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Faculty of Electrical Engineering
and Computer Science
Power Engineering Laboratory

IMPACT OF THE LOAD MODELING ON THE OPTIMAL SELECTION OF ROOFTOP SURFACES FOR PV INSTALLATION

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TU Graz

Motivation

Numerous studies focus on:

- determining photovoltaic (PV) potential of rooftop surfaces
- PV system integration regarding the PV potential
- PV system integration regarding the distribution network (DN) operation
- participation of active elements
- optimization of DN operation

combining these approaches for optimization of DN operation

Research goal

Methodology for minimization of annual energy losses in DN by optimal placement of PV systems

- *high-resolution PV potential of rooftop surfaces*
- *time-dependent network operation*

SOLVING THE PROBLEM OF SELECTION OF OPTIMAL ROOFTOP SURFACES FOR PV INSTALLATION

Identification of the additional factor:

dependency of power consumed from a supply voltage

i.e. ***LOAD MODELING***

Presentation overview

Introduction

Methodology

Case study on real urban low voltage DN

- test network
- operation scenarios

Results

Conclusion

Introduction

- Evolution of DN from a passive to an active element of electric power system
- Technical, economic, social, regulatory impact
  - Active participation of different elements of DN, promoted by political directives
  - Proliferation in renewable energy resources (DER) integration
  - Different methodologies for minimization of DN losses

Methodology

- Selection of rooftop surfaces for installation of PV systems, optimal from:

  - **Solar energy availability standpoint**
    - PV potential assessment

  - **Distribution network operation standpoint**
    - minimization of annual energy losses
    - ensuring operational constraints

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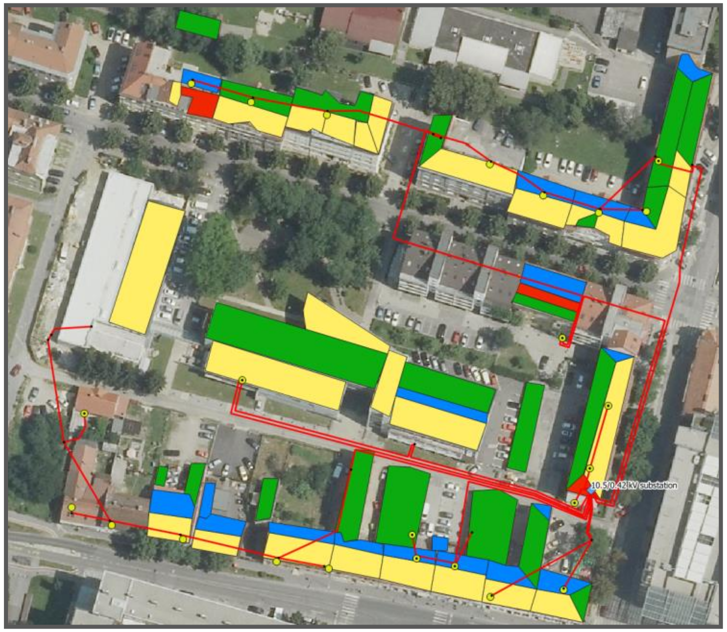
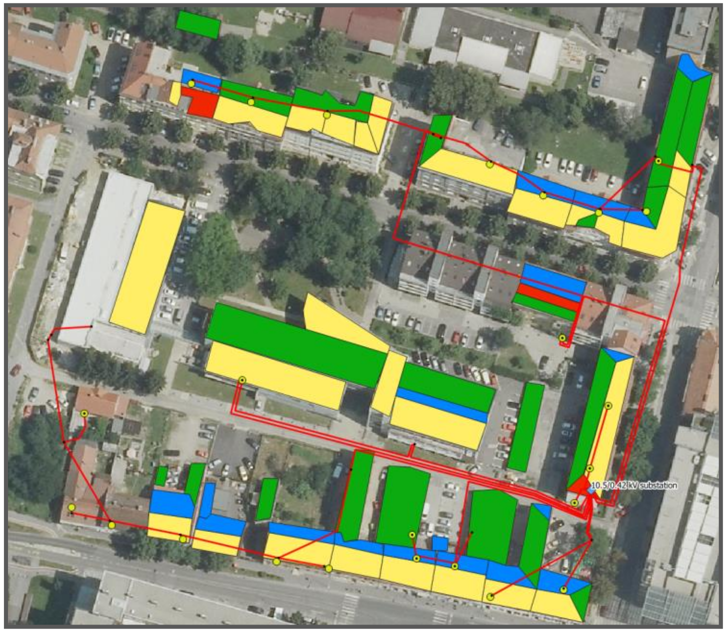
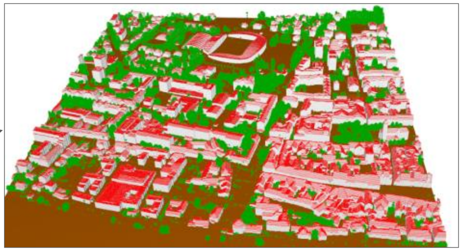




Layer 1: predprocessing
LiDAR data



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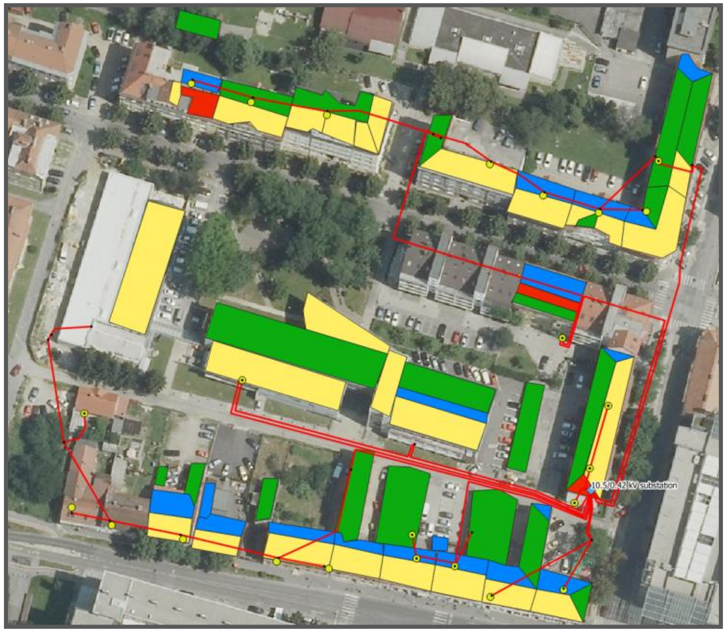
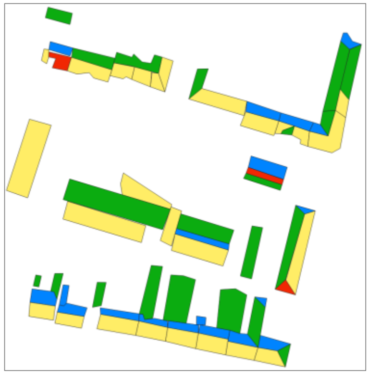


Layer 2: assessing PV potential and rating rooftop surfaces



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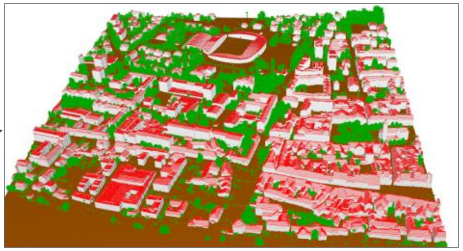
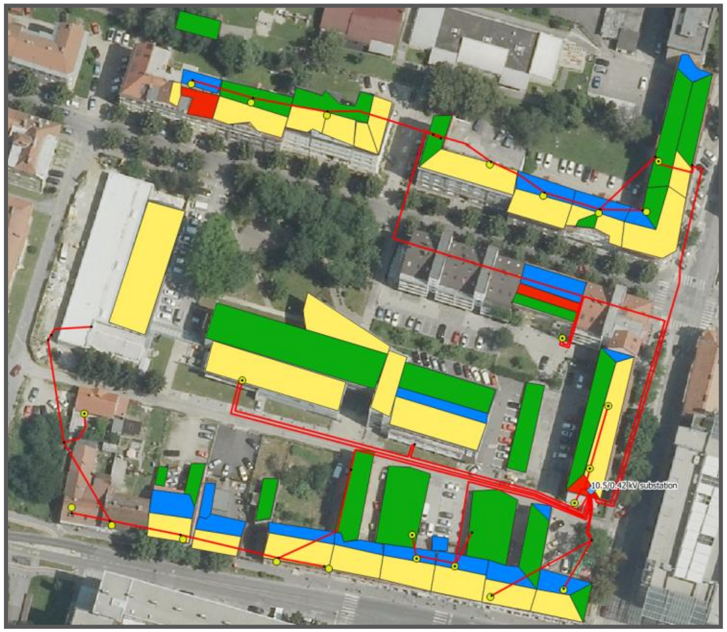
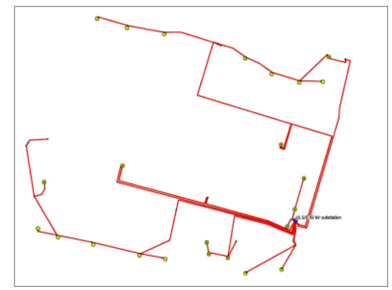




Layer 3: modeling distribution network



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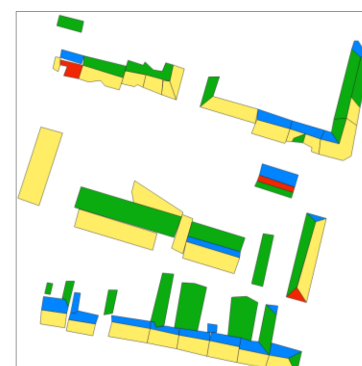

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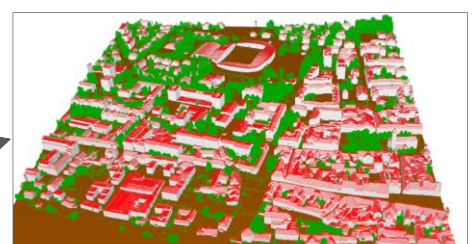
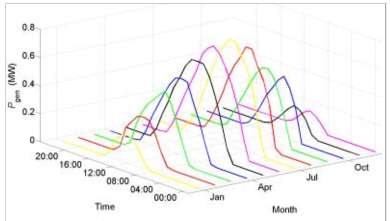
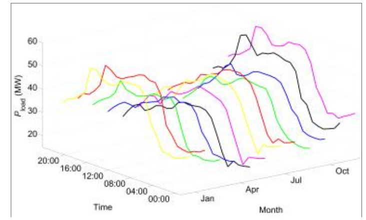
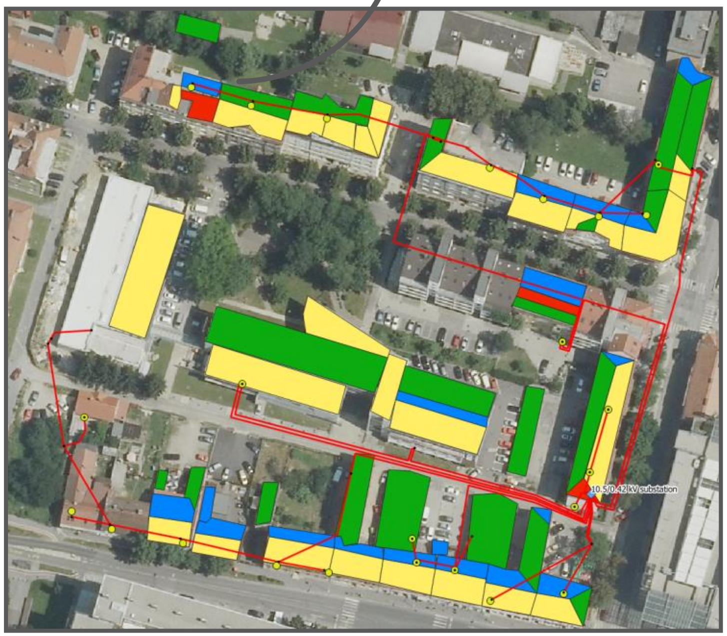


Layer 4: time-dependent loading and generation profiles







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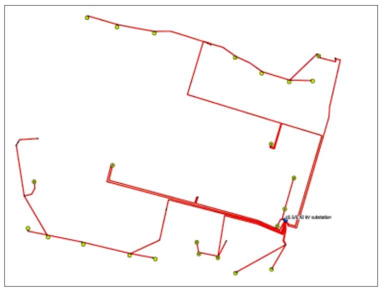

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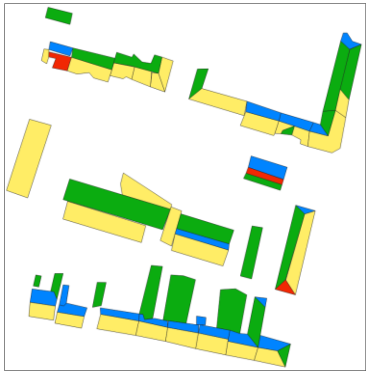

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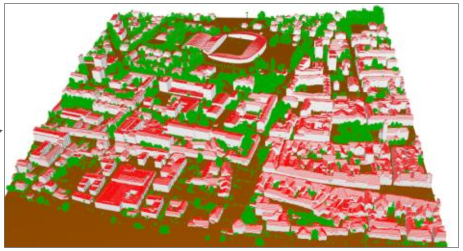
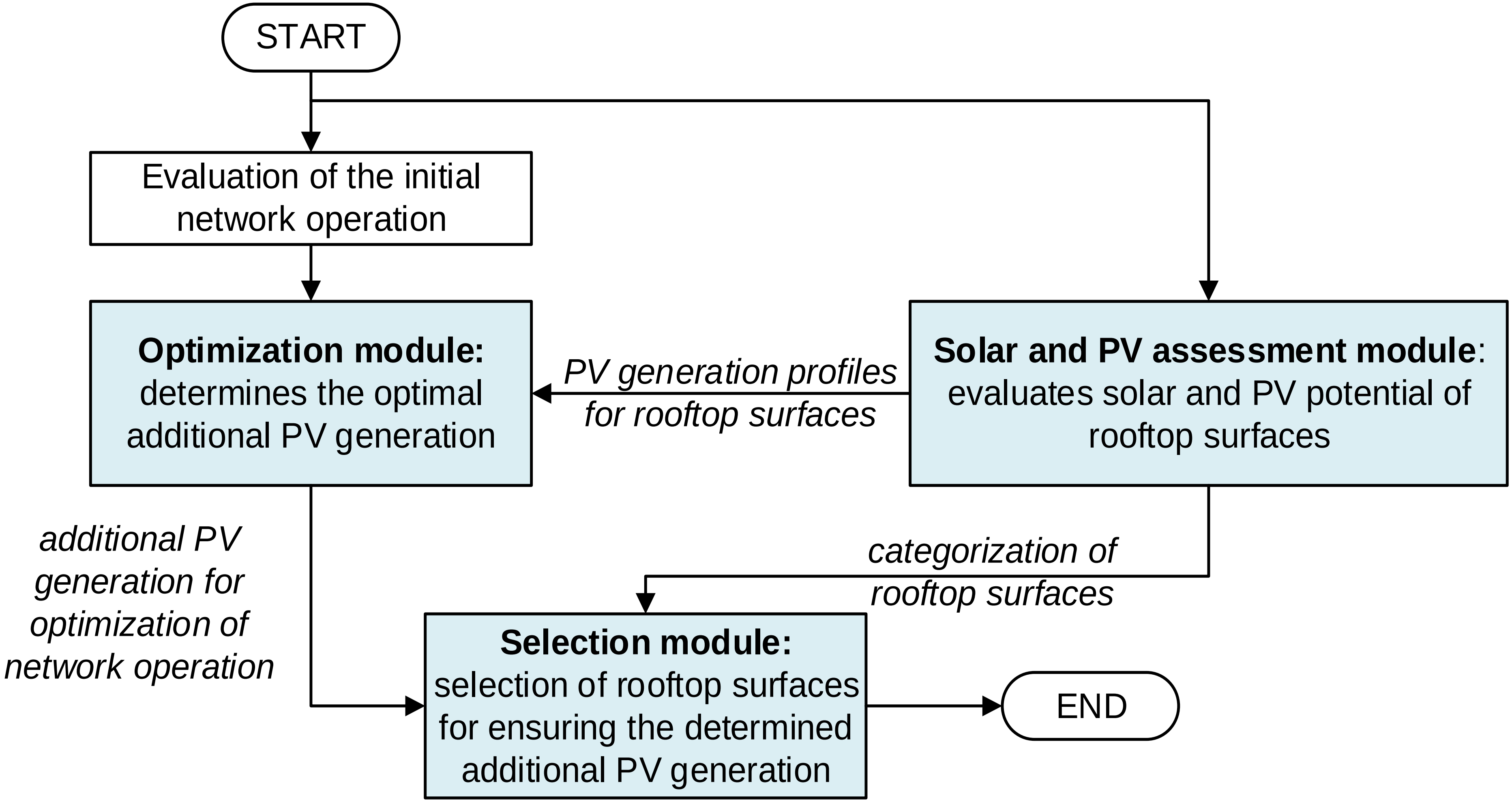


Simplified block diagram



Solar and PV potential assessment module

LiDAR data, pyranometer measurements of direct and diffuse irradiance, algorithm for consideration of shadowing, module inclination and efficiency characteristics

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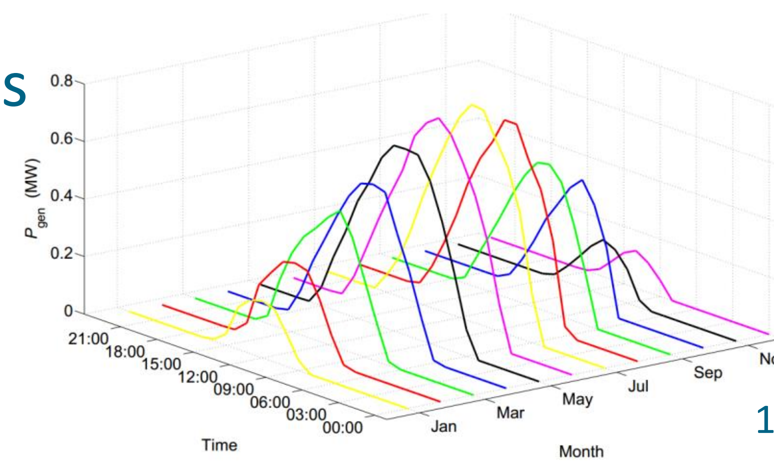
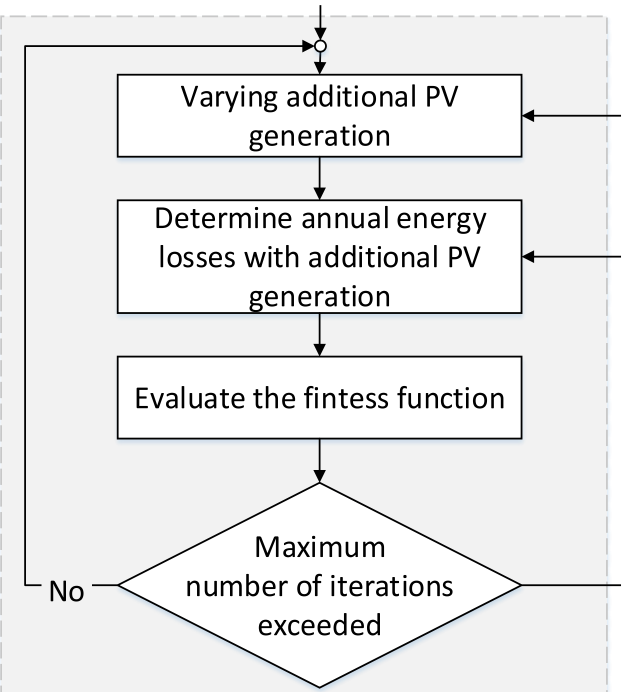
- Solar and PV potential assessment
- Categorization of rooftop surfaces *(suitability categories: very high, high, medium, low)*
- Hourly power generation profiles



Optimization module



Optimization:
Additional PV generation, yielding minimum annual energy losses determined

Differential Evolution

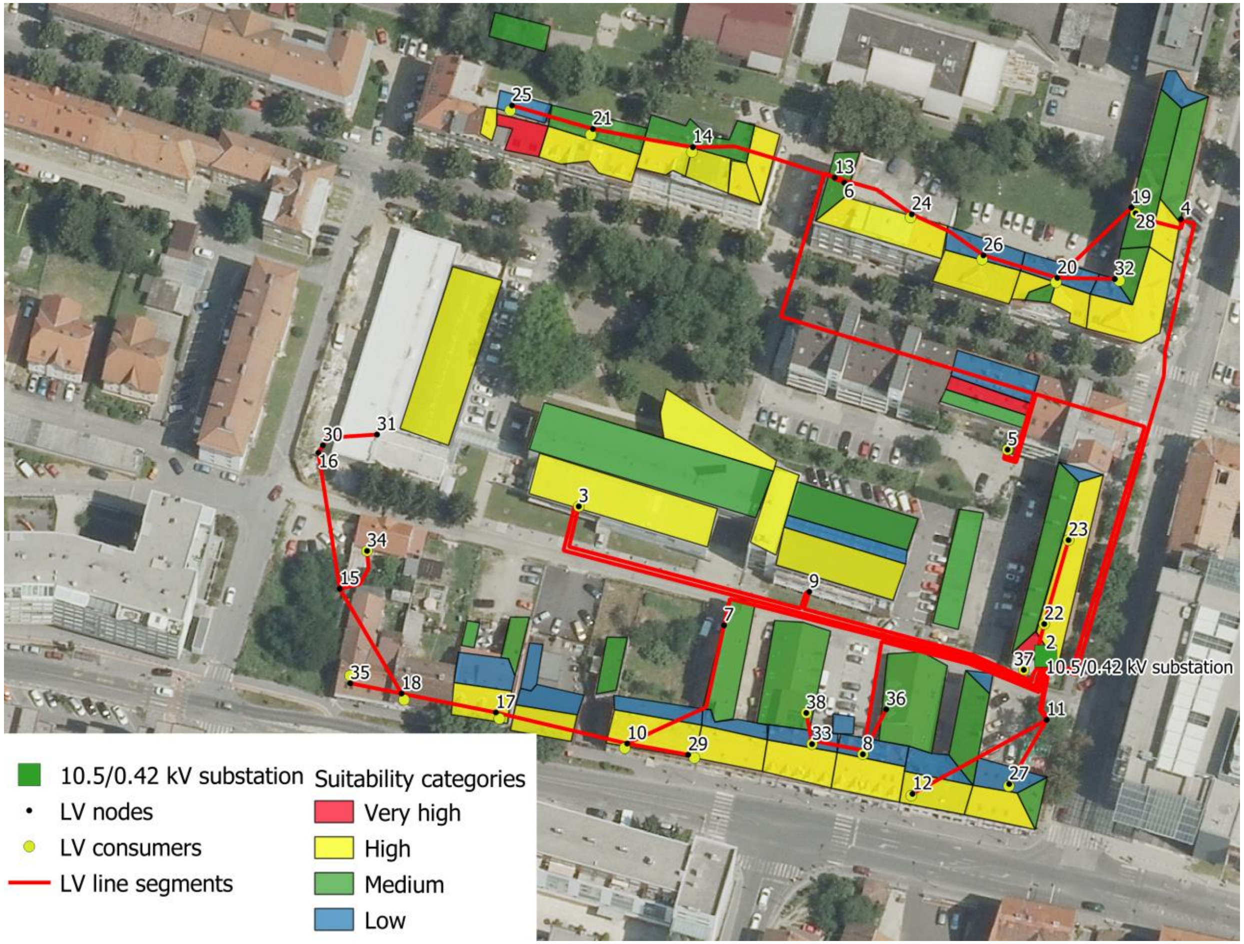
Optimal solution is the one yielding the minimum annual energy losses

- Objective function:

$$q_{\mathrm{fun}} = \frac{W_{\mathrm{loss\_addPV}}}{W_{\mathrm{loss}}} + p$$

Penalties p ensure that voltage profiles and currents are kept within the prescribed limits

Test DN – real urban LV



LV node	Number of connected rooftops
3	3
5	3
8	3
9	5
10	3
12	4
14	5
17	7
20	4
21	2
22	2
23	2
24	2
25	4
26	2
27	3
28	4
29	3
31	1
32	3
33	3
38	1

DE search parameters $\{x_{\mathrm{p},1}, x_{\mathrm{p},2} \dots x_{\mathrm{p},22}\}$ – **optimal locations for PV system installation**

Loading model

Polynomial models of the active $P_{\mathrm{load,n}}$ and reactive powers $Q_{\mathrm{load,n}}$, consumed at node n

$$P_{\mathrm{load,n}} = P_{\mathrm{load,n}}\left(a_0 + a_1\left|\underline{U}_{\mathrm{n}}\right| + a_2\left|\underline{U}_{\mathrm{n}}\right|^2\right)$$

$$Q_{\mathrm{load,n}} = Q_{\mathrm{load,n}}\left(r_0 + r_1\left|\underline{U}_{\mathrm{n}}\right| + r_2\left|\underline{U}_{\mathrm{n}}\right|^2\right)$$

(a_0, r_0) - dependence on the supply voltage $\underline{U}_{\mathrm{n}}$

(a_1, r_1) - linear dependence on the supply voltage $\underline{U}_{\mathrm{n}}$

(a_2, r_2) - quadratic dependence on the supply voltage $\underline{U}_{\mathrm{n}}$

$$a_0 + a_1 + a_2 = 1$$

$$r_0 + r_1 + r_2 = 1$$

Optimization scenarios

Constant power loading model (**CPM)**

$$a_0 = r_0 = 1 \quad \text{and} \quad a_1 = a_2 = r_1 = r_2 = 0.$$

$$P_{\mathrm{load,n}} = P_{\mathrm{load,n}}$$

$$Q_{\mathrm{load,n}} = Q_{\mathrm{load,n}}$$

Constant impedance loading model (**CIM)**

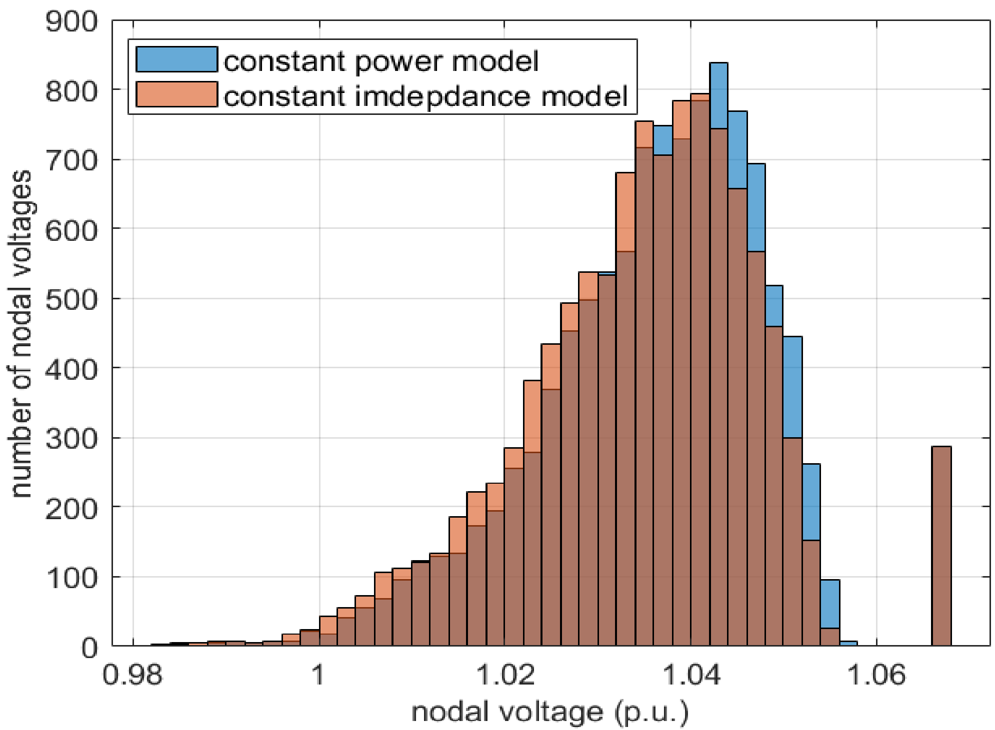
$$a_2 = r_2 = 1 \quad \text{and} \quad a_0 = a_1 = r_0 = r_1 = 0.$$

$$P_{\mathrm{load,n}} = P_{\mathrm{load,n}} \left|\underline{U}_{\mathrm{n}}\right|^2$$

$$Q_{\mathrm{load,n}} = Q_{\mathrm{load,n}} \left|\underline{U}_{\mathrm{n}}\right|^2$$

Results: Original network operation

	constant **power** loading model	constant **impedance** loading model
Original network annual energy losses	57.78 MWh	63.65 MWh

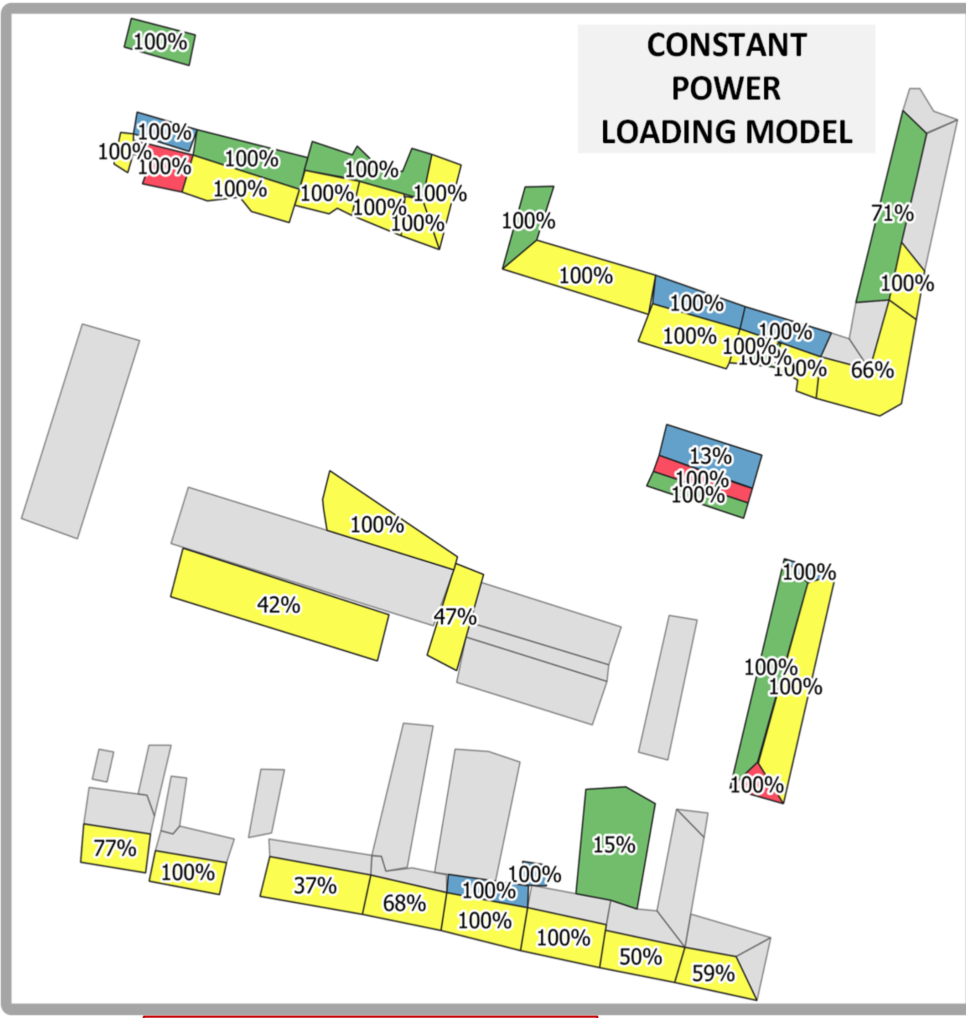


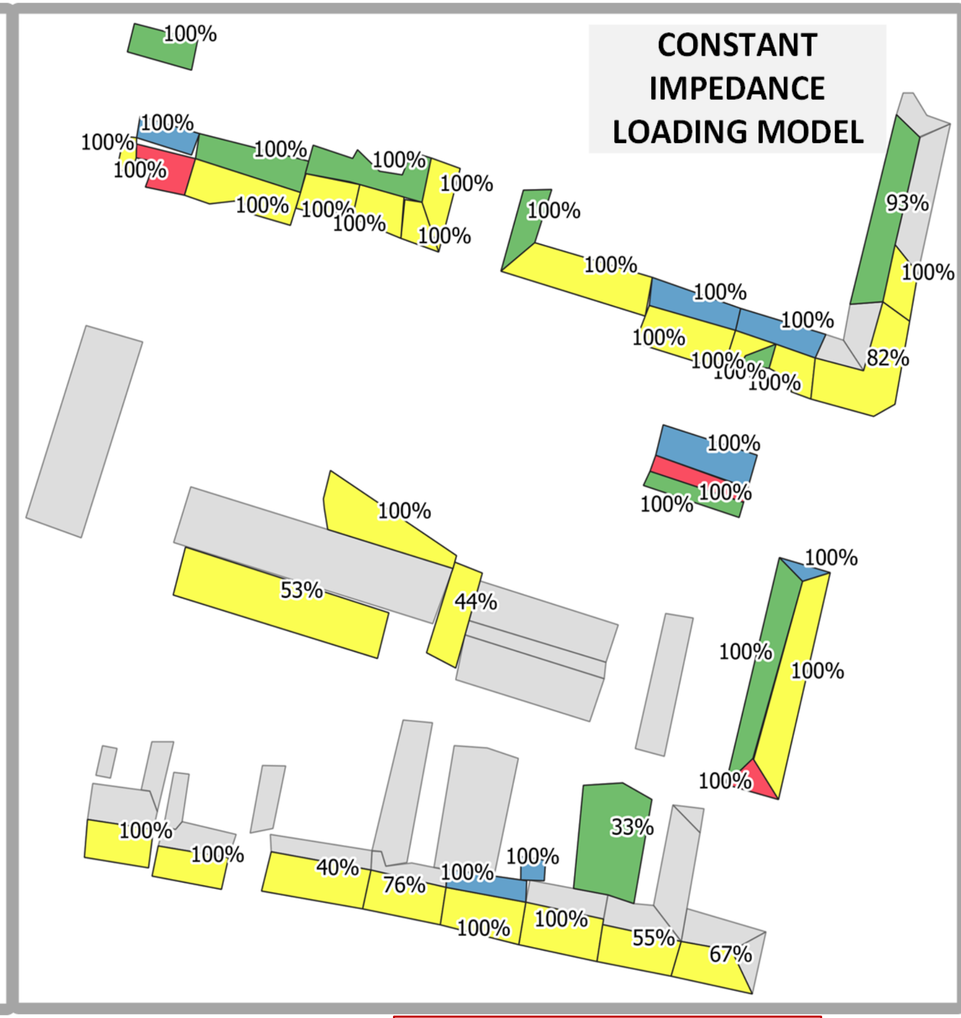
Distribution of the nodal voltages throuought the year

Results: Optimized network operation

	constant power loading model	constant impedance loading model
Original network losses	57.78 MWh	63.65 MWh
Losses after the optimization	38.79 MWh (32.9% reduction)	43.19 MWh (32.1% reduction)
Rated power of installed PV systems	267.0 kWp	287.9 kWp
Number of selected rooftop surfaces	32 whole, 11 partial	34 whole, 9 partial

Results: Selection of rooftop surfaces





267.0 kWp accomodated

- all rooftop surfaces

Suitability for PV installation of selected surfaces

- Very high
- High
- Medium
- Low

287.9 kWp accomodated

Conclusion

- Evaluation of impact of load modeling on PV system system placement
- PV system integration → *increase of voltage profile*
- Results of a case study on a real urban LV DN :
    - **increase in PV accommodation if the loading changes with supply voltage**
- Importance of the load modeling consideration increases with the **participation of active elements in modern DN operation**

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Thank you for your attention!

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Detailed block diagram