0.15	Maximum charging flux (kW)	2.50
Reference irradiance for NOCT (W/m ²)	800.00	Maximum discharging flux (kW)	2.50
Shading factor	1.00	Storage capacity (kWh)	6.00
Temperature coefficient (/K)	0.0001	Stored energy indirect CO2 emissio...	0.28

BENE-3		BENE-4	
Data Inspector		Data Inspector	
Property	Benetutti, Italy	Property	Benetutti, Italy
Name	PV	Name	PV
ID	f49c2de3-0d05-4e6c-1	ID	3fcd70a0-4872-4607-1
Object Type	PV Array	Object Type	PV Array
▼ iVN PV array		▼ iVN PV array	
Category	Custom	Category	Custom
Area (m ²)	22.30	Area (m ²)	13.30
Available provision profile	On continuously	Available provision profile	On continuously
Azimuth (°)	180.00	Azimuth (°)	180.00
Degradation factor	1.00	Degradation factor	1.00
Electrical conversion	1.00	Electrical conversion	1.00
Inclination (°)	15.00	Inclination (°)	15.00
Nominal cell temperature (°C)	45.00	Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.22	PV Module nominal efficiency	0.23
Reference irradiance for NOCT (W/m ²)	800.00	Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00	Shading factor	1.00
Temperature coefficient (/K)	0.0001	Temperature coefficient (/K)	0.0001

BENE-5

Data Inspector	
Property	Benetutti, Italy
Name	PV
ID	49646711-8c7b-4213-
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	19.90
Available provision profile	On continuously
Azimuth (°)	180.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	15.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.19
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BENE-6

Data Inspector	
Property	Benetutti, Italy
Name	PV
ID	1e9dd5a1-4bcf-4e50-
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	36.50
Available provision profile	On continuously
Azimuth (°)	180.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	15.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.10
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BENE-7

Data Inspector	
Property	Benetutti, Italy
Name	PV
ID	26ae2891-d1d6-4f0d-
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	11.40
Available provision profile	On continuously
Azimuth (°)	190.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	15.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.23
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BENE-8

Data Inspector	
Property	Benetutti, Italy
Name	PV
ID	84b573e2-e263-429c-
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	30.80
Available provision profile	On continuously
Azimuth (°)	72.80
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	15.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.20
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BENE-10

Data Inspector	
Property	Benetutti, Italy
Name	PV
ID	3c7b4ca9-570e-4ea3-
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	19.10
Available provision profile	On continuously
Azimuth (°)	180.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	10.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.19
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BENE-11

Data Inspector	
Property	Benetutti, Italy
Name	PV
ID	dc7f131b-aa22-4dd9-
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	35.00
Available provision profile	On continuously
Azimuth (°)	225.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	10.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.11
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BENE-12

Data Inspector	
Property	Benetutti, Italy
Name	PV
ID	dcc819bc-fb3f-4dc7-8
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	22.00
Available provision profile	On continuously
Azimuth (°)	180.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	10.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.18
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BENE-14

Data Inspector	
Property	Benetutti, Italy
Name	PV
ID	b0725f6d-2079-4a51-
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	35.00
Available provision profile	On continuously
Azimuth (°)	225.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	15.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.18
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BENE-15

Data Inspector	
Property	Benetutti, Italy
Name	PV
ID	db082704-9de7-4c0f-
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	10.00
Available provision profile	On continuously
Azimuth (°)	180.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	15.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.20
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BENE-16

Data Inspector	
Property	Benetutti, Italy
Name	PV South
ID	2649641b-8ecc-4966-
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	18.00
Available provision profile	On continuously
Azimuth (°)	180.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	15.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.10
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BENE-16

Data Inspector	
Property	Benetutti, Italy
Name	PV West
ID	e7ed262a-064f-4d88-
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	13.00
Available provision profile	On continuously
Azimuth (°)	90.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	15.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.10
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BENE-17

Data Inspector	
Property	Benetutti, Italy
Name	PV 1
ID	256479ba-d53a-4d64-
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	27.40
Available provision profile	On continuously
Azimuth (°)	180.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	15.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.23
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BENE-17

Data Inspector	
Property	Benetutti, Italy
Name	PV 2
ID	1cfbb3a0-1e71-4d70-
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	27.40
Available provision profile	On continuously
Azimuth (°)	215.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	15.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.23
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BENE-18

Data Inspector	
Property	Benetutti, Italy
Name	PV
ID	c5bafa88-2a1a-4be0-
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	50.00
Available provision profile	On continuously
Azimuth (°)	210.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	15.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.23
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BENE-19

Data Inspector	
Property	Benetutti, Italy
Name	PV
ID	0aab1575-8763-42ec-
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	70.80
Available provision profile	On continuously
Azimuth (°)	210.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	15.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.23
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

Figure 8: Renewables in iVN in Benetutti.

Hagedorn

The terrain created in iCD was imported in iCIM and iVN.



Figure 9: iCD and iCIM terrains in Hagedorn.



Figure 10: iVN terrain in Hagedorn.

The iSCAN channels of all appliances are automatically assigned to the iVN buildings. Here an example for House 2. For each appliance in iVN there are 2 profiles, baseline, and default, corresponding to simulation results and utility bills data respectively.

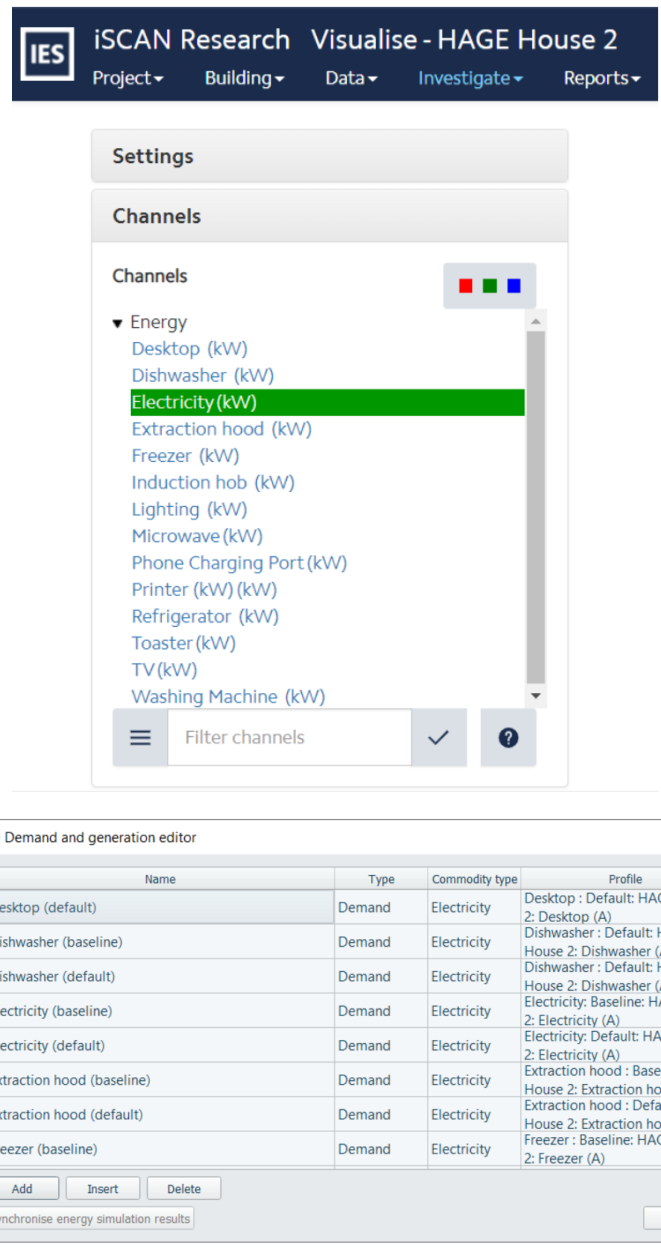


Figure 11: Appliances channels in iSCAN (first image on top) and in ivN (second image on the bottom).

Once the iCIM was imported, it was possible to create the Electricity Network, shown in the image below.

The buildings are directly connected with the Grid and the renewable sources.



Figure 12: Electricity Network of Hagedorn.

Buildings 3, 4, 7, 11, 14, 24, 32, and 42 have PV panels.

Buildings 17 and 26 have Solar Heating panels.

The pictures below show the details of some buildings with renewable sources.

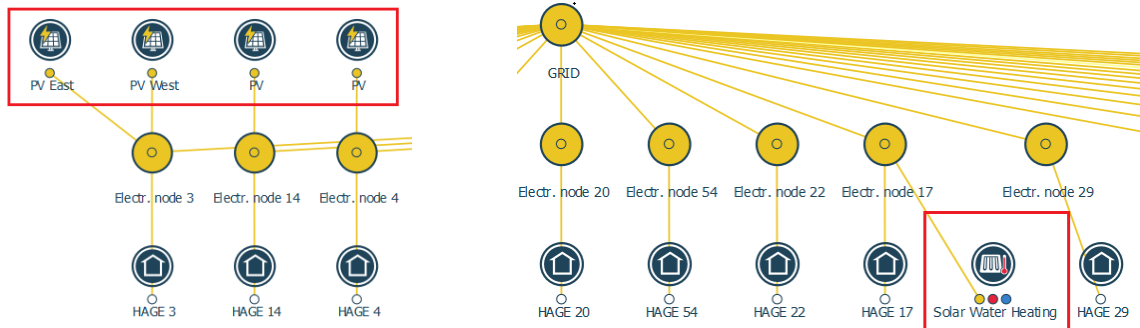


Figure 13: Details of the Electricity Network.

Finally, renewable sources were manually characterised. Specifically:

- Area, inclination, and Azimut for PV panels and Solar heating panels were extracted from google maps;
- The efficiency of the PV panels of HAGE-3 and HAGE-4 was calculated considering the peak load and the area occupied;
- The efficiency of PV panels assigned to the rest of the buildings is 0.18, which is the average value for PV panels present in the market, due to lack of model specifications;
- The efficiency of Solar heating panels assigned is 0.76, which is the average value for solar heating panels present in the market, due to lack of model specifications.

The following tables showcase the renewables settings for each building.

- HAGE-4, HAGE-7, HAGE-11, HAGE-14, HAGE-42 have PV panels facing one side;
- HAGE-3, HAGE-24, HAGE-32 have PV panels facing two different sides, so they have been separated and assigned a different Azimut;
- HAGE-17 and HAGE-26 have solar heating panels;
- The rest of the buildings do not have integrated renewables.

HAGE-3

Data Inspector		Data Inspector	
Property	TWINErgy Hagedorn, G	Property	TWINErgy Hagedorn, G
Name	East PV	Name	West PV
ID	527fb497-eb51-4ae6-9	ID	05f99a5f-bf58-41af-a7
Object Type	PV Array	Object Type	PV Array
▼ iVN PV array		▼ iVN PV array	
Category	Custom	Category	Custom
Area (m ²)	35.00	Area (m ²)	10.00
Available provision profile	On continuously	Available provision profile	On continuously
Azimuth (°)	270.00	Azimuth (°)	90.00
Degradation factor	1.00	Degradation factor	1.00
Electrical conversion	1.00	Electrical conversion	1.00
Inclination (°)	35.00	Inclination (°)	35.00
Nominal cell temperature (°C)	45.00	Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.21	PV Module nominal efficiency	0.21
Reference irradiance for NOCT (W/m ²)	800.00	Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00	Shading factor	1.00
Temperature coefficient (/K)	0.0001	Temperature coefficient (/K)	0.0001

HAGE-3

HAGE-4

Data Inspector		Data Inspector	
Property	TWINErgy Hagedorn, G	Property	TWINErgy Hagedorn, G
Name	South PV	Name	PV
ID	d5f9a547-7ae1-4448-a	ID	431bb973-a2fe-4c7e-a
Object Type	PV Array	Object Type	PV Array
▼ iVN PV array		▼ iVN PV array	
Category	Custom	Category	Custom
Area (m ²)	63.00	Area (m ²)	72.00
Available provision profile	On continuously	Available provision profile	On continuously
Azimuth (°)	190.00	Azimuth (°)	190.00
Degradation factor	1.00	Degradation factor	1.00
Electrical conversion	1.00	Electrical conversion	1.00
Inclination (°)	45.00	Inclination (°)	45.00
Nominal cell temperature (°C)	45.00	Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.23	PV Module nominal efficiency	0.18
Reference irradiance for NOCT (W/m ²)	800.00	Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00	Shading factor	1.00
Temperature coefficient (/K)	0.0001	Temperature coefficient (/K)	0.0001

HAGE-7

HAGE-11

Data Inspector		Data Inspector	
Property	TWINErgy Hagedorn, G	Property	TWINErgy Hagedorn, G
Name	PV	Name	PV
ID	9f2f2059-4228-4b72-bf	ID	7ab867cc-bca6-4f8e-a3
Object Type	PV Array	Object Type	PV Array
▼ iVN PV array		▼ iVN PV array	
Category	Custom	Category	Custom
Area (m ²)	52.00	Area (m ²)	24.00
Available provision profile	On continuously	Available provision profile	On continuously
Azimuth (°)	180.00	Azimuth (°)	180.00
Degradation factor	1.00	Degradation factor	1.00
Electrical conversion	1.00	Electrical conversion	1.00
Inclination (°)	45.00	Inclination (°)	45.00
Nominal cell temperature (°C)	45.00	Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.18	PV Module nominal efficiency	0.18
Reference irradiance for NOCT (W/m ²)	800.00	Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00	Shading factor	1.00
Temperature coefficient (/K)	0.0001	Temperature coefficient (/K)	0.0001

HAGE-14

HAGE-24

Data Inspector	
Property	TWINErgy Hagedorn, G
Name	PV South
ID	dc5f0a37-5e8a-4fe7-96
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	30.00
Available provision profile	On continuously
Azimuth (°)	185.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	40.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.18
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

HAGE-24

Data Inspector	
Property	TWINErgy Hagedorn, G
Name	PV East
ID	62d13ee6-c203-4f20-af
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	25.00
Available provision profile	On continuously
Azimuth (°)	95.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	40.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.18
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

HAGE-32

Data Inspector	
Property	TWINErgy Hagedorn, G
Name	PV West
ID	52ed01e9-92ee-40e7-8
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	8.80
Available provision profile	On continuously
Azimuth (°)	270.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	45.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.18
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

HAGE-32

Data Inspector	
Property	TWINErgy Hagedorn, G
Name	PV East
ID	197480ab-5a5c-4d6d-9
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	35.00
Available provision profile	On continuously
Azimuth (°)	90.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	45.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.18
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

HAGE-42

Data Inspector	
Property	TWINErgy Hagedorn, G
Name	PV
ID	22e0418b-1135-48c7-a
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	22.50
Available provision profile	On continuously
Azimuth (°)	180.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	50.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.18
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

HAGE-17		HAGE-26	
Property	TWINErgy Hagedorn, Ger	Property	TWINErgy Hagedorn, Ger
Name	Solar Water Heating	Name	Solar Water Heating
ID	4306776a-9aea-48ed-9d	ID	35908059-5a1c-4354-ac:
Object Type	Solar Water Heating	Object Type	Solar Water Heating
▼ iVN solar water heating		▼ iVN solar water heating	
Category	Custom	Category	Custom
Area (m ²)	3.75	Area (m ²)	7.50
Available provision profile	On continuously	Available provision profile	On continuously
Azimuth (°)	250.00	Azimuth (°)	180.00
Conversion efficiency at ambient temperature	0.76	Conversion efficiency at ambient temperature	0.76
Degradation factor	1.00	Degradation factor	1.00
Electricity consumption metered	false	Electricity consumption metered	false
First order heat loss coefficient (W/(m ² ·K))	4.00	First order heat loss coefficient (W/(m ² ·K))	4.00
Coolant flow rate (l/(h·m ²))	50.000	Coolant flow rate (l/(h·m ²))	50.000
Maximum outlet flow rate (l/h)	50.000	Maximum outlet flow rate (l/h)	50.000
Outlet flow rate profile	On continuously	Outlet flow rate profile	On continuously
Heat exchange effectiveness	0.40	Heat exchange effectiveness	0.40
Inclination (°)	35.00	Inclination (°)	35.00
Initial tank temperature (°C)	52.00	Initial tank temperature (°C)	52.00
Pump power (kW)	0.20	Pump power (kW)	0.20
Second order heat loss coefficient (W/(m ² ·K ²))	0.0100	Second order heat loss coefficient (W/(m ² ·K ²))	0.0100
Shading factor	1.00	Shading factor	1.00
Storage tank storage loss at maximum (kWh/(l·d))	0.0075	Storage tank storage loss at maximum (kWh/(l·d))	0.0075
Storage tank volume (l)	1,000.00	Storage tank volume (l)	1,000.00
Tank inlet temperature (°C)	10.00	Tank inlet temperature (°C)	10.00
Tank supply temperature (°C)	60.00	Tank supply temperature (°C)	60.00
Water consumption metered	false	Water consumption metered	false

Figure 14: Renewables in iVN.

Bristol

The terrain created in iCD was imported in iCIM and iVN. In the images below, a detail of the entire site.



Figure 15: iCD and iCIM terrains in Bristol.

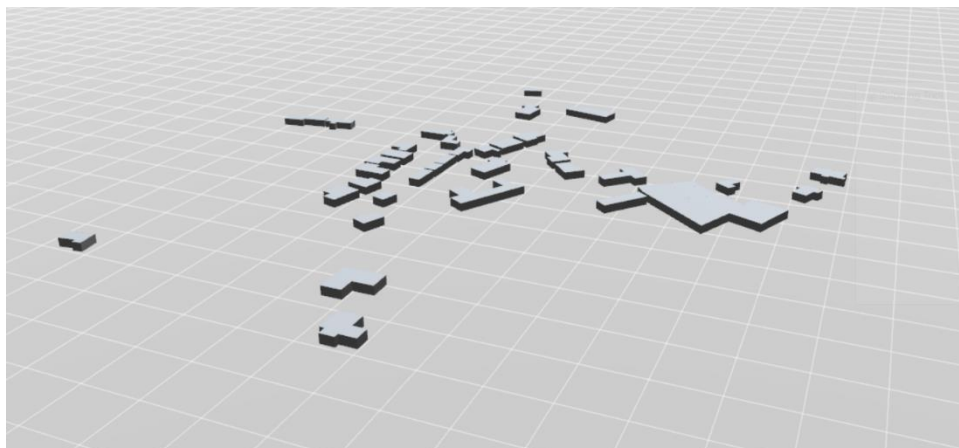


Figure 16: iVN terrain in Bristol.

The iSCAN channels of all appliances are automatically assigned to the iVN buildings. Here an example for Building 6. For each appliance in iVN there are 2 profiles, baseline, and default, corresponding to simulation results and utility bills data respectively.

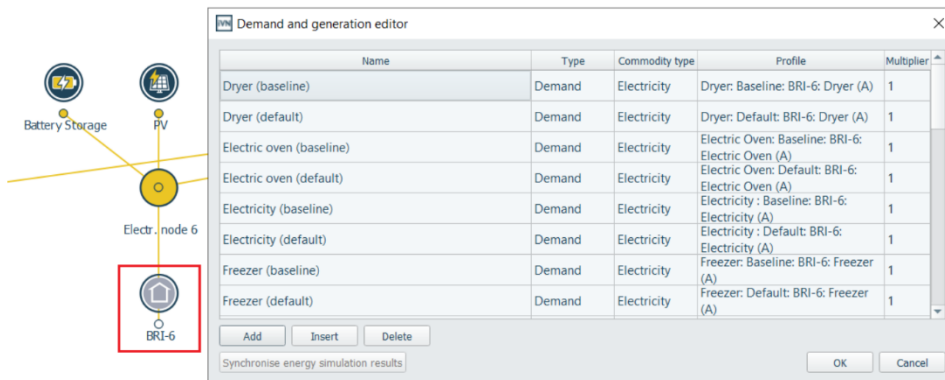
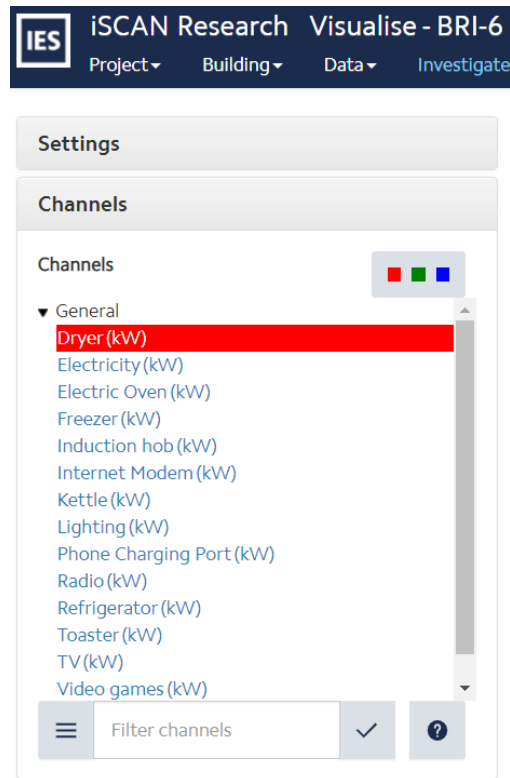


Figure 17: Appliances channels in iSCAN (first image on top) and in iVN (second image on the bottom).

Once the iCIM was imported, it was possible to create the Electricity Network, shown in the image below.

The buildings are directly connected with the Grid and the renewable sources.

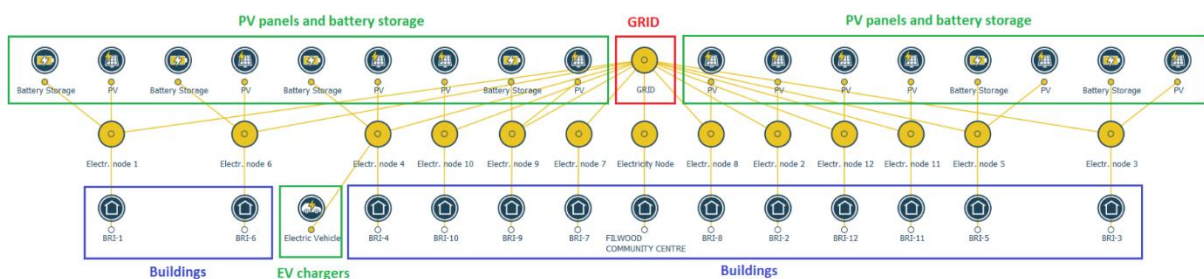


Figure 18: Electricity Network of Bristol.

All buildings have PV panels, except for the Filwood Community Centre.

Buildings 1, 3, 4, 5, 6, 9 have also a battery storage.

Only building 4 has EV chargers.

The pictures below show the details of some buildings with renewable sources.

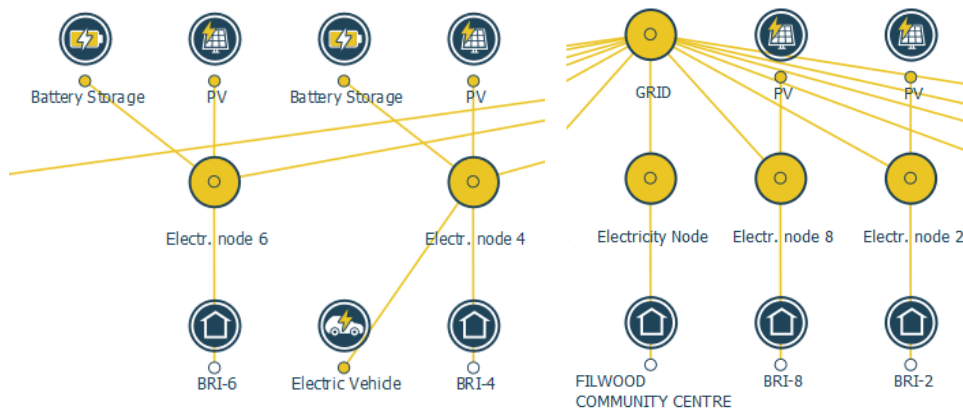


Figure 19: Details of the Electricity Network of Bristol

Finally, renewable sources were manually characterised. Specifically:

- Area, inclination, and Azimut for PV panels and Solar heating panels were extracted from google maps;
- The efficiency of the PV panels was either directly extracted from the datasheet (if their model was known) or calculated considering the peak load and the area occupied;
- The battery storages were populated with data from the technical sheet;
- The EV charger power consumption of BRI-4 was assigned according to the datasheet.

The following tables showcase the renewables settings for each building.

BRI-1

Data Inspector	
Property	TWINErgy Bristol, UK
Name	PV
ID	2784a2df-6282-46f6-9720-
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	32.00
Available provision profile	On continuously
Azimuth (°)	135.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	50.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.10
Reference irradiance for NOCT...	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BRI-1

Data Inspector	
Property	TWINErgy Bristol, UK
Name	Battery Storage
ID	421da2cc-f49e-425a-871
Object Type	Electricity Storage
▼ iVN electricity storage	
Category	Custom
Available charging flux profile	On continuously
Available discharging flux profile	On continuously
Charge loss factor	0.05
Control type	Passive
Discharge loss factor	0.05
Initial stored energy (kWh)	0.00
Leakage loss factor (/30d)	0.02
Maximum charging flux (kW)	2.50
Maximum discharging flux (kW)	2.50
Storage capacity (kWh)	14.00
Stored energy indirect CO2 emissi...	0.28

BRI-2

Data Inspector	
Property	TWINErgy Bristol, UK
Name	PV
ID	6471d42a-57f6-4fc6-
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	15.00
Available provision profile	On continuously
Azimuth (°)	115.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	35.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.10
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BRI-3

Data Inspector	
Property	TWINErgy Bristol, UK
Name	Battery Storage
ID	86bbfc1d-d7ab-481d-8c
Object Type	Electricity Storage
▼ iVN electricity storage	
Category	Custom
Available charging flux profile	On continuously
Available discharging flux profile	On continuously
Charge loss factor	0.05
Control type	Passive
Discharge loss factor	0.05
Initial stored energy (kWh)	0.00
Leakage loss factor (/30d)	0.02
Maximum charging flux (kW)	2.87
Maximum discharging flux (kW)	2.87
Storage capacity (kWh)	5.70
Stored energy indirect CO2 emiss...	0.28

BRI-3

Data Inspector	
Property	TWINErgy Bristol, UK
Name	PV
ID	1d7f63fe-b5b3-4bce
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	15.00
Available provision profile	On continuously
Azimuth (°)	180.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	45.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.10
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BRI-4

Data Inspector	
Property	TWINErgy Bristol, UK
Name	PV
ID	441af136-d799-4fcf-1
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	15.00
Available provision profile	On continuously
Azimuth (°)	176.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	35.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.18
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BRI-4

Data Inspector	
Property	TWINErgy Bristol, UK
Name	Battery Storage
ID	f4f7dc53-615a-4e01-934
Object Type	Electricity Storage
▼ iVN electricity storage	
Category	Custom
Available charging flux profile	On continuously
Available discharging flux profile	On continuously
Charge loss factor	0.05
Control type	Passive
Discharge loss factor	0.05
Initial stored energy (kWh)	0.00
Leakage loss factor (/30d)	0.02
Maximum charging flux (kW)	2.50
Maximum discharging flux (kW)	2.50
Storage capacity (kWh)	6.40
Stored energy indirect CO2 emis...	0.28

BRI-4

Data Inspector	
Property	TWINErgy Bristol, UK
Name	Electric Vehicle
ID	3f88391b-c102-46b6-ba53-c1
Object Type	Electric Vehicle
▼ iVN electric vehicle	
EV charging station category	Custom
Electricity modulating profile	On continuously
Maximum output (kW)	0.77

BRI-5

Data Inspector	
Property	TWINErgy Bristol, UK
Name	PV
ID	0b7ee098-401c-4d5c
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	10.00
Available provision profile	On continuously
Azimuth (°)	180.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	35.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.19
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BRI-5

Data Inspector	
Property	TWINErgy Bristol, UK
Name	Battery Storage
ID	b07a2b6a-5519-4dfd-b
Object Type	Electricity Storage
▼ iVN electricity storage	
Category	Custom
Available charging flux profile	On continuously
Available discharging flux profile	On continuously
Charge loss factor	0.05
Control type	Passive
Discharge loss factor	0.05
Initial stored energy (kWh)	0.00
Leakage loss factor (/30d)	0.02
Maximum charging flux (kW)	2.50
Maximum discharging flux (kW)	2.50
Storage capacity (kWh)	13.00
Stored energy indirect CO2 emissi...	0.28

BRI-6

Data Inspector	
Property	TWINErgy Bristol, UK
Name	Battery Storage
ID	09d78d90-43a7-44f4-8c
Object Type	Electricity Storage
▼ iVN electricity storage	
Category	Custom
Available charging flux profile	On continuously
Available discharging flux profile	On continuously
Charge loss factor	0.05
Control type	Passive
Discharge loss factor	0.05
Initial stored energy (kWh)	0.00
Leakage loss factor (/30d)	0.02
Maximum charging flux (kW)	2.50
Maximum discharging flux (kW)	2.50
Storage capacity (kWh)	5.50
Stored energy indirect CO2 emissi...	0.28

BRI-6

Data Inspector	
Property	TWINErgy Bristol, UK
Name	PV
ID	53806cee-b929-49af
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	10.00
Available provision profile	On continuously
Azimuth (°)	160.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	30.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.17
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BRI-8

Data Inspector	
Property	TWINErgy Bristol, UK
Name	PV
ID	1d042bd3-9245-45aa
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	20.00
Available provision profile	On continuously
Azimuth (°)	20.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	35.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.10
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BRI-9

Data Inspector	
Property	TWINErgy Bristol, UK
Name	Battery Storage
ID	678be68e-641c-40c2-8
Object Type	Electricity Storage
▼ iVN electricity storage	
Category	Custom
Available charging flux profile	On continuously
Available discharging flux profile	On continuously
Charge loss factor	0.05
Control type	Passive
Discharge loss factor	0.05
Initial stored energy (kWh)	0.00
Leakage loss factor (/30d)	0.02
Maximum charging flux (kW)	2.87
Maximum discharging flux (kW)	2.87
Storage capacity (kWh)	5.70
Stored energy indirect CO2 emissi...	0.28

BRI-9

Data Inspector	
Property	TWINErgy Bristol, UK
Name	PV
ID	55ef7dd3-7cbd-4eba
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	9.00
Available provision profile	On continuously
Azimuth (°)	137.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	30.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.22
Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BRI-10

Data Inspector	
Property	TWINErgy Bristol, UK
Name	PV
ID	e17da9fb-23b0-4170-aecb
Object Type	PV Array
▼ iVN PV array	
Category	Custom
Area (m ²)	10.00
Available provision profile	On continuously
Azimuth (°)	110.00
Degradation factor	1.00
Electrical conversion	1.00
Inclination (°)	45.00
Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.10
Reference irradiance for NOCT...	800.00
Shading factor	1.00
Temperature coefficient (/K)	0.0001

BRI-11

BRI-12

Data Inspector		Data Inspector	
Property	TWINEgy Bristol, UK	Property	TWINEgy Bristol, UK
Name	PV	Name	PV
ID	214d3455-e1c4-4956	ID	3afc7abd-9f1f-4ef5-t
Object Type	PV Array	Object Type	PV Array
▼ iVN PV array		▼ iVN PV array	
Category	Custom	Category	Custom
Area (m ²)	15.20	Area (m ²)	9.00
Available provision profile	On continuously	Available provision profile	On continuously
Azimuth (°)	160.00	Azimuth (°)	185.00
Degradation factor	1.00	Degradation factor	1.00
Electrical conversion	1.00	Electrical conversion	1.00
Inclination (°)	35.00	Inclination (°)	45.00
Nominal cell temperature (°C)	45.00	Nominal cell temperature (°C)	45.00
PV Module nominal efficiency	0.18	PV Module nominal efficiency	0.18
Reference irradiance for NOCT (W/m ²)	800.00	Reference irradiance for NOCT (W/m ²)	800.00
Shading factor	1.00	Shading factor	1.00
Temperature coefficient (/K)	0.0001	Temperature coefficient (/K)	0.0001

Figure 20: Renewables in iVN.

Athens

The terrain created in iCD was imported in iCIM and iVN. In the images below, it is visible a detail of the entire site.



Figure 21: iCD and iCIM terrains.



Figure 22: iVN terrain.

The iSCAN channels of all appliances are automatically assigned to the iVN buildings. Here an example for Building 6. For each appliance in iVN there are 2 profiles, baseline and default, corresponding to simulation results and utility bills data respectively.

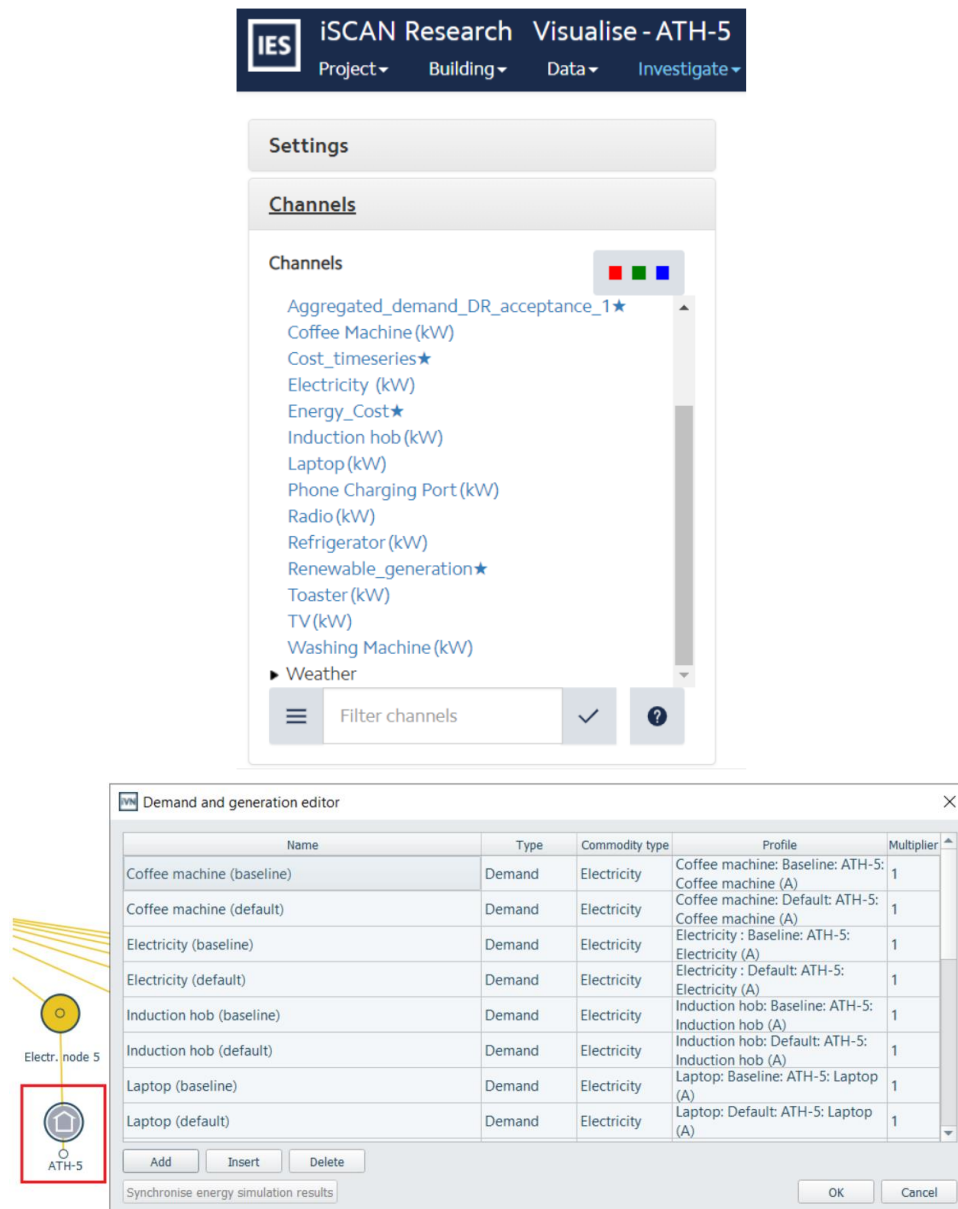


Figure 23: Appliances channels in iSCAN (first image on top) and in iVN (second image on the bottom).

Once the iCIM was imported, it was possible to create the Electricity Network, shown in the image below.

The buildings are directly connected with the Grid.

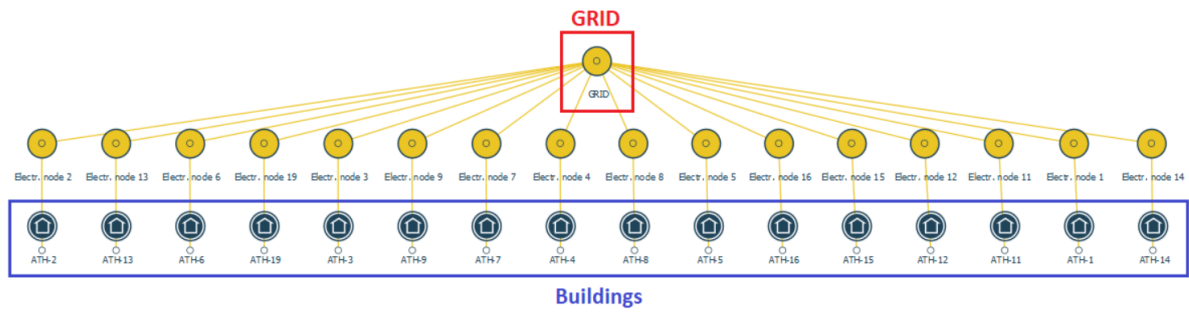


Figure 24: Electricity Network of Athens.

The picture below shows the detail of some buildings.

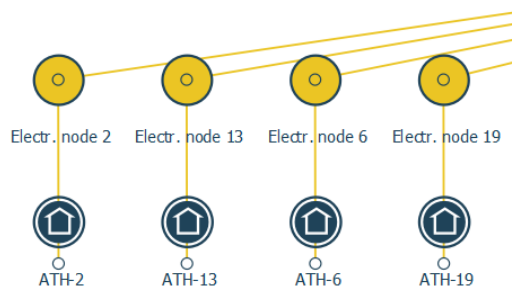


Figure 25: Detail of the Electricity Network of Athens

3. Methodology for calculating and profiling

3.1 Summary

This section summarises the development work related to the Twinergy's demand side management and flexibility algorithms. The description is divided in four main parts. Initially, a description of the methods employed to characterise the end-uses of each customer and each building will be provided. Then the main components of the flexibility and DSM algorithms will be described with examples from the pilot case studies. Following this, a description of the current and possible API access points for communication with the cloud implementation of the algorithms will be provided. Finally, future work is described with reference to improvements related to each algorithm.

3.2 End-uses characterisation

The objective of this section is to summarise the work related to the characterisation of the electric end-uses of each customer in the four pilot case studies, and to explain how electric demand is modelled across different customers. The described modelling approaches are required to substitute the lack of metered data coming from the pilots' sites. Nevertheless, the methodologies and algorithms described in the following sections have been developed with the intent to be adaptable in the case of synthetic and real data coming from the case studies.

Two main techniques have been employed for the characterisation of the electric demand of the buildings: (i) the use of a building dynamic simulation software (IES-VE) to incorporate schedules of use of each appliance and to extract the disaggregated demand profiles over the period of simulation; (ii) the use of a stochastic residential occupancy behaviour library for the generation of probabilistic schedules of use of appliances.

3.2.1 Appliance modelling in a dynamic simulation software

Appliance modelling in the dynamic simulation software IES-VE can be summarised in seven main steps:

1. **Model creation.** An initial model of the building is generated either using the IES's SketchUp plugin or the software VE depending on the users' convenience. After completing the modelling step the geometry needs to be converted to a VE model for additional characterization.

2. **Evaluation of the input parameters.** This step requires the definition in the dynamic simulation software of all the known inputs for the building under analysis such as internal gains, HVAC systems, schedules of operation etc... The characterization of the appliances starts by cross-referencing of the building checklists provided by clients/pilot site's leader. In this context multiple cases may occur:
 - a. **A reference model is already available.** In this case, it is necessary to find the technical datasheet of the appliance online on the manufacturer's website in order to represent the system or the appliance precisely.
 - b. **Only a brief description is provided** (type, manufacturer, age, ...). In this case, average or standard values, reported in specific documentation or online about the desired system, is used as an input for the model. Age, country or building type may have an impact on this so it is important to include these parameters in the research.
3. **Creation of the profiles for internal gains:** starting from the building checklist and personal expertise, internal gain profiles are defined in a way that reflects the ones described in the documentation or considering the most relevant ones based on the consumption associated to each one. Whenever the input data from the demo-sites are not available energy rates from normative values are used to characterize the demand (CIBSE guide A, CIBSE guide G, ASHRAE guidelines). An example of the normative documents used in this step is provided below:

Table 6.17 Typical rates of heat gain from restaurant and cooking equipment⁽¹⁾ — continued

Appliance	Size	Energy rate / W		Rate of heat gain / W			
		Rated	Standby	Without hood			With hood
				Sensible	Latent	Total	Latent
Range (burners), per 2 burner section	2–10 burners	9840	390	—	—	—	1930
Range (hot top or fry top), per m ² of cooking surface	0.26–0.74 m ²	37 200	1040	—	—	—	10 700
Range (large stock pot)	3 burners	29 300	580	—	—	—	5740
Range (small stock pot)	2 burners	11 700	390	—	—	—	2290
Range top, open burner (per 2 element section)	2–6 elements	11 700	4000	—	—	—	640
<i>(e) Steam</i>							
Compartment steamer, per kg of food capacity/h	21–204 kg	180	—	14	9	23	7
Dishwasher (hood type, chemical sanitising), per 100 dish/h	950–2000 dish/h	920	—	260	110	370	120
Dishwasher (conveyor, water sanitising), per 100 dish/h	950–2000 dish/h	920	—	290	120	410	130
Dishwasher (conveyor, chemical sanitising), per 100 dish/h	5000–9000 dish/h	350	—	41	97	138	44
Dishwasher (conveyor, water sanitising), per 100 dish/h	5000–9000 dish/h	350	—	44	108	152	50
Steam kettle, per litre of capacity	12–30 litre	160	—	12	8	20	6

Figure 26 CIBSE GUIDE A, Typical rates of heat gains from equipment

4. **Creation of a specific meter for each electrical consumption.** Meters is the object used in VE to associate end-uses to cumulative variables for estimation of energy vectors. Initially, all the internal gains will be assigned to the default single VE meter (Electricity: Meter1). The user creates and assigns a virtual meter per

appliance/consumption. An example of the meter definition in VE is provided in Figure 2 and Figure 3.

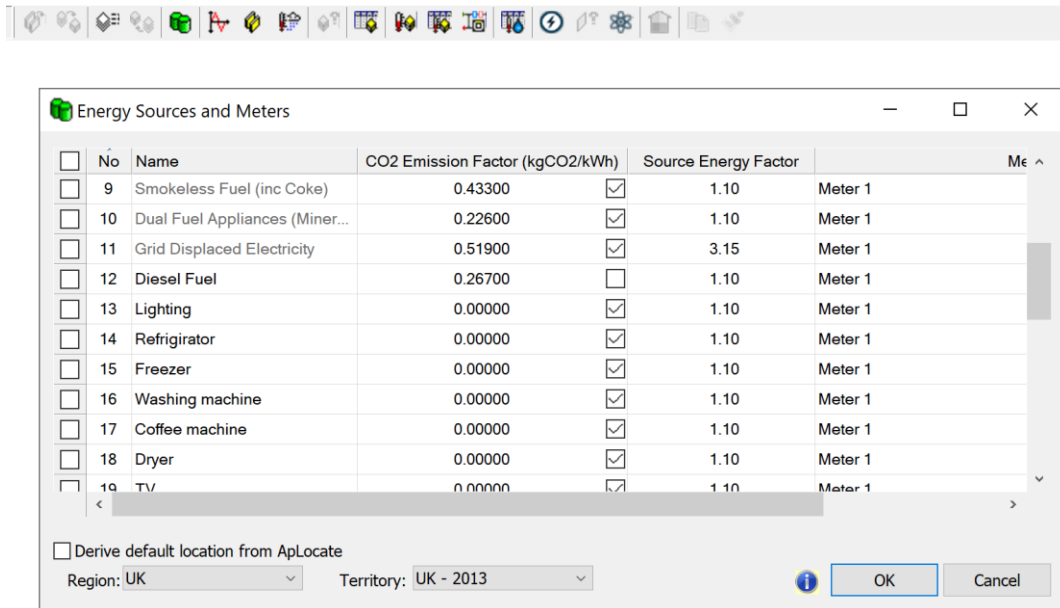


Figure 27 Meters definition in VE 1/2

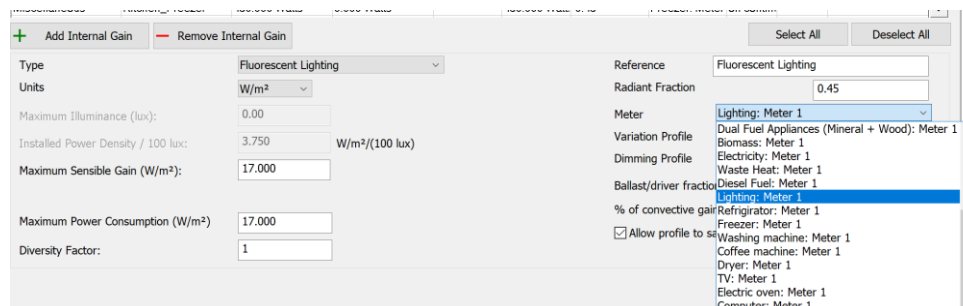


Figure 28 Meters definition in VE 2/2

- 5. Definition of the onsite PV generation for each building.** The PV type and area are used as an input in the VE model. If not possible, an estimate of the PV installed area will be derived from Google maps images.
- 6. Simulation and analysis.** A simulation with a 10 minutes resolution is run for the entire period of analysis. Information about annual electrical consumption data from the building in the demo sites is used to tune building simulation input for the appliances. The sum of the electrical consumption (equipment, lighting, auxiliary, heating, cooling, etc.) is used to compare the results with metered data. A $\pm 5\%$ error is considered as an acceptable discrepancy value for the difference between the simulation results and actual electrical consumption. In addition, the following procedure has been used:

- Check if indoor environment variables have reasonable values with respect to the HVAC strategy implemented.
- Check for any unusual or unexpected energy pattern over the period of simulation (peaks, gaps, valleys, et...).
- Check that the PV generation does not exceed PV peak generation reported in the documentation.
- Finally, check if the simulated data matches measured data (yearly bills and aggregates of electrical consumption and PV generation).
- Adjust PV generation or internal gains depending on the simulation results and confidence in the input parameters: all the equipment with less information (no model number/pictures/online data) are iterated several times to get closer to the metered values. Each appliance data is compared with similar equipment online or values proposed in the normative guides.
- Re-simulate if needed.

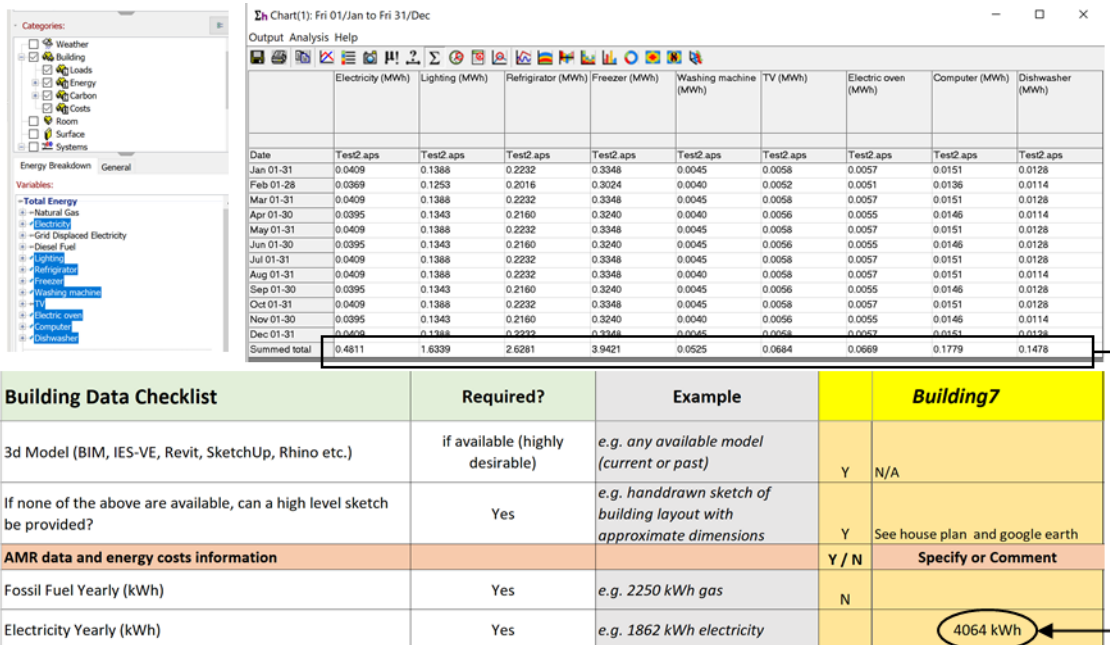


Figure 29 Comparison of simulated and metered annual electricity use

7. **Data export to iSCAN.** The time-series data from each meter are copied and organized in a CSV file before importing it into iSCAN. A single channel for each appliance is generated. An example of the aggregated demand for a single customer is provided in the Figure 30 below:

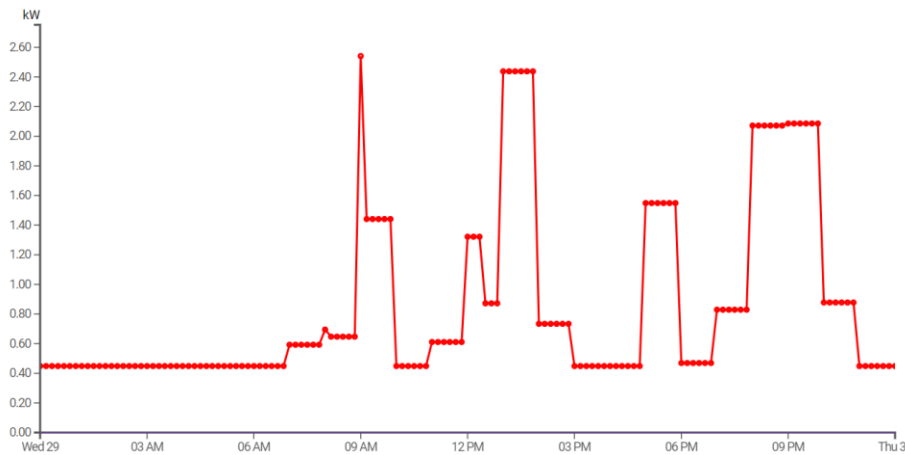


Figure 30 Example of customer level aggregated demand from electric appliances simulated in VE (Benetutti)

3.2.2 Stochastic occupant behaviour model to simulate appliance use.

In the case of missing data or high uncertainties for the modelling inputs of the buildings considered in the analysis, a stochastic occupant behaviour model has been used for the characterisation of the appliances of the residential buildings. The stochastic approach is the StRoBe module [1]. StROBe is an open-source tool developed at the KU Leuven Building Physics Section to model the missing boundary conditions in integrated district energy assessment simulations related to human behaviour, such as the use of appliances and lighting, space heating settings and domestic hot water redraws. StRoBe simulates appliance use starting from information derived from surveys for estimation of time of use to evaluate the stochastic presence of occupants and their interactions with appliances. As a minimum requirement to use the library, the building typology, the family composition and the list of appliances for each house is required. As output the library produces demand time-series for each appliance. This is used to populate the relative building project in iSCAN. An example of the demand generated by the StRoBe library is provided in Figure 31. For the investigated case studies the building checklist has been used as the main source of information to derive the required inputs for the StRoBe library. Once the StRoBe simulation is completed, each appliance profile has been uploaded to corresponding iSCAN channels for the selected period of simulation.

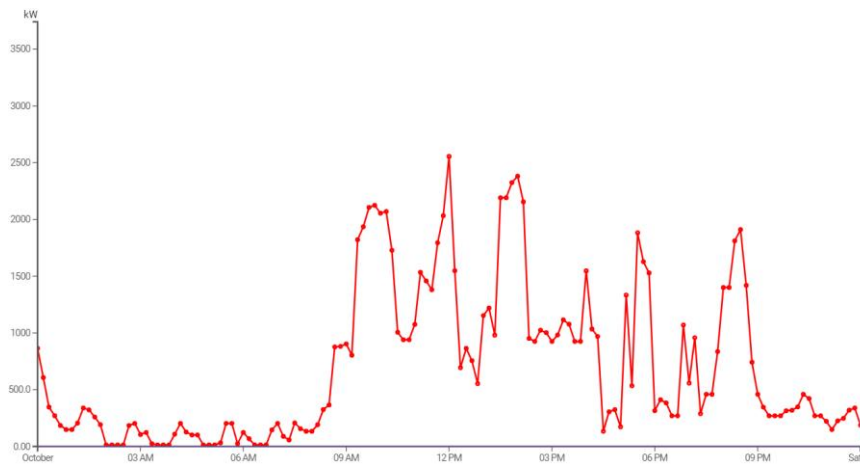


Figure 31 Example of customer level aggregated demand from electric appliances simulated in Strobe (Benetutti)

3.3 Algorithm description

This section describes the main components of the flexibility and DSM algorithm and provides examples of results at customer, building and community level for the investigated pilot sites. First, an overview of the overall workflow is provided, then, specific examples are investigated to show properties of the algorithms with discussion of the main findings. Limitations of the proposed approach and future work is described at the end of this section.

3.3.1 Main components

Figure 32 shows the main components of the flexibility and DSM algorithms. Six main components can be identified from the overall workflow:

1. iVN Engine. The iVN engine is used to define the energy networks available in the pilot sites. In particular, the interconnection between local renewable systems and buildings is defined first using the iVN main software and then simulated in the iVN engine. The engine is called every time an optimisation is required to forecast the next day local renewable generation. The forecasted generation profile is included in the definition of the objective functions of the algorithms.
2. iSCAN. The iSCAN cloud software is used as data storage and analysis facility for the visualization and interrogation of the results of the algorithms. It constitutes a repository for all the synthetic or metered time-series coming from the pilots' buildings. Each building has its own iSCAN project. The user can visualize data starting from the device level up to the community aggregated results.
3. DSM/Flexibility script. The set of algorithms that generates optimal results for flexibility and demand side management of the pilot sites is the core of the presented workflow. The script coordinates all the different components and prepares the different inputs to solve the various optimisation problems related to demand rescheduling and flexibility scenarios.

4. pyGMO. The pyGMO module [2] is employed to solve the optimisation problems. pyGMO constitutes a framework for defining and solving multi-objective optimisation problems. The framework offers the selection of a variety of possible algorithms, most of them heuristic.
5. StRoBe library [1]. The StRoBe module has been described in 3.2.2. It is a stochastic occupant behavior model used to model the interaction between end users and appliances in a building.
6. Entso-e API. ENTSO-E is the European association for the cooperation of transmission system operators (TSOs) for electricity. It offers an API for accessing forecasts of energy prices in most European countries [3].

Four main input files are required for the workflow: (i) a json file containing information required to characterize each building and existing connections with renewable systems; (ii) an iVN model package of the investigated pilot site extracted from the iVN front-end; (iii) a token to access iSCAN API; (iv) a token to access the ENTSO-E API.

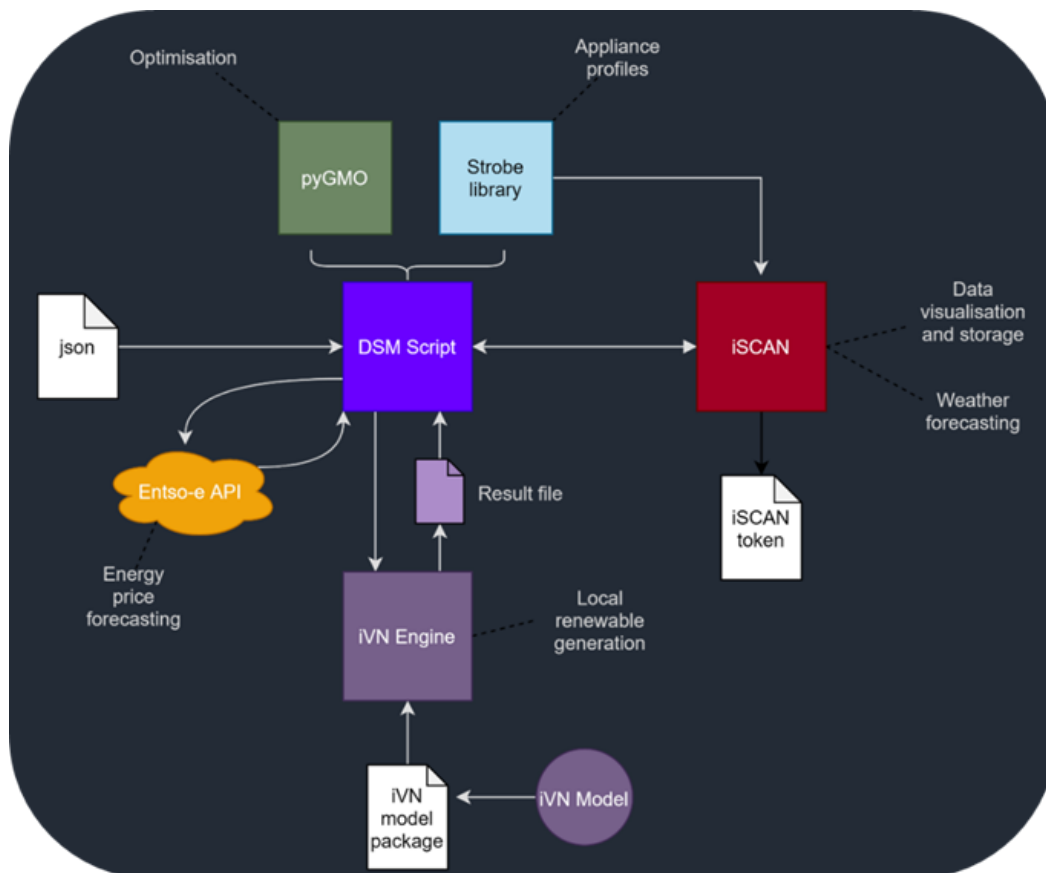


Figure 32 Main components of the Flexibility and DSM algorithm

3.3.2 Workflow and phases

Figure 33 describes the different steps of the workflow for the Flexibility and DSM algorithm. The workflow can be described in two main phases: (i) a setup phase where data (metered or synthetic) coming from the pilot sites are organised in iSCAN; (ii) optimisation phase where different objective functions related to DSM and flexibility scenarios are investigated.

3.3.2.1 Setup phase

In this phase of the workflow, an initial input file in json format is provided to the algorithm with information about the buildings in the pilot sites, their available data and if synthetic data from simulations in StRoBe are required. Following this, information in the input file is used to create relative iSCAN projects and relative buildings to store the available time-series data. The automated project creation method generates the data structure for each single customer/building and for the community level results. For single customers/buildings data from single appliances are stored in dedicated channels. In the case of existing time series metered values, data channels will be already available for that building. In the case that synthetic data is required to initially characterize the building, either coming from VE simulation or StRoBe, each data channel will be generated. In addition to the demand data channels, weather data channels and energy price channels will be added to the same project. Each building project has its own aggregated demand channel which stores the sum of all the appliances simulated for that building. For the community level analysis, an additional iSCAN project is generated with data channels to store results of the optimized rescheduling of the demand, cost analysis, renewable generation and channels for flexibility level assessment described as end user acceptance ratio into the DSM program.

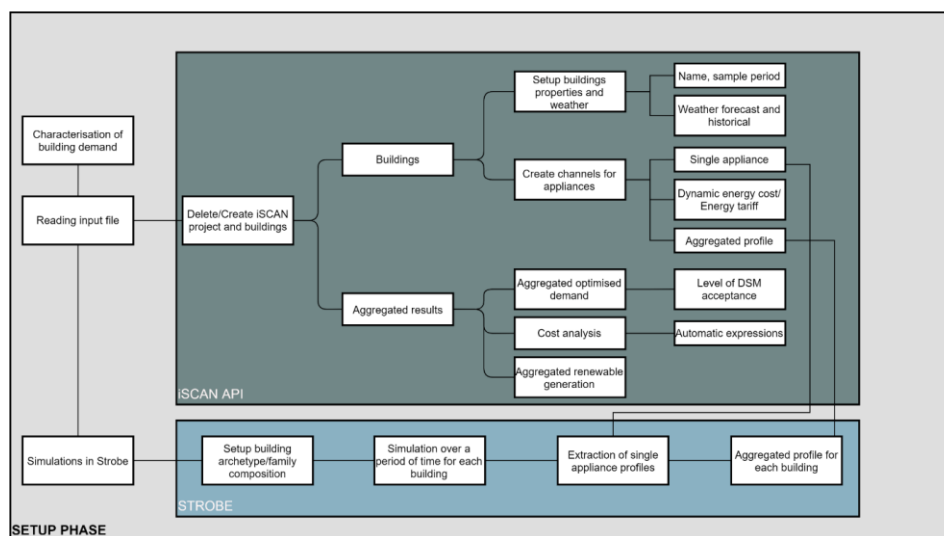


Figure 33 Setup phase of the Flexibility and DSM algorithm

3.3.2.2 Optimisation phase

Figure 34 shows the different steps of the optimisation phase. First, the information contained in an input file is elaborated by the algorithm that identifies the different flexibility scenarios to be simulated (percentage of acceptance of the end user in the DSM scheme). Then, the algorithm defines each acceptance scenario to be simulated and the time period selected. Local renewable generation is estimated calling the iVN engine. The engine uses iSCAN forecast weather data for the selected location, runs a simulation of the selected model and generates a profile for each renewable system selected. After this, the energy price API is called to generate a time series value of the electricity price for the next day. The data is uploaded into the corresponding iSCAN channels. Following this, a data-mining approach is employed to evaluate the most important properties of each appliance and to reconstruct its standard demand profile. This is achieved by using the iSCAN API to retrieve the time series data of the buildings and standard Python libraries to identify the pattern of use of the smart appliance in the last 30 days. This information is used to reconstruct the next day predicted demand profile for the customer/building. For this, the standby power, operating cycle properties, peak power consumption and duration are used to generate the standard profile of use. In addition, it is possible to specify if an appliance is “shiftable” or not for the next day. In case the appliance is considered as shiftable it is possible to define a time-window for the algorithm to search the best time of use taking into account the user’s preferences. Each profile of use is provided as input to the optimisation algorithm, whose goal is to identify the best starting point in time for the appliance. All the forecast profiles are resampled at the same time resolution and sent to the optimisation interface. Once the optimisation problem is solved best results are selected and the corresponding time series data are sent to iSCAN channels for each customer/building and in the community level project.

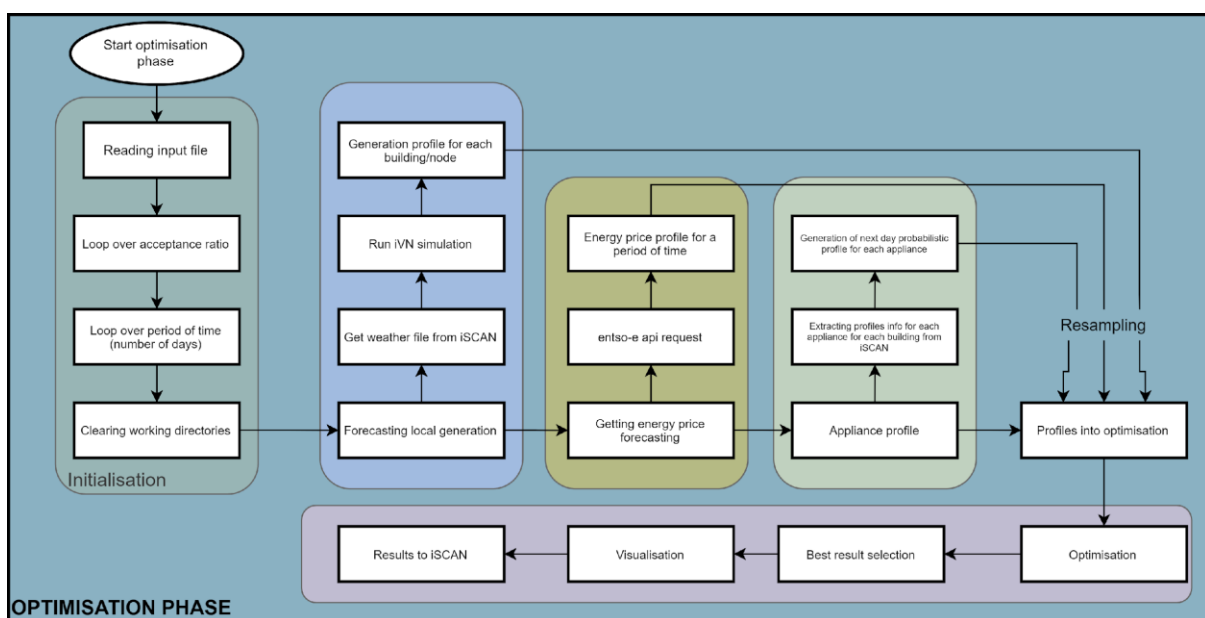


Figure 34 Optimisation phase of the Flexibility and DSM algorithm

The optimisation framework can optimise a combination of three objective functions: minimisation of cost of use of appliances, maximisation of the use of renewable resources on site and diversification of the aggregate demand if required. While appliance use is optimised singularly, operational costs are evaluated first for each building considered on its own and then aggregated for the group of buildings. For the majority of the results presented in this section the Non-dominated Sorting Genetic Algorithm II (nsga2) has been used to solve the multi-objective optimisation problems. The decision vector during the different steps of the optimisation problem will represent the list of each starting point in minutes over the day for every single smart appliance. Once the starting point has been defined, the reconstructed demand profile will be allocated to that time interval. Optimised profile of each appliance is then sent to the corresponding aggregated data channel for that customer. Building and customers data are aggregated to derive the community based optimisation results. Different flexibility scenarios are implemented by considering an acceptance rate of the end users into the DSM programme.

3.3.3 Results

This section provides an overview of the main results that is possible to analyse in iSCAN for each pilot site.

3.3.3.1 *Optimisation cost and renewable generation*

Figure 10 shows an example of an optimisation job conducted on a group of buildings of the Bristol case study. The image shows a comparison of the demand of the group of buildings without optimisation (orange line) and the one optimised (blue line). In the same graph the energy cost (green line) and the renewable generation (grey line) is visualised. The algorithm attempts to shift the demand in hours of the day where the renewable generation is maximum and where at the same time there is a good trade-off with the electricity price.

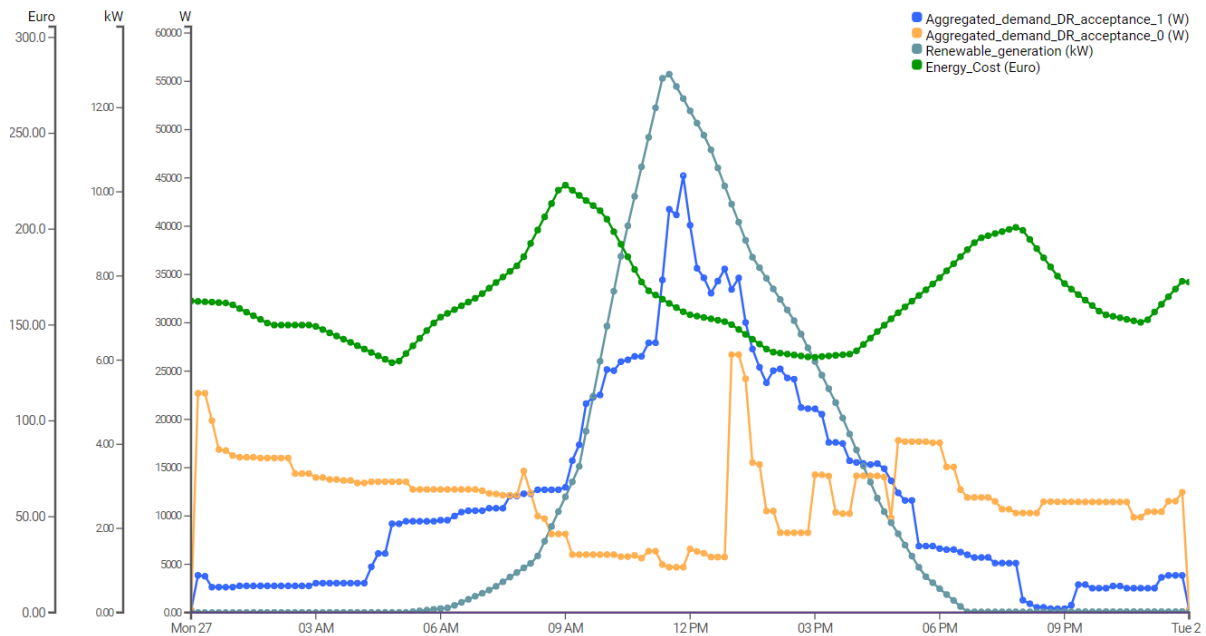


Figure 35 Example of optimisation of cost and renewable generation (Bristol)

3.3.3.2 Flexibility example

Figure 36 shows an example of the estimation of flexibility achievable by modelling different levels of engagement of the end-users in the DSM program. The graph shows the effect of considering 0, 25, 50, 75 and 100 acceptance rates of the end users in the DSM program. The results underline how the demand from appliances is shifted towards periods of the day where renewable production and cost are optimal. It is clear how the flexibility defined in terms of acceptance rate of engagement of the end user in the DSM program has a large impact on the final results as well as on the aggregated demand for community level assessments.

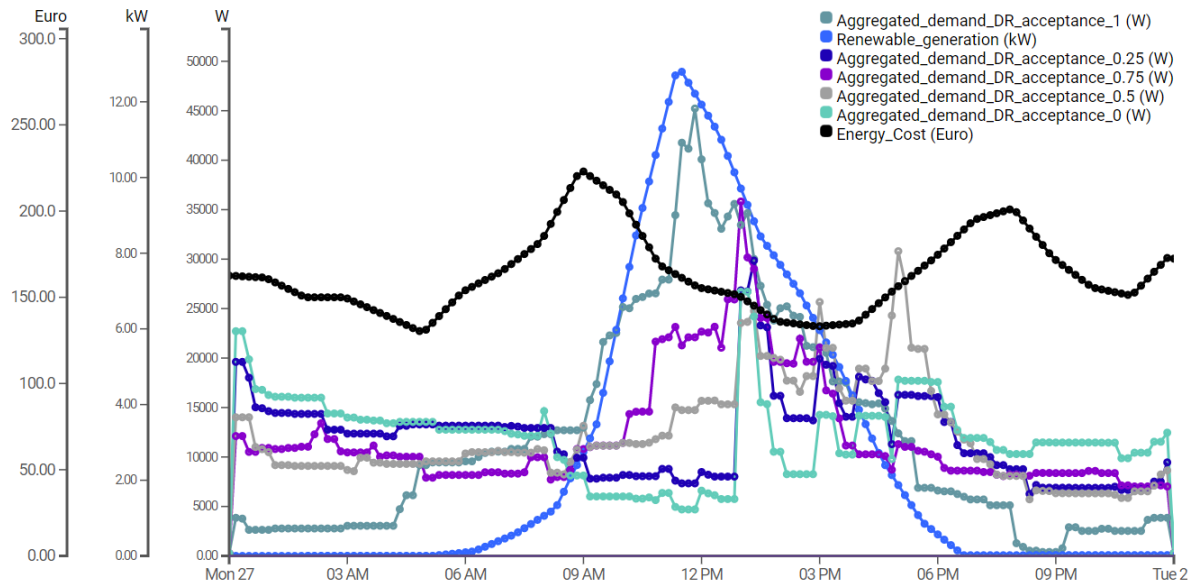


Figure 36 Example of optimisation taking into account different levels of flexibility (Bristol)

3.3.3.3 Cost analysis

Figure 37 shows an example of the cost calculation performed over a period of a week for a group of buildings of one of the case studies (Benetutti). The bar chart presents the cost associated with the operational schedules of the appliances. Different flexibility scenarios are included in the calculation each one leading to different operational costs. The highest energy savings are recorded for 100% of acceptance of the end users into the DSM scheme.

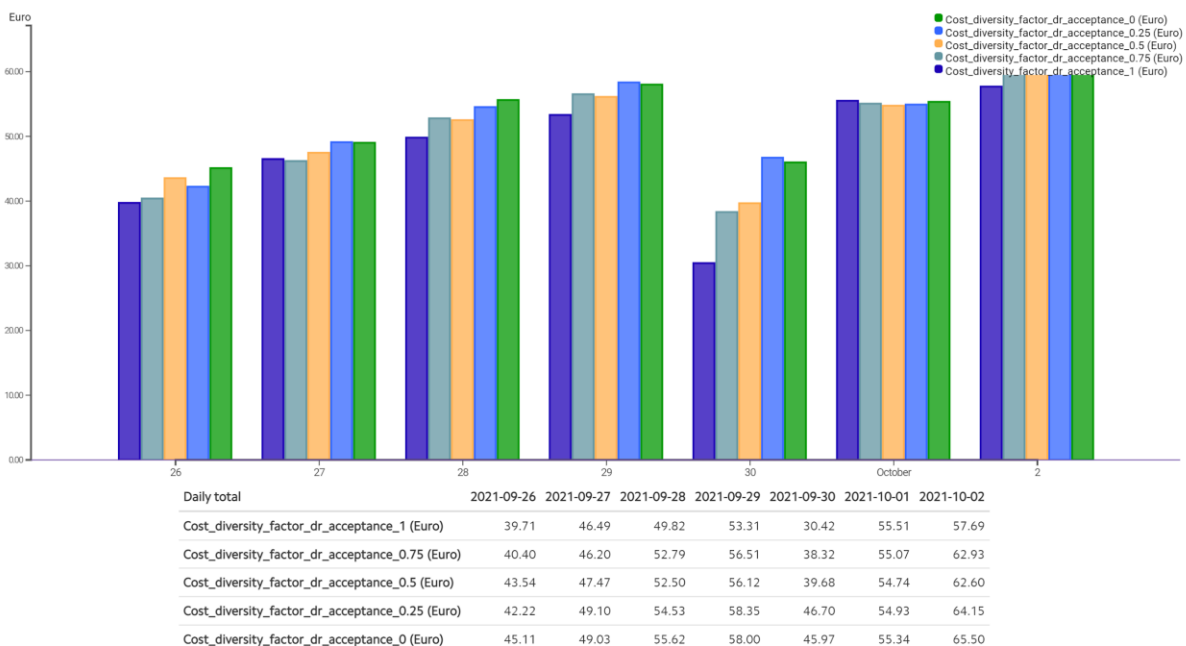


Figure 37 Example of cost analysis for a group of buildings in the Benetutti pilot site

3.4 APIs

Results of the DSM and flexibility tool can be accessed in the corresponding project directory in iSCAN cloud application while DSM jobs can be defined by using a dedicated API call to submit requests for a new optimisation scenario.

For access to the iSCAN API the user is required to register to the portal and be added to the list of users of a corresponding project. From iSCAN the user can access the following data

- Customer/building level:
 - Single appliance profile
 - Aggregated appliance profile
 - Energy price forecasting
 - Renewable generation forecasting (if available)
 - Optimal next day aggregated profile for appliances
 - Flexibility scenarios
- Community level
 - Aggregated profile at community level
 - Energy price forecasting
 - Total on site renewable generation (when available)
 - Optimal aggregated demand profile
 - Demand profiles with different flexibility scenarios
 - Cost evaluation baseline and cost for different flexibility scenarios

The results described above can be accessed either in the iSCAN web UI or through dedicated iSCAN API if required.

In addition, a dedicated API was developed to submit new DSM jobs or interact with the existing ones. The API documentation can be found at:

- [Swagger UI \(ies-dsm-as-01.azurewebsites.net\)](https://ies-dsm-as-01.azurewebsites.net)

The API allows the end user to

- Invoke a DSM job
- Get the current status of the DSM optimisation
- Cancel the current job

The API call for a new DSM job requires: (i) a json input file with the required details for each building to be analysed (ii) an iVN model package file extracted from iVN and consumed by the iVN engine (iii) a token file to access the relative project in iSCAN.

As output, the user can check the status of the current job. When the optimisation task is completed, the results are sent to iSCAN to predefined data channels for visualisation and further analysis.

5 Conclusions & Next Steps

Future work may include the following topics based on the project requirements:

- Evaluation of summary data analytics or metrics/KPIs calculated and made available through the API. This can be achieved by generating tailored KPIs from the list of results available at the end of an DSM optimisation job.
- Simulation results for shared DER assets such as EV charging point, PV, small wind turbine, batteries and related analytics. In this case the iVN engine could be further interrogated to extract relevant results from the simulated network and made available through the API.
- Recommendation for end-users performance or behavioural consumption change.
- Breakdown of building consumption by device.
- Demand side management optimisation and flexibility assessments considering storage units. This requires the inclusion of storage units in the DSM problem definition and the assessment of storage on the flexibility of each building.
- Inclusion of heating and cooling devices in the DSM workflow.

References

- [1] Baetens, R. and Saelens, D., 2016. Modelling uncertainty in district energy simulations by stochastic residential occupant behaviour. *Journal of Building Performance Simulation*, 9(4), pp.431-447.
- [2] Biscani, F. and Izzo, D., 2020. A parallel global multiobjective framework for optimization: pagmo. *Journal of Open Source Software*, 5(53), p.2338.
- [3] Hirth, L., Mühlenpfordt, J. and Bulkeley, M., 2018. The ENTSO-E Transparency Platform—A review of Europe's most ambitious electricity data platform. *Applied energy*, 225, pp.1054-1067.
- [4] [Department of Energy](#), [Crystalline Silicon Photovoltaics Research](#)