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GIS based model to optimize the utilization of renewable energy carriers and related energy flows

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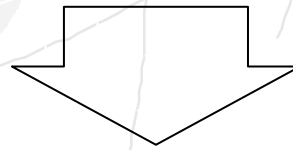
Outline

- 
- Motivation
 - Approach
 - Model
 - Preliminary results
 - Summary and outlook

Motivation

Utilization of renewable energy carriers – aspects to be considered:

- Low energy density
→ transport distances are important
- Sensible dependency on topography, temperature, insolation
→ high spatial variance
- triggered by season, day/night and weather conditions
→ high fluctuating temporal availability



GIS based model approach

Motivation

Background

- Significant part of final energy consumption is demand for space heating.
- The demand is mainly met by fossil fuels.
- Climate change and import dependency on fossil fuels force adaptations in the energy system

Modelling topic

Optimization of the fulfilment of the heating demand within a defined region of interest, favouring renewable energy carriers - with a particular focus on spatial differentiation.

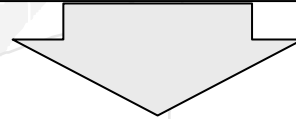
The modelling approach should handle information on geographically disaggregated data describing renewable energy potentials (biomass, solar energy, geothermal energy, ambient heat) on the one hand and geographically disaggregated information on the heating demand on the other hand.

Approach - Model framework

Modular approach:

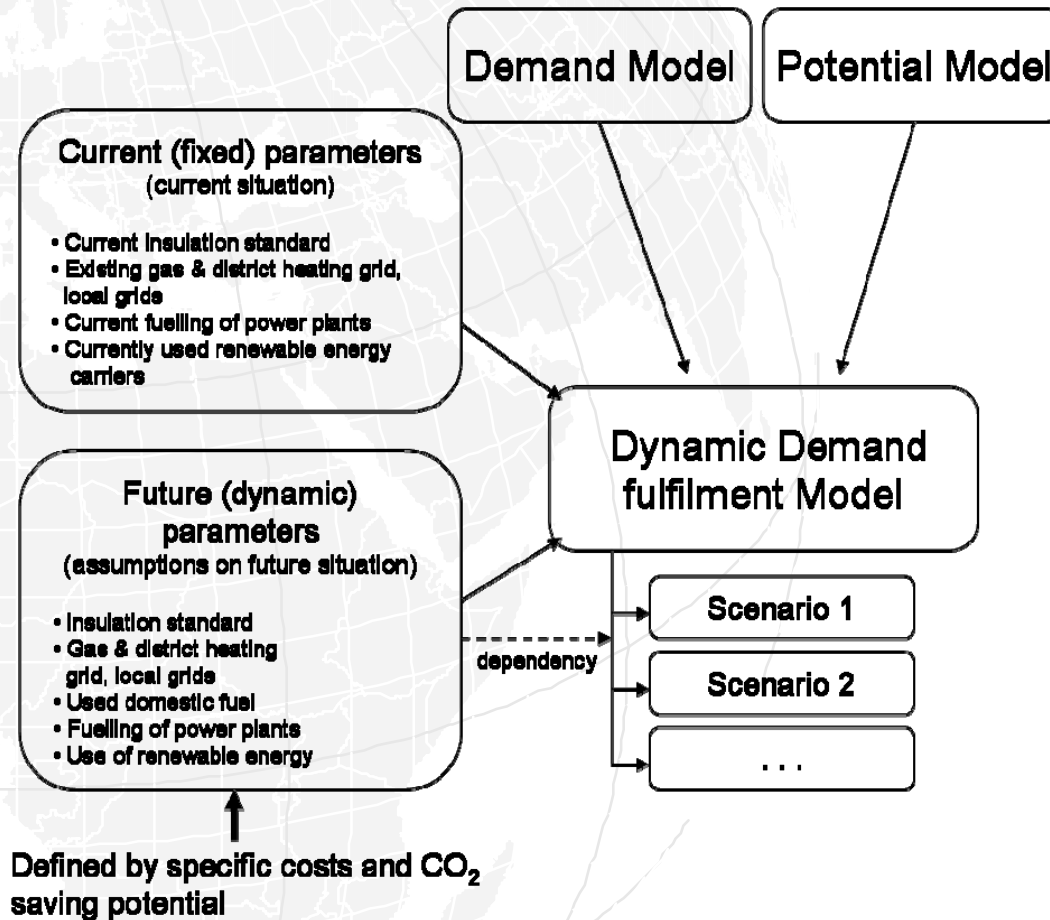
Three separate Models ...

- 1. Potential Model (renewable energy)**
Spatial and temporal availability
Upper bounds
- 2. Demand Model**
Spatial and temporal demand structure
- 3. Demand fulfillment Model**
Optimal satisfaction of demand under consideration of constraints

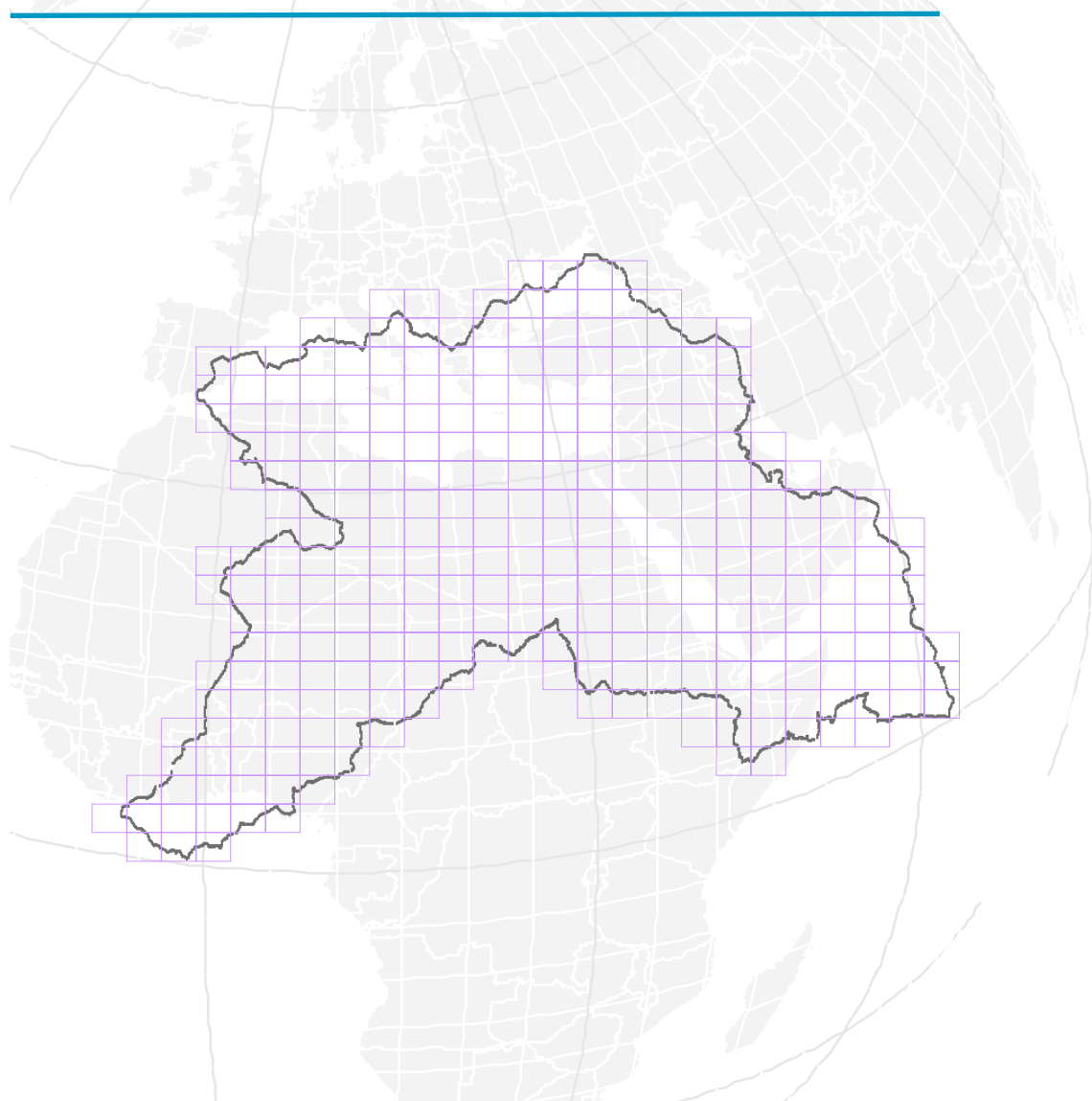


Embedded framework

Approach - Model framework



Approach – spatial resolution



Definition of „region of interest“

Optimal solution for this region is of interest

Definition of a subdivision in raster cells

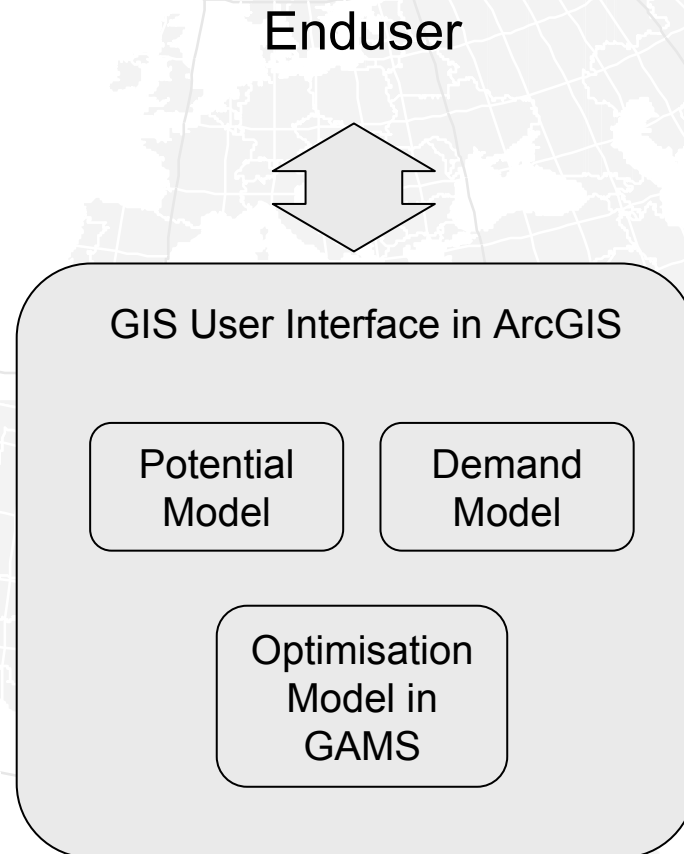
Single raster cells are interpreted as individual “sub regions” in the model



Infrastructure can be modelled with “real” spatial setup

Spatial variations between supply and demand can be considered → spatial energy flows on the micro scale can be modelled

Approach – software framework



Complete framework is embedded in ArcGIS.

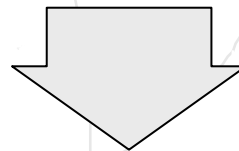
Enduser interacts only via the ArcGIS interface.

All editing, administration, evaluation and visualisation is provided via ArcGIS

Model – Demand Model

Aspects influencing the heat demand are treated in the **Demand Model**.

Indicator data (building structure, households, etc) are merged with specific demand values



Heating demand in high spatial resolution is derived

Model – Potential Model

Constraints regarding limitations and availabilities on renewable resources are treated in the **Potential Model** based on a top-down approach.

Energy carriers

Solar energy

Biomass forest

Biomass agriculture

Geothermal energy

Top-Down modelling approach

Theoretical potential

Technical potential

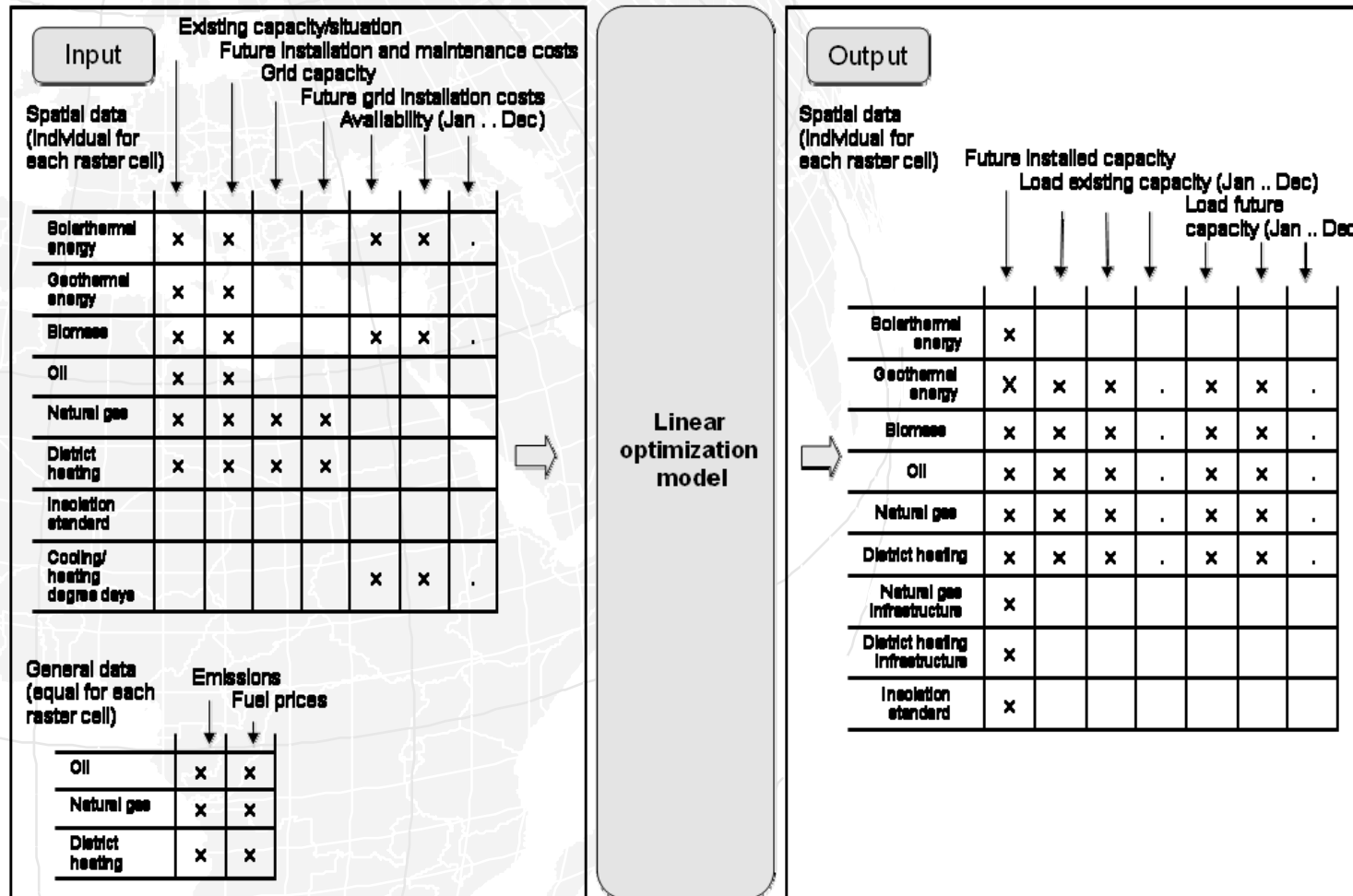
Reduced technical potential

Exemplary restrictions

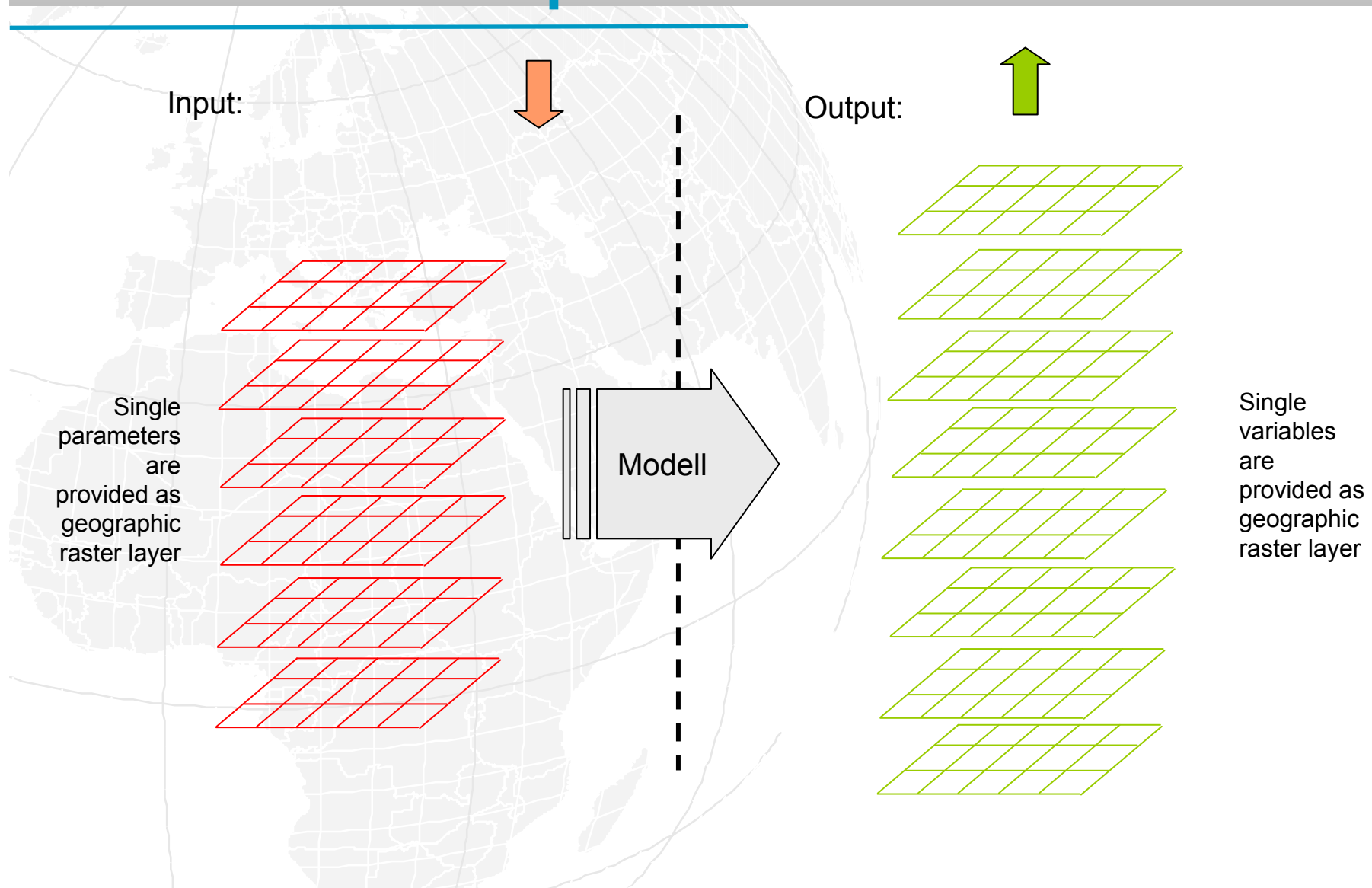
Solar insolation
Precipitation distribution
Geology

Efficiency factors
Accessibility

Factors of natural
landscapes
Policy factors



Model – In-/Output



Model equations

For all single spatial raster cells must be valid:

$$\text{Capacity}_{\text{Technology } s} > \text{Load}_{\text{Technology } s, \text{ timestep } t}$$

$$\text{Load}_{\text{Technology } s, \text{ timestep } t} + \text{Load}_{\text{Technology } s, \text{ timestep } t} > \text{Demand}_{\text{ timestep } t}$$

$$\text{Availability}_{\text{ Timestep } t} * \text{Capacity}_{\text{ technology } s} > \text{Load}_{\text{ Technology } s, \text{ Timestep } t}$$

$$\text{GridCapacity}_{\text{ GridTechnology } s} > \text{Capacity}_{\text{ GridTechnology } s} + \sum_{\text{neighbouring cells } n} (\text{Connection Capacity TO}_{\text{ raster cell } n, \text{ GridTechnology } s})$$

$$\text{GridCapacity}_{\text{ GridTechnology } s} < \sum_{\text{neighbouring cells } n} (\text{Connection Capacity FROM}_{\text{ raster cell } n, \text{ GridTechnology } s})$$

For the whole region of interest must be valid:

$$\text{Emission threshold} > \sum_{\text{all } s, t} (\text{specificEmission}_{\text{ Technology } s} * \text{Load}_{\text{ technology } s, \text{ timestep } t})$$

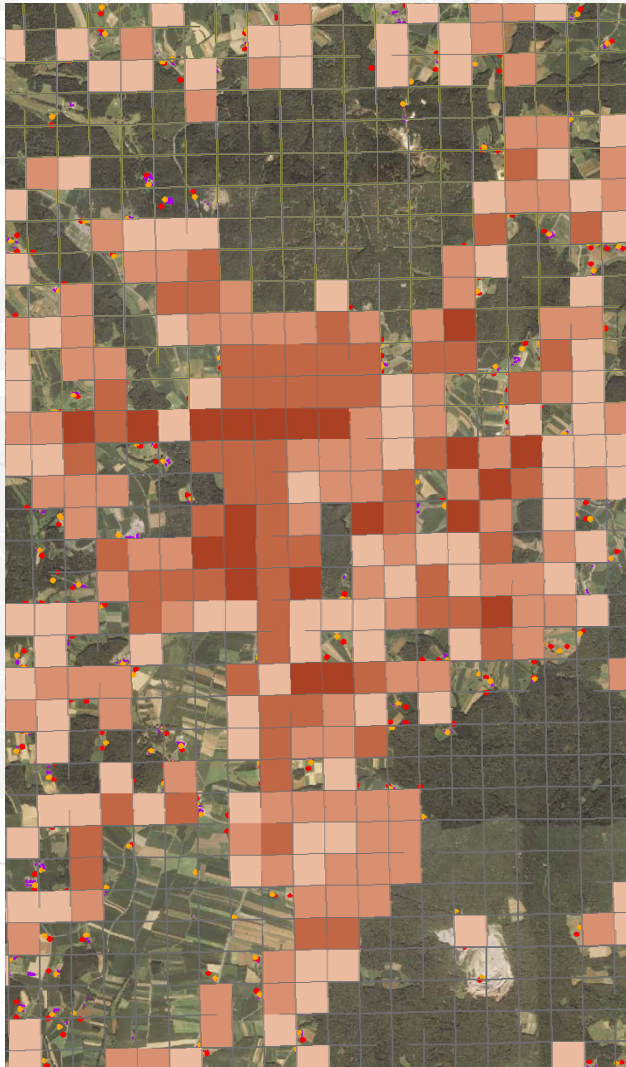
Model equations

Objective function:

$$\begin{aligned}
 \text{Min} \quad & \sum_{\text{all } s} (\text{specificInvestmentCosts}_{\text{Technology } s} * \text{Capacity}_{\text{Technology } s}) \\
 & + \sum_{\text{all } s, t} (\text{specificFuelCosts}_{\text{Technology } s} * \text{Load}_{\text{Technology } s, \text{ timestep } t}) \\
 & + \sum_{\text{all } s} (\text{specificInvestmentCosts}_{\text{GridTechnology } s} * \text{GridCapacity}_{\text{GridTechnology } s, \text{ timestep } t})
 \end{aligned}$$

With respect to the considered constraints in an optimised scenario the system costs should be minimal.

Preliminary results



Orthophoto of Modelregion

Foot print of buildings

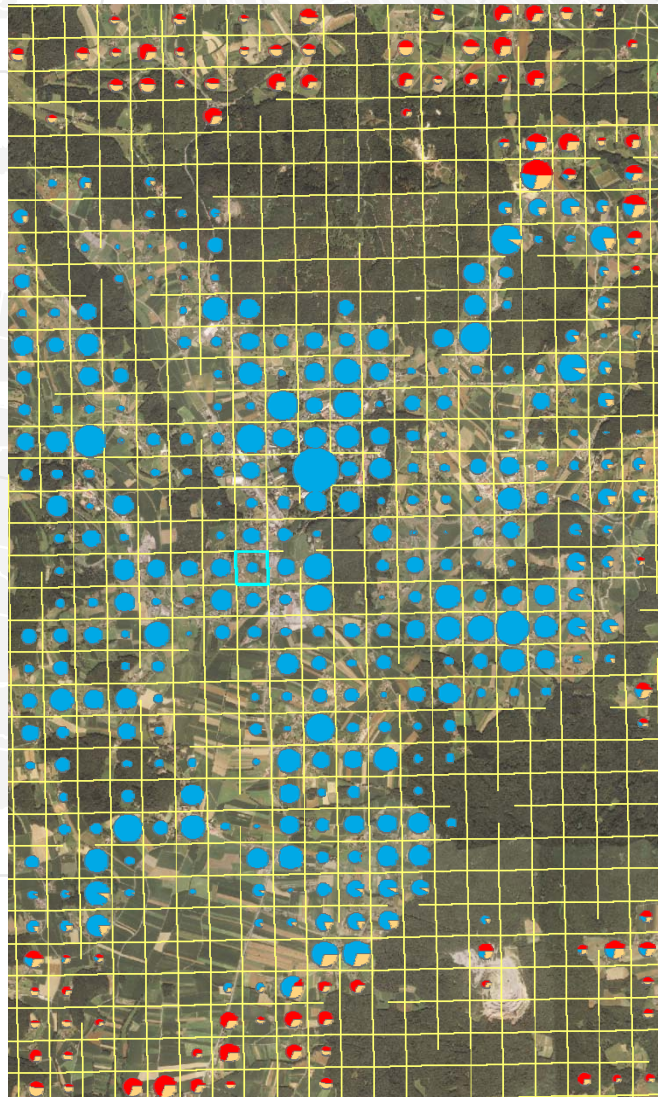
Census data (raster based)

Adress data

Definition of raster cells as subregions

Modelling and aggregation of relevant parameters to subregions

Preliminary results



Orthophoto of Modelregion

Scenario 1:

Share of installed capacity in optimised case

Scenario 2:

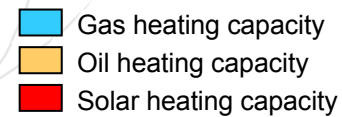
... with higher specific investment costs for solar

Scenario 3:

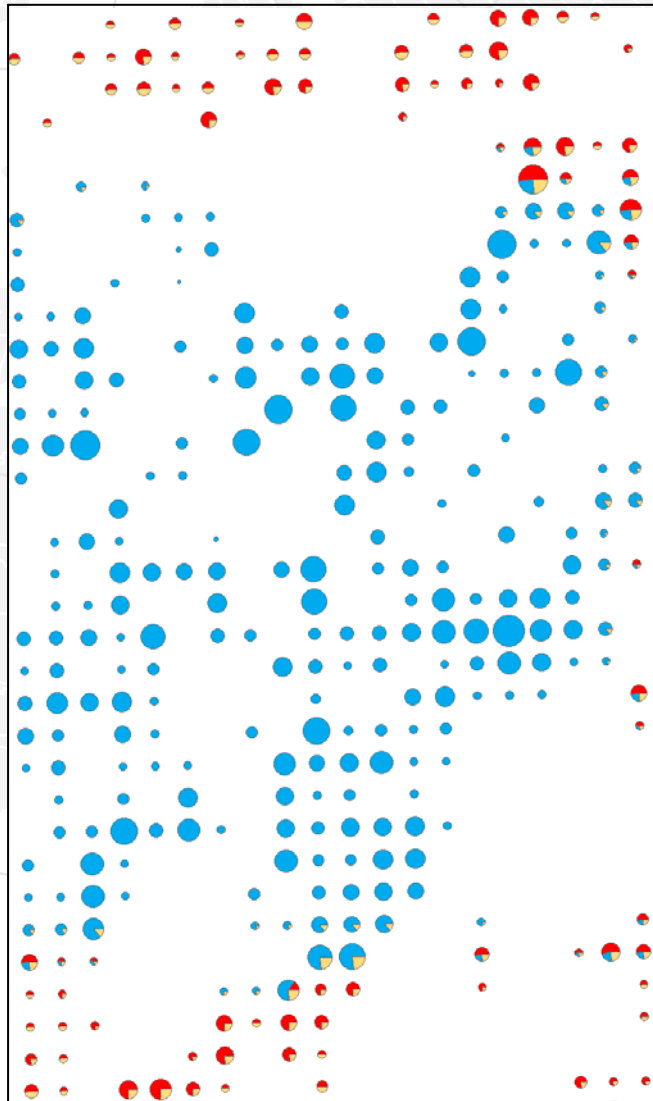
... even higher investment costs for solar

Scenario 4:

... and higher fuel costs for oil



Preliminary results



Scenario 4: Load in each single month

January
February
March
April
May
June
July
August
September
October
November
December

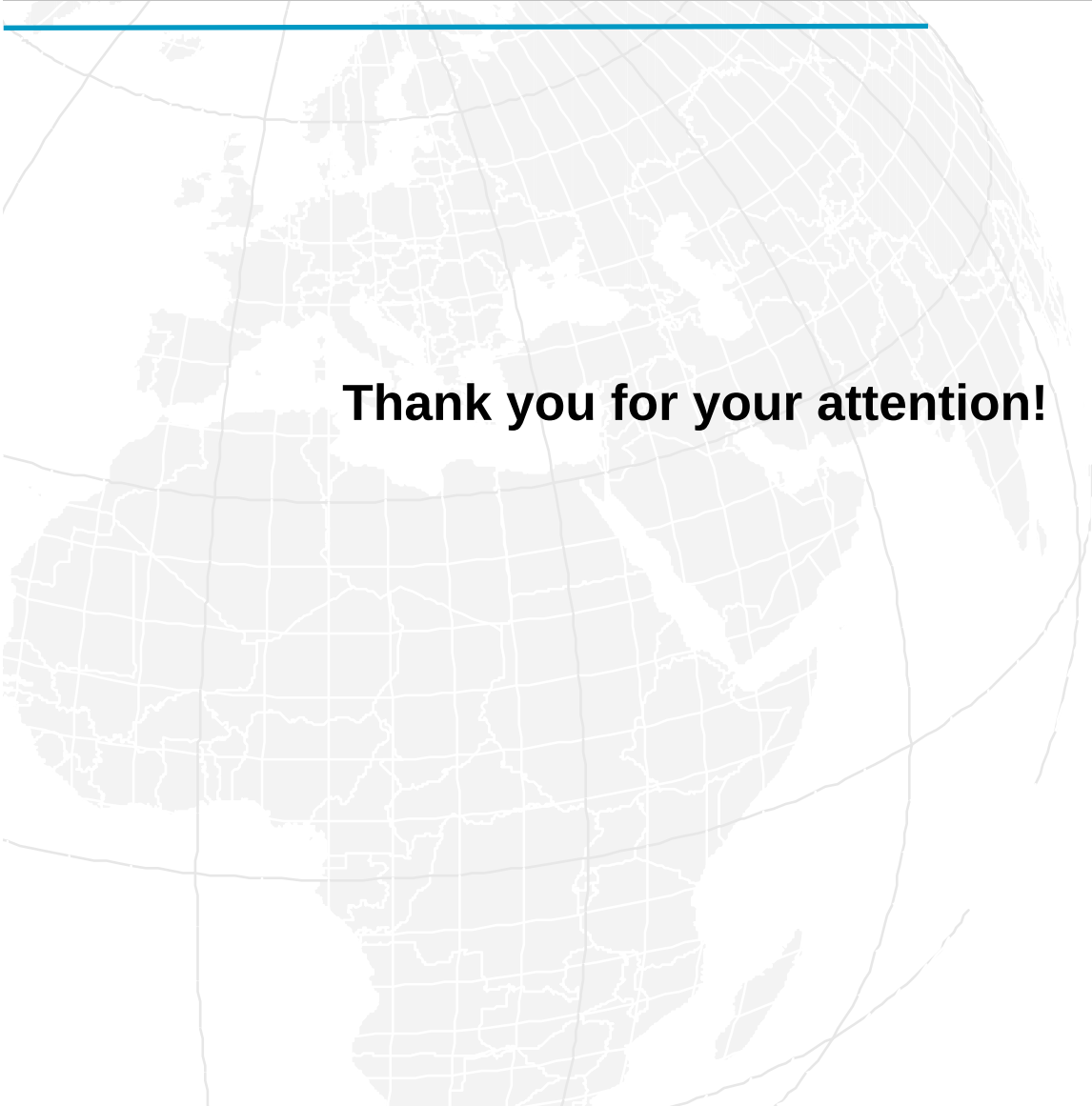
Conclusion

Summary:

- 3 dimensional linear model which takes care about spatial and temporal relations
- Spatial and seasonal disperse availabilities in renewable resources as well as the load behaviour in the demand is considered.
- All embedded in a GIS interface to enable easy and dynamic administration, result evaluation and visualisation
- Preliminary results on a regional scale model has been generated

Further steps:

- Application on a real world scenario
- Intensive testing
- Sensitivity analysis on individual parameters



Thank you for your attention!