ENROAD

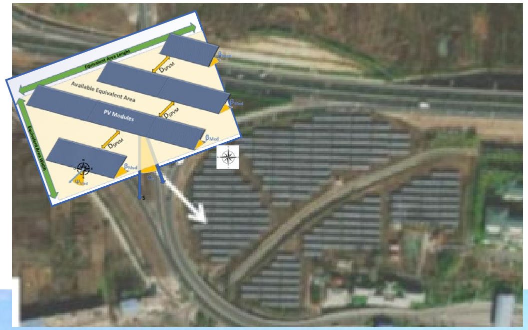
MODELLING OF THE SELECTED RENEWABLE ENERGY GENERATION TECHNOLOGIES AND RELATED/ADDITIONAL ACTIVITIES

CEDR 2019 Renewable Energy in Road Infrastructure
FINAL CONFERENCE – 24 October 2023

CEDR
Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

Introduction

- Modelling and parametrization of RETs for their evaluation within Renewable Energy Generation projects in road administration land/assets.
- Renewable Energy Generation Projects:
  - <u>Wind Energy projects:</u>
    - Small wind turbines (<50-100 kW per turbine)
    - Large wind turbines (>500 kW per turbine)
  - <u>Solar Energy Projects:</u>
    - PV modules/arrays: Monocrystalline vs. Polycrystalline technologies
- Alternatives for the integration of renewable energy generation projects into the road infrastructure:
  - <u>*In spare spaces without traffic loads and next to the road.*</u>
    - *Like in medians/slopes of roads and open spaces in interchanges, as well as noise barriers.*
  - *In accessory, buildings, and facilities.*
    - *Building/facilities rooftop, parking lots, road accessories (light-poles)*
  - *In conjunction with the traffic loads, on or above the road (out of scope).*
    - *Supporting the traffic load in walkways, bicycle-lanes, and motorways; as well as integrated into road tunnels and roof for roads.*

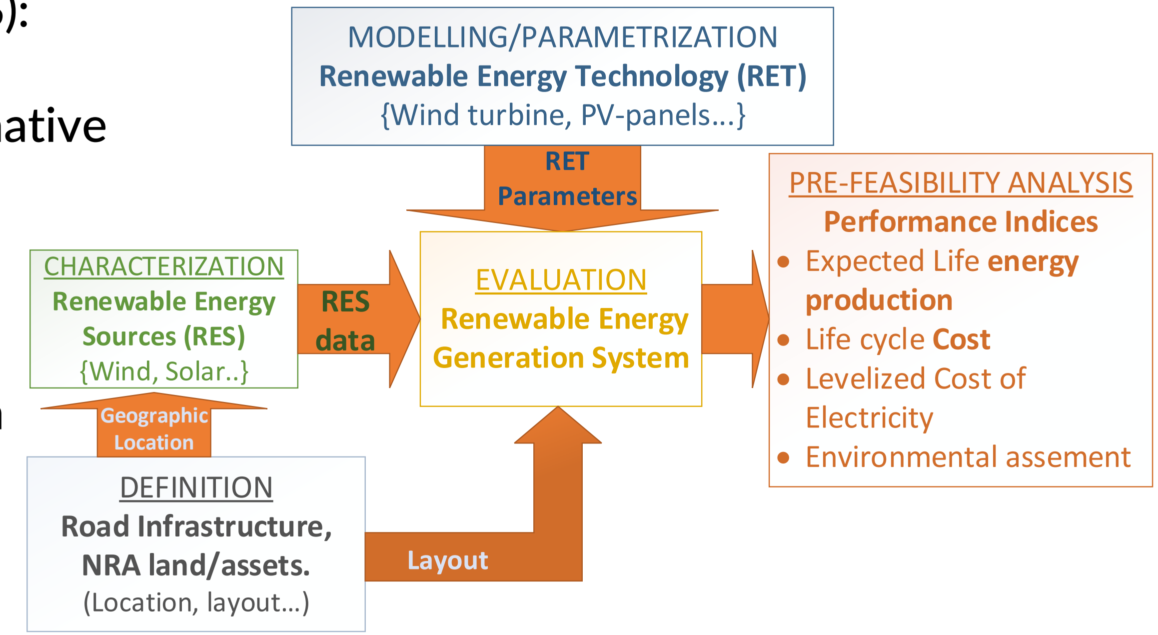


General Methodology/approach

Evaluation of Renewable Energy Generation Systems (REGS):

- Definition of Road infrastructure case / integration alternative
  - Location, terrain, surroundings
  - Available space / layout and constraints
- Characterization of Renewable Energy Sources (RES)
  - RES variability ➔ Typical Meteorological Yearly data
  - Time series: Wind-speed, Solar-irradiance, ambient-temperature.
- Modelling/Parametrization of RET devices
  - From discrete device (Turbine, PV module) to the complete REGS (Wind/PV farm)
  - Identification of relevant RET device parameters
  - RET device output power as function of RES time series and RET device performance:

$$P_{RETd}(RES(t), k_{RETd})$$



Evaluation considering relevant degrees of freedom in the REGS design

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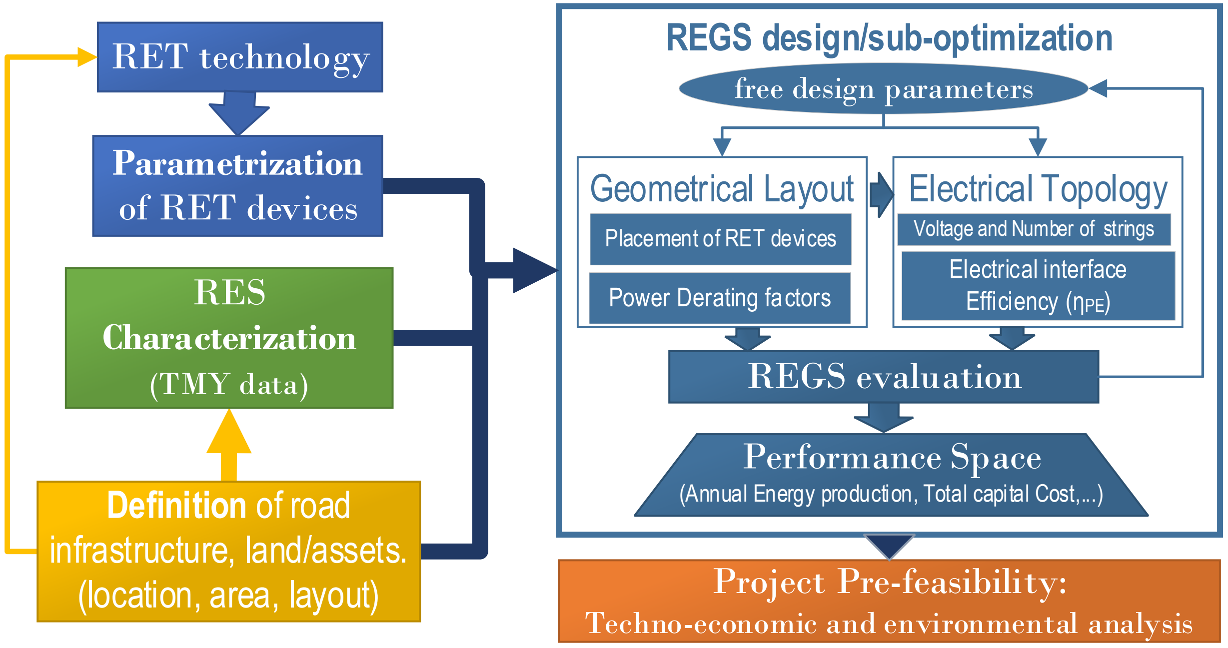
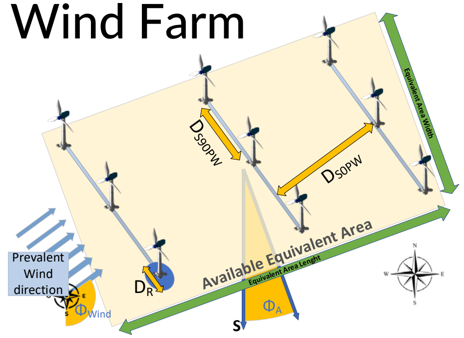
Evaluation considering relevant degrees of freedom in the REGS design

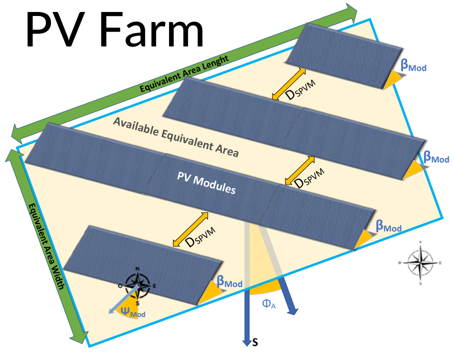


Simplified approach for REGS design and sub-optimization considering geometrical layout and power derating factors (ξ_{DF}) related to relative device placement

Wind Farm



PV Farm



REGS expected Life Energy Production (LEP) accounting for RET device power degradation (γ)

$$LEP \approx \sum_{i=1}^{N_{LTY}} AEP_0 \cdot \gamma_i$$

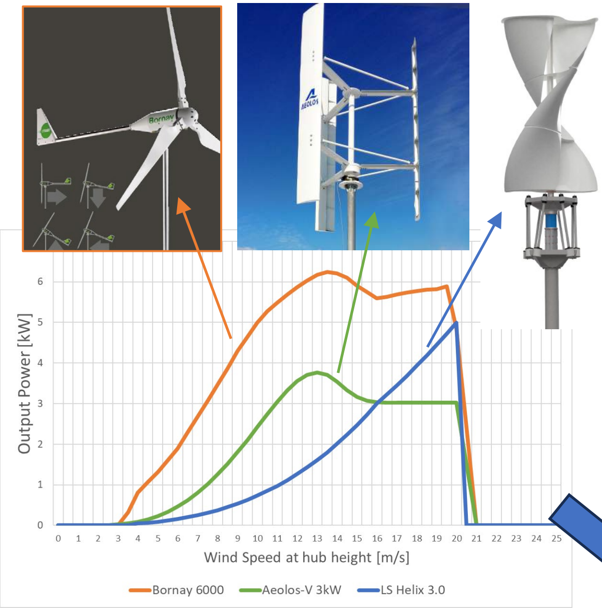
Expected initial Annual Energy Production (AEP_0):

$$AEP_0 = \eta_{GC} \cdot \sum_{i=1}^{N_{RETd}} \sum_{t_h=1}^{8760} \eta_{PC(i)} \cdot \xi_{DF(i)} \cdot P_{RETd}\big(RES(t_h), k_{RETd(i)}\big)$$

$$AEP_0 \approx \eta_{ePC} \cdot \xi_{eDF} \cdot N_{RETd} \cdot \sum_{t_h=1}^{8760} P_{RETd}\big(RES(t_h), k_{RETd}\big)$$

Wind Energy Projects

Wind Turbine Power Curve



Wind turbine parameters:

- Power curve normally provided by the manufacturer
- Physical dimensions: diameter, height…
- Capital Cost: Turbine, tower, converter
- Expected Lifetime

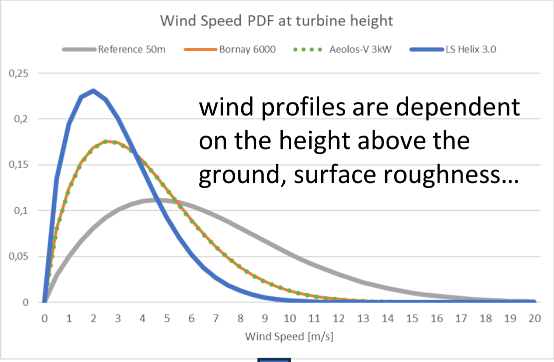
Wind source characterization

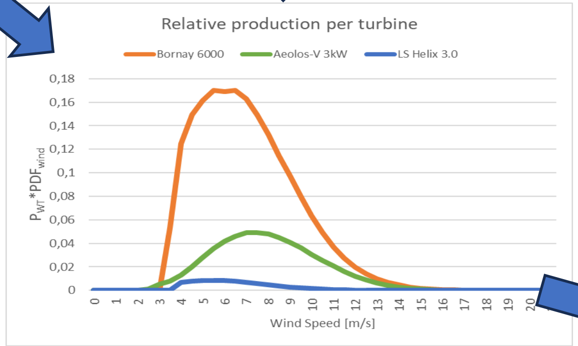
(Wind speed and direction)

Wind time series

Wind Profile

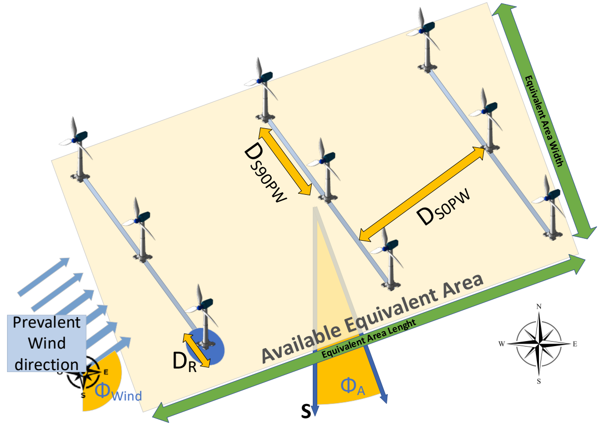
- Wind Probability Distribution Function (PDF)
- Prevalent wind direction





Simplified wind farm layout problem

Wind farm layout considering equivalent area and aligned with prevalent wind direction.



Total wind farm expected AEP_0

$$AEP_{WF0} = \sum_{k=1}^{N_{WTRows}} AEP_{WTF0} \cdot N_{WTperRow(k)} \cdot k_{WTD}(k)$$

k_{WTD} → *accounting for the power ratio of downstream wind turbines respect to upstream wind turbine. A function of distance between turbines*

Expected contribution of front wind turbines to the total AEP_0

$$AEP_{WTF0} = 8760 \cdot k_{WTA} \cdot \sum_{i=1}^{N_{vw}} \eta_{WFCT}(v_{wi}) \cdot P_{WT}(v_{wi}) \cdot PDF_W(v_{wi})$$

Solar PV Projects

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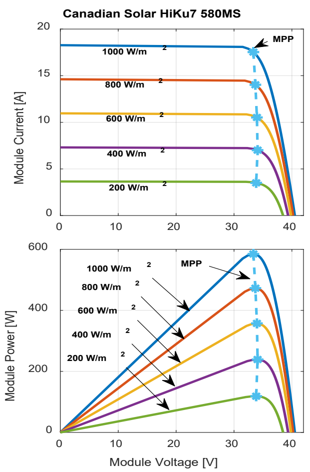
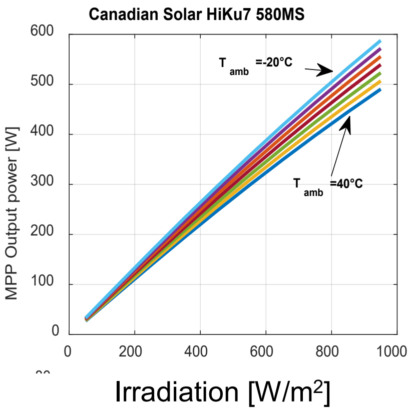
PV module





PV module output power as function of PV Irradiance and ambient temperature.

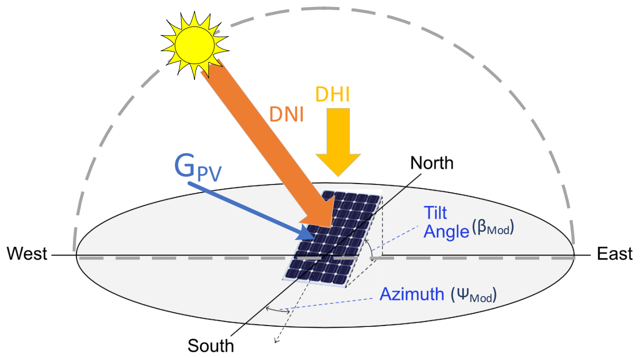
1. **V-I Characteristic** - single-diode model equivalent circuit. – MPP operation.
2. Method to estimate **circuit model parameters** from datasheet information.
3. **Thermal model** - convective and radiative heat exchange.

$$AEP_{PVM} = \sum_{t_h=1}^{8760} P_{MPP}\big(G_{PV}(t_h), T_{amb}(t_h)\big)$$

Solar Radiation characterization

Solar irradiance → Direct Normal Irrad. (DNI)

Diffuse Horizontal Irrad. (DHI)



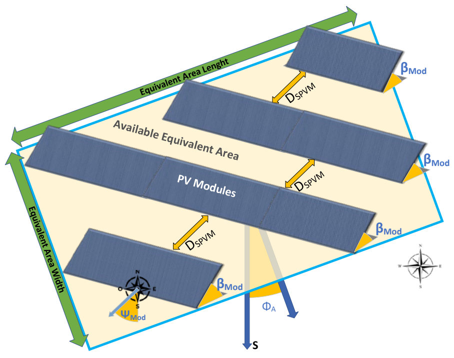
Total PV module irradiation: direct + diffuse

$$G_{PV} = B_{PV} + D_{PV}$$

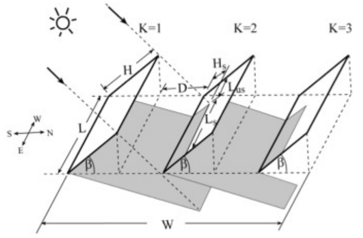
Depends on:

- PV module tilt and azimuth angle
- DNI and DHI
- Latitude
- Relative sun position: Sun declination and Hour angle.

PV farm layout problem



Simulation of relative sun position and self-shading of PV modules



Total PV farm expected AEP_0

$$AEP_{PVF0} = \sum_{k=1}^{N_{Rows}} N_{MR(k)} \cdot k_{SNR}(k) \cdot \eta_{PE} \cdot AEP_{PVM}$$

k_{SNR} → models the effect whereby PV rows cause shading of subsequent rows

Design accounting degrees of freedom in the PV module orientation and distance between PV rows

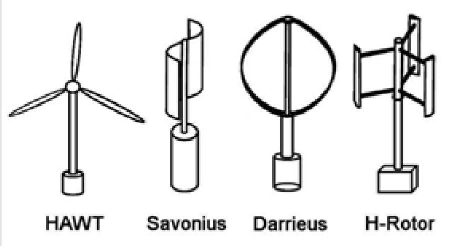
Analysis of technology trends of relevant parameters of the RET devices and general performance comparison of RETs.

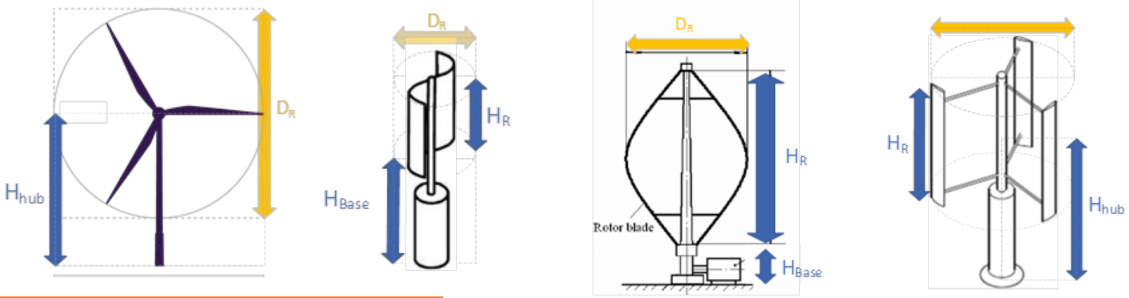
- Database for small scale wind energy and solar PV generation devices.
- Representative meta-parameters and technology trends for small- and large-scale wind turbines as well as solar PV modules based on Silicon crystalline technologies.
- A general methodology for the comparison of the considered RETs based on the application of the proposed methods.

Methodology for evaluation of system topologies and locations for future energy hubs with renewable generation

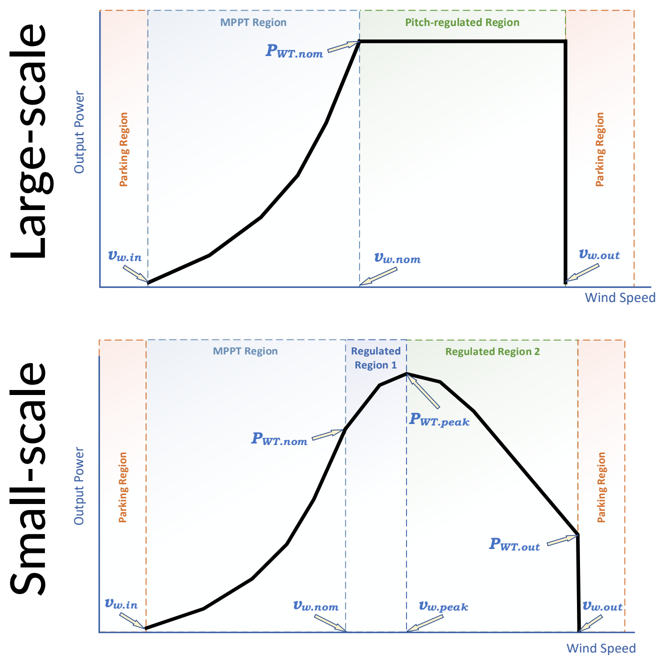
Wind Turbines Meta-parametrization

Wind turbines:

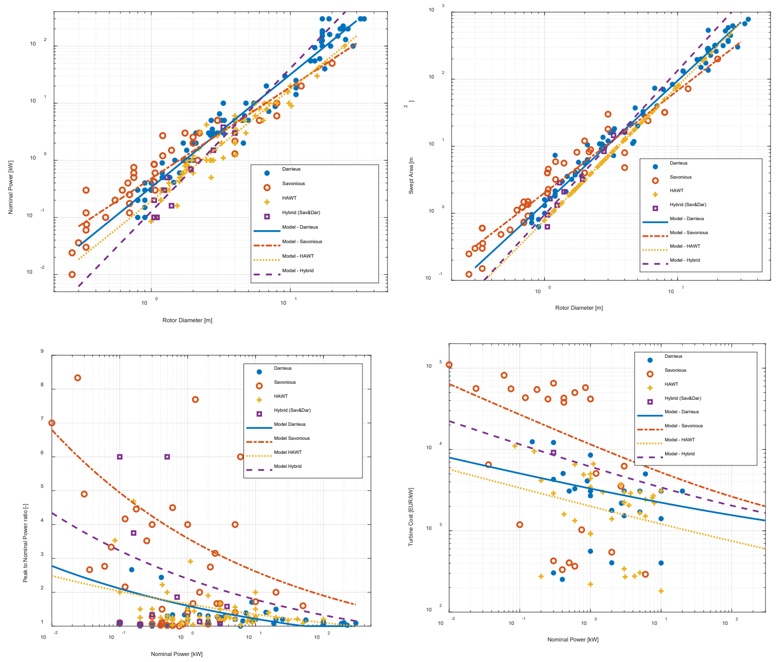


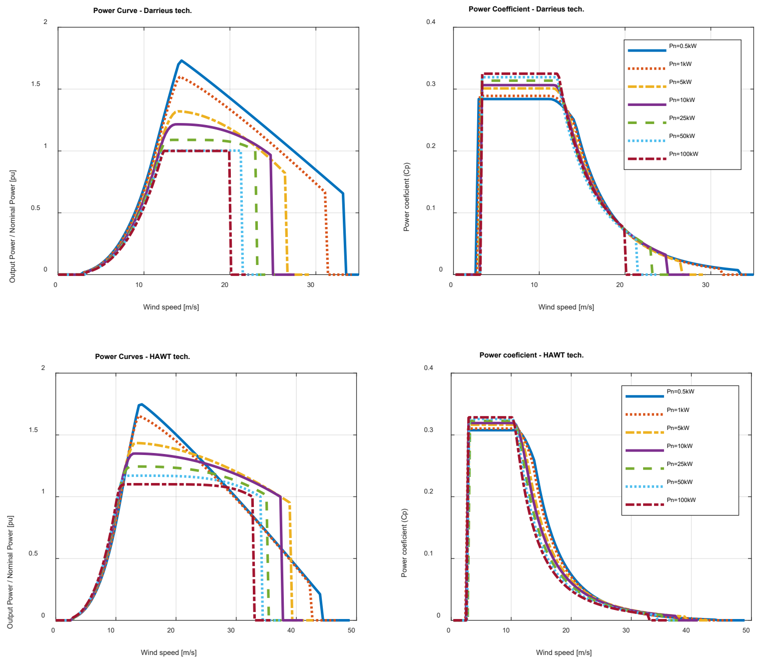


Power curve Parametrization

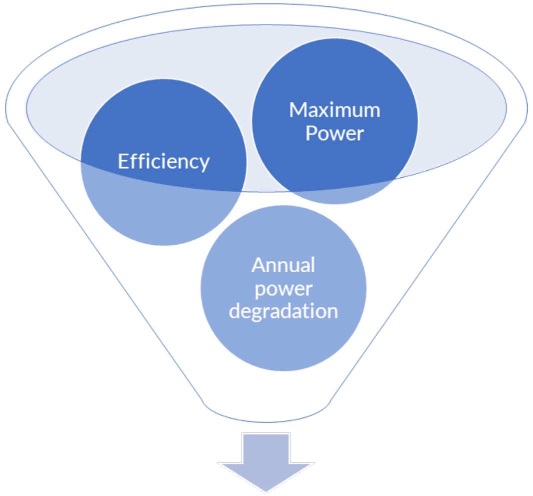


Meta-Parametrization





PV modules Meta-parametrization



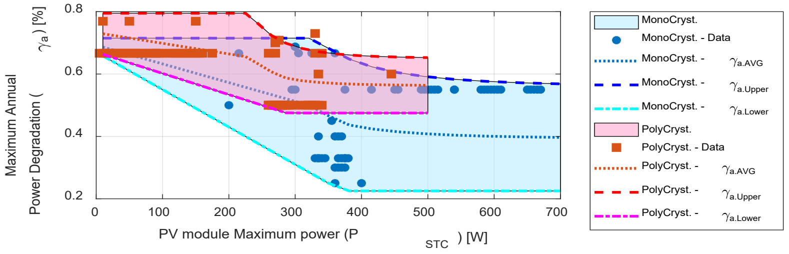
PV Module Parameter

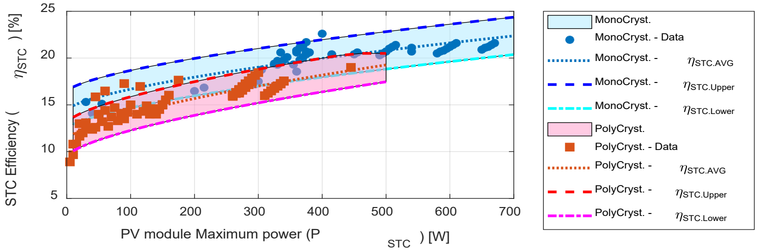
Physical dimensions

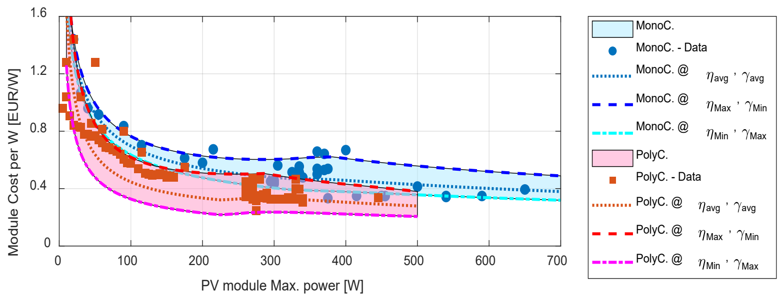
Module Cost

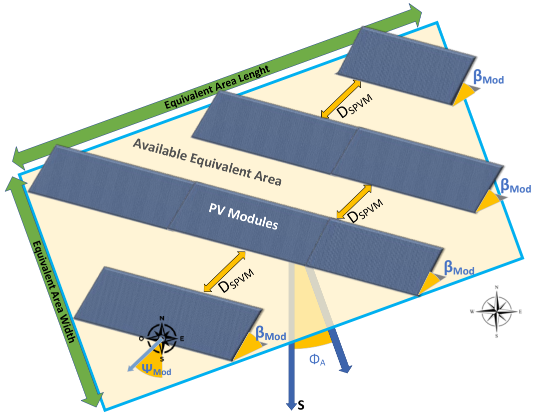
Output Power

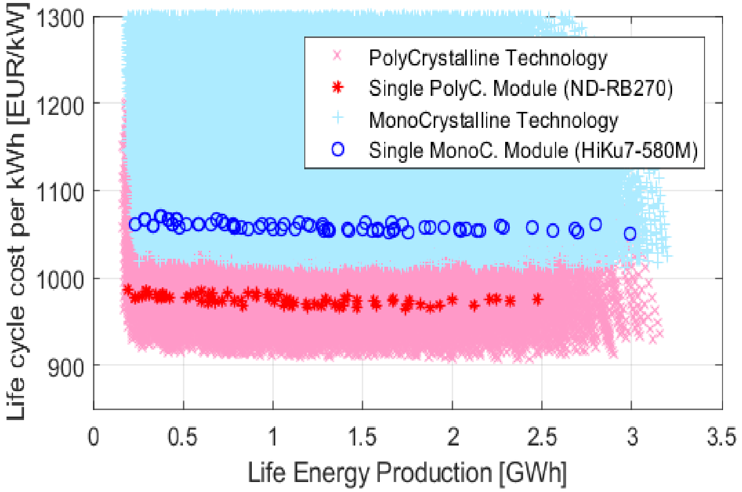
Module voltage











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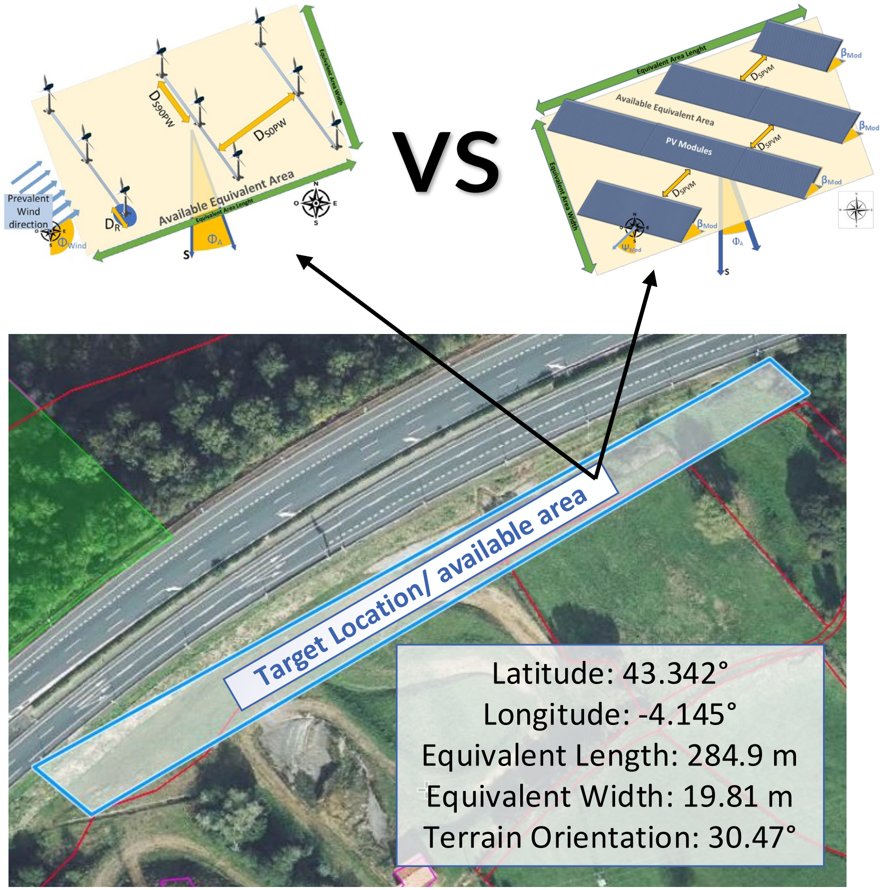
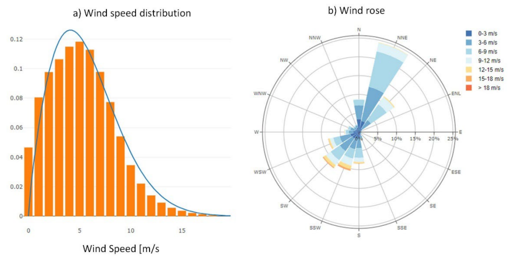
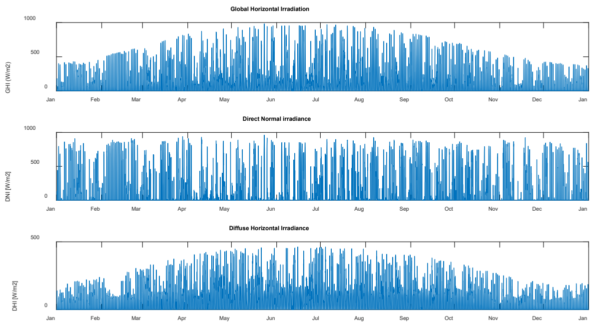
Analysis of RETs trends and general performance comparison

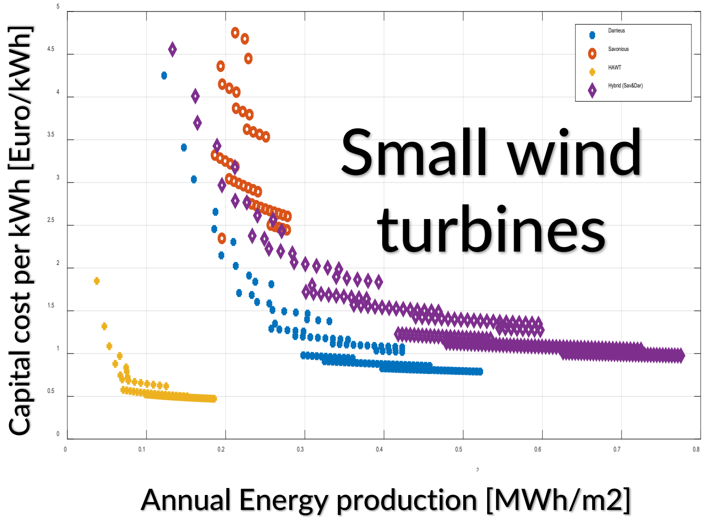


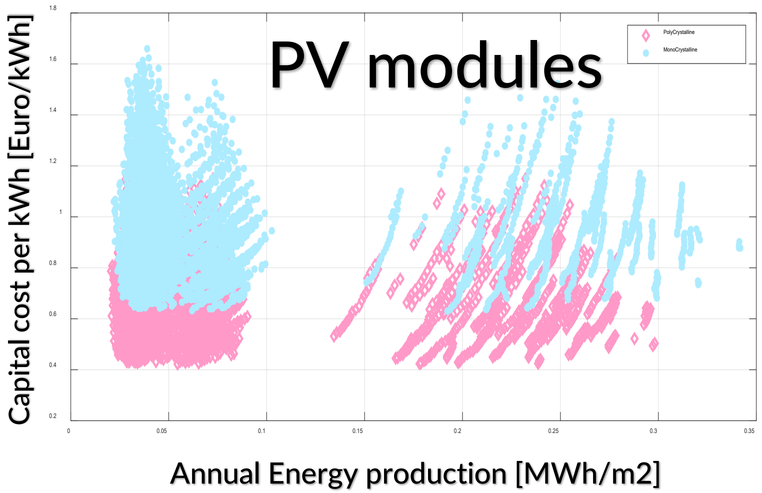
Wind Profile



Solar Irradiance







Task 2.3 Evaluation of system topologies and locations for future energy hubs with renewable generation

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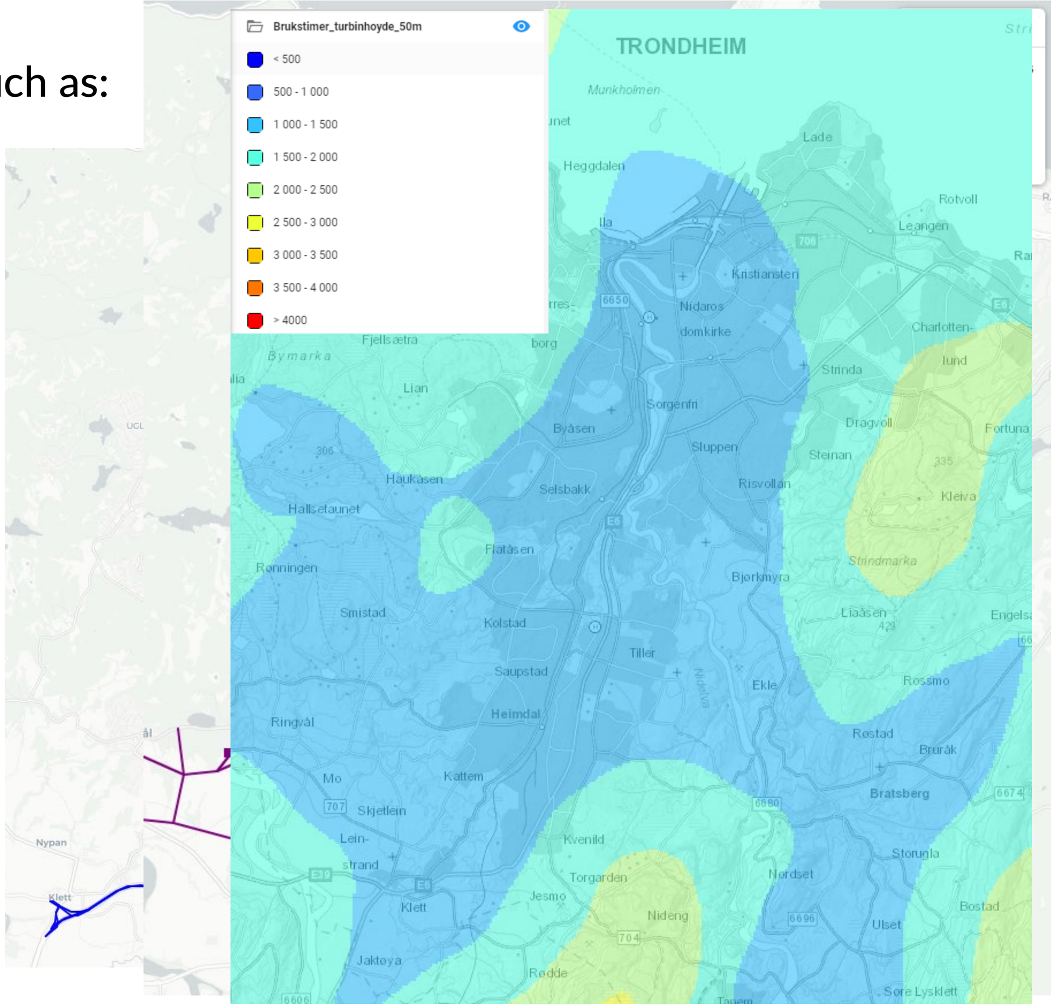
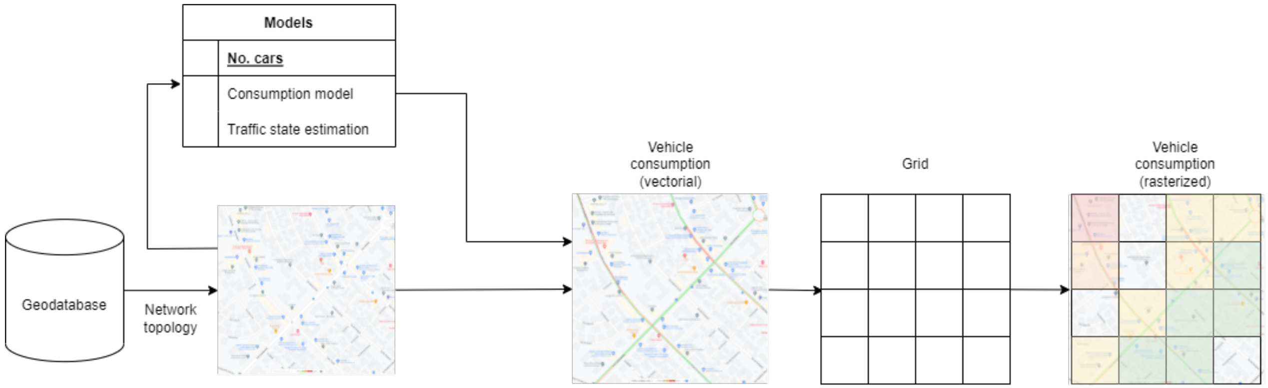
- Aim: Develop a method for evaluating and selecting the optimum locations for future energy hubs with renewable generation along road infrastructure
- Data needs: Information and data from open-source data sources, such as:
  - Weather data (solar irradiance, wind speed etc.)
  - Power system data (grid capacity, electrical load etc.),
  - Traffic flow data / charging pattern data
  - Geographical data (terrain, road network etc.)
- Identified sources:
  - OpenStreetMap:
    - Streetmap topology
    - Power features (power grid)
    - Other: Public on-surface parking area
  - Statens Vegvesen:
    - Inductive loops location
    - Traffic recorded data
  - NVE:
    - Wind atlas



Consumption processing

- 8760 traffic values
- State estimation (non-negative least squares (nnls) solver is used)
- Power Consumption $P(l,h) = \sum_{v \in V} D(v,l,h) \cdot C(\mathrm{v}) \cdot \vartheta(v)^{-1} \cdot p(v,l,h)$
- Energy Consumption $L(l) = \sum_{h=1}^{8760} \sum_{v \in V} D(v,l,h) \cdot C(\mathrm{v}) \cdot \vartheta(v)^{-1} \cdot p(v,l,h)$

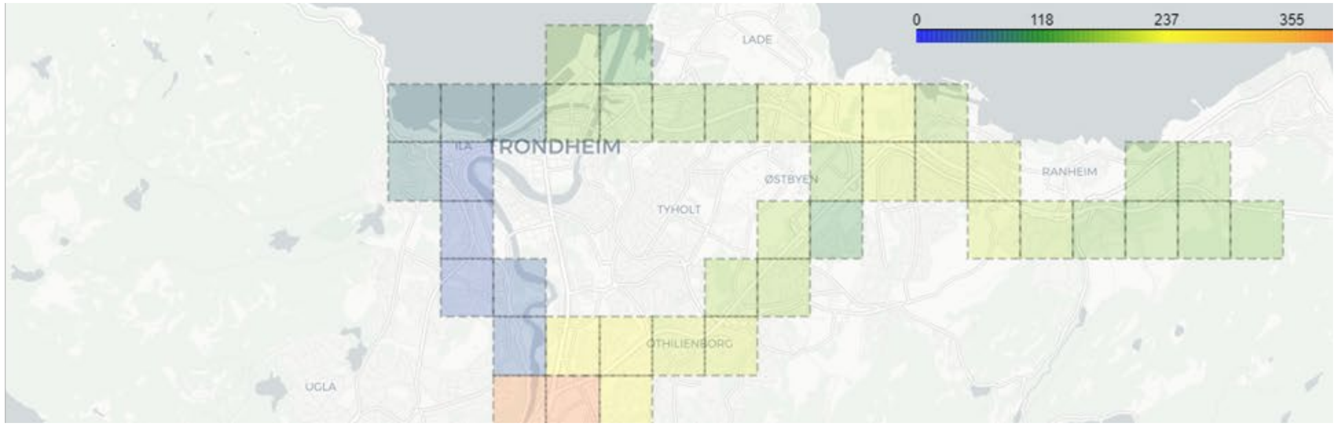
- A rasterization of power consumption information has been applied



- For power consumption, the 60 percentile has been used to size the charging stations

Consumption and generation processing

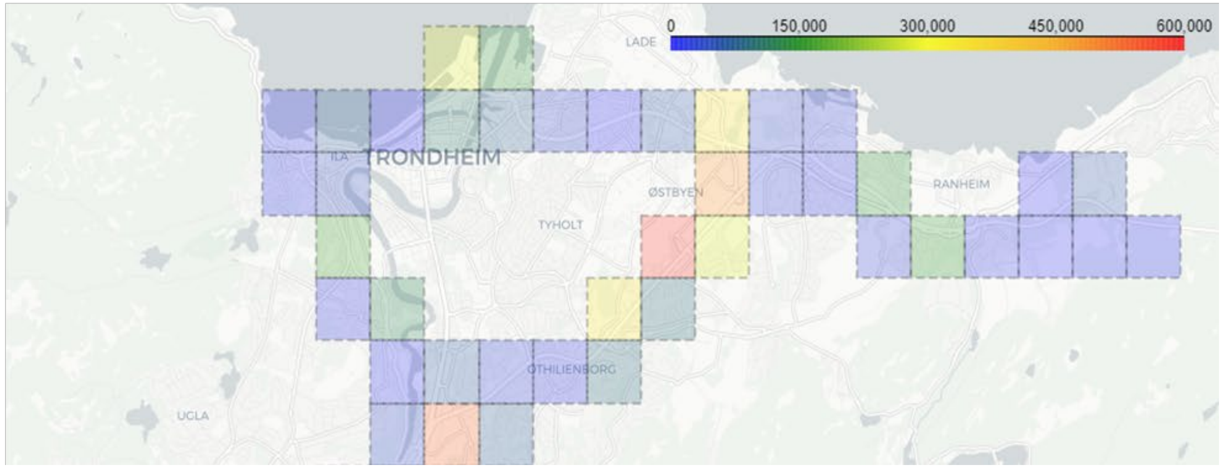
- Consumption



- Generation

Table 3. Characteristics of Bornay 6000 turbine

Item	Unit	
Reference turbine		Bornay 6000
Rotor Architecture		HAWT
Manufacturer		BORNAY
Nominal Power	kW	6
Peak Power	kW	6,2
Rotor Diameter	m	4



Minimization problem

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- Energy consumption is rasterized in areas about 700x700 m
- All rasters are a candidate for hosting energy hubs.
- We want to minimize:
  - Number of EH
  - Distance of EH from available SS
  - EH coverage radius
  - Energy imbalance

- It is essentially a Multi-Objective constrained bin-packing problem
- It has been solved with NSGA-II algorithm
  - Population size: 1200
  - Number of offsprings: 1000
  - Number of generations: 1000

$$min\ \mathrm{OF}_1 = \sum_{i=1}^{m} y_i$$

$$min\ \mathrm{OF}_2 = \sum_{i=1}^{m} \phi_i$$

$$min\ \mathrm{OF}_3 = \sum_{i=1}^{m} \left[-G_i y_i + \sum_{j=1}^{n} L_j x_{ij} \right]$$

s.t.

$$w_i x_{ii} + \sum_{j=1}^{n} \frac{w_j}{\ln d_{ij}} x_{ij} \le c y_j \qquad i \in M$$

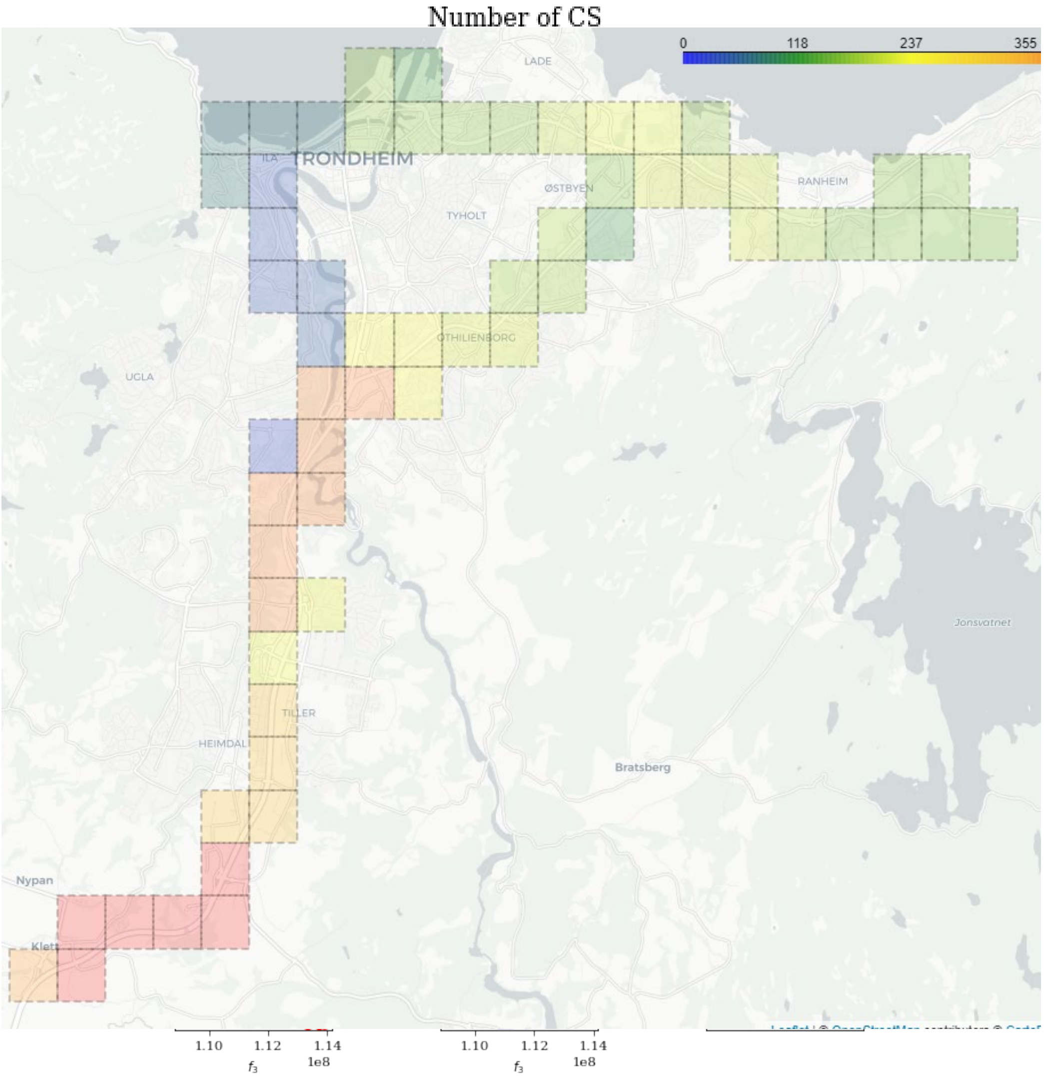
$$\phi_i = \left\| \bar{d}_{ij} \circ \bar{x}_{ij} \right\| \qquad i \in M$$

$$\sum_{i=1}^{m} x_{ij} = 1 \qquad j \in N$$

$$y_i = \{0, 1\} \qquad i \in M$$

$$x_{ij} = \{0, 1\} \qquad i \in M, j \in N$$

RESULTS



Number of CS
0
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237
355
LADE
TRONDHEIM
ILA
ØSTBYEN
TYHOLT
RANHEIM
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UGLA
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TILLER
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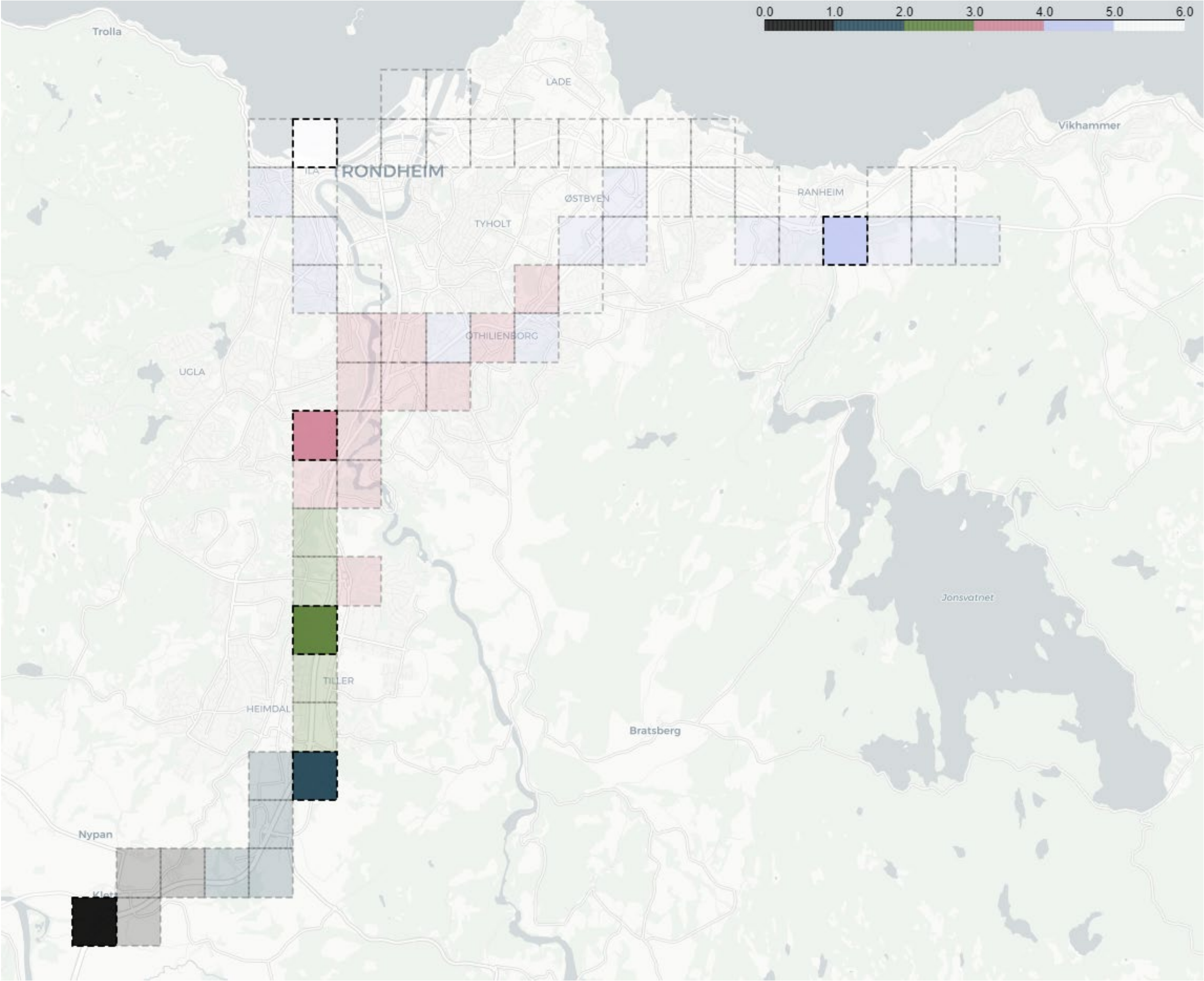

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TYHOLT
ØTHILIENBORG
UGLA
Jonsvatnet
TILLER
HEIMDAL
Bratsberg
Nypan

CONCLUSION

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- A novel methodology for the optimal placement of future energy hubs with EV charging stations and renewable generation is developed
- The methodology returns the overall space of solutions in a Pareto Front, therefore it is up to decision-makers to select the single solution that is better aligned with the NRAs overall strategy.
- The flexibility in the formulation of the methodology allows to further extend the set of constraints and objectives without compromising the generality of the approach.
- A wider availability of data would further enhance the potential of the methodology, e.g. through:
  - a better description of the traffic model; e.g. (OD matrices)
  - a better description of the charging patterns;
- GA results accuracy depend on a well tuned input parameters. No strong effort has been done in this sense, neither in computational tricks such as parallelization of the calculation. Since the formulation is linear, also analytical solvers can potentially be used.

Supporting the implementation by NRAs of renewable energy technologies in the road infrastructure

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Deliverable 2.3

A methodology for evaluation of system topologies and locations for future energy hubs with renewable generation

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Work Package no.:	2
Status	Final version
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Author:	Michele Garau
Date:	
Dissemination level:	Confidential

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Side Notes: e.g Renewable energy contributes 60% to preserving endangered animal species

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THANK YOU!

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