Data Driven Smart Building Symposium 2023

AALBORG UNIVERSITY
DENMARK

IEA EBC Annex 81 - C3
Building-to-Grid Applications

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IEA: International Energy Agency

- EBC: Energy in Buildings and Communities Programme
  - Annex 81: Data-Driven Smart Buildings
    - Subtask C: Applications and Services
      - Activity C3: Building-to-Grid (B2G) Applications
        - ~20 active participants and contributors

IEA EBC Annex 81 - C3

Active participants and contributors:

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- Tianzhen Hong
- Jérôme Le Dréau
- Anthony Maturo
- Mingjun Wei
- Zoltan Nagy
- Bing Dong
- Donal Finn
- Shohei Miyata
- Kathryn Kaspar
- Kingsley Nweye
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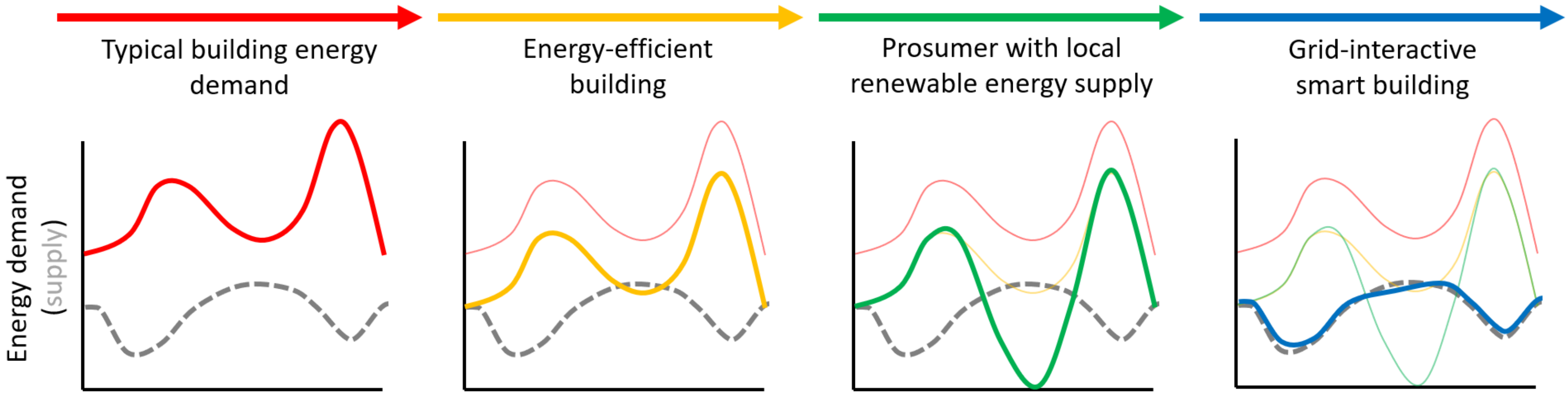
- Ali Saberi-Derakhtenjani
- Anna Marszal-Pomianowska
- Yicheng Li
- Zhelun Chen
- Lasitha Chamari
- Ekaterina Petrova
- Yapan Liu
- Fabiano Pallonetto

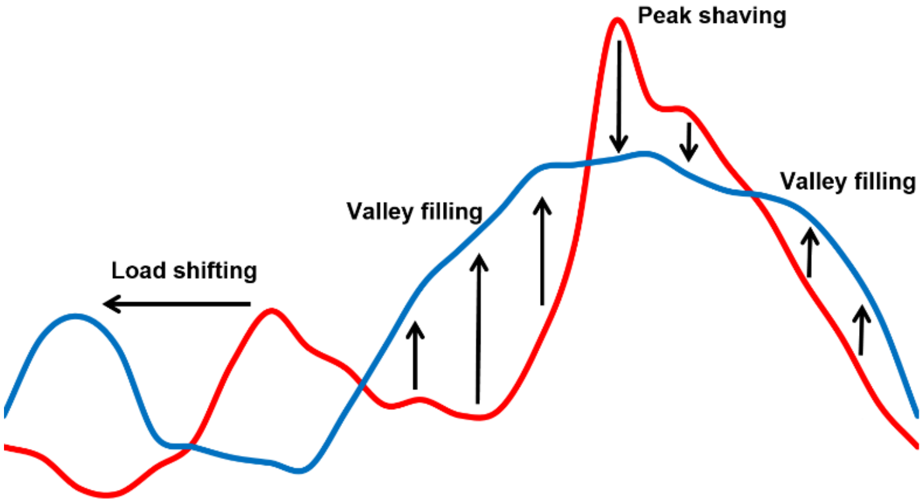
Context



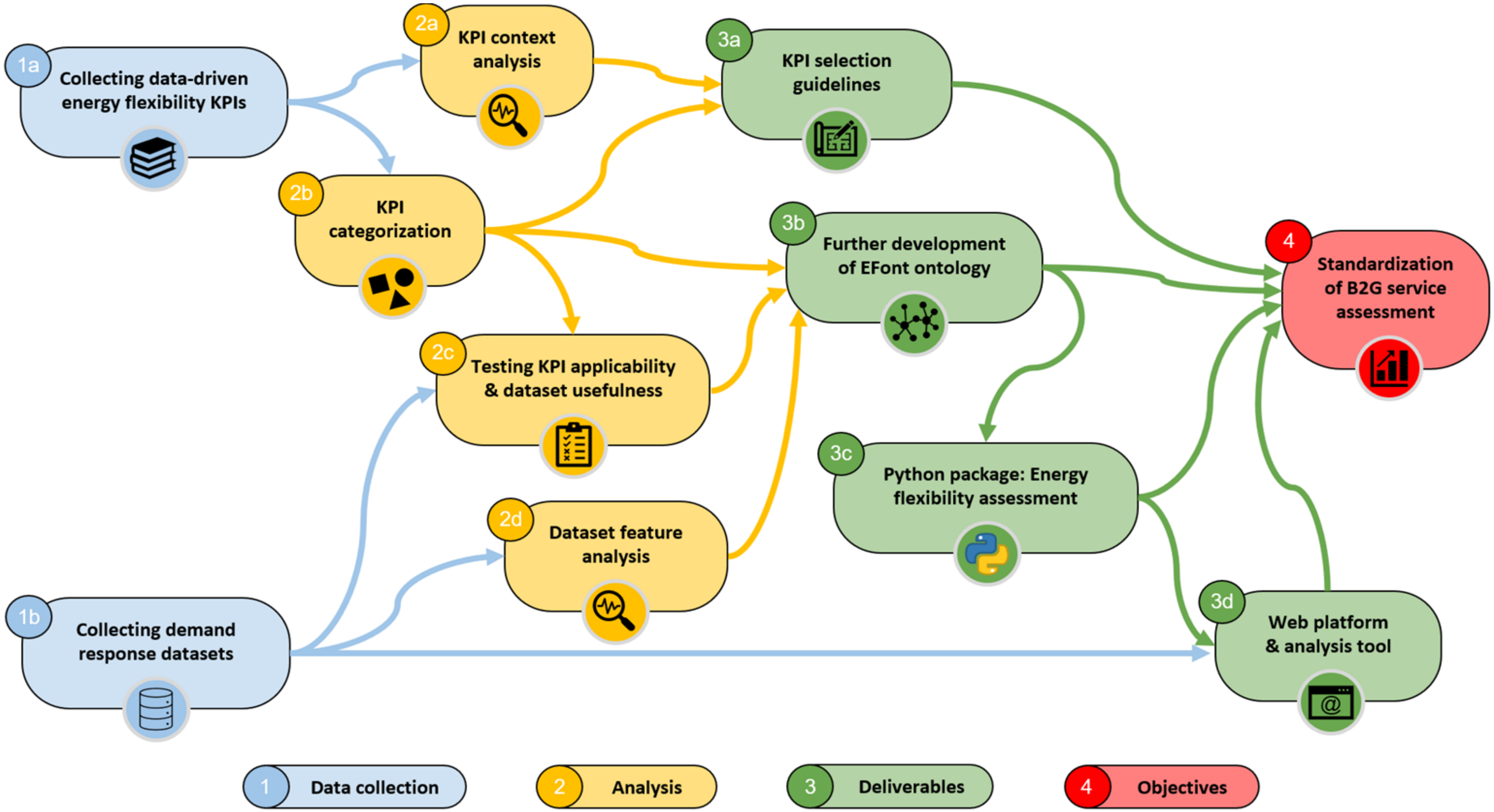
Massive deployment of smart building-to-grid services to improve sustainability and reliability of energy grids dominated by intermittent renewable energy sources.

A81 - C3: Scope and Objectives

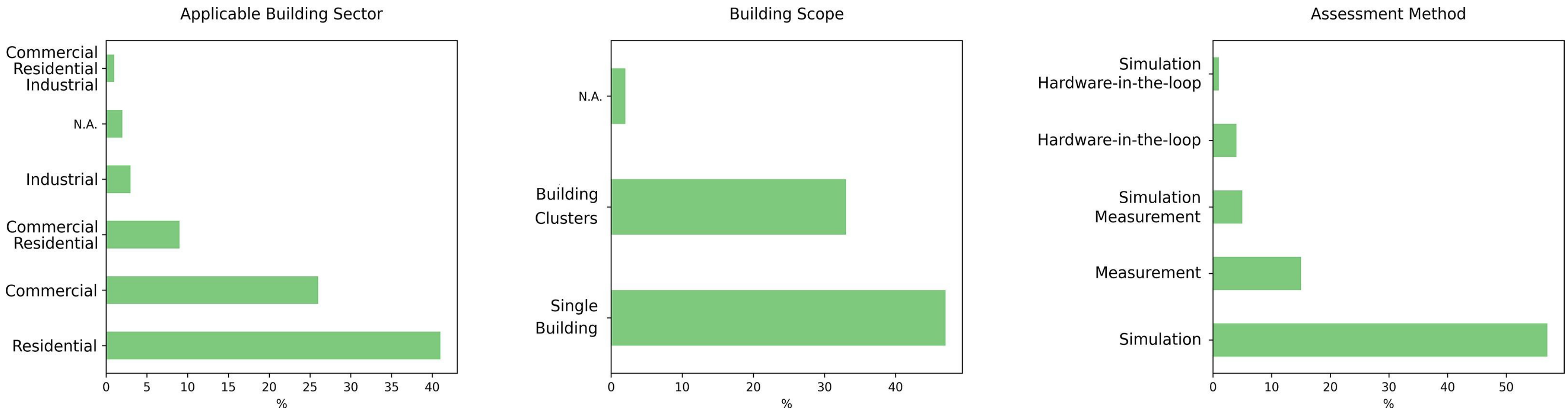
“Develop an online platform to gather, evaluate, compare, present and promote **building-to-grid services**, such as demand response, allowing users to assess their building **datasets** based on multiple **energy flexibility KPIs**”.



A81 - C3: Workflow



Review of Energy Flexibility Literature



Distribution of the reviewed studies using data-driven energy flexibility KPIs

Review of Energy Flexibility KPIs

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Review of 81 data-driven energy flexibility KPIs for buildings in the operational phase:

- Type
- Scale
- Building types
- Baseline requirements
- Complexity
- Data requirements

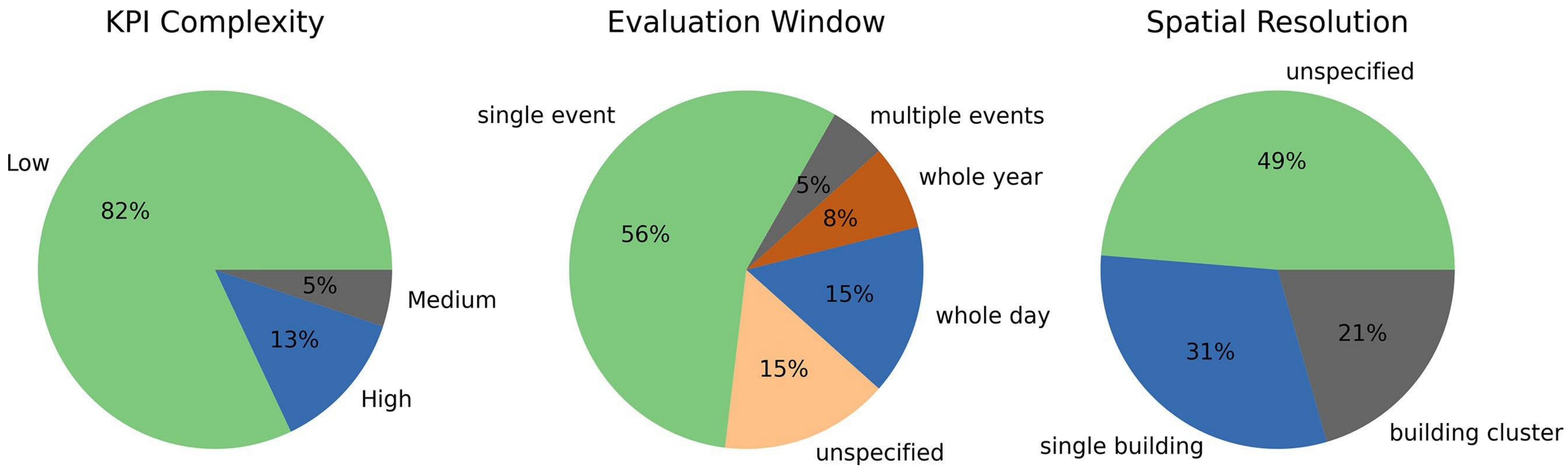
Review of Energy Flexibility KPIs

48 data-driven KPIs in 12 main energy flexibility KPI categories:

- Peak power shedding
- Energy / average power load shedding
- Peak power / energy rebound
- Valley filling
- Load shifting
- Demand profile reshaping
- Energy storage capability
- Demand response energy efficiency
- Demand response costs / savings
- Demand response emission / environmental impact
- Grid interaction
- Impact on indoor environmental quality

+ 29 generic KPIs in 4 categories associated with energy flexibility studies

Review of Energy Flexibility KPIs



Distribution of the baseline-required energy flexibility KPIs

Review of Energy Flexibility KPIs

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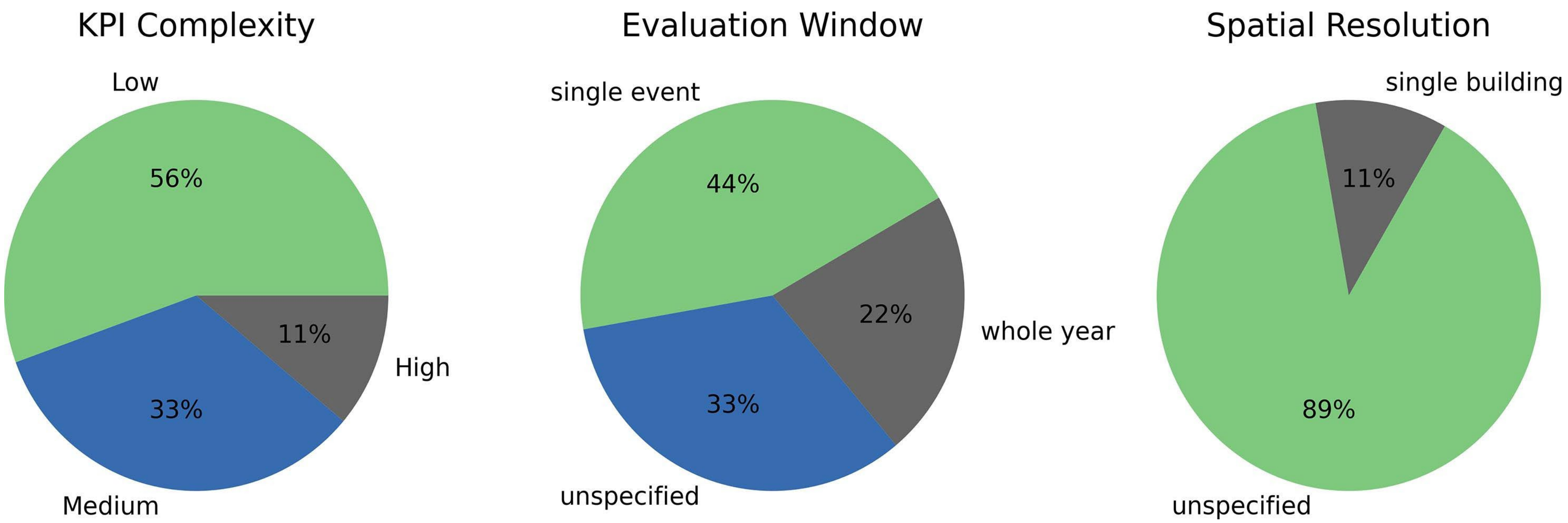


Distribution of the baseline-free energy flexibility KPIs

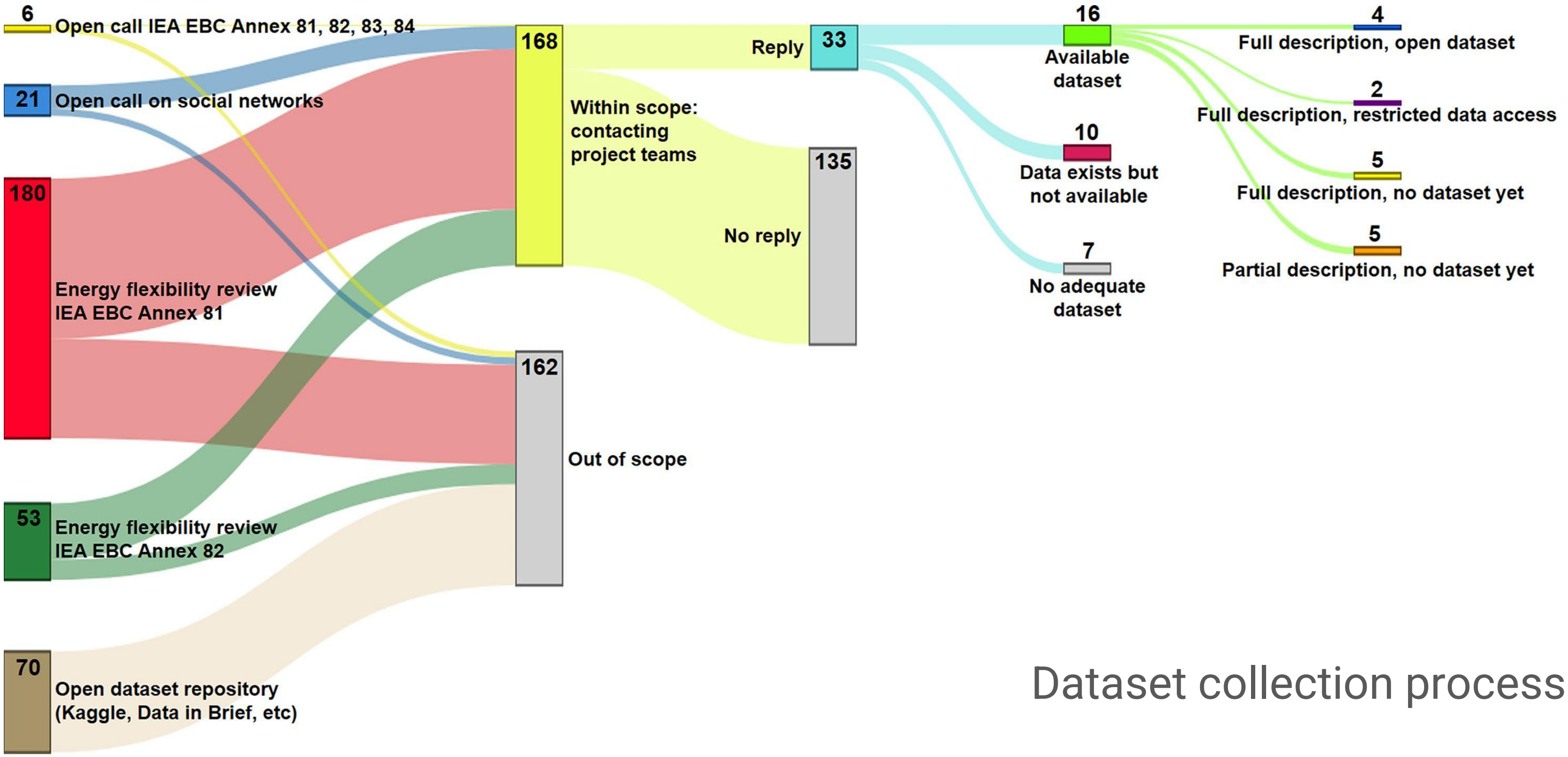
Review of Energy Flexibility KPIs

KPI	Formula	Type
Energy Efficiency of Demand Response Action	$$\eta_{ADR} = 1 - \frac{\int_0^{\infty}(Q_{ADR}-Q_{ref})dt}{\int_0^{length}(Q_{ADR}-Q_{ref})dt}$$	Baseline- required
Flexibility Savings Index	$$FSI = \frac{Cost\ of\ flexible\ operation}{Cost\ of\ baseline\ operation}$$	
Peak Power Shedding	$$\Delta P = P_{baseline,\,peak} - P_{flexible,\,peak}$$	

KPI	Formula	Type
Flexibility Factor	$$FF = \frac{\int q_{non\ peak}\cdot dt - \int q_{peak}\cdot dt}{\int q_{non\ peak}\cdot dt + \int q_{peak}\cdot dt}$$	Baseline- free
Energy Shift Flexibility Factor	$$FS = \frac{\int q_{heating\ (low\ price)}\cdot dt - \int q_{heating\ (high\ price)}\cdot dt}{\int q_{heating\ (low\ price)}\cdot dt + \int q_{heating\ (high\ price)}\cdot dt}$$	
Load Factor	$$LF = \frac{AVG_L}{max_L}$$	

Most popular energy flexibility KPIs

Review of Demand Response Datasets



Dataset collection process

Review of Demand Response Datasets

Collection of 16 open datasets performing B2G services:

- Building types
- Load shape strategies
- Flexibility resources
- Data availability

Review of Demand Response Datasets

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KPIs' required variables **vs** datasets' available variables:

- Required variables are not always the most common ones
- Additional modelling and calculations can be used to estimate variables such as event timing and power demand
- Providing identification for key variables that would facilitate future research

Primitive variables	% required by KPIs	% available in datasets
Event timing	37.66%	18.75%
Energy consumption	35.06%	81.25%
Power demand	32.47%	6.25%
Event request action	24.68%	37.50%
Price signal	16.88%	50.00%
Energy generation	12.99%	25.00%
Event request size	11.69%	0.00%
Indoor temperature	5.19%	93.75%
Thermostat setpoint	5.19%	62.50%
Emission signal	3.90%	12.50%
Storage volume	2.60%	0.00%
Monetary incentives	2.60%	0.00%
Occupancy	1.30%	56.25%
Indoor CO2	1.30%	12.50%

Problem statement

Scalability of KPIs calculation

Lack of shared knowledge for characterization and quantification

$$FF = \frac{\int q_{non\ peak} \cdot dt - \int q_{peak} \cdot dt}{\int q_{non\ peak} \cdot dt + \int q_{peak} \cdot dt}$$

$$t = \frac{\overline{P}_{wm,P} - \overline{P}_{wm,R}}{\sqrt{\frac{(N_P-1)s^2_{wm,P}+(N_R-1)s^2_{wm,R}}{(N_P+N_R-2)}} \cdot \sqrt{\frac{1}{N_P}+\frac{1}{N_R}}}$$

$$RIB = \frac{\sum_{i=1}^{n}(E^i_{el} \cdot p^i) - \sum_{i=1}^{n}(E^i_{el} \cdot p_{min})}{\sum_{i=1}^{n}(E^i_{el} \cdot p_{max}) - \sum_{i=1}^{n}(E^i_{el} \cdot p_{min})} (-)$$

$$P_l^{res} = \frac{\sum_{i=2}^{i=d_l} u_{t_l+i} - y_{t_l+i}}{n_l(d_l - 1)}$$

Scalability of dataset use

Characterized by heterogeneous data representation

cerc_templogger_1

Building90_TZ0

Indoor_Tind_avg

Summer_Ambient_Temperature

Need for manually mapping required variable from every dataset to every KPI

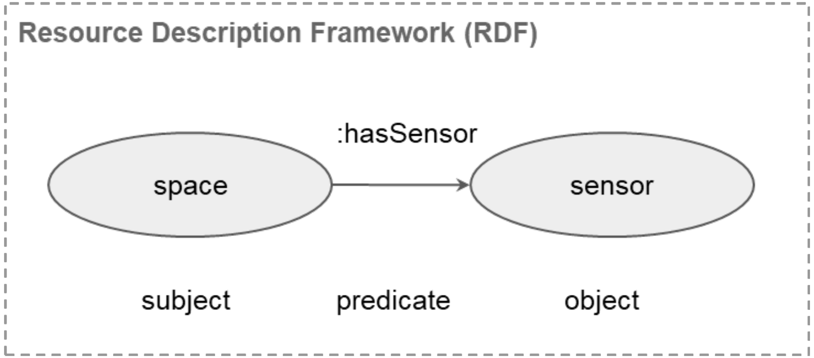
➔ Repeated effort ➔ Time consuming ➔ Error-prone

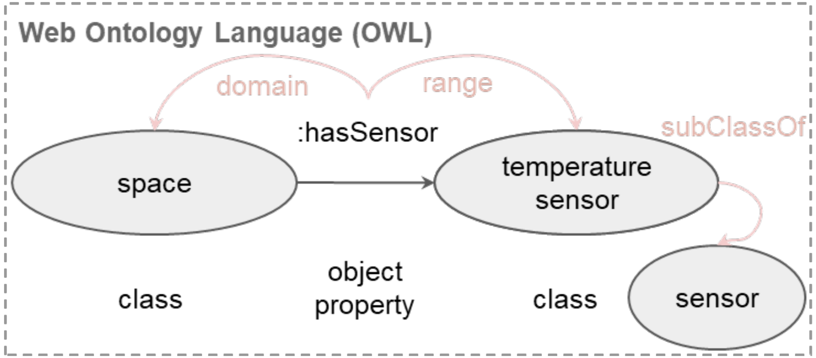
Using Semantic Principles

Semantic principles provide guidance and best practices on how to **structure** and **represent** information in a **meaningful** and **consistent** way

Ontologies are one of the information models used to implement semantic principles:

- define the **meaning** and **relationships** of concepts within a specific domain in an **unambiguous** way
- **formal**, well-defined, precise language
- shared understanding and communication of information among **different systems** and **users**

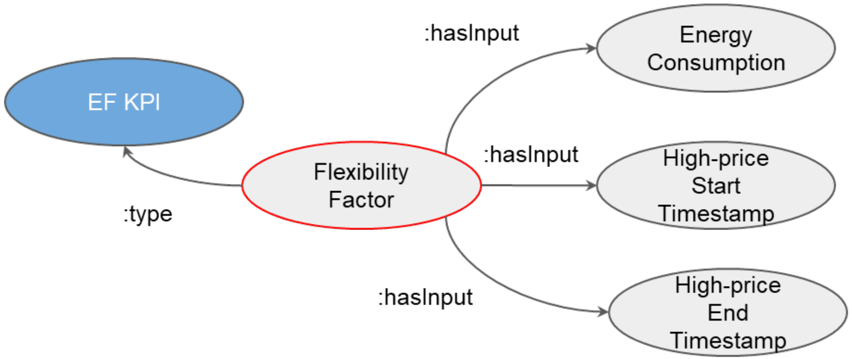




Using Semantic Principles

Represent and normalize the meaning and relationships of concepts (variables) from the KPIs formulation and the collected datasets:

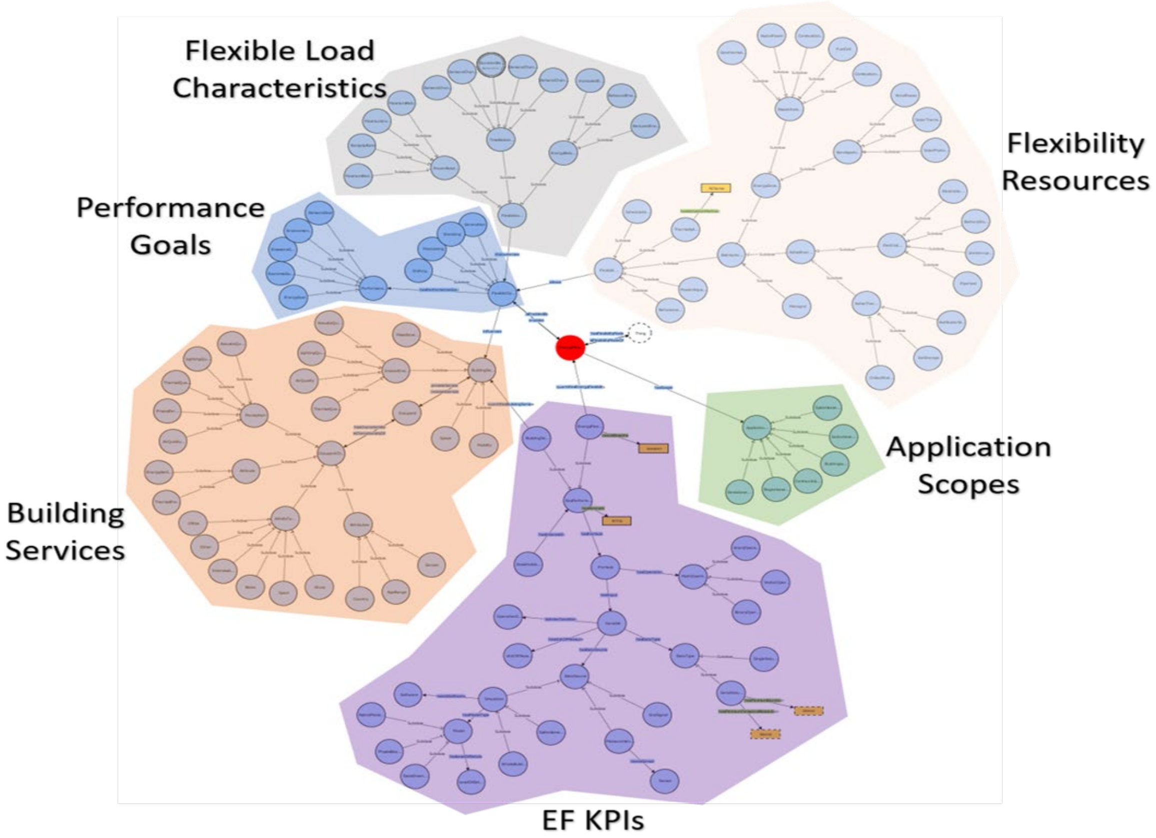
- ➢ Facilitate application portability, improve cross-domain understanding
- ➢ Guide data retrieval, reuse of datasets and applications
- ➢ Link data points to applications, disambiguation, faster and easier use, less prone to errors



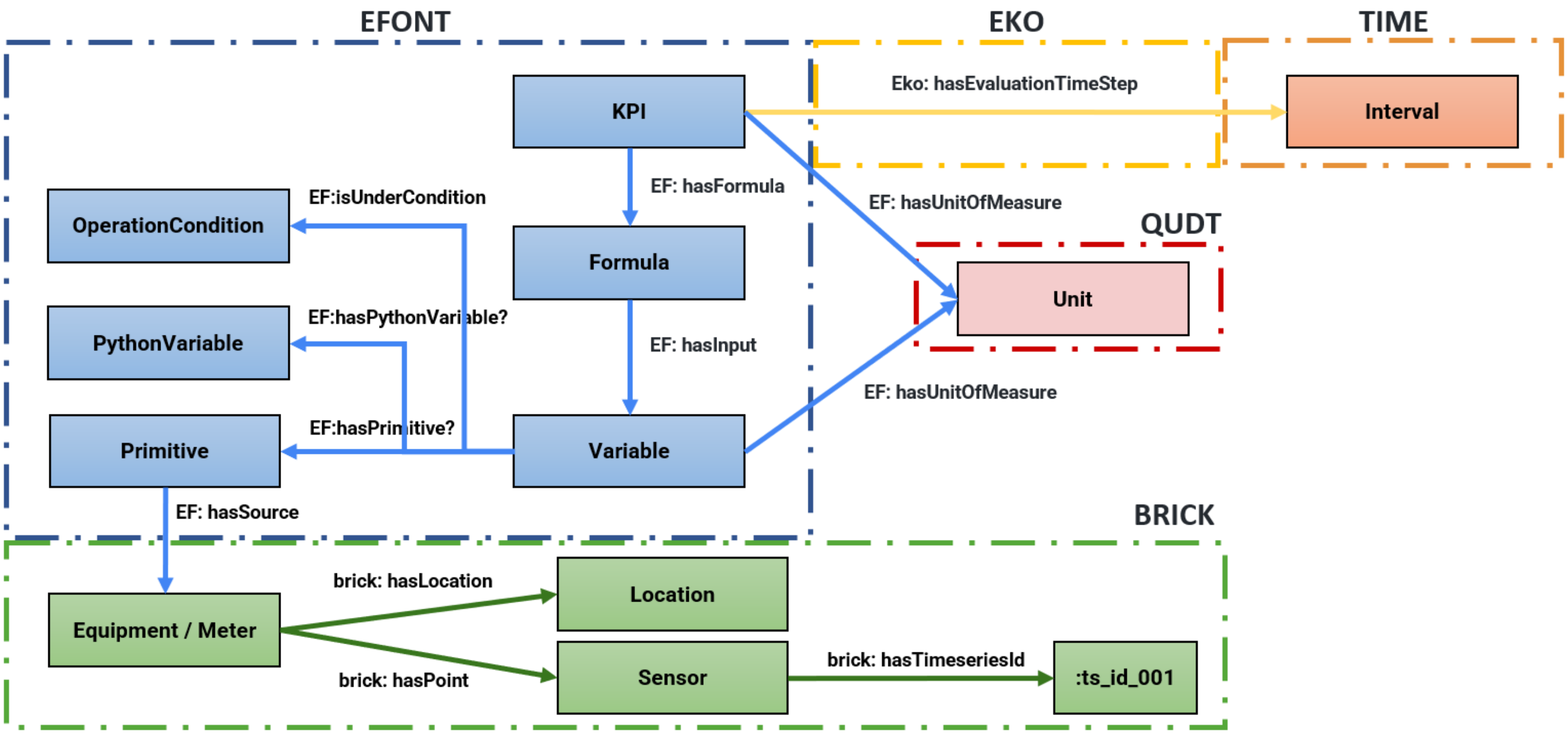
$$FF = \frac{\int q_{non\,peak} \cdot dt - \int q_{peak} \cdot dt}{\int q_{non\,peak} \cdot dt + \int q_{peak} \cdot dt}$$

Reusing EFOnt Semantic Ontology

EFOnt: developed by LBNL, USA (*Han Li & Tianzhen Hong, 2022*)



Energy Flexibility Ontology



Ontology ecosystem: alignment between EFOnt, Brick and other ontologies

Energy Flexibility Ontology

Key questions:

- What **variables** are needed to calculate the KPIs and how to keep the calculation process **agnostic** to different datasets?
- How do we **standardize** and automate the data collection from different datasets?
- How do we standardize the definitions of different concepts (e.g., evaluation window, operation **conditions** such as DR event start time and duration)?

Energy Flexibility Ontology

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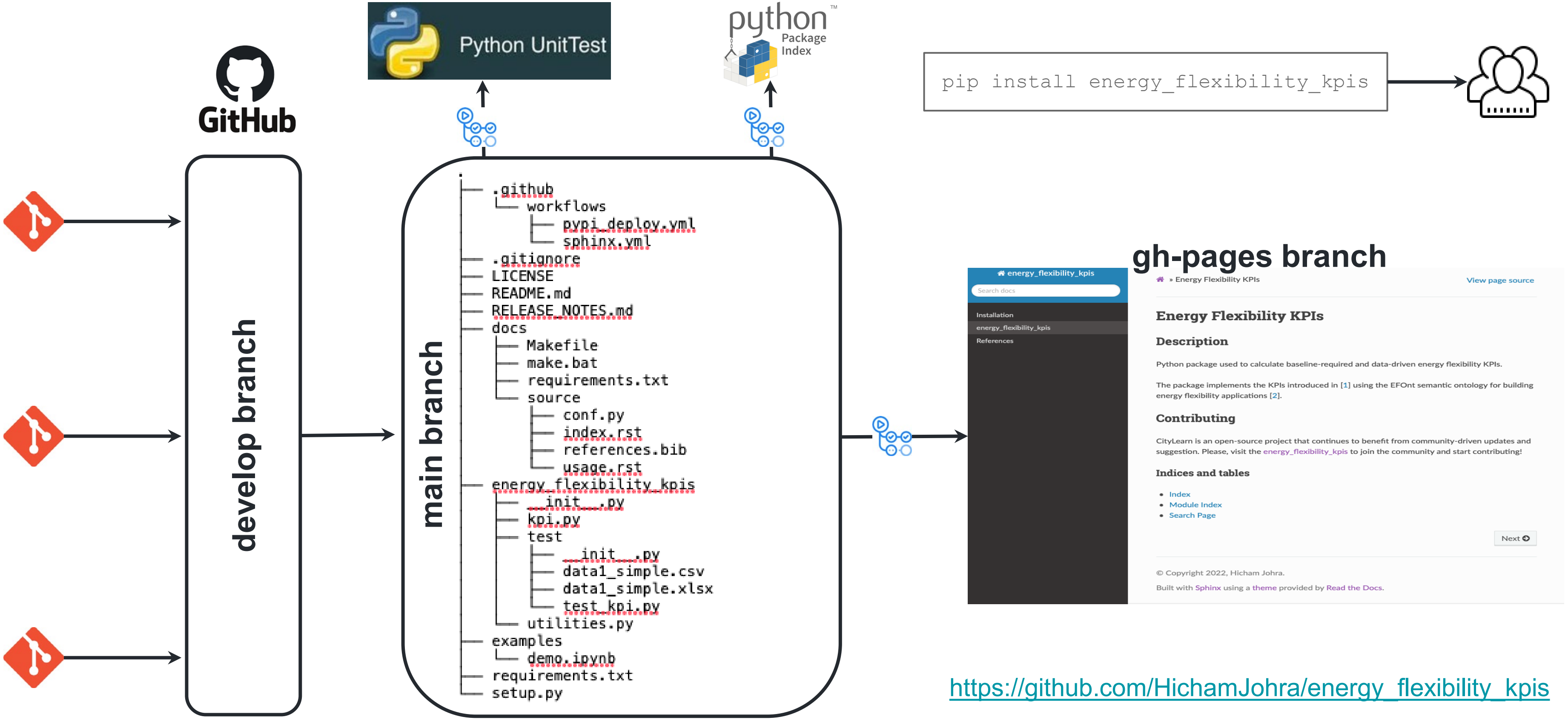
Standardization of data & variable definitions for data-driven quantification

Variable	Primitive Type	Value Type	Unit	Measurement Condition	Data Source	Ontological Definition	
						EFOnt URI	Brick URI
baseline electric power profile	power demand	Serial	kW	baseline	electricity meter		Power sensor
flexible electric power demand profile	power demand	Serial	kW	flexible	electricity meter		Power sensor
baseline electricity consumption profile	energy consumption	Serial	kWh	baseline	electricity meter		Energy sensor
baseline natural gas consumption profile	energy consumption	Serial	kWh	baseline	natural gas meter		
flexible electric power profile	power demand	Serial	kW	flexible	electricity meter		Power sensor
flexible electricity consumption profile	energy consumption	Serial	kWh	flexible	electricity meter		Energy sensor
flexible natural gas consumption profile	energy consumption	Serial	kWh	flexible	natural gas meter		
generic electric power profile	power demand	Serial	kW	N.A.	electricity meter		Power sensor
generic electricity consumption profile	energy consumption	Serial	kWh	N.A.	electricity meter		Energy sensor
generic natural gas consumption profile	energy consumption	Serial	kWh	N.A.	natural gas meter		
load profile peak timestamp	timestamp	Single	N.A.	N.A.	time - meter		
load profile valley timestamp	timestamp	Single	N.A.	N.A.	time - meter		
grid peak timestamp	timestamp	Single	N.A.	N.A.	time - grid signal		
high-price start timestamp	timestamp	Single	N.A.	N.A.	time - grid signal		
high-price end timestamp	timestamp	Single	N.A.	N.A.	time - grid signal		
high-emission start timestamp	timestamp	Single	N.A.	N.A.	time - grid signal		
high-emission end timestamp	timestamp	Single	N.A.	N.A.	time - grid signal		

KPI (list)	Data requirement			
	Input Variable 1	Input Variable 2	Input Variable 3	Input Variable 4
Flexibility factor	generic electricity consumption profile	high-price start timestamp	high-price end timestamp	
Load factor	generic electric power profile	load profile peak timestamp		
Peak power reduction	baseline electric power profile	flexible electric power profile	grid peak timestamp	
Peak energy shedding?	baseline electricity consumption profile	flexible electricity consumption profile	grid peak timestamp	
Building energy flexibility index	baseline electric power profile	flexible electric power profile	evaluation start timestamp	evaluation end timestamp

Python Package



https://github.com/HichamJohra/energy_flexibility_kpis

Energy Flexibility Assessment Service

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1

IMPORT DATASET
➔Upload/connect to time series raw data (CSV/API)

FILTER KPI SEARCH (optional)
➔Define stakeholder
➔Define performance goals
➔Define flexibility modes

SPECIFY KPI SETTINGS
➔Define evaluation window
➔Select utility function for DR event time definition (optional)

User interface
Manual

2

IMPORT METADATA

2a
UPLOAD METADATA
➔Upload semantic model (e.g., Brick)

OR

2b
DEFINE METADATA MANUALLY
➔Download data mapping template
➔Fill out/upload required identifiers for time series data

User interface + EFOnt + Brick/Config file
Semi-automated/Manual

3

METADATA ANALYSIS
➔Verify metadata/semantic sufficiency based on EFOnt
➔Query EFOnt for required variables
➔Query semantic model or data mapping file for required time series data identifiers

TIME SERIES DATA ANALYSIS
➔Query time series data based on KPI settings and required identifiers
➔Verify data quality and features (e.g., sampling rate, data gap distribution)

KPI ANALYSIS
➔Filter suitable KPIs

SHACL + EFOnt + Python package
Semi-automated

4

KPI SELECTION
➔Selection of KPI to calculate

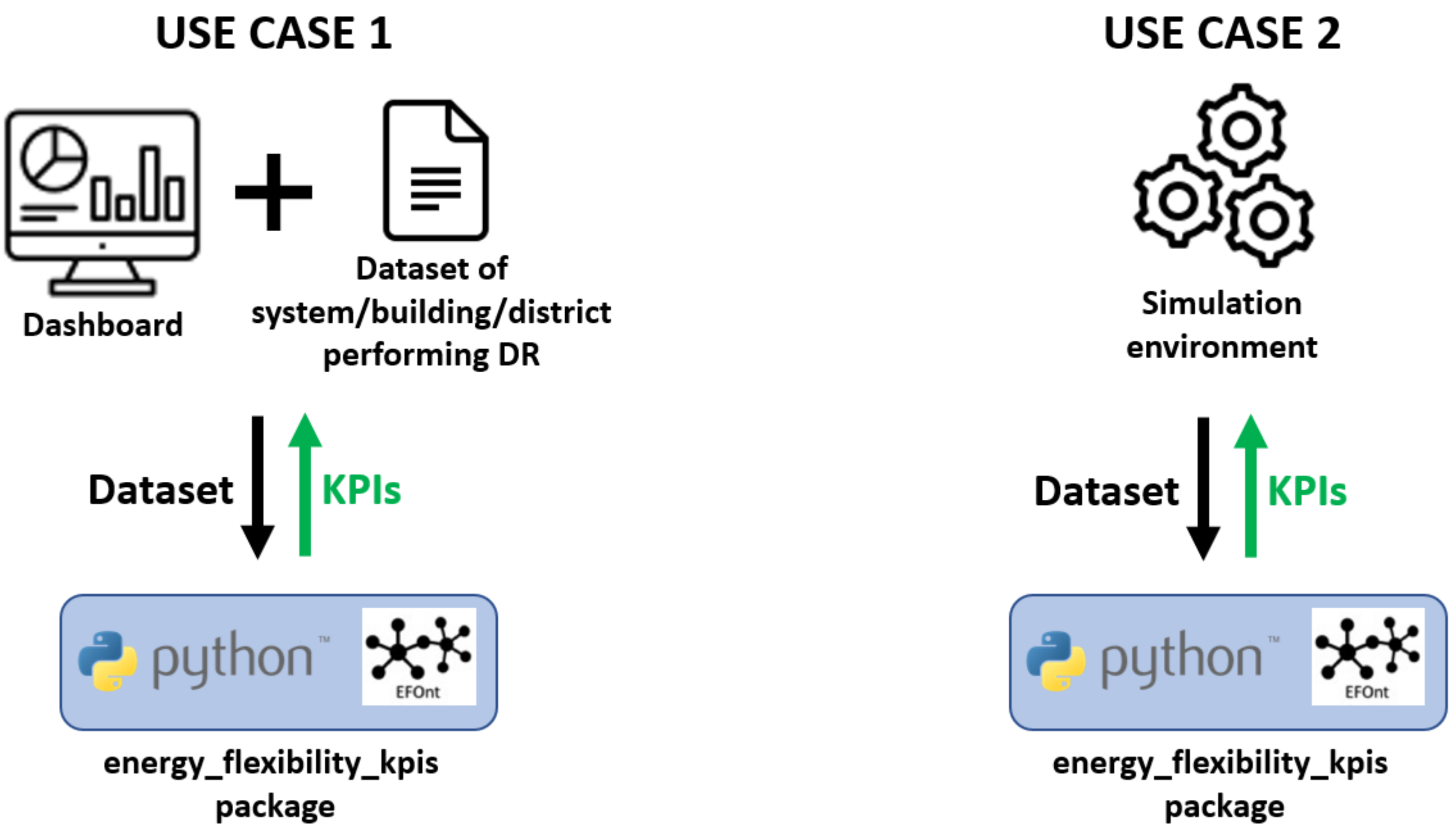
PROCESS DATA
➔Clean time series data
➔Aggregate time series data (e.g., average, maximum)

GENERATE BASELINE (optional)
➔Generate baseline

COMPUTE KPI
➔Calculate KPI
➔Visualize KPI results

User interface + Python package
Semi-automated

Energy Flexibility Assessment Service



Future Steps

- Publish Python package for energy flexibility assessment based on the EFOnt ontology and standardized variables and procedures
- Implement Python package into Dash-based web-app to ease and spread use of KPIs
- Exemplify concrete applications of the EFOnt ontology
- Deeper analyses of energy flexibility KPIs by systematic computation on collected datasets of building performing demand response

Concluding remarks

- **Shared definition** of energy flexibility KPIs is essential for comparing and benchmarking energy flexibility applications at scale
- Collecting datasets is **hard**: low response rate, confidentiality concerns, and lack of dataset documentation:
  - We **continue** to **collect** more datasets and encourage researchers to share their data
- Semantic interoperability is a persisting issue that needs to be evolved into a practical solution
- We hope that open tools like the present will help the standardization of demand response assessment and enhance the large-scale development of B2G services

Publications

- Data-driven key performance indicators and datasets for building energy flexibility: A review and perspectives (*Applied Energy, 2023*): https://doi.org/10.1016/j.apenergy.2023.121217

- State-of-the-Art Report on Data-Driven Smart Buildings - IEA EBC Annex 81: Report (*soon published*)

- IEA EBC Annex 81 - Data-Driven Smart Buildings: Building-to-Grid Applications (*accepted to IBPSA Building Simulation Conference: Shanghai 2023*)

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Thank you!

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