The essence of geography in energy sciences

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Why geography is part of energy sciences

- Demand, infrastructures and resources are spatially distributed
- Sustainable energy systems have a higher association to space, location, and distance than fossil fuelled energy systems
- Renewable energy sources are seemingly abundant. They are limited only by spatial constraints
- Much of the currently available energy system data is aggregated to the macro level, needs to be disaggregated
- Spatially distributed energy processes require spatially explicit decision support models.

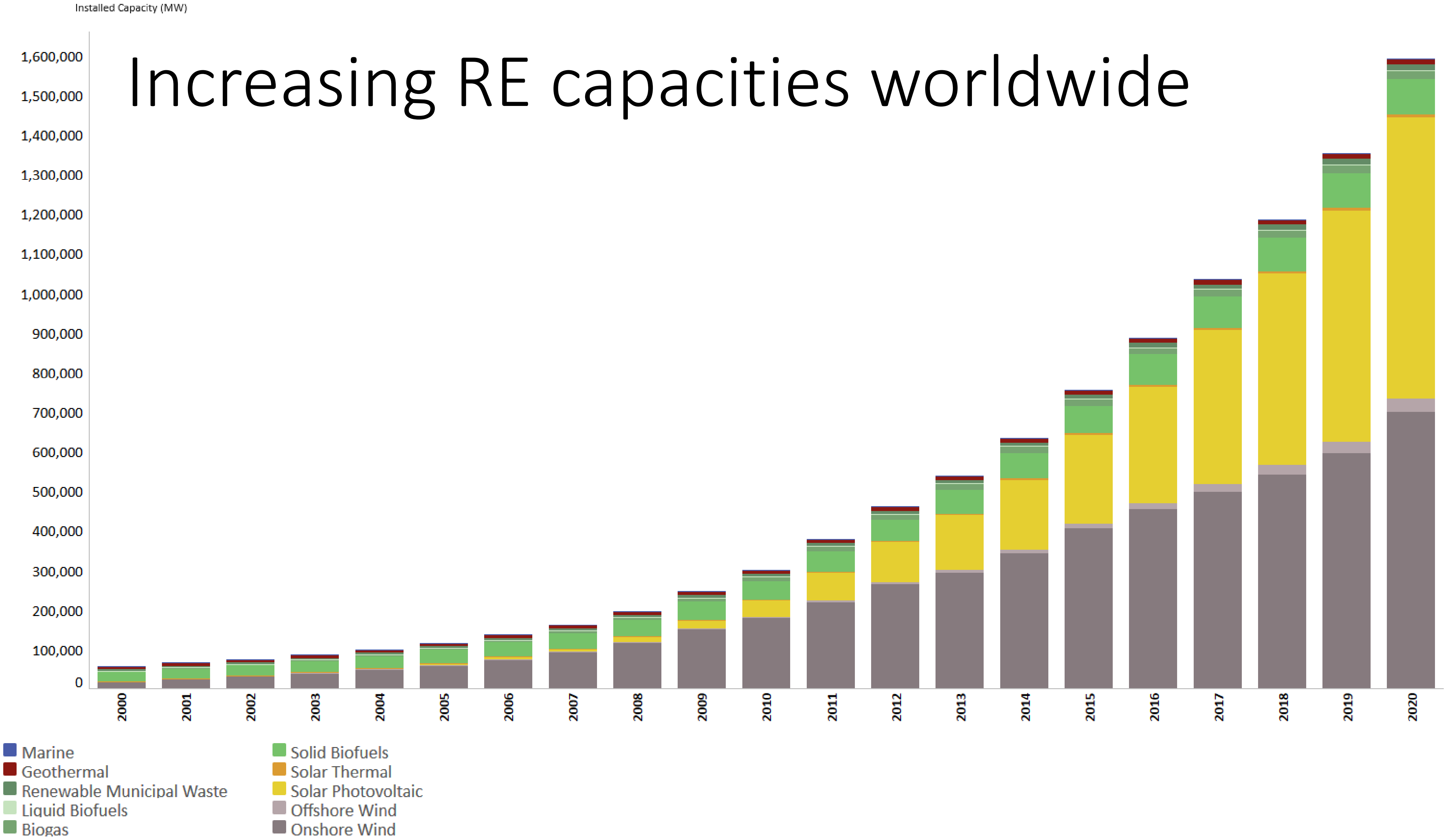
The geographical dimension

- When passing beyond the interest for the absolute, planning and modelling is going to show interest in the relative and the marginal.
- An increasing emphasis is on the location and distribution of energy resources, infrastructures and efficient demand in terms of amounts and costs.
- Decision support systems must therefore increasingly address the small scale geography of the present.

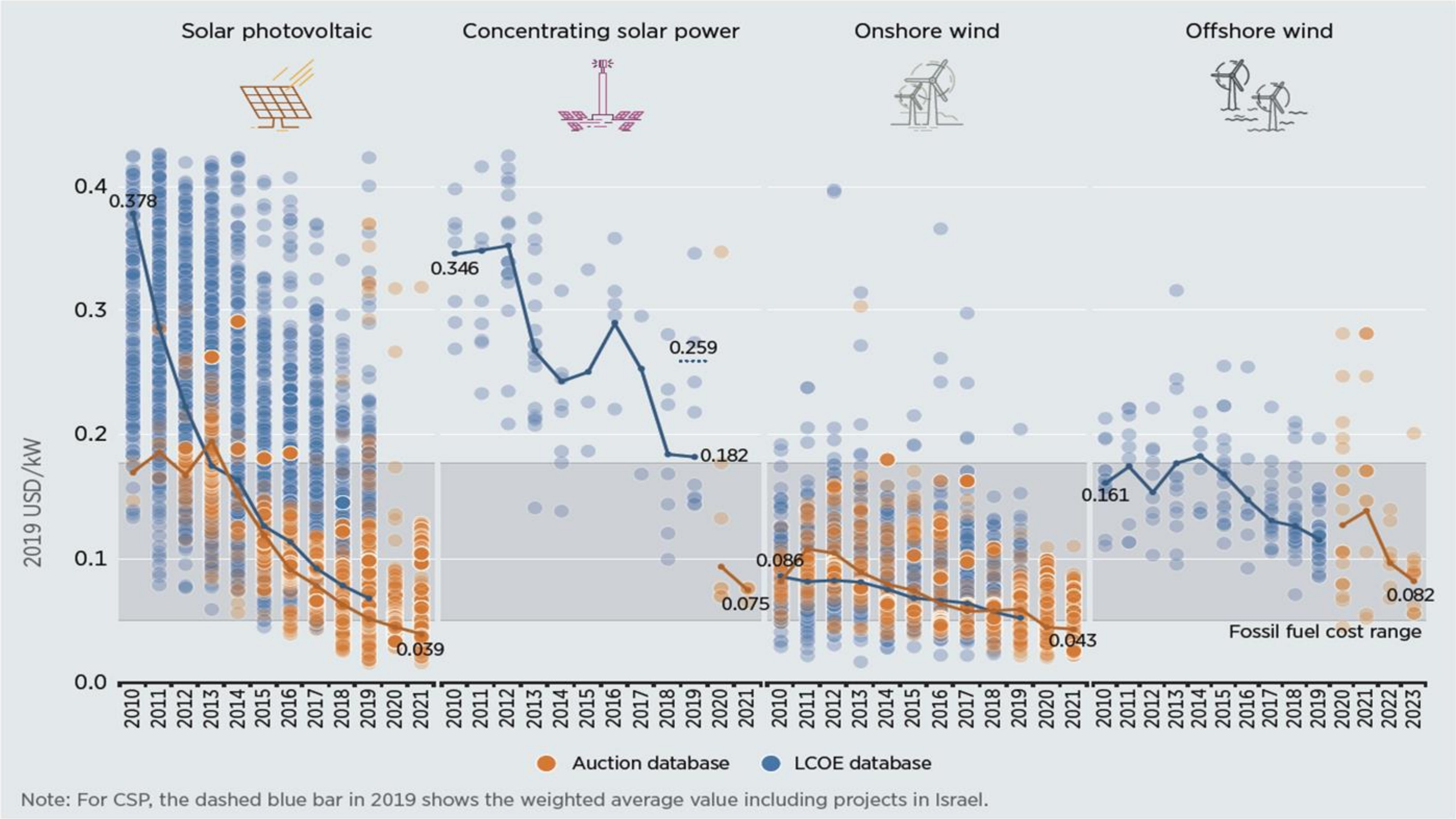
Current trends in renewable energy: Increasing shares, decreasing costs, less available space

What is the motivation for working spatially?

Increasing RE capacities worldwide

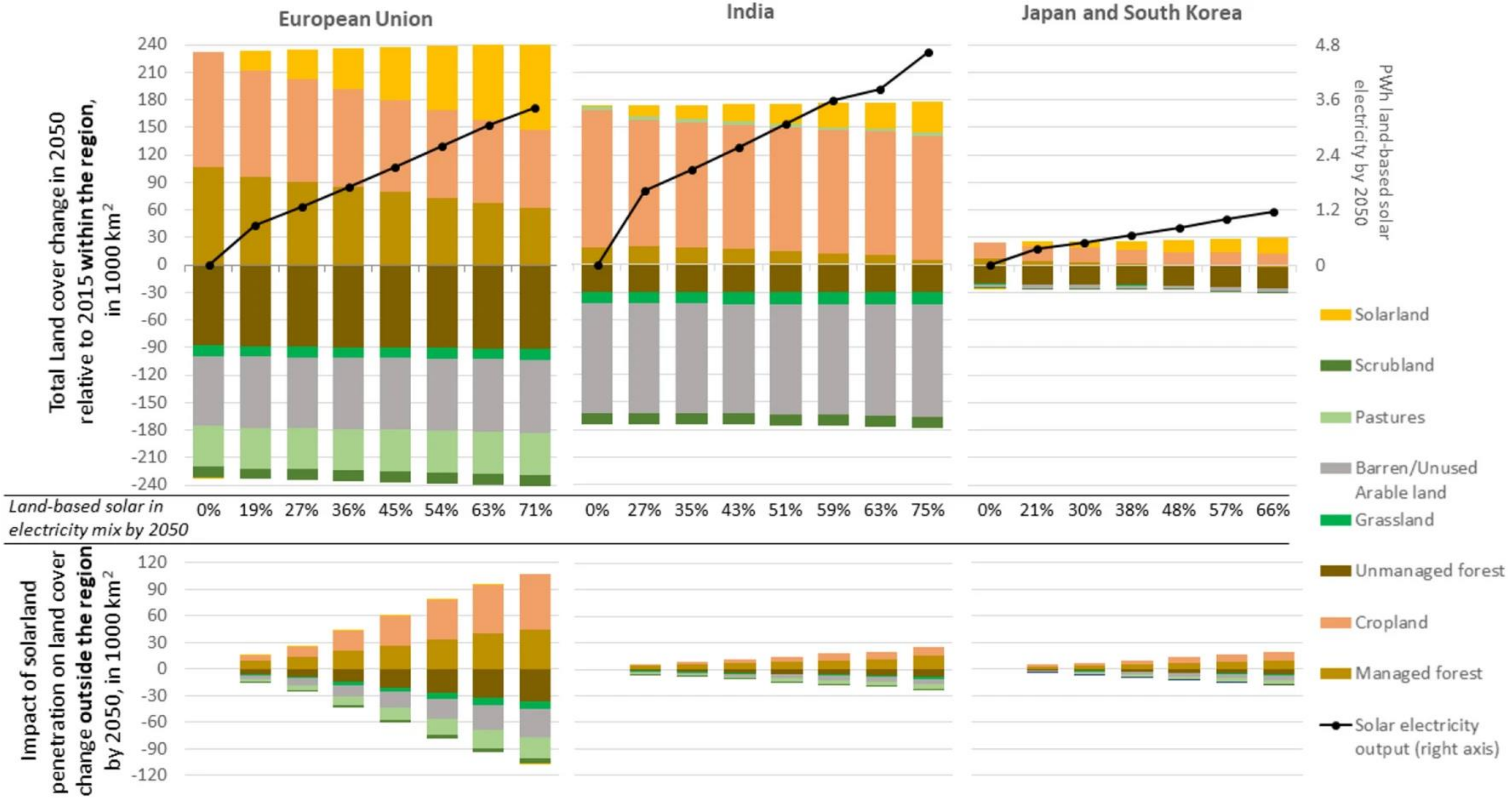


Falling costs of renewable energy



Source: IRENA Renewable Cost Database.

Increasing competition for land



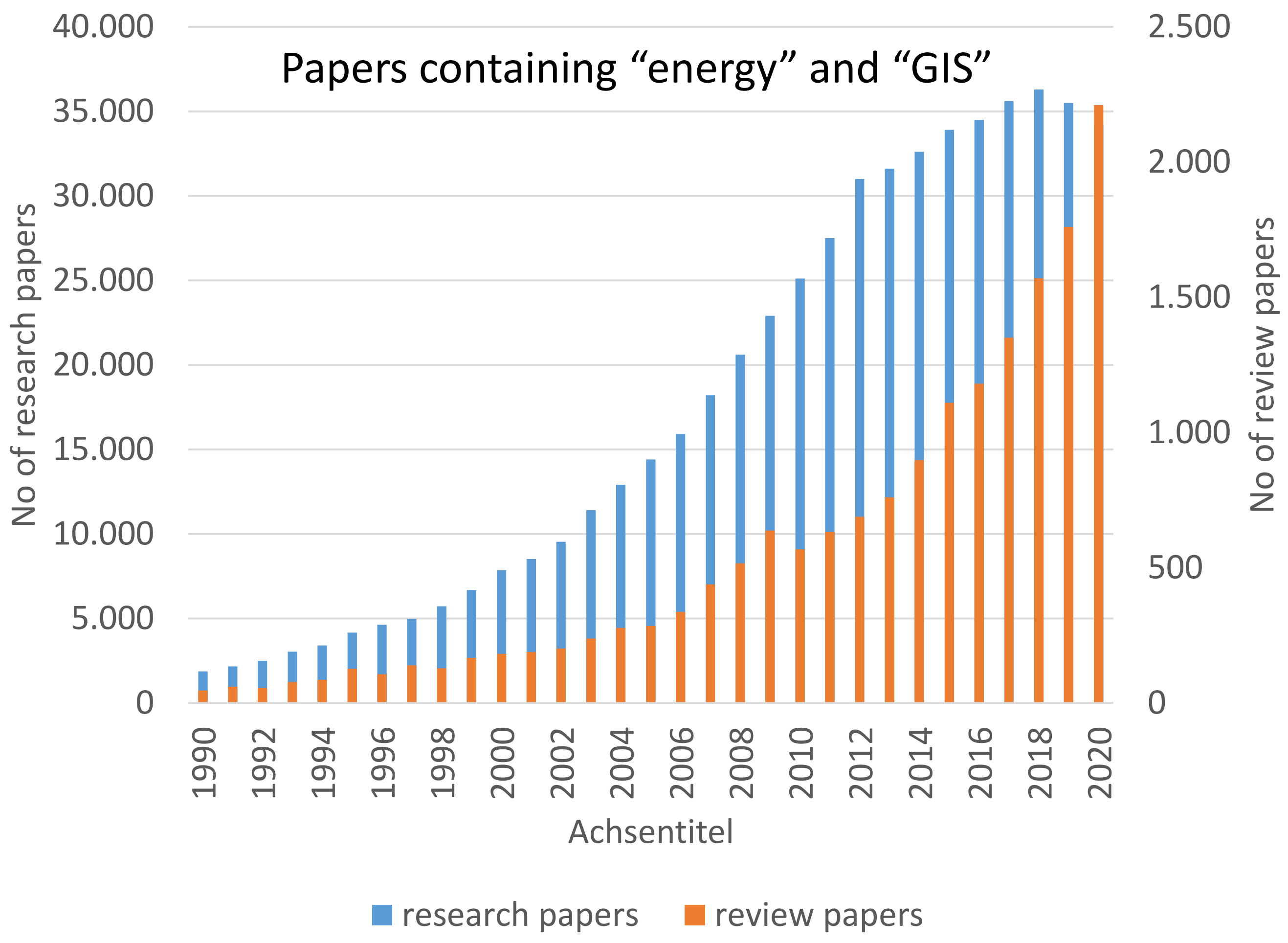
van de Ven, DJ., Capellan-Peréz, I., Arto, I. *et al.* The potential land requirements and related land use change emissions of solar energy. *Sci Rep* **11,** 2907 (2021). https://doi.org/10.1038/s41598-021-82042-5

Important questions to ask

- How can the quantitative basis for scenarios of energy system transition towards spatiotemporal processes be established?
- Geographically, what limits the potential of distributed resources like wind, biomass, district heating?
- How much of a local or regional energy source is within economic reach, environmentally benign, and socially acceptable?

Use of GIS in energy science

- Exceptional in the 1990s, pretty commonplace today
- Follows the general trend of data availability and digitalisation
- Explosive growth in openly available data and information
- Increasingly complex modelling at high spatial resolution
- From making “nice maps” to using GIS as integral part of energy research.



Source: Google Scholar, Oct. 2021

Focus on geospatial methods

An essence of GIS in energy science

Methodological considerations

- Basic methods
  - Data collection, processing, management
  - Data sharing
  - Visualisation

…but GIS is more than making “nice maps”!

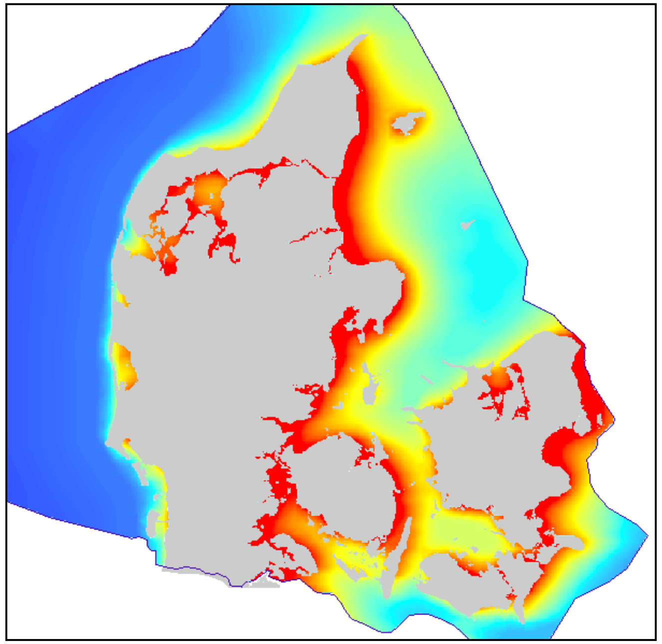
Three central methods

For a spatially explicit modelling of distributed resources and their association to elements of energy systems:

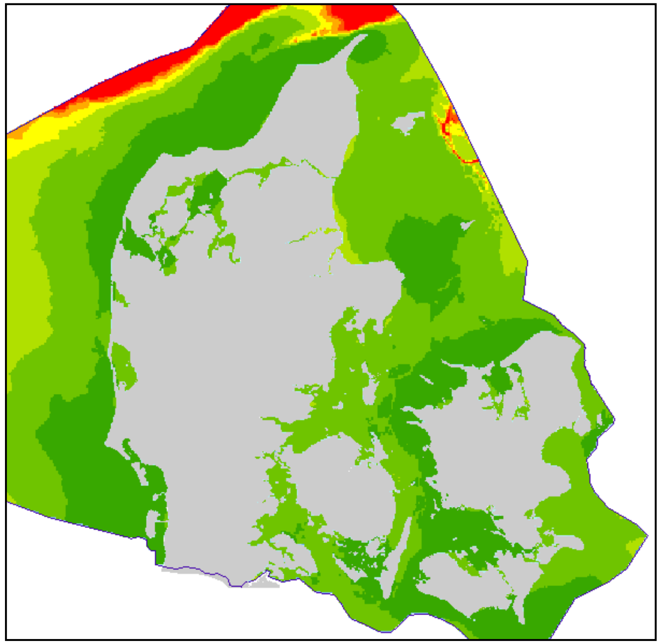
- Spatial disaggregation: mapping the uncharted
- Cost-supply modelling: from available technical to economically accessible potential
- Spatial allocation: matching supply and demand locally

Cost-supply analysis

Suitable areas



Energy production [MWh/km^2]

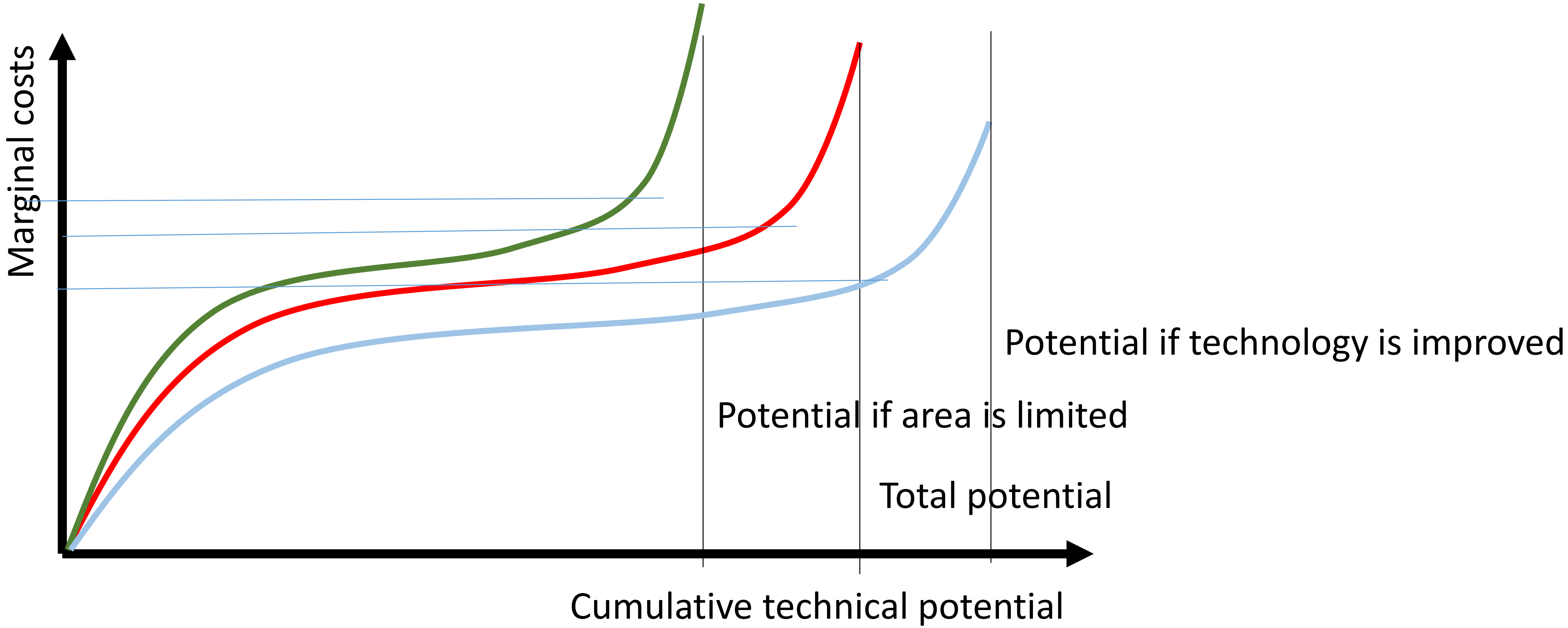


Production costs [€/MWh]

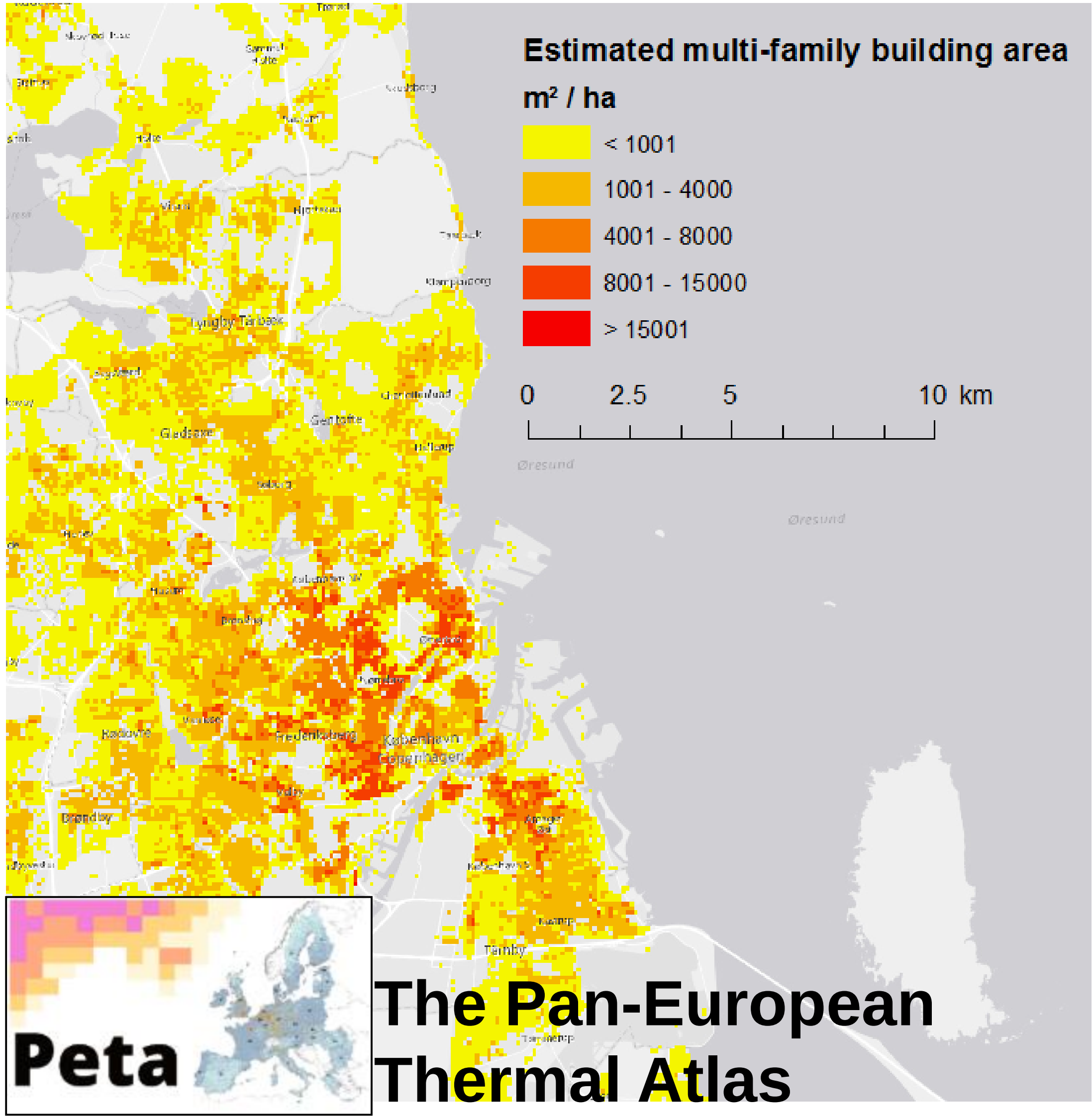
- Resources AND costs AND restrictions must be known for each location in a uniform grid.
- A spatially explicit supply model may summarise the resources ***w*** available at each available location ***i,j*** by their localised costs ***c***.

$$S = \sum_{c=1}^{n} w_{i,j}; c_{i,j}$$

Cost-supply curve analysis



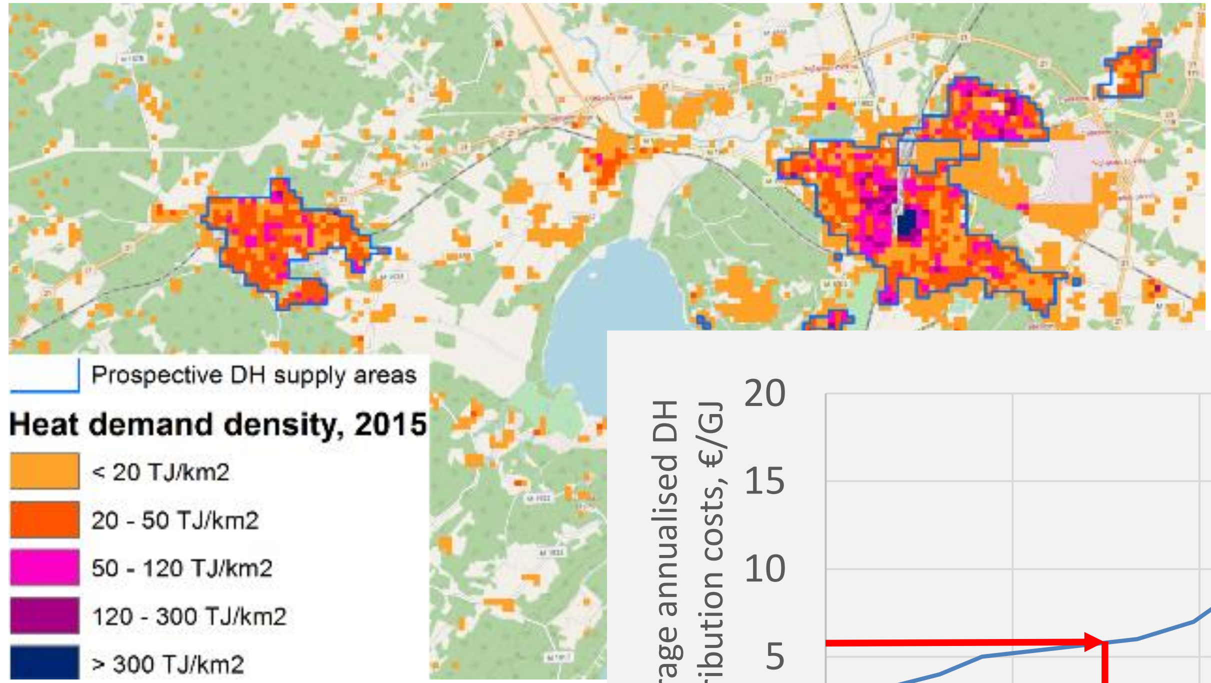
The case of mapping heat demands across Europe by means of spatial disaggregation



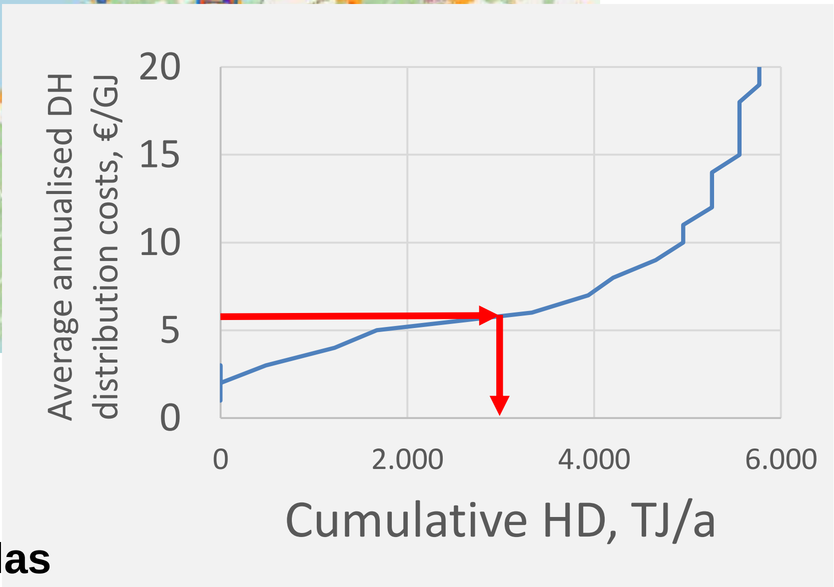
- More than often the quantitative basis of energy modelling does not exist at local levels
- Regression techniques allow for a model of spatially distributed phenomena, based on already mapped items
- Here, the distribution of floor space is modelled using built-up intensity and population density.

Heat Roadmap Europe: Europe – Identifying Local Heat Demand and Supply Areas with a European Thermal Atlas. Möller, Bernd; Wiechers, Eva; Persson, Urban; Grundahl, Lars and Connolly, David. Energy 158 (2018) 281-292.

The case of Heat Roadmap Europe: Defining economic potentials of district heating



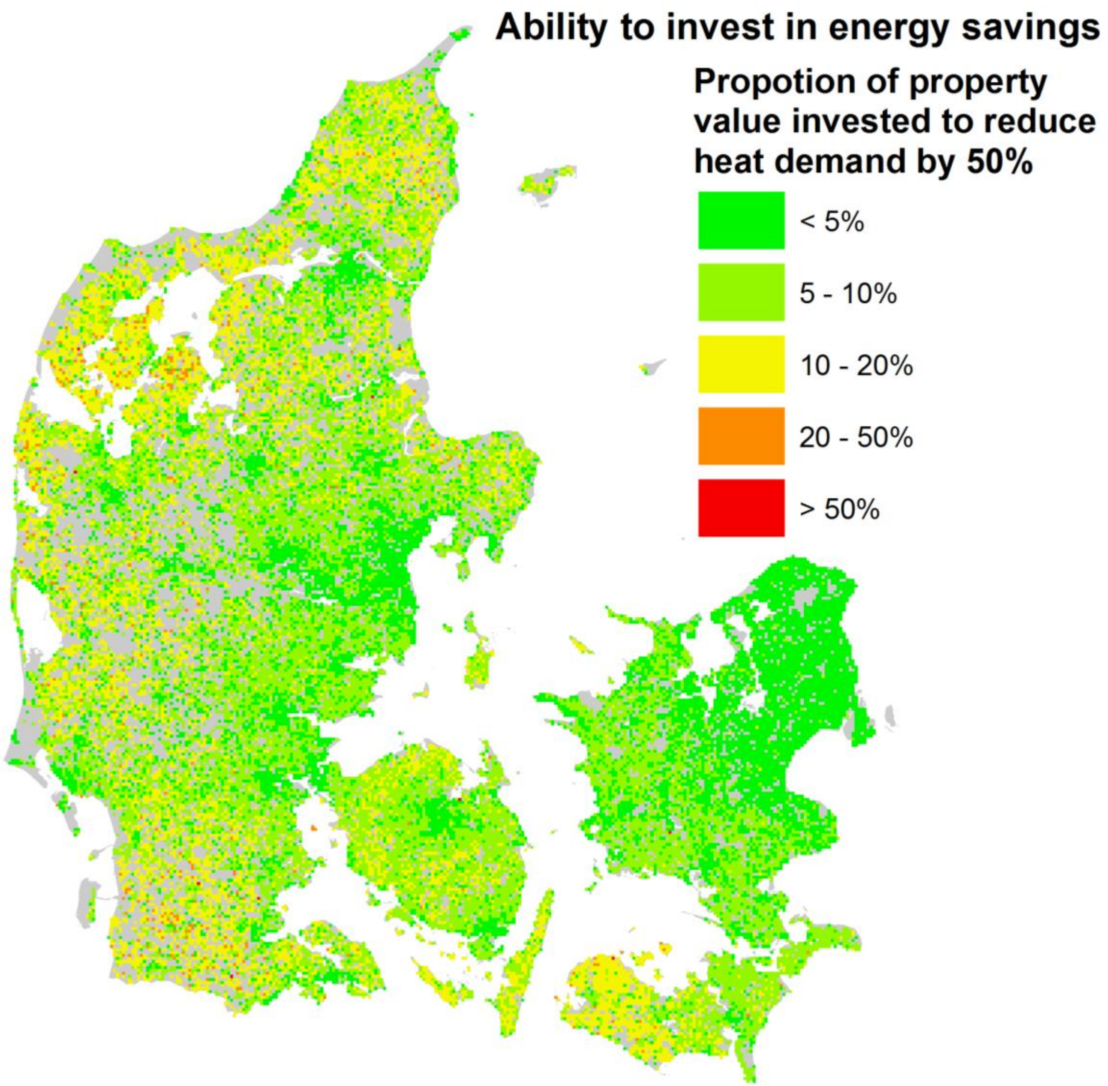
The Pan-European Thermal Atlas



- A pan-European heat demand model at 100m resolution
- Potentials, costs and zoning of heat supply are mapped to produce the basis for cost-supply analysis.
- Spatial cost supply curves of investments in heat distribution grids make local economic potentials of district energy explicit.

Heat Roadmap Europe: Europe – Identifying Local Heat Demand and Supply Areas with a European Thermal Atlas. Möller, Bernd; Wiechers, Eva; Persson, Urban; Grundahl, Lars and Connolly, David. Energy 158 (2018) 281-292.

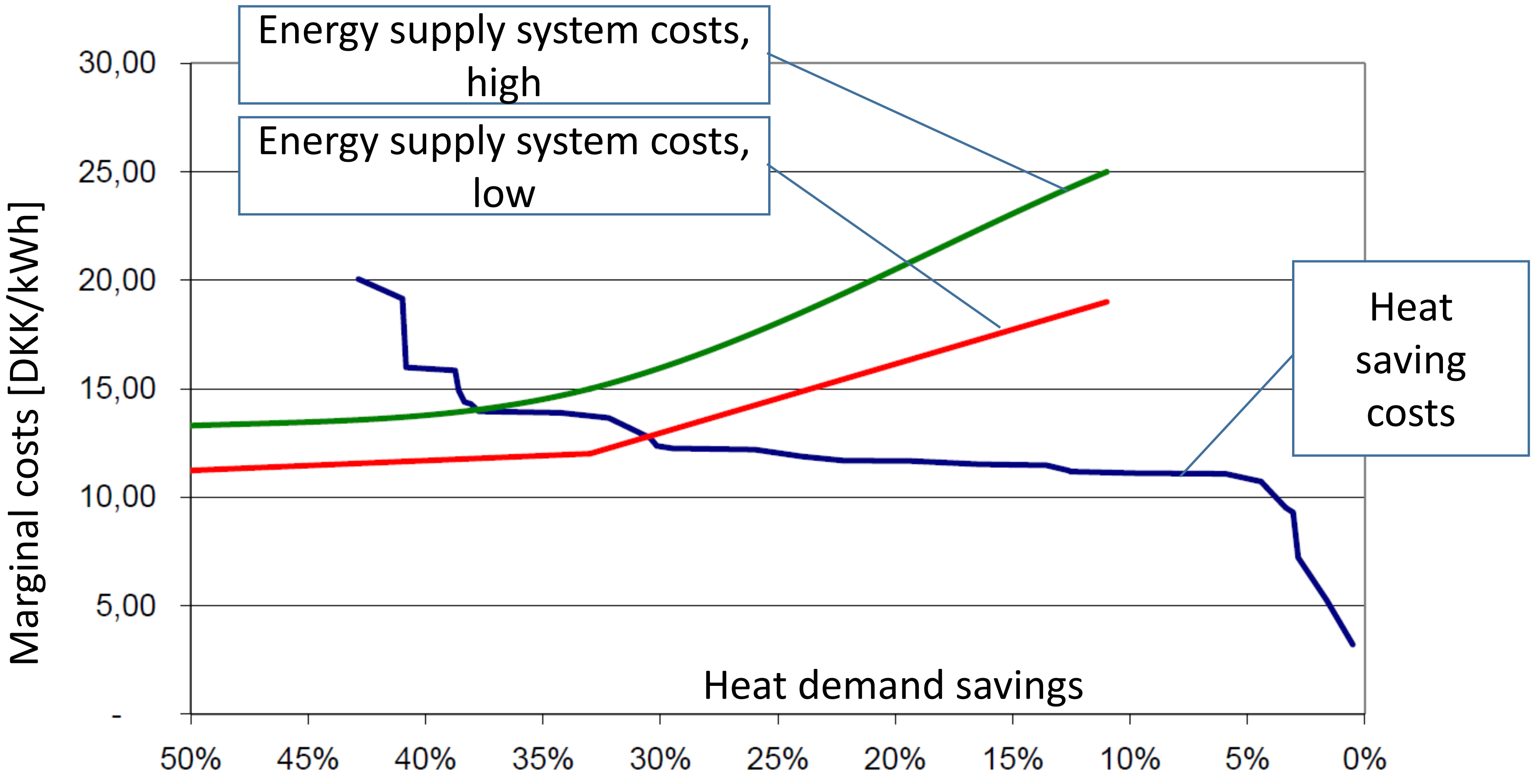
The case of energy justice: Distributed socio-economics of energy efficiency



- Unequal division of property value, income and energy supply options.
- No equal opportunities to significantly reduce energy demand in existing buildings.
- Increasing rural-urban inequity necessitates to see problems as opportunities by localised support to structurally weak areas.

Möller B: Managing energy vulnerability and resilience for rural communities in Northern Denmark by means of energy atlases. Association of American Geographers' Annual Meeting – Seattle, 2011.

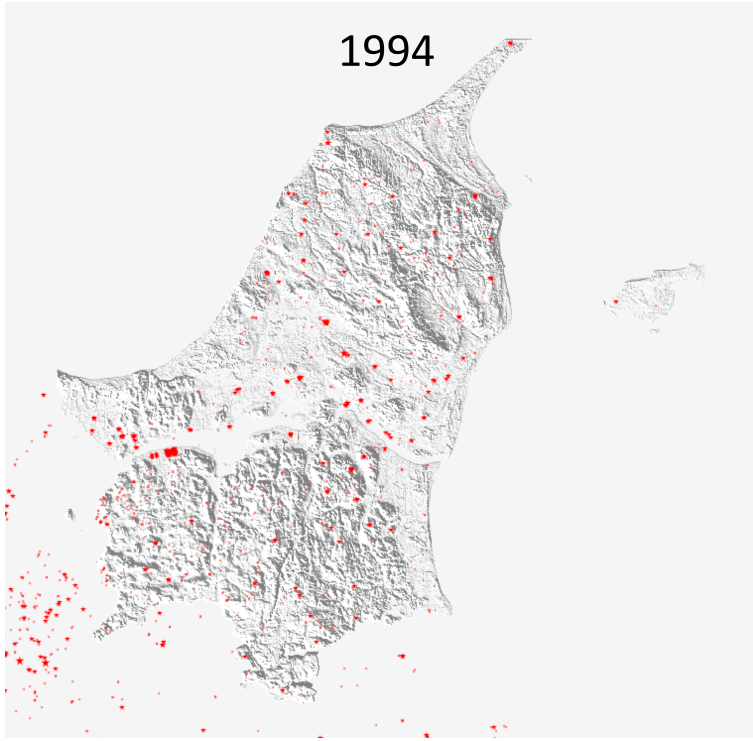
The case of energy efficiency: Development of low energy buildings and low-carbon heat supply

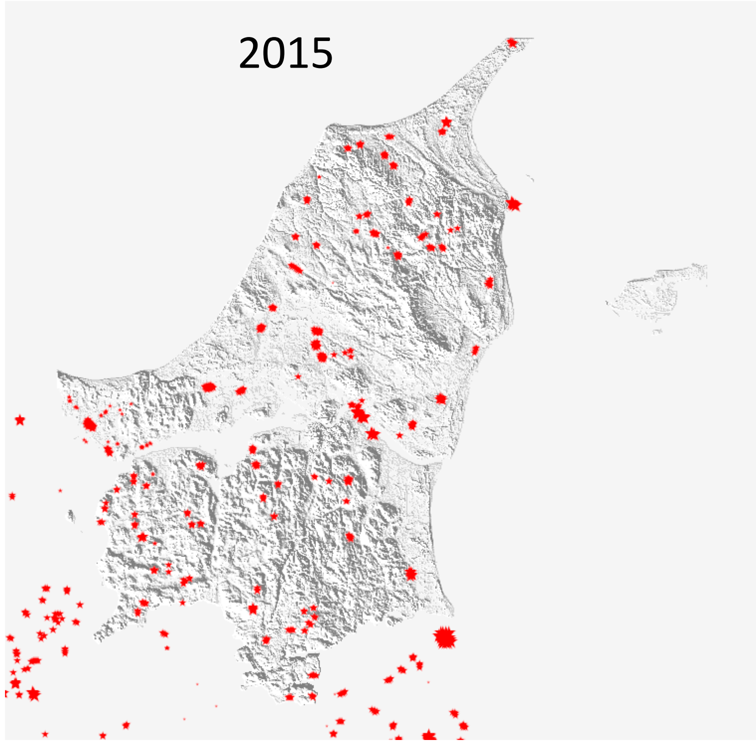


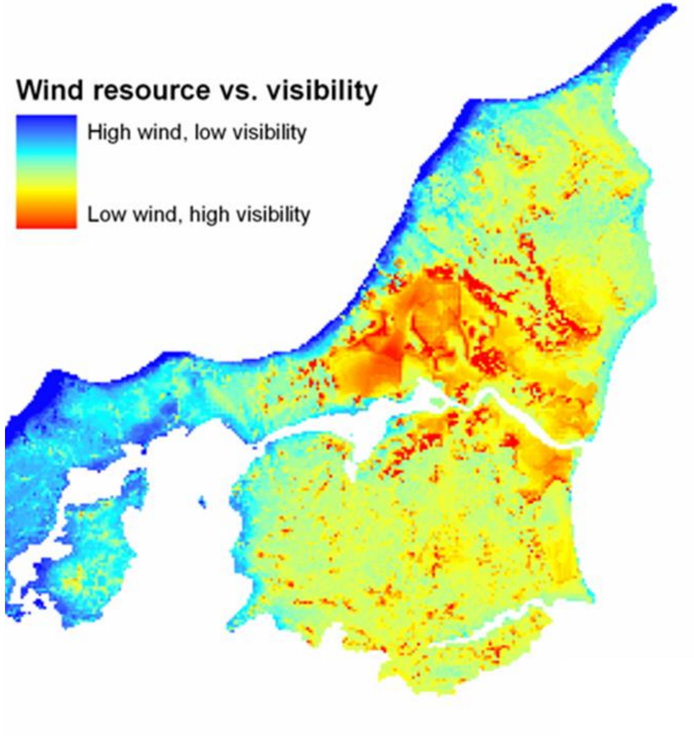
A renewable energy scenario for Aalborg Municipality based on low-temperature geothermal heat, wind power and biomass. Østergaard PA, Mathiesen BV, Möller B, Lund H. Energy 35 (2010) 4892-4901.
Heat Saving Strategies in Sustainable Smart Energy Systems. Lund, H., Thellufsen, J. Z., Aggerholm, S., Wittchen, K. B., Nielsen, S., Mathiesen, B. V. & Möller, B. International Journal of Sustainable Energy Planning and Management. 4 (2014) 1-15.

- Applying the Energy Efficiency First principle of the European Commission
- Studies of energy efficiency in the built environment as well as the supply system
- Spatially disaggregated data for the energy retrofit as well as district heating potentials.

The case of dynamic wind energy landscapes







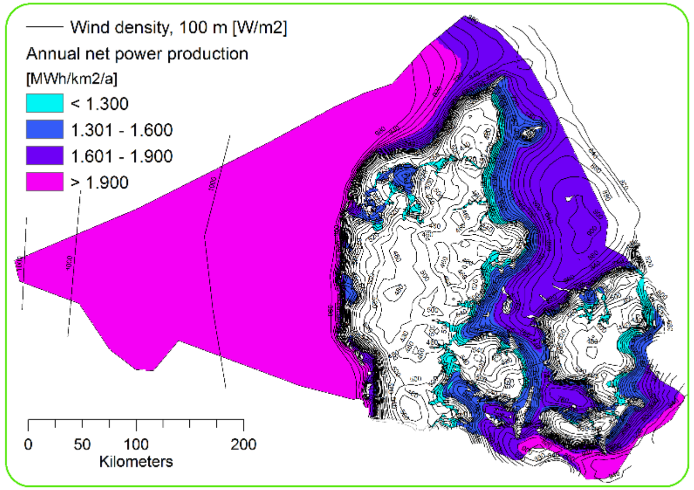
Visual influence of turbines on landscapes changed with installing more and bigger plants. Smaller plants will subsequently disappear again, visual impact will be less homogenous. Development of planning tools for analysing generation versus impact.

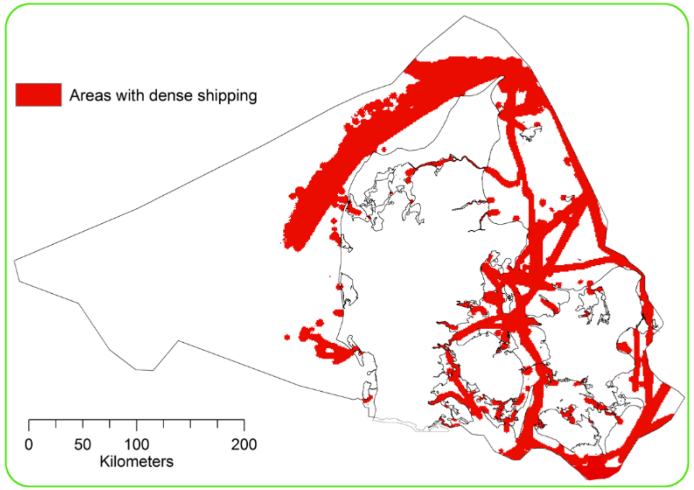
Möller, B: Spatial analyses of emerging and fading wind energy landscapes in Denmark. Land Use Policy. 27 (2010) 233-241.

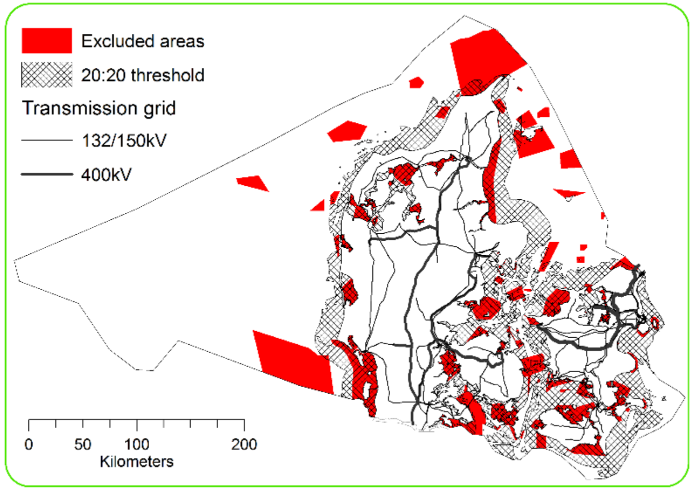
Möller, B 2006, *Changing wind-power landscapes: regional assessment of visual impact on land use and population in Northern Jutland, Denmark*', Applied Energy, vol. 83, no. 5, pp. 477-494.

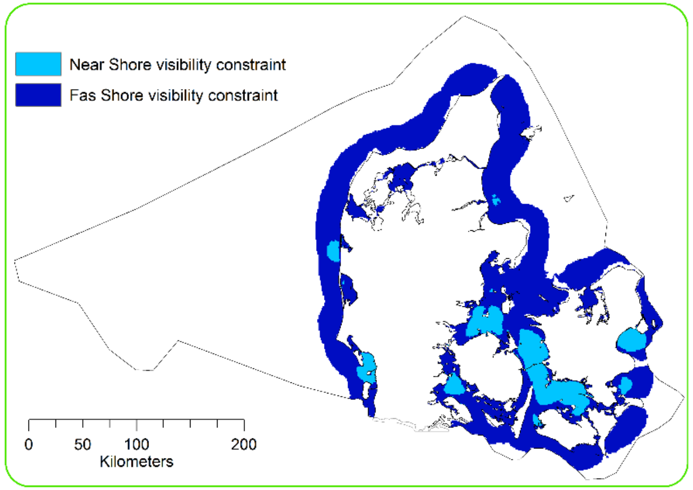
The case of offshore wind

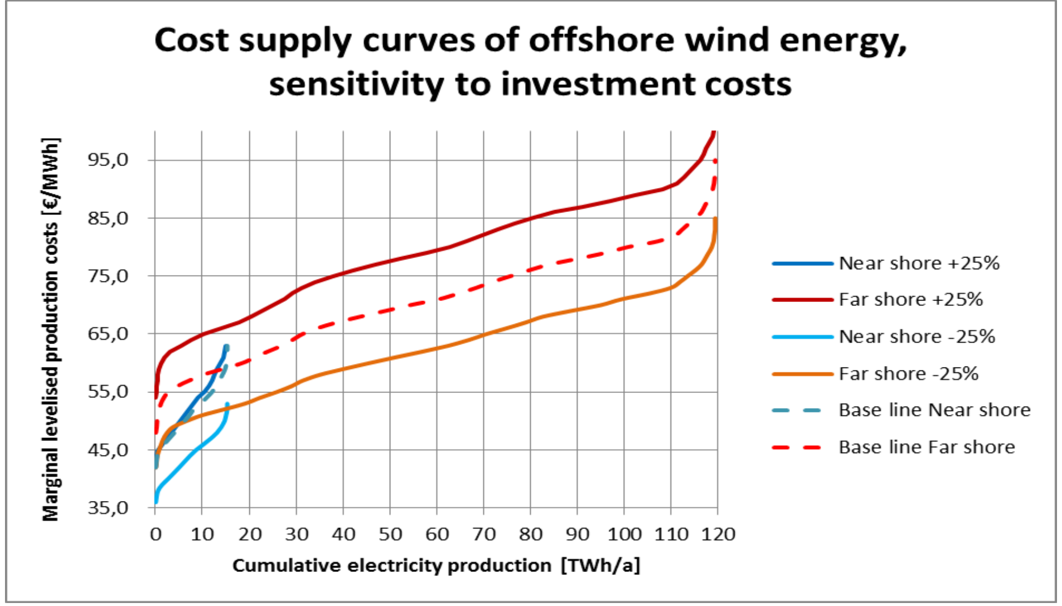
Large-scale, far shore or small-scale, near shore?

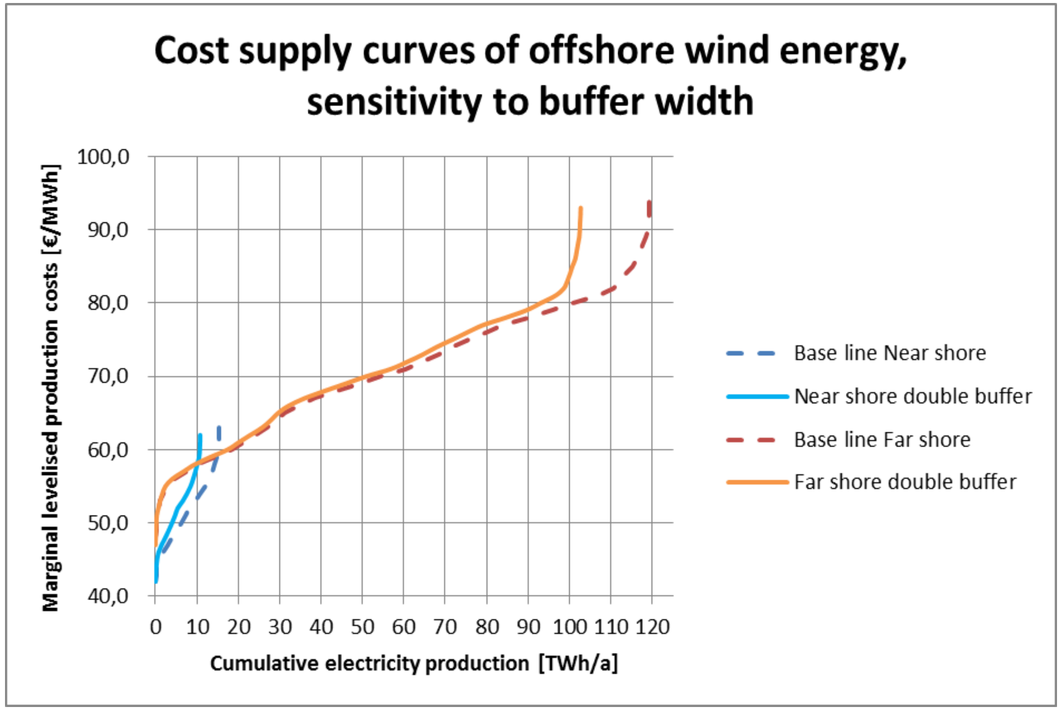








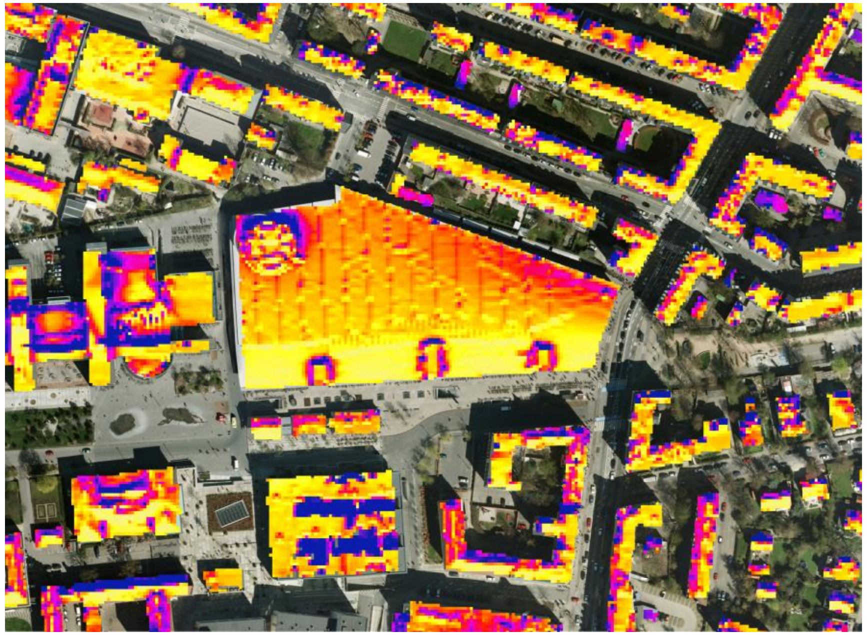




Evaluation of offshore wind resources by scale of development. / Möller, Bernd; Hong, Lixuan; Lonsing, Reinhard; Hvelplund, Frede. Energy 48/1 (2012) 314-322.

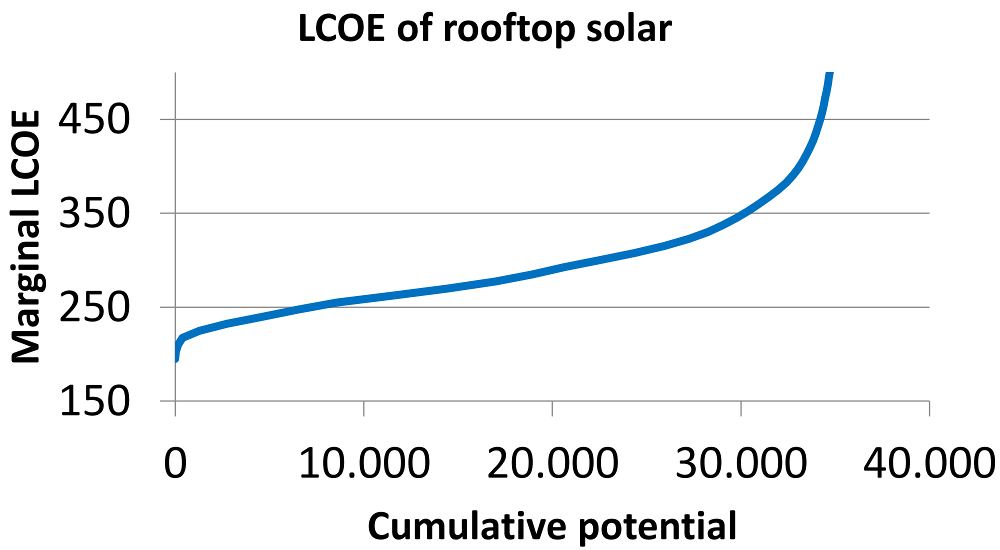
The case of rooftop PV

- LiDAR-based elevation models of buildings allow for assessing electricity generation
- Not all roofs are likely suitable, and roof area is limited.
- Cost-supply studies of rooftop areas establish a first estimate of potentials and costs.



Potential electricity generation on roofs

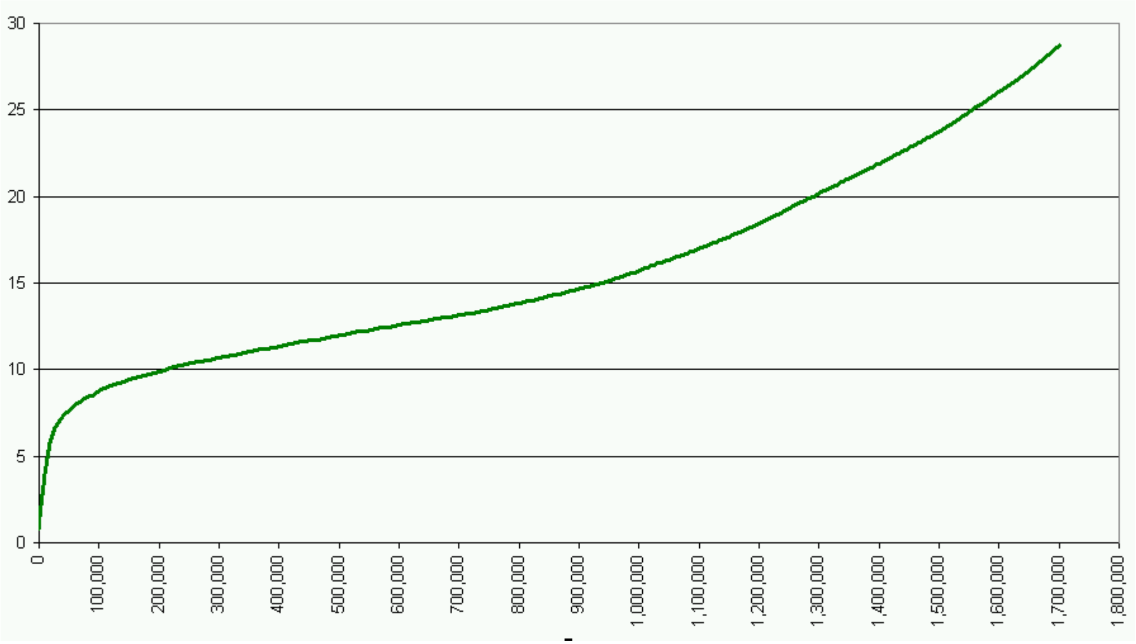
LCOE of rooftop PV electricity

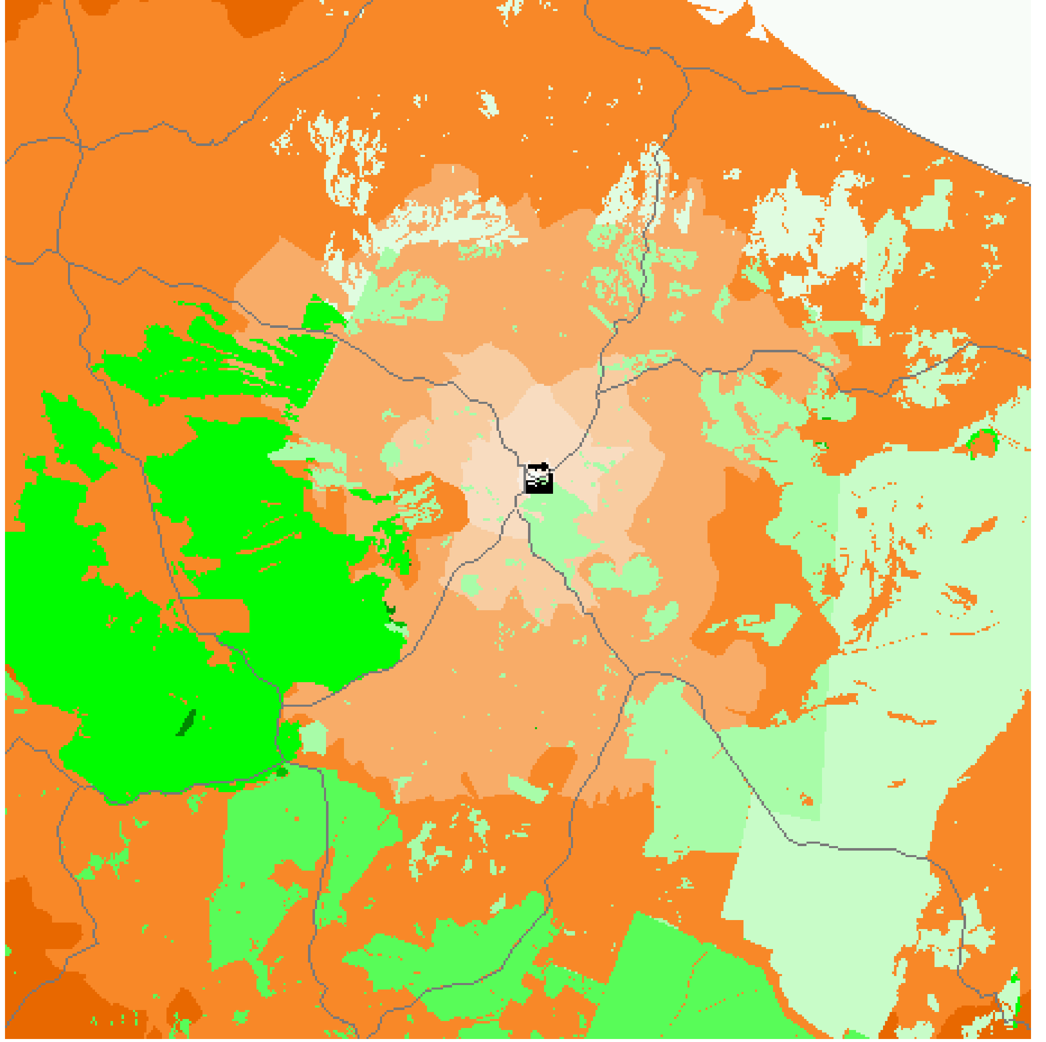


Möller B, Nielsen S, Sperling K: A Solar Atlas for Building-Integrated Photovoltaic Electricity Resource Assessment. 5th International Conference on Sustainable Energy and Environmental Protection, Dublin 2012.

The case of biomass logistics

- An overlay of in-forest residues and transport costs facilitates to evaluate site-specific amount and cost of biomass.
- By applying spatial statistics each lot of biomass is assigned a cost.

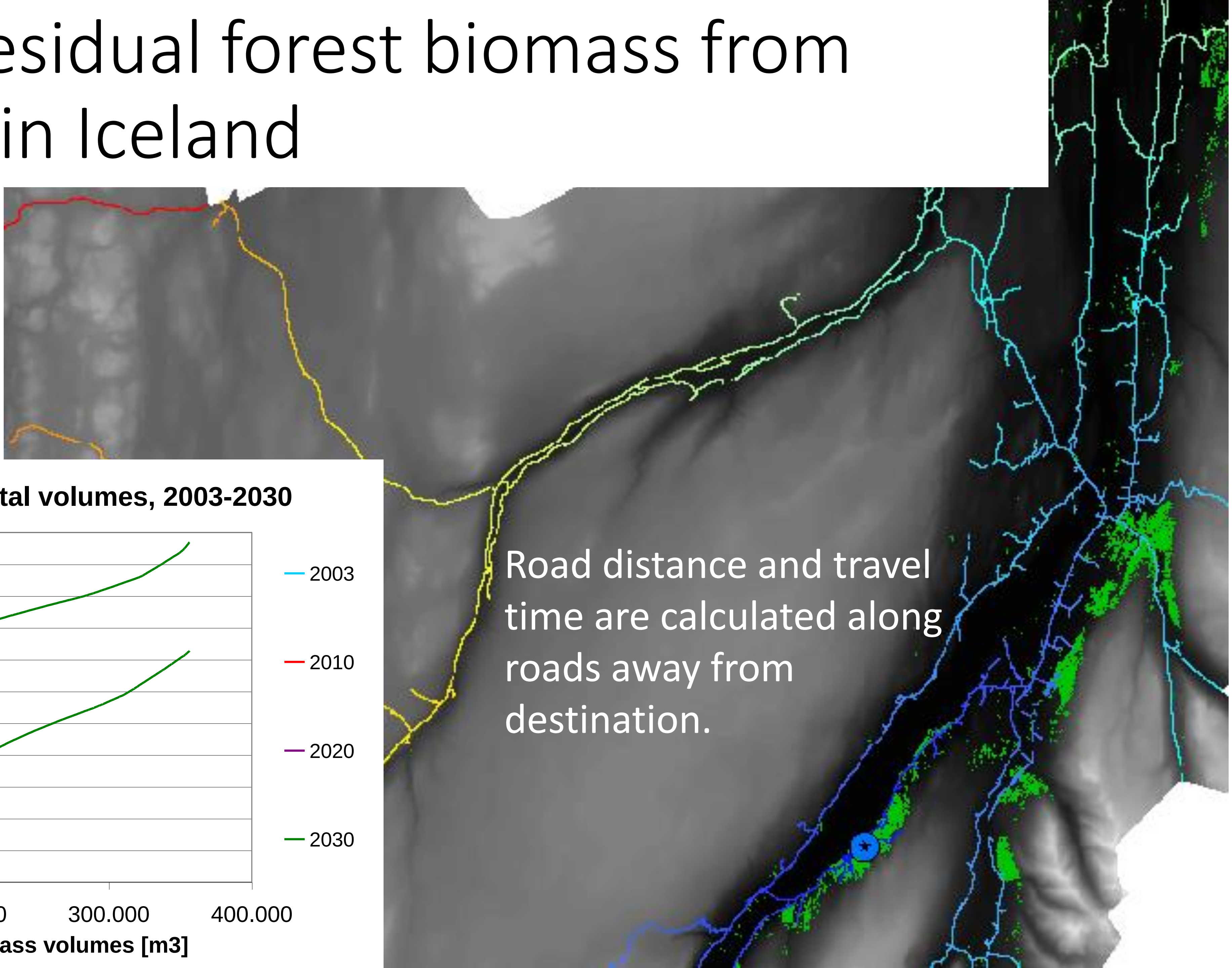


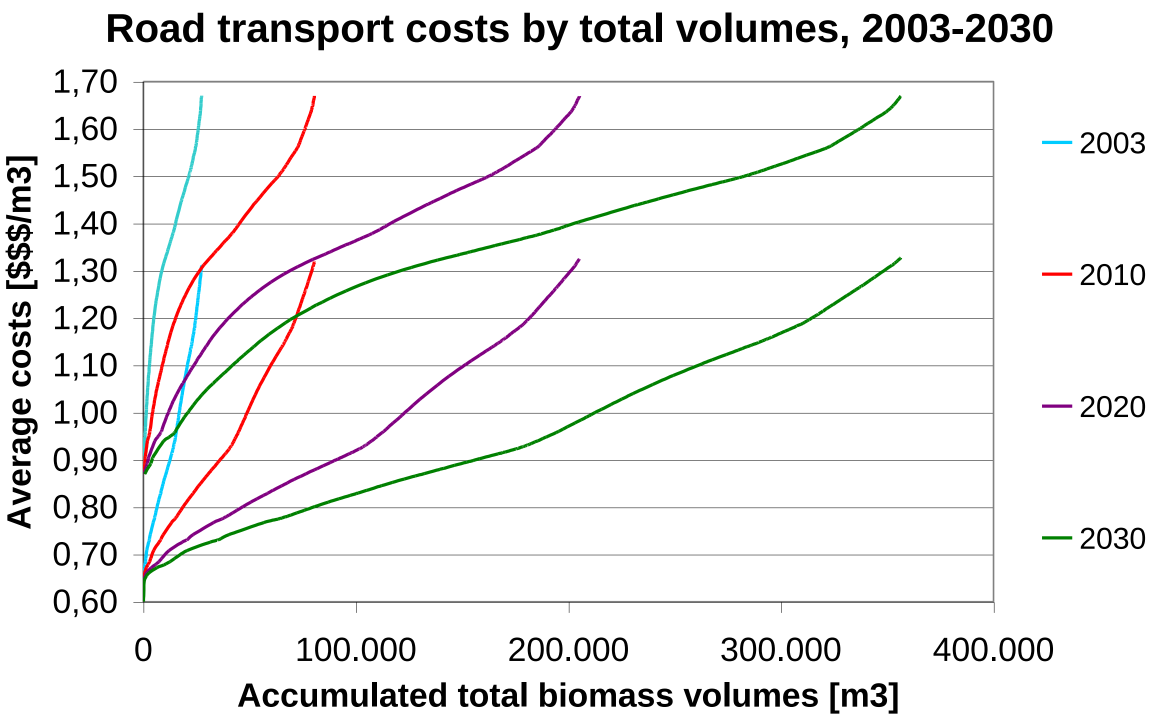


Understanding forest-derived biomass supply with GIS modelling. Hock, B. K., Blomqvist, L., Hall, P., Jack, M., Möller, B. & Wakelin, S. J.Journal of Spatial Science. 57,(2012) 213-232.

The case of residual forest biomass from afforestation in Iceland

Available resources from newly established forests help paying for forest management activities.

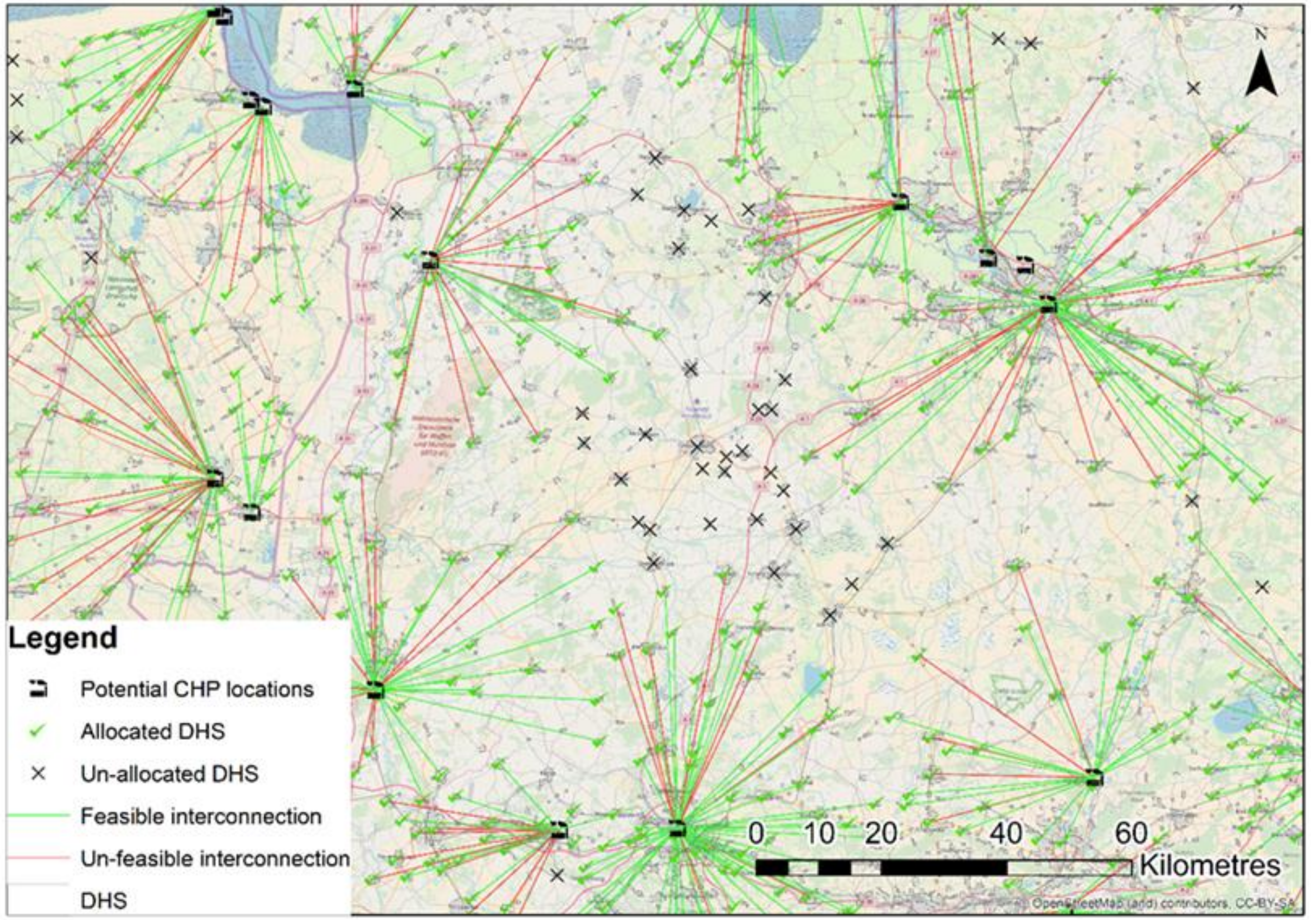




Road distance and travel time are calculated along roads away from destination.

The case of spatial allocation of excess heat to potential district heating areas

- Specifying how local supplies and local demands overlap.
- P-Median allocation of excess heat to prospective district heating systems



- Local geography limits how demand and supply can be matched.
- Methods from operations research are used to allocate constrained resources to the nearest consumers in a least cost manner.

Lessons learned

- Sustainable energy needs geographical studies, and this has taken a while to understand
- Energy economics are determined by location, distribution and distance, but only now do we have the means to analyse this
- Land conflict is inevitable, but so is the inclusion of geo-science in sustainable energy planning.

Outlook

- Social and environmental, geographical constraints will gain importance:
  - Available space for renewables is getting limited
  - Prioritised areas are increasingly subjected to area competition
  - The use of inferior locations makes site assessment more critical
  - Inclusion of more parameters is needed in site assessments
  - Geospatial methods will gain importance in conflict prevention and in planning

Thank you very much!

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Questions via the online conference portal

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