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Towards an assessment of the interaction between buildings and electrical grids

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Building Physics and Sustainable Design - KU Leuven

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Content

- Grid interaction: Neighborhood (grid) perspective
  - Grid impact assessment & Metamodeling
- Grid interaction: Building perspective
  - Rating building performance: Qualitative & Quantitative approaches
  - Quantitative grid interaction assessment
  - Indicators for building-grid interaction
  - Defining reference results
  - Challenges
- Conclusion

Building-grid interaction perspectives

Neighborhood

Assess neighborhood’s or grid’s vulnerability to the integration of DG new electrical loads in buildings.

Building

Assess building’s grid-friendliness, based on its potential to create issues in the grid.

Neighborhood (grid) perspective

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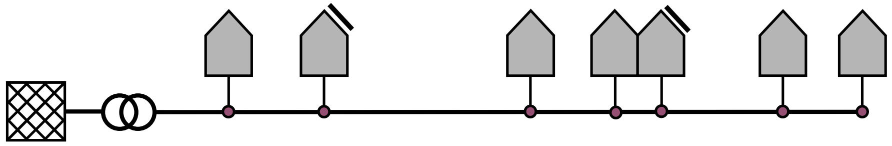
Grid impact assessment

Purpose:
Assess impact of future buildings and technical systems on neighborhoods (= low-voltage feeders)



Method:
Representative grids and building stock
Building & grid dynamic simulations
Probabilistic framework

Grid Impact Indicators:
Voltage levels
Transformer or cable overloading
Need for intervention (e.g. reinforcement)

Metamodel:
Simplified, fast models trained on detailed simulation results
Predict grid indicators based on integration rates of technical systems, grid and building properties
Linear Regression, Logistic Regression, Neural Networks, …

Metamodels of grid impact indicators

Voltage violation metamodel

Logistic regression model

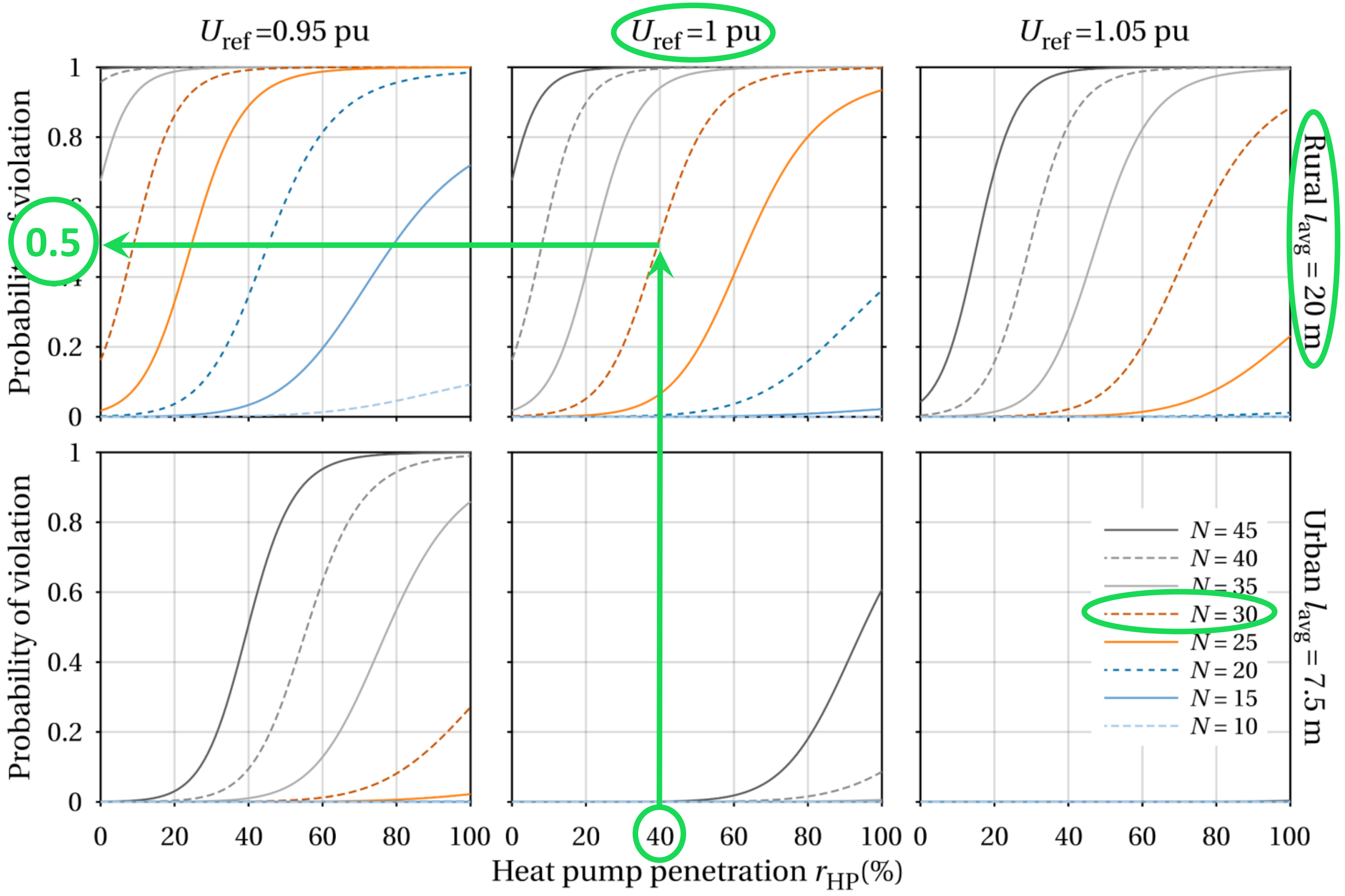
$$\ln\left(\frac{\hat{p}}{1-\hat{p}}\right) = \beta_0 + \sum_{i=1}^{q} \beta_i x_i + \sum_{i=1}^{q} \beta_{ii} x_i^2 + \sum_{i=1}^{q-1} \sum_{j>i}^{q} \beta_{ij} x_i x_j$$

Output:

- Probability of violating low voltage limit (0.85 pu)

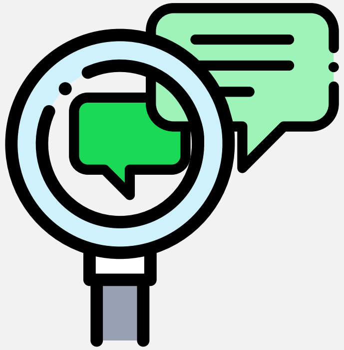
Inputs:

- type & size of neighborhood
- penetration of HP & PV
- grid properties
- building thermal quality



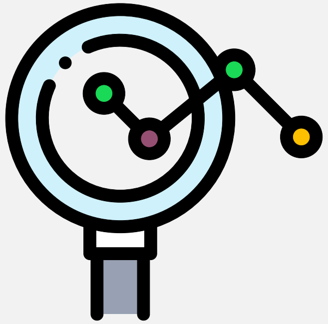
Building perspective

Rating building performance



Qualitative approach

- Green building rating schemes
  - BREEAM
  - LEED
  - Green Star
  - …
- Smart Readiness Indicator (Verbeke et al., 2019)



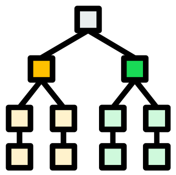
Quantitative approach

- Energy performance assessment
  - ANSI/RESNET/ICC 301
  - ISO 52000-series
  - Flemish EPB-EPC
  - …
- Flexibility Performance Indicator (Arteconi et al., 2019)

Verbeke, S., Aerts, D., Reynders, G., Ma, Y., & Waide, P. (2019). *INTERIM REPORT JULY 2019 OF THE 2ND TECHNICAL SUPPORT STUDY ON THE SMART READINESS INDICATOR FOR BUILDINGS*.
Arteconi, A., Mugnini, A., & Polonara, F. (2019). Energy flexible buildings: A methodology for rating the flexibility performance of buildings with electric heating and cooling systems. *Applied Energy*, *251*.

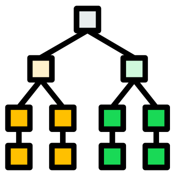
Qualitative rating approaches

Categories



- Objectives
- Topics
- Sub-categories
- Weighting

Items



- Indicators
- Criteria
- Features
- Weighting

Scoring

- Credits
- Requirements
- Reference values
- Bonus

Rating

- Certification
- Rating

Quantitative rating approaches

Boundary conditions

- Weather
- Occupants
- Economic factors

Calculation method

- Tool/software
- Interval
- Assumptions

Indicator(s)

- Combination
- Weighting
- Normalization

Reference

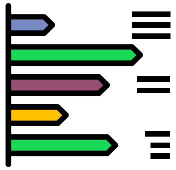
- Reference building
- Stock reference
- Requirements

Rating

- Performance class
- Certification
- Compliance

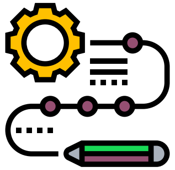
Quantitative grid-interaction assessment

Indicator(s)



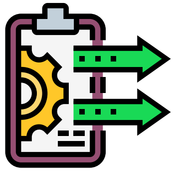
Literature review
- (net)ZEB related

Calculation method



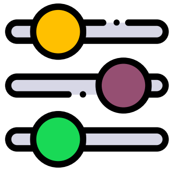
Depends on indicator
- High-res. load profile

Boundary conditions



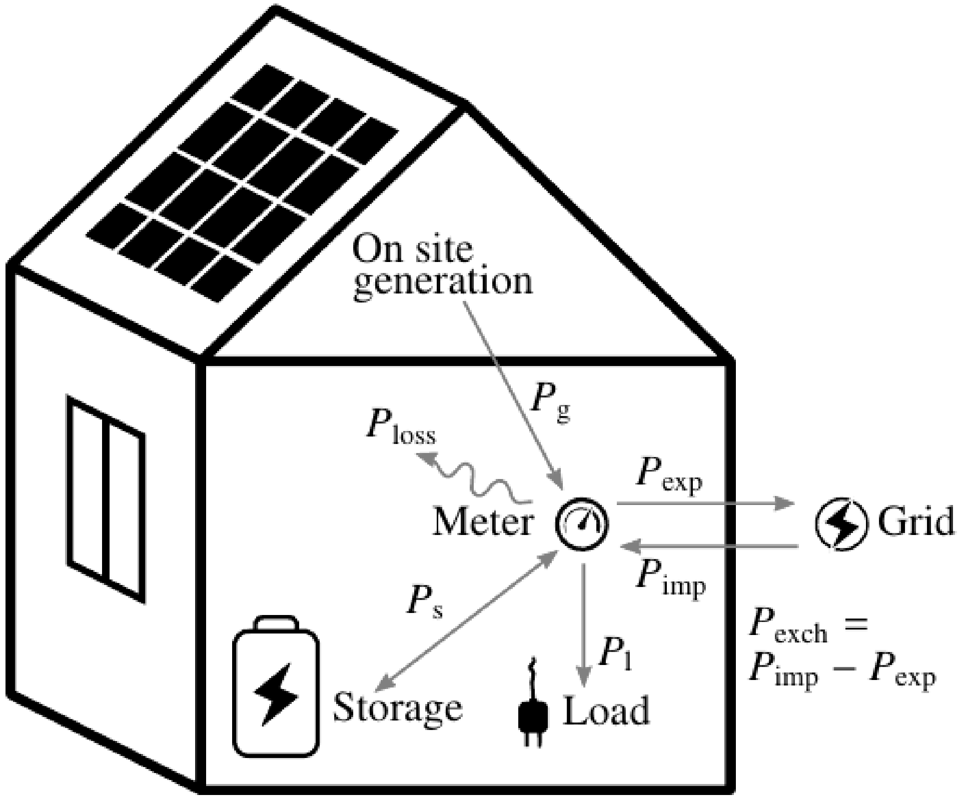
Depend on method
- Building properties
- Occupants (incl. appliance use)
- Weather

Reference



Based on simulations
- Reference grids & conditions
- Reference stock value
- Requirements

Indicators: Building perspective



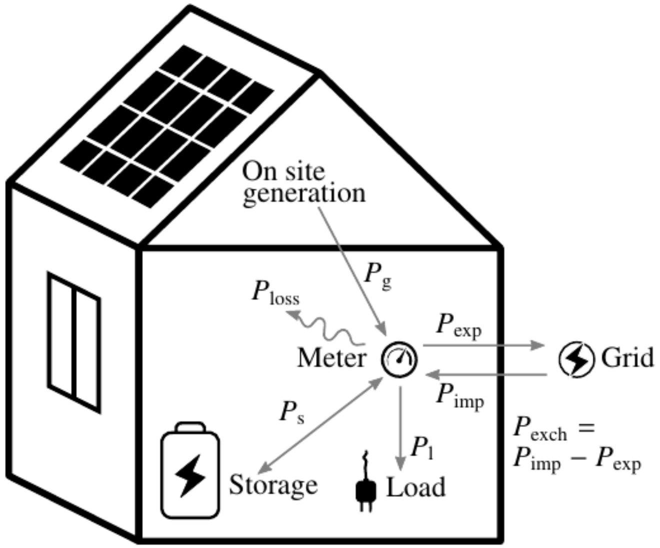
Most indicators

- come from (net)ZEB literature
- are based on depicted energy flows
- require high-resolution load & generation profiles
- require also loads for appliances and lighting
- are used for comparison of design solutions
- do not explicitly consider the grid in their calculation

- Load Matching
- Power System Matching
- Grid Interaction

Load Matching Indicators

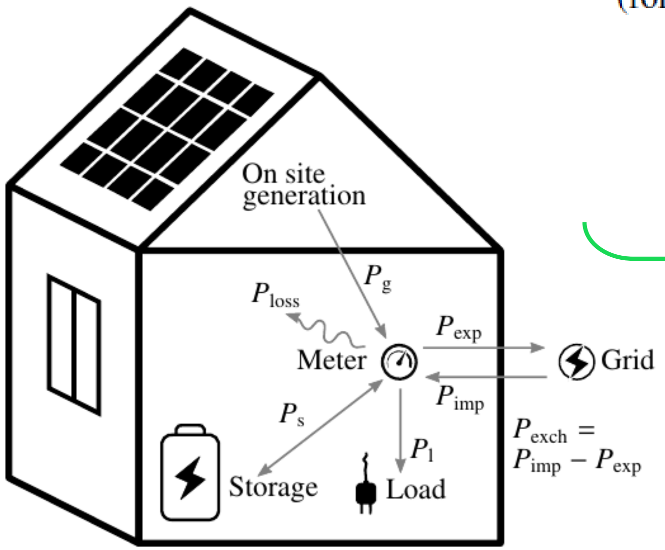
Load match index	$\mathrm{LMI}[-] = \min(1, \frac{\int P_g \, \mathrm{d}t}{\int P_l \, \mathrm{d}t})$
Load and generation cover factors	$\gamma_{\mathrm{load}}[-] = \frac{\int \min(P_g, P_l) \, \mathrm{d}t}{\int P_l \, \mathrm{d}t}, \quad \gamma_{\mathrm{gen}}[-] = \frac{\int \min(P_g, P_l) \, \mathrm{d}t}{\int P_g \, \mathrm{d}t}$
Loss-of-load probability	$\mathrm{LOLP}[\%] = \frac{t_{P_l > P_g}}{\Delta t} 100\%$



- Focus on balance of load and generation within building.
- Mostly used to size generation system.
- Can describe grid-dependence (self sufficiency), but not grid impact.

Power System Matching Indicators

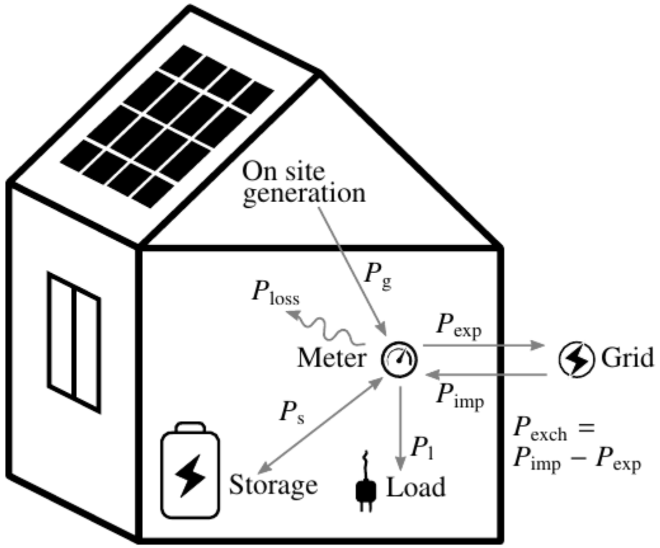
Grid compensation score	$\mathrm{GCS}[-] = \int (P_{gs} - \overline{P}_{gs})(P_{gs} - (P_l - P_g))\,dt$ with P_{gs} the electricity demand for dispatchable units in the system (characteristic of grid) and $\overline{P}_{gs} = \mathrm{mean}(P_{gs})$ the equivalent constant demand. All profiles are first normalized.
Mismatch compensation factor	$f_{\mathrm{MMC}}[-] = \frac{C_{\text{cost balance}}}{C_{\text{energy balance}}}$, where C is the PV capacity if designed for zero energy or cost balance respectively.
Market matching	$\Delta V[€] = \int a(P_g - P_l)\,dt$, where a is the market price of electricity.
Grid citizenship tool (for microgrids)	Component: $\mathrm{CR}[-] = \frac{C_g - P_{l,\text{rated}}}{C_g + P_{l,\text{rated}}}$, C_g the aggregated generation capacity, $P_{l,\text{rated}}$ the rated load Storage: $\mathrm{SR}[-] = \frac{C_g - C_s}{C_g \mp C_s}$, C_s the aggregated storage capacity Intermittency: $\mathrm{IR}[-] = \frac{P_{g,\text{day,avg}} - C_s}{C_g + C_s}$, $P_{g,\text{day,avg}}$ the average daily generation (only active hours).



- Require information on the power system (demand profile or prices), and costs.
- Require multi annual assessment, or definition of *standard* inputs.
- Don't consider distribution grid impacts.

Grid Interaction Indicators

- Focus on energy exchange with the grid.
- Require profiles at least in hourly resolution.
- Mostly used to compare building designs.
- Need definition of reference values for comparison.



Peak power	$P_{max}[kW] = \max(P)$ or $P_{max}[-] = \frac{\max(P)}{P_{cap}}$, with P as P_g, P_l or $\lvert P_{exch}\rvert$, and P_{cap} the connection capacity
One percent peak power	$\mathrm{OPP[kW]} = \frac{E_{1\%peak}}{\Delta t/100}$, with $E_{1\%peak}$[kWh] the energy in 1% peaks
Peaks above limit	$\mathrm{PAL}[\%] = \frac{t_{\lvert P_{exch}\rvert > P_{lim}}}{\Delta t} 100\%$
Generation multiple	$\mathrm{GM}_{g/l}[-] = \frac{\max(P_g)}{\max(P_l)}$, and $\mathrm{GM}_{e/i}[-] = \frac{\max(P_{exp})}{\max(P_{imp})}$
Dimensioning rate & kVA credit	$\mathrm{DR}[-] = \frac{\max(\lvert P_{exch}\rvert)}{P_{cap}}$, and $C_{kVA}[-] = 1 - \frac{\max(\lvert S\rvert)}{S_{max,ref}}$
Capacity (utilization) factor	$\mathrm{CF}[-] = \frac{\int \lvert P_{exch}\rvert \, dt}{P_{cap}\Delta t}$
No grid interaction probability	$\mathrm{P}_{E\approx 0}[\%] = \frac{t_{\lvert E_{exch}\rvert < 0.001}}{\Delta t} 100\%$, with $E_{exch} = \int P_{exch}\, dt$
Grid interaction index	$\mathrm{GII}[-] = \mathrm{std}_{year}\left(\frac{P_{exch}}{\max(\lvert P_{exch}\rvert)}\right)$
Grid matching	Difference in any other indicator caused by adding building profile to grid profile.

Defining the reference based on grid simulations

Purpose:
Define reference values for
building-level grid-friendliness indicators

Method:
Representative grids and building stock
Building & grid dynamic simulations
Probabilistic framework

Grid Impact Indicators:
Voltage levels
Transformer or cable overloading
Need for intervention (e.g. reinforcement)

Reference:
Find average value of indicator in stock
Correlate building-level indicators (e.g. $P_{E\approx0}$) with grid impact indicators (e.g. overloading)
Define building stock reference and regulation reference

Example

$P_{E\approx0}$ normal range: 0-100%

Based on building stock:

- Average $P_{E\approx0}$=80% → stock ref.

Based on grid simulations:

- $P_{E\approx0}$ <60% has zero probability of causing problems → regulation ref.

Classification:

Class	A	B	C	D	E
$P_{E\approx0}$[%]	0-40	40-**60**	**60**-70	70-**80**	**80**-87

Challenges

- **Data requirements**
  - Sub-hourly demand profiles needed.
  - All electricity end-use.
- **Occupant influence**
  - Load profiles highly depend on specific control settings, occupant preferences,...
  - Use *average* occupants and *average* (but variable enough) base-load?
  - Possibility to use measured consumption? Data privacy issues.
- **Coverage**
  - To determine reference values, grid simulations should sufficiently cover all possible cases (technical systems, control strategies,…).
- **Complexity**
  - The grid simulations are complex (many inputs and assumptions) and time consuming.

Some example results

- **Base cases**
  - HP has more impact than PV
  - Challenge: how to avoid the indicators negatively impact innovative or low-carbon technologies!

Some example results

- **Influence of thermal and electrical storage**

a grid friendliness assessment for buildings

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Take away messages

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Building-grid interaction assessment and rating

- Quantitative approach based on the PhD research of Christina Protopapadaki
- Starting point is the impact of the electric load of buildings on the low voltage grid and how this impacts different grid indicators. Currently heat pumps (HP) and photovoltaics (PV) are implemented
- In general HPs cause more issues than PV integration, it should be analyzed how to avoid that indicators negatively impact innovative or low-carbon technologies.
- Composite indicators will be needed as no single choice indicator is capable of addressing all issues
- The optimal indicator depends on the stakeholder
- The indicator depends on the load on the grid and will thus vary over time
- Fairness and impact on disadvantaged or vulnerable households need to be considered

Building-grid interaction assessment and rating

Neighborhood

Simulations
Metamodels

Identification and quantification of potential problems

Challenges

Data requirements
Occupant influence
Coverage
Complexity

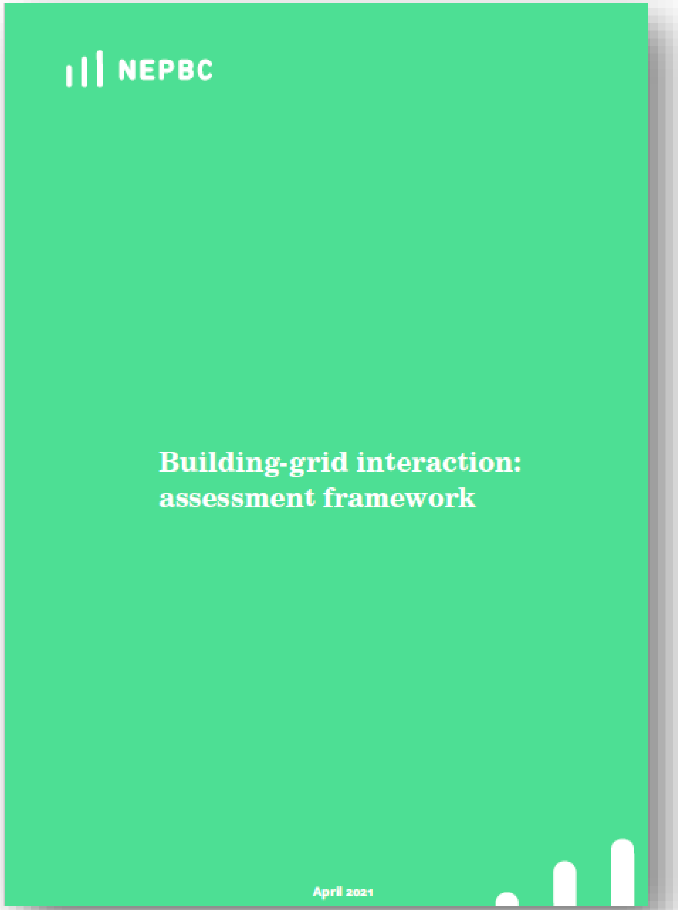
Building

Indicators
Simulations
Reference values

Rating of building’s grid-friendliness

Challenges

Further reading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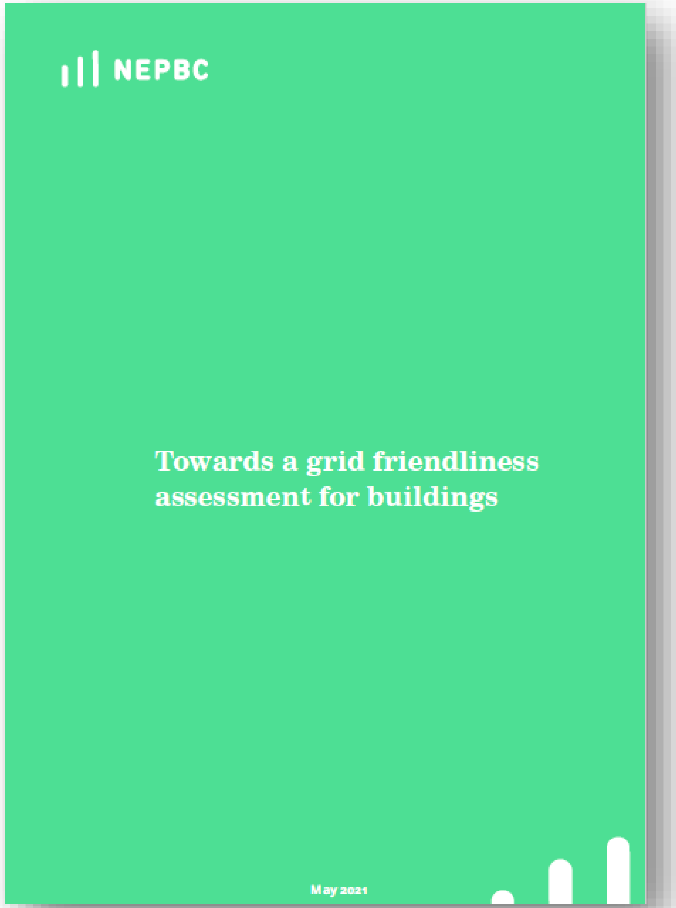
Building-grid interaction: assessment framework

April 2021

Report 1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Towards a grid friendliness assessment for buildings

May 2021

Report 2

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