Transition to a low-emission economy in Poland in view of the results of multisectoral energy model

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Presentation plan

1. Introduction.
2. Current condition of the energy system.
3. Model structure.
4. Scenarios of a low-emission transition.
5. Results.
6. Conclusions and directions of the further research.
1. Introduction

• Polish energy system is facing the biggest challenge in its history;
• Low-emission transition process needs long-term planning;
• The scope of two main government plans for the energy system:


1. Introduction

Tab. 1. EU and Polish objectives on climate and energy

<table>
<thead>
<tr>
<th></th>
<th>CO2 emission mitigation [in %]</th>
<th>RES share in final energy consumption [in %]</th>
<th>Energy efficiency improvement [in %]</th>
<th>Documents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EU</td>
<td>PL</td>
<td>EU</td>
<td>PL</td>
</tr>
<tr>
<td>2020</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>15</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>2030</td>
<td>40</td>
<td>30</td>
<td>32</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>21</td>
<td>32,5</td>
<td>23</td>
</tr>
<tr>
<td>2050</td>
<td>80-95</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>?*</td>
<td>?</td>
<td>Road Map50</td>
</tr>
</tbody>
</table>

Source: Own elaboration.

* - more than 80% of electricity will be produced from RES
2. Current condition of the energy system

Facts:

- Polish energy sector is historically based on fossil fuels;
- large use of coal causes high cost of buying CO2 emission allowances;
- noticeable significant lower capacity factor of RES.

Tab. 2. Structure of C and electricity generation in Polish electric power system as at 31 December 2017

<table>
<thead>
<tr>
<th>Power plant type</th>
<th>Installed capacity [in MW]</th>
<th>%share</th>
<th>Electricity generation [in GWh]</th>
<th>%share</th>
</tr>
</thead>
<tbody>
<tr>
<td>hard coal</td>
<td>20 247</td>
<td>46.6</td>
<td>79 868</td>
<td>48.2</td>
</tr>
<tr>
<td>lignite</td>
<td>9 352</td>
<td>21.5</td>
<td>51 983</td>
<td>31.3</td>
</tr>
<tr>
<td>natural gas</td>
<td>2 341</td>
<td>5.4</td>
<td>7 172</td>
<td>4.3</td>
</tr>
<tr>
<td>captive</td>
<td>2 813</td>
<td>6.5</td>
<td>10 057</td>
<td>6.1</td>
</tr>
<tr>
<td>hydropower</td>
<td>2 328</td>
<td>5.4</td>
<td>7 172</td>
<td>4.3</td>
</tr>
<tr>
<td>wind and other renewables</td>
<td>6 341</td>
<td>14.6</td>
<td>14 005</td>
<td>8.4</td>
</tr>
<tr>
<td>TOTAL</td>
<td>43 422</td>
<td>100.0</td>
<td>165 852</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: PSE S.A. (Polish Electricity Networks Inc.) Databases.

Pic. 1. Electricity production by energy carrier in Poland in 2017

2. Current condition of the energy system

Facts:
- the majority of existing power plants and installations are old;
- energy sector requires significant investments...

Tab. 3. Scenarios for disabling the obsolete power plant blocks [power loss in MW]

<table>
<thead>
<tr>
<th></th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>„Modernization” scenario</td>
<td>3000</td>
<td>3200</td>
<td>5700</td>
<td>13900</td>
</tr>
<tr>
<td>&quot;Turn off&quot; scenario</td>
<td>6600</td>
<td>9900</td>
<td>17300</td>
<td>20300</td>
</tr>
</tbody>
</table>

Source: PSE S.A. (Polish Electricity Networks Inc.) Databases.

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2. Current condition of the energy system

**Facts:**

- we made a huge progress in the development of RES...
- ... but we won’t reach the level of 15% of share requirement in 2020.

**Tab. 2. Increase of RES installed capacity [MW] in Poland in 2005-2018**

<table>
<thead>
<tr>
<th>Year</th>
<th>Solar</th>
<th>Wind</th>
<th>Biogas</th>
<th>Biomass</th>
<th>Hydro</th>
<th>Total %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.9</td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9.3</td>
</tr>
<tr>
<td>2015</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11.7</td>
</tr>
<tr>
<td>2016</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11.3</td>
</tr>
<tr>
<td>2017</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10.9</td>
</tr>
</tbody>
</table>

Source: wysokienapiecie.pl
2. Current condition of the energy system

Facts:
• increasing transformation energy intensity in petroleum refining and coking sector;
• very low utilization of electricity in transportation sector;
• ensuring energy security by changing import directions of natural gas.

Pic. 3. Primary energy intensity [TJ/mln zl] of transformation processes in the petroleum refining and coking sector

Pic. 4. Direct energy consumption in the transportation sector in 2017

Tab. 4. Historical and planned main directions of crude oil and natural gas import

Source: Own calculations.

2. Current condition of the energy system

Solutions for Polish energy system:

• first nuclear power plant in Poland (availability factor in GW):

<table>
<thead>
<tr>
<th>Year</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2033</th>
<th>2035</th>
<th>2040</th>
<th>2043</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear power plant</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.0-1.5</td>
<td>1.5-2.6</td>
<td>4.5-5.2</td>
<td>6.0-9.0</td>
</tr>
</tbody>
</table>


• supporting offshoring programme:
  a) more than 23 bln EUR budget;
  b) building 8-15 GW of offshore installed capacity in 2020-2035.

• strong support for the development of RES:

• decentralization of electricity generation. Industrial and individual prosumption;

• big hope in a new technologies of the energy storage;

• utilization of alternative fuels. Development of electro-mobility.
3. Model structure

Main features of the MEM model:
• combines i-o analysis with econometric methods (economic core);
• there is a loop between i-o core and stochastic equations;
• has energy (16 energy carriers) and environmental (CO2 emissions) extensions;
• distinguishes 77 sectors + HH;
• covers mainly the period 1996-2017;
• operates on unified unique database, based on Statistics Poland data;
• developed in InterDyme software;
3. Model structure

- **Macrovariables**
  - Input: \(\text{rlosm, pmi}\)
  - Output: \(\text{prodR scalars}\)

- **Investment module**
  - Input: \(\text{prodR scalars}\)
  - Output: \(\text{Output (prodR)}\)

- **Consumption module**
  - Input: \(\text{pcesP%1, pcePtot}\)
  - Output: \(\text{gdpR}\)

- **Leontief inverse matrix**
  - \(\text{Output (prodR)} = \text{Leontief inverse matrix} \times \text{Final demand}\)

- **Value added**
  - Input: \(\text{unit values mult.}\)
  - Output: \(\text{Total va}\)

- **Final demand components**
  - Input: \(\text{const. shares}\)
  - Output: \(\text{Import}\)

- **Sum of columns**
  - Input: \(\text{FMm row sum}\)
  - Output: \(\text{imRtot index}\)

- **Taxes**
  - Input: \(\text{Fd}\)
  - Output: \(\text{Fd taxes}\)

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3. Model structure

- **prodR vector**:
  - prodR_iENd (direct energy coefficients) = ENd (direct energy consumption)
  - prodR_iENT (transformation energy coefficients) = ENt (transformation input energy consumption)

- **Energy module**:
  - EN (total energy consumption) = \( \sum \text{prodR} \cdot \text{iENd} \) + \( \sum \text{prodR} \cdot \text{iENT} \)

- **Emission module**:
  - EN (total energy consumption) \( \cdot \text{ebemul} \) = VCEF (Varied carbon emission factors) = EM (CO2 emissions)

- **K-type total energy consumption**:
  - Total CO2 emissions by energy carrier

Source: Own elaboration
4. Scenarios of a low-emission transition

Scenario for macrovariables (*.xg file):

- Sources: Eurostat and *Macroeconomic Outline* by the Ministry of Finance
- Time scope: 2015(2017)-2040

Pic. 5. Forecast of main ingredients of the final demand [left scale, in bln zł] and real GDP growth rate [right scale, in %]

Source: Own elaboration
4. Scenarios of a low-emission transition

**pce module:**

```plaintext
id pceRtot = pceincS * gdpR
f pcepctot = pceRtot / pop
f dpcepctot = pcepctot - pcepctot[1]

do{
  fex pcepc%1 = pcesR%1 / pop
  f pcerP%1 = pcesP%1 / pcePtot
r pcepc%1 = pcepctot, dpcepctot, pcerP1
id pcesR%1 = pcepc%1 * pop
cc pces[%1] = pcesR%1[t];
}(1-44)
```

**Scenario for pce module (*.xg file):**

```plaintext
# pces%1 - indexed by CPI target 2,5%
fdates 2017 2050
f yearNo = @cum(yearNo,1,0)-1
f rat25 = @exp(yearNo * @log(1+0.025))
do{
  f pcesP%1 = pcesP%1{2017} * rat25
}(1-44)
```

# pceincS[t] = pceincS{2017} = 0.58

**Pic. 6.** Population [in th., left scale] and pce price index [2010=1, right scale] forecasts

Source: Own elaboration

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4. Scenarios of a low-emission transition

inv module:

• Investment expenditures in specific sector -> bridge -> investment demand for a product;

• individual analytical approach to each of the sector;

• base model:

\[ r_{\text{invs}R1} = \text{!caprep}, \ d_{\text{prod}R1}, \ d_{\text{prod}R1[1]}, \ d_{\text{prod}R1[2]}, \ r_{\text{rلومر}}, \ r_{\text{rلومر}[1]}, \ pmi \]

Soft constraints: \text{con} \ [[] \ 1=a1

Scenario for investment module:

• rلومr – close to 0% value [Fisher formula];

• pmi:

\[ \# \ pmi \to \text{CAGR from last available years} \]

\[ \text{fdates 2017 2050} \]

\[ f_{\text{rat005}} = \exp(yearNo \cdot \log(1+0.005)) \]

\[ f_{\text{pmi}} = \text{pmi[2017]} \cdot \text{rat005} \]
4. Scenarios of a low-emission transition

- ODN scenario (BAU) [*.vfx file]

Tab. 5. Structure of transformations input in energy sector

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2033</th>
<th>2035</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>0.89</td>
<td>0.85</td>
<td>0.84</td>
<td>0.83</td>
<td>0.74</td>
<td>0.66</td>
<td>0.45</td>
</tr>
<tr>
<td>Petroleum products</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Natural gas</td>
<td>0.04</td>
<td>0.07</td>
<td>0.09</td>
<td>0.09</td>
<td>0.13</td>
<td>0.17</td>
<td>0.23</td>
</tr>
<tr>
<td>RES</td>
<td>0.06</td>
<td>0.07</td>
<td>0.07</td>
<td>0.08</td>
<td>0.09</td>
<td>0.10</td>
<td>0.11</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.03</td>
<td>0.07</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Tab. 6. Structure of transformations input in coke-petroleum sector

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>0.27</td>
<td>0.26</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Crude oil</td>
<td>0.67</td>
<td>0.67</td>
<td>0.68</td>
<td>0.68</td>
<td>0.68</td>
<td>0.68</td>
</tr>
<tr>
<td>Natural gas</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>RES</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Petroleum products</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Tab. 7. Dynamics of final energy intensity in indicated groups

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2033</th>
<th>2035</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing</td>
<td>1.000</td>
<td>0.958</td>
<td>0.854</td>
<td>0.764</td>
<td>0.735</td>
<td>0.715</td>
<td>0.674</td>
</tr>
<tr>
<td>Agriculture</td>
<td>1.000</td>
<td>1.026</td>
<td>1.014</td>
<td>1.003</td>
<td>0.996</td>
<td>0.991</td>
<td>0.980</td>
</tr>
<tr>
<td>Services</td>
<td>1.000</td>
<td>0.914</td>
<td>0.829</td>
<td>0.743</td>
<td>0.709</td>
<td>0.686</td>
<td>0.600</td>
</tr>
<tr>
<td>Transport</td>
<td>1.000</td>
<td>1.126</td>
<td>1.098</td>
<td>1.058</td>
<td>1.016</td>
<td>0.988</td>
<td>0.924</td>
</tr>
<tr>
<td>Households</td>
<td>1.000</td>
<td>1.018</td>
<td>1.006</td>
<td>0.997</td>
<td>0.992</td>
<td>0.988</td>
<td>0.981</td>
</tr>
</tbody>
</table>

Source: Own elaboration
4. Scenarios of a low-emission transition

- PEK scenario (introducing of energy & climate policy) [*vfx file]

Tab. 8. Structure of transformations input in energy sector

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2033</th>
<th>2035</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>0.89</td>
<td>0.86</td>
<td>0.81</td>
<td>0.75</td>
<td>0.67</td>
<td>0.58</td>
<td>0.41</td>
</tr>
<tr>
<td>Petroleum products</td>
<td>0.00</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Natural gas</td>
<td>0.04</td>
<td>0.06</td>
<td>0.08</td>
<td>0.10</td>
<td>0.12</td>
<td>0.14</td>
<td>0.18</td>
</tr>
<tr>
<td>RES</td>
<td>0.06</td>
<td>0.07</td>
<td>0.10</td>
<td>0.14</td>
<td>0.15</td>
<td>0.16</td>
<td>0.17</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.06</td>
<td>0.12</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Tab. 9. Structure of transformations input in coke-petroleum sector

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>0.27</td>
<td>0.27</td>
<td>0.27</td>
<td>0.27</td>
<td>0.27</td>
<td>0.27</td>
</tr>
<tr>
<td>Crude oil</td>
<td>0.67</td>
<td>0.68</td>
<td>0.67</td>
<td>0.67</td>
<td>0.67</td>
<td>0.66</td>
</tr>
<tr>
<td>Natural gas</td>
<td>0.02</td>
<td>0.01</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>RES</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Petroleum products</td>
<td>0.05</td>
<td>0.04</td>
<td>0.04</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Tab. 10. Dynamics of final energy intensity in indicated groups

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2033</th>
<th>2035</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing</td>
<td>1.000</td>
<td>0.924</td>
<td>0.799</td>
<td>0.694</td>
<td>0.661</td>
<td>0.639</td>
<td>0.597</td>
</tr>
<tr>
<td>Agriculture</td>
<td>1.000</td>
<td>1.000</td>
<td>0.960</td>
<td>0.919</td>
<td>0.897</td>
<td>0.882</td>
<td>0.847</td>
</tr>
<tr>
<td>Services</td>
<td>1.000</td>
<td>0.886</td>
<td>0.743</td>
<td>0.657</td>
<td>0.606</td>
<td>0.571</td>
<td>0.514</td>
</tr>
<tr>
<td>Transport</td>
<td>1.000</td>
<td>1.034</td>
<td>0.955</td>
<td>0.876</td>
<td>0.834</td>
<td>0.805</td>
<td>0.743</td>
</tr>
<tr>
<td>Households</td>
<td>1.000</td>
<td>0.993</td>
<td>0.882</td>
<td>0.797</td>
<td>0.781</td>
<td>0.770</td>
<td>0.754</td>
</tr>
</tbody>
</table>

Source: Own elaboration

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5. Results
Run specification

Pic. 7. Transformation input consumption in energy sector for electricity & heat production [in EJ]

Source: Own elaboration

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5. Results

Pic. 8. Transformations input in coke-petroleum sector [in EJ]

Pic. 9. Direct energy consumption in the economy [in EJ]

Source: Own elaboration
5. Results

Pic. 10. Households energy consumption [in TJ]

Source: G7 software. Own elaboration

Tot diff. {2040} = 23.1%
5. Results

Pic. 11. CO2 emissions by the main „air poisoners”

CO2 emissions by energy sector [in mln tons]

- **ODN**
- **PEK**

**Diff. {2040} = 21.3%**

CO2 emissions by households [in mln tons]

- **ODN**
- **PEK**

**Diff. {2040} = 23.1%**

CO2 emissions by land transportation sector [in mln tons]

- **ODN**
- **PEK**

**Diff. {2040} = 19.6%**

Source: Own elaboration
6. Conclusions and directions of the further research

DIRECTIONS OF FURTHER RESEARCH:

I. Inclusion of VCEF (Varied carbon emission factors) scenario.
II. Implementation of changes in energy prices.
III. Comparison of the results (own research vs. policy makers’ analysis).
IV. Checking the feasibility of achieving the climate and energy EU objectives.

SUMMARY:

I. Results from MMM with eco-energy extension can enrich the discussion about the future of Polish energy system.
II. There is substantial difference between ODN and PEK simulation results, both in energy and emission dimension.
III. Introducing PEK scenario into the national energy policy can really change the dramatic situation in Polish energy system and could help the economy enter the low-emission track.