Accounting uncertainty for spatial modeling of greenhouse gas emissions in the residential sector: fuel combustion and heat production

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Agenda

- Introduction
- Methodology
- Inventory results: Poland and Ukraine
- Validation of approach
- Conclusions
Essence of the approach

Disaggregation algorithms and data processing

Mathematical model:
\[ E^G_{Res}(\delta) = \sum_{i=1}^{E_F} \left( \sum_{j=1}^{M^o} F_{i,Res}^R EF_{Res,j}^G + \sum_{j'=1}^{J_0} M^o F_{j',Res}^R EF_{Res,j'}^G \right) \]

f(x; \mu, \sigma) = \frac{1}{x\sigma\sqrt{2\pi}} \exp \left( -\frac{(\ln(x) - \mu)^2}{2\sigma^2} \right), x > 0

Monte-Carlo method, 95%, ……

Emissions CO₂, CH₄, N₂O: ???
Uncertainties: ???

Uncertainty analysis

Uncertainty of Input Data

Results of spatial inventory

Database of geo-referenced data

Visualization of results

Map of emission sources

All regions

Country

Region

All settlements

Emission, екв. CO₂, Гг

Number of occurrences in the interval

Emission, екв. CO₂, Гг

Number of occurrences in the interval

Uncertainty analysis

Monte Carlo method, 95%
What **determines the amount** of GHG emissions in the residential sector **at the level of geographical elementary objects**?
Methodology

Spatial inventory of GHG emissions: households

**Algorithm**

- **Step 1:** Input data collection
- **Step 2:** Energy demand assessment
- **Step 3:** Fossil fuel disaggregation
- **Step 4:** GHG emission estimation
Input data

(1) official statistical information
(2) country-specific emission factors
(3) digital maps of investigated area
  - population density map
    raster data on population density
    disaggregated with CLC (Gallego, 2010)
    a) update of the map (2010 data)
    b) urban/rural characteristics were added
  - Heating-Degree Days map (HDD)
Energy demand assessment

\[ Q = Q_c + Q_w + Q_h \]

**Cooking:**

\[ Q_c = Q_{c,rs} + Q_{c,agri} \]

The average energy demand for:
- cooking per person,
- feed cooking,
- water heating for drinking and sanitary per 1 head of cattle.

**Water heating:**

\[ Q_w = Q_{w,summer} + Q_{w,winter} \]

Average hot water consumption (norms):
- 48 dm³ – dwelling,
- 35 dm³ – detached house (55°C per person).

**Space heating:**

\[ Q_h = k_{HDD} \cdot f(Q_{h,sqm}, LA, \varepsilon) \]

- relative change of HDD
- living area (LA) per person
- energy demand per sq m of LA
- characteristics of living area
- efficiency coefficient

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**Energy demand structure**

- cooking for families
- cooking for livestock
- water heating
- space heating

- 70.94%
- 6.33%
- 11.43%
- 11.30%
Disaggregation algorithm

\[ M_{i,n} = M_{i,R} \cdot F_{type,i}^n, \quad n = 1, N, \]

\( M_{i,R} \) - consumed fossil fuel \( i \) in region \( R \),

\( type \) - characterizes affiliation of elementary object to urban or rural area,

\( F_{type,i}^n \) - disaggregation coefficient.

**Country (or region) \( R \)**

- **Statistical data:**
  - fossil fuel consumption

**Disaggregation algorithm**

**Regions (or municipalities)**

\[ 1, 2, \ldots, N-1, N \]

Elementary objects
GHG emission estimation

\[ E_{i,n}^G = M_{i,n} \cdot EF_{i,n}^G, \quad n = 1, N, \]

- \( EF_{i,n}^G \) - emission factor of greenhouse gas \( G \)

Step 4:

**GHG emission estimation**
Inventory results: Poland

Specific GHG emissions in residential sector (mln kg/sq.km., CO2-eq., Poland, 2010)

Structure of GHG emissions by type of fossil fuel for administrative regions (mln kg, CO2-eq., Ukraine, 2010)
Inventory results: Ukraine

Specific GHG emissions in residential sector (mln kg/sq.km., CO2-eq., Ukraine, 2010)

Structure of GHG emissions by type of fossil fuel for administrative regions (mln kg, CO2-eq., Ukraine, 2010)
Inventory results: Ukraine (Lviv region)

Prosm-map of specific GHG emissions in residential sector (mln kg/sq.km., CO2-eq., Lviv region, Ukraine, 2010)
Comparison of GHG inventory results:
South-Eastern Poland and Western Ukraine
Comparison of GHG inventory results: South-Eastern Poland and Western Ukraine

Fig. 1. Structure of GHG emissions per capita by type of fossil fuel (thousands kg per capita, CO₂–eq., South-Eastern Poland, 2010)

Fig. 2. Structure of GHG emissions per capita by type of fossil fuel (thousands kg per capita, CO₂–eq., Western Ukraine, 2010)
GHG emissions from the heat production

Greenhouse gas emissions from heat production in Poland
(thousands tons, CO$_2$-equivalent, 2010)
Uncertainty analysis: Monte-Carlo method

Fuel types: (coal, brown coal, nat. gas, oil, ...)

Types of GHG: CO₂, CH₄, N₂O

Result: Total emission/uncertainties: CO₂, CH₄, N₂O, CO₂-eq.

Iterative process:
- Number of realization...
- Fuel types (coal, brown coal, nat. gas, oil, ...)
- Types of GHG: CO₂, CH₄, N₂O

Inventory level:
- Settlement
- Region
- Country

Uncertainty analysis: Monte-Carlo method

\[ Q_{E_n,f} \left( \xi_{E_n,p} \right) \cdot K_{E_n,f}^g, C_f \]
## Uncertainty analysis: Monte-Carlo method

<table>
<thead>
<tr>
<th>Voivodeship</th>
<th>$\text{CO}_2$, Gg (uncertainty, %)</th>
<th>$\text{CH}_4$, Gg (uncertainty, %)</th>
<th>$\text{N}_2\text{O}$, Gg (uncertainty, %)</th>
<th>Total emission Gg (uncertainty, %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Silesian</td>
<td>2635,8 (-12,9 : +14,9)</td>
<td>5,4 (-21,4 : +25,5)</td>
<td>0,03 (-19,7 : +23,2)</td>
<td>2780,50 (-13,2 : +15,2)</td>
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<tr>
<td>Kuyavian-Pomeranian</td>
<td>1741,5 (-14,5 :+16,7)</td>
<td>4,0 (-21,5 : +25,5)</td>
<td>0,02 (-19,9 : +23,4)</td>
<td>1848,54 (-14,7 : +16,9)</td>
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<tr>
<td>Lublin</td>
<td>1982,9 (-14,3 : +16,5)</td>
<td>4,5 (-21,5 : +25,6)</td>
<td>0,03 (-19,8 : +23,4)</td>
<td>2103,56 (-14,5 : +16,8)</td>
</tr>
<tr>
<td>Lubusz</td>
<td>700,4 (-11,8 : +13,6)</td>
<td>1,3 (-21,3 : +25,4)</td>
<td>0,01 (-19,3 : +22,7)</td>
<td>735,77 (-12,1 : +14,0)</td>
</tr>
<tr>
<td>Łódź</td>
<td>2451,2 (-15,0 : +17,3)</td>
<td>5,8 (-21,6 : +25,6)</td>
<td>0,03 (-20,0 : +23,6)</td>
<td>2606,73 (-15,2 : +17,5)</td>
</tr>
<tr>
<td>Lesser Poland</td>
<td>3091,0 (-12,7 : +14,7)</td>
<td>6,3 (-21,4 : +25,5)</td>
<td>0,04 (-19,7 : +23,3)</td>
<td>3258,20 (-13,0 : +15,0)</td>
</tr>
<tr>
<td>West Pomeranian</td>
<td>1163,7 (-9,6 : +11,0)</td>
<td>1,8 (-21,0 : +25,1)</td>
<td>0,01 (-18,6 : +21,9)</td>
<td>1210,98 (-9,9 : +11,3)</td>
</tr>
<tr>
<td>Greater Poland</td>
<td>3013,4 (-12,4 : +14,3)</td>
<td>5,9 (-21,3 : +25,4)</td>
<td>0,04 (-19,5 : +22,9)</td>
<td>3172,27 (-12,7 : +14,6)</td>
</tr>
<tr>
<td>Lesser Poland</td>
<td>900,1 (-13,0 : +15,0)</td>
<td>1,9 (-21,4 : +25,5)</td>
<td>0,01 (-19,5 : +23,0)</td>
<td>949,97 (-13,2 : +15,3)</td>
</tr>
<tr>
<td>Warmian-Masurian</td>
<td>700,4 (-13,0 : +15,0)</td>
<td>1,3 (-21,3 : +25,4)</td>
<td>0,01 (-19,5 : +23,0)</td>
<td>949,97 (-13,2 : +15,3)</td>
</tr>
</tbody>
</table>
Validation of the approach: Ukraine, wood combustion

Statistical data devided by disaggragated data
(black dots – forest cover)
Validation of the approach: Poland, natural gas

Natural gas combustion at the level of municipalities

Urban areas

Rural areas
Conclusions

- A new understanding of the residential sector
- Lack of detailed data on FF combustion -> dissagregation -> spatial uncertainty
- Validation and uncertainty analysis are important components of spatial inventory
Thank you for your attention!

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