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Spatial mapping of future renewable energy potential in Flanders

Combining CA-based land use modelling and GIS

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European Directive on renewable energy

- 20% RE of the total gross energy consumption by 2020
  - Belgium: 13% (4.6% in 2009!)
    - 20.9% RES-E (6% in 2009)
    - 11.9% RES-H&C
    - 10.1% RES-T (3.3% in 2009)
Objectives

» Develop geographically explicit projections of renewable energy in Flanders in 2020

» Focus:
  » Onshore wind energy: NREAP target of 4320 MW onshore/offshore wind energy (currently: ± 1750 MW installed capacity in Belgium)
  » Solar energy (photovoltaic electricity): NREAP target of 1300 MW (currently: ± 1400 MW installed capacity in Flanders)
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  » Onshore wind energy: NREAP target of 4320 MW onshore/offshore wind energy (currently: ± 1750 MW installed capacity in Belgium)
  » Solar energy (photovoltaic electricity): NREAP target of 1300 MW (currently: ± 1400 MW installed capacity in Flanders)

» Develop SDSS by coupling a CA-based land-use model for Flanders with a GIS-based approach
Land-use change projections

» Constrained Cellular Automata model for Flanders (RuimteModel Vlaanderen)
Land-use change projections

» Constrained Cellular Automata model for Flanders (RuimteModel Vlaanderen)
» Implemented and calibrated to run simulations covering the period 2010 until 2020
» Business-as-usual scenario
» Model output at the local level: land-use map for 2010-2020, showing the 37 simulated land-use classes at a resolution of 1 ha
RuimteModel Vlaanderen
BAU scenario
2010-2050

37 land-use categories
1 ha resolution
Runs 2010-2050
1 year time steps
Simulation in 30 min.
RuimteModel Vlaanderen – BAU scenario

<table>
<thead>
<tr>
<th>Land-use category</th>
<th>2010 (ha)</th>
<th>2020 (ha)</th>
<th>Difference (ha)</th>
<th>Daily difference (ha/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>244.947</td>
<td>266.968</td>
<td>22.021</td>
<td>+6.0</td>
</tr>
<tr>
<td>Industrial/commercial</td>
<td>126.144</td>
<td>128.936</td>
<td>2.792</td>
<td>+0.8</td>
</tr>
<tr>
<td>Open space</td>
<td>929.892</td>
<td>905.174</td>
<td>-24.718</td>
<td>-6.8</td>
</tr>
</tbody>
</table>

Urban expansion in the surroundings of already urbanised cells, both in highly urbanised regions (around city centres) and in more or less ‘rurban’ regions in Flanders

→ Highly dispersed RE production and consumption
→ Limited space for placing wind turbines
Land-use change projections

» Constrained Cellular Automata model for Flanders (RuimteModel Vlaanderen)
» Implemented and calibrated to run simulations covering the period 2010 until 2020
» Business-as-usual scenario
» Model output at the local level: land-use map for 2010-2020, showing the 37 simulated land-use classes at a resolution of 1 ha
» 2 spatial indicators:
  » Degree of urbanisation
  » Cluster size of the open space (natural, agricultural, recreational land use, water, parks)
Wind energy potential - Methodology

- Bottom-up approach
- 2 step procedure
## Positive criteria

<table>
<thead>
<tr>
<th>Positive criteria</th>
<th>Buffer distance</th>
<th>Output of RuimteModel (dynamic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial areas (zoning plans)</td>
<td>250m</td>
<td></td>
</tr>
<tr>
<td>Industrial land uses</td>
<td>250m</td>
<td>x</td>
</tr>
<tr>
<td>Distance to roads</td>
<td>250m</td>
<td></td>
</tr>
<tr>
<td>Distance to transmission lines</td>
<td>250m</td>
<td></td>
</tr>
<tr>
<td>Distance to main canals</td>
<td>250m</td>
<td></td>
</tr>
<tr>
<td>Degree of urbanisation &gt; 50%</td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2020</th>
<th>Difference 2020-2010</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>444484.1 ha</td>
<td>467344.8 ha</td>
<td>22860.7 ha</td>
</tr>
<tr>
<td></td>
<td>(±33%)</td>
<td>(±35%)</td>
<td>(+5.1%)</td>
</tr>
</tbody>
</table>

Degree of urbanisation > 50% in 2010

Degree of urbanisation > 50% in 2020

Difference 2020-2010: 22860.7 ha (+5.1%)
Negative criteria

Buffer distance

Output of RuimteModel (dynamic)

Natura2000 Habitat sites
Natura2000 Bird sites
Natural conservation areas
Flemish Ecological Network (VEN)
Flood risk zones
Landscapes of inheritance
Valuable landscapes
Residential areas (zoning plans)

300m
Residential land use

50m
Buildings

150m
Distance to roads
Distance to transmission lines
Distance to main canals
Distance to pipelines
Distance to Seveso installations
Distance to operational wind turbines
Airports

CTR zones
High danger zones for military defence
VOR/NBD radarzones

Distance to military radars

15km
Open space clusters > 1000ha

Water surfaces
Flood risk zones
Nature conservation areas
Flemish ecological network
Natura2000 Habitat sites
Natura2000 Bird sites
Estimating the wind energy potential

Spatial-explicit land use model (RuimteModel)

Positive (suitable) criteria
- Dynamic criteria
  - Maps 2010
  - Maps 2020
- Static criteria

Negative (exclusion) criteria
- Static criteria
- Dynamic criteria
- Maps 2010
- Maps 2020

Boolean overlay procedure

Potential zones for windturbines

Number of windturbines

Optimisation criteria (GIS)

Wind energy potential in 2020
Allocate wind turbines inside suitable zones

GIS-based optimization procedure

1. Remove polygons that are too small (minimum criterion: circle with 5 m radius)
2. Define Bounding box (minimum bounding rectangle) around each polygon
3. Calculate the number of wind turbines inside each polygon:
   
   \[ N = \frac{\text{Area}_{\text{polygon}}}{\text{Area}_{\text{br}}} \]

4. Allocate the calculated number of polygons inside each polygon
5. Remove isolated wind turbines (minimum cluster size = 3 wind turbines)
Estimated potential for wind turbines

- Estimated potential for wind turbines
  - Wind turbines in 2010: 1249 turbines (3747 MW)
  - Wind turbines in 2020: 1101 turbines (3303 MW)

Map legend:
- Residential land 2010
- New residential land 2020
- Industrial/commercial zones
- Suitable locations for wind turbines 2010
- Suitable locations for wind turbines 2020
- Major road network
- Potential locations for wind turbines in 2020
Solar energy potential - Methodology

- Top-down approach

Diagram:
- Environmental Costing model
- Spatial-explicit land use model (RuimteModel)
- Land cover map 2020
- Solar energy potential in Flanders in 2020 (MW)
- Average proportion of buildings per ha per (urban) land use category, per degree of urbanisation
- Urban land in 2020
- Degree of urbanisation in 2020
- Dasymetric mapping procedure (GIS)
- Spatial distribution of solar energy potential in 2020 (MW/cell)

Inputs:
- Urban land in 2010
- Degree of urbanisation in 2010
- Cadastral building map 2010
1. Estimating the solar energy potential in Flanders

- Environmental Costing Model
- Technical-economic Markal-based model
- BAU-scenario vs. PRO-scenario 2020 for Flanders

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<td>PV [GWh]</td>
<td>34</td>
<td>440</td>
<td></td>
<td>1377</td>
<td></td>
<td></td>
<td>2015</td>
<td></td>
</tr>
<tr>
<td>PV [MWe]</td>
<td>40</td>
<td>670</td>
<td>1170</td>
<td>1470</td>
<td>1620</td>
<td>1770</td>
<td>2070</td>
<td>2370</td>
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+1700 MW
2. Allocating the solar energy potential

» Dasymetric mapping technique based on the results of the land-use change model
Allocating the solar energy potential

Fraction of 1ha cells for different land-use categories and degree of urbanisation that is built-up

Average rooftop area per (1 ha) cell
Allocating the solar energy potential

Estimated capacity in 2020 (for Flanders)

- +1700MW

Dasymetric mapping

2020

Average rooftop area per cell

On average: 9.5 W/m² total rooftop area

Installed capacity per ha

- < 4 kW
- 4-6 kW
- 6-8 kW
- 8-10 kW
- > 10 kW
Conclusions

» Geographically-based potential for wind energy in Flanders: 3300MW by 2020
  » Well above the target for wind energy put forward in the Belgian NREAP!
  » However! Market conditions in the near future and the legal/administrative/political situation in Flanders will have the largest influence on the real market-technical potential for wind energy in the future
  » Moreover, the methodology makes abstraction of the specific terrain conditions and the onshore wind resources → the indicated suitable zones might not be the most optimal locations regarding wind speed and wind intensity and thus power output
Conclusions

» Total peak-capacity of installed PV in 2020: 2.4 GW
  » Well above the 1.3 GW that was mentioned in the NREAP
  » However! Highly dependent on changing policies related to the system of ‘green certificates’ (GCS) and the investment costs

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<tbody>
<tr>
<td>Zon [GWh]</td>
<td>34</td>
<td>174</td>
<td>308</td>
<td>508</td>
<td>935</td>
</tr>
<tr>
<td>Zon [MWe]</td>
<td>200</td>
<td>583</td>
<td>1072</td>
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Conclusions

» Results have shown the applicability of a CA-based land-use change model for making estimates about future renewable energy production in a spatially-explicit and dynamic way

» SDSS should incorporate land-use models in order to get a more complete/correct view of the future potential for renewable energy

» These coupled systems should help grid operators in their effort to develop energy- and cost-effective energy systems within a spatial context of expanding urban regions

» Beyond this, the method supports a more integrated approach to spatial planning in that it can inform spatial planners about the unwanted effects of the diffuse urbanization patterns that are taking place in Flanders