UNCERTAINTY ANALYSIS ON THE POTENTIALS OF RENEWABLE ENERGY SOURCES

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Problem definition

- According to most organizations like IEA or IIASA, oil companies like BP and reports from institutions like European Commission, the primary energy consumption (PEC) will continue to increase in the next years:

- 2016 PEC = 13,5 Gtoe

- In 2050, the PEC will reach around 17-25 Gtoe according to different scenarios.

Source: INDC Scenario, Global Energy and Climate Outlook 2017: How climate policies improve air quality
Problem definition

The global energy system is facing a historic moment of constant change:

- The fossil resources, according to several research, have already reached its peak or they are close to reach it.

Source: Capellán-Pérez (2017), D4.1 (D13) Global Model: MEDEAS-World Model and IOA implementation at global geographical level. MEDEAS H2020 project (http://www.medeas.eu/)
Problem definition

- The increasing international concern about the energy security and the climate change. (Paris Agreement in 2015)

**WHY SAFE CLIMATE TARGETS MATTER**

- Paris Actions Actual Warming Path: 3°
- Paris Upper Limit Goal: 2°
- Warming Already in the System - Paris Lower Limit Goal: 1.5°
- Additional Warming Over the Past 30 Years: 1°
- Holocene: Warming Range of Last 11,000 Years: 0.5°

Source: Breakthrough National Centre for Climate Restoration.
Problem definition

All of these reasons have implied every prospect to be established in the renewable production, but:

- Renewable energy sources (RES) covered in 2015 only 0.1336 of the total primary energy supply (TPES).
- The annual year growth of renewable sources vs TPES is growing less than 1% in the world.

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Finland</td>
<td>0.2393</td>
<td></td>
<td>0.392</td>
<td>0.3228</td>
<td>2.02%</td>
</tr>
<tr>
<td>Spain</td>
<td>0.0559</td>
<td></td>
<td>0.1551</td>
<td>0.1397</td>
<td>6.30%</td>
</tr>
<tr>
<td>World</td>
<td>0.1285</td>
<td></td>
<td>0.1312</td>
<td>0.1336</td>
<td>0.26%</td>
</tr>
<tr>
<td>European Union-28</td>
<td>0.0581</td>
<td></td>
<td>0.1296</td>
<td>0.133</td>
<td>5.68%</td>
</tr>
<tr>
<td>People’s Republic of China</td>
<td>0.1346</td>
<td></td>
<td>0.081</td>
<td>0.0844</td>
<td>-5.42%</td>
</tr>
<tr>
<td>United States</td>
<td>0.0449</td>
<td></td>
<td>0.0674</td>
<td>0.0672</td>
<td>2.72%</td>
</tr>
<tr>
<td>Japan</td>
<td>0.0307</td>
<td></td>
<td>0.0434</td>
<td>0.0532</td>
<td>3.73%</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>0.0292</td>
<td></td>
<td>0.0248</td>
<td>0.0245</td>
<td>-1.16%</td>
</tr>
</tbody>
</table>

Source: IEA (2018), "World Indicators", IEA World Energy Statistics and Balances (database)

- Also, there is a great uncertainty about the maximum potential that renewable energies sources could reach.
Problem definition

What is the potential of Renewable Energy Sources?

Several levels of renewable energy supply potentials can be identified: *(IPCC, 2010)*

- **Theoretical**
- **Geographical**
- **Technical**
- **Economic**
- **Sustainable**
The main aim of this study is to carry out an uncertainty analysis about the maximum potentials of RENEWABLE ENERGY SOURCES in a simulation model.
Methodology

4. Monte-Carlo simulation to obtain results
Data collection

• More than 200 studies have been analyzed in this review.

• As previously noted, there is a big uncertainty on the maximum potential that renewable energies sources could reach. The difference between authors lies in several orders of magnitude.

• In our study, we do not consider theoretical potentials. We focus in technical potentials.

• Hydropower, wind onshore and offshore, solar PV and CSP, oceanic and geothermal energy sources for electricity production are taking account.

• Some of RES potentials found in the literature are shown in the next slides.
Data collection

HYDRO

- The hydropower case is different of the other RES, the potentials reported in the literature are similar for different studies.
Data collection

**WIND ONSHORE**

Potential (EJ/year)

- Gross et al., 2003
- Gräßl et al., 2004
- Archer et al., 2005
- de Vries et al., 2007
- Zerfa et al., 2008
- Resch et al., 2008
- Honnery et al., 2008
- Lu et al., 2009
- Klimenko et al., 2009
- Cho et al., 2010
- Tomabechi et al., 2011
- Jacobson et al., 2011
- Miller et al., 2011
- Krewitt et al., 2012
- Zhou et al., 2012
- Silva Herrán et al., 2016
- EurekeT et al., 2017
- Bosch et al., 2017
- Dupont et al., 2017

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Data collection

WIND OFFSHORE

Potential (EJ/year)

SOLAR PV & CSP

Potential (EJ/year)

GEOTHERMAL

Potential (EJ/year)

OCEANIC

Potential (EJ/year)
Methodology (probability ranges)

- Due to the great uncertainty in the potentials, a method to classify them to its later use in simulation models has been suggested.
- For each RES, three different groups of potentials has been done (low, medium and high potentials) using logarithmic scale.

<table>
<thead>
<tr>
<th>EJ/Year</th>
<th>HYDRO</th>
<th>WIND ON</th>
<th>WIND OFF</th>
<th>SOLAR (PV &amp; CSP)</th>
<th>OCEANIC</th>
<th>GEOTHERMAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low potentials</td>
<td>24-38</td>
<td>30-133</td>
<td>8-43</td>
<td>60-210</td>
<td>1-3</td>
<td>10-25</td>
</tr>
<tr>
<td>Medium potential</td>
<td>38-58</td>
<td>133-596</td>
<td>43-230</td>
<td>210-738</td>
<td>3-10</td>
<td>25-60</td>
</tr>
<tr>
<td>High potentials</td>
<td>58-92</td>
<td>596-2660</td>
<td>230-1240</td>
<td>738-2592</td>
<td>10-30</td>
<td>60-150</td>
</tr>
</tbody>
</table>

- Each group of potentials is considered as a different case.
- Within each group, a probability range are given following a uniform distribution:
Methodology (model)

MEDEAS, based in system dynamics, is an energy-economy environment model structured in six modules with multiple feedbacks. (Capellán-Pérez, 2018)
Methodology (model)

• There are more than 4000 variables in MEDEAS model.

• Scarcity feedback is deactivated in MEDEAS model.

• GREEN GROWTH scenario is simulated in this study. “Strong orientation towards environmental protection and reducing inequality, based on solutions found through global cooperation, lifestyle change and technology”. (Capellán-Pérez, 2014)

• Some assumption in this scenario are:
  – Very rapid growth in renewable energy sources.
  – Electrification of energy system (particularly transport sector).
  – High technology development.
Preliminary results

ELECTRICITY GENERATION
RENEWABLE SOURCES

LOW POTENTIALS
(~50000-70000 TWh)

MEDIUM POTENTIALS
(~80000-90000 TWh)

HIGH POTENTIALS
(~115000 TWh)
Preliminary results

LOW POTENTIALS
(~0.2-0.5)

MEDIUM POTENTIALS
(~0.53-0.82)

HIGH POTENTIALS
(~0.84-0.94)
Preliminary results

SHARE RES vs TPES

LOW POTENTIALS
(~0.5-0.55)

MEDIUM POTENTIALS
(~0.6)

HIGH POTENTIALS
(~0.6)
Preliminary results

LAND REQUIREMENT
RENEWABLE ELECTRICITY

LOW POTENTIALS
(~120-200 MHa)

MEDIUM POTENTIALS
(~275-300 MHa)

HIGH POTENTIALS
(~375 MHa)

Current urban surface

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Conclusions

- There are many studies that evaluate the maximum potentials of RES. According to most of them the potential is unlikely to be a limiting factor for RES deployment. However, there are some studies that make a very detailed analysis and they conclude that the limits in RES are much smaller than in other studies.

- In high potentials range, the RES can cover the electricity demand in 2060. However, they require as land as currently urban surface, which could generate other problems like economics or a strong competition for land use. Also, due electricity covers a small part of total energy demand, the fossil fuel dependence will continue. A big change in our energy system will be necessary.

- The simulation of the low range of potentials, show that in 2060 the limit in RES have appeared. In these case, the renewable production cannot cover the electricity demand in 2060. Using this potentials, a 100% RES system only would be possible with a reduction of energy consumption.
Limitations and further work

• The study could be completed with the analysis of other renewable energy sources as the biomass, biofuels,… Also, solar thermal and geothermal direct use should be analyzed.

• The analysis could be improved with the identification of the variables that explain most of the uncertainty in the outputs (global sensitivity analysis).

• Other options of MEDEAS model could be selected and added to this study like use of other scenarios, activate scarcity feedback, evaluate other variable as CO$_2$ emissions,…
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THANK YOU

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Problem definition

- Primary energy consumption per capita is different among countries:
- In 2050, world population according UN scenarios will reach 9-10 billion people.

<table>
<thead>
<tr>
<th>PEC per capita in 2015 (toe/cap)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qatar</td>
</tr>
<tr>
<td>United States</td>
</tr>
<tr>
<td>Finland</td>
</tr>
<tr>
<td>Russian Federation</td>
</tr>
<tr>
<td>Japan</td>
</tr>
<tr>
<td>European Union-28</td>
</tr>
<tr>
<td>People's Republic of China</td>
</tr>
<tr>
<td>World</td>
</tr>
<tr>
<td>India</td>
</tr>
</tbody>
</table>

Source: IEA (2018), "World Indicators", IEA World Energy Statistics and Balances (database)

- If current levels of PEC per capita are maintained in 2050 near of 19 Gtoe of energy will be consumed in the world.
- If World consume as EU PEC per capita level, the PEC would reach near of 30 Gtoe in 2050.
Extra slides

PEC per capita year growth (2000-2015)

<table>
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<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Qatar</td>
<td>18.416</td>
<td>...</td>
<td>20.4364</td>
<td>26.3336</td>
<td>0.66%</td>
</tr>
<tr>
<td>United States</td>
<td>8.0501</td>
<td>...</td>
<td>6.9442</td>
<td>6.6021</td>
<td>-1.12%</td>
</tr>
<tr>
<td>Finland</td>
<td>6.2573</td>
<td>...</td>
<td>6.2434</td>
<td>5.9271</td>
<td>-0.36%</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>4.2243</td>
<td>...</td>
<td>5.0377</td>
<td>4.9254</td>
<td>1.03%</td>
</tr>
<tr>
<td>Japan</td>
<td>4.0835</td>
<td>...</td>
<td>3.4552</td>
<td>3.3846</td>
<td>-1.24%</td>
</tr>
<tr>
<td>Memo: European Union-28</td>
<td>3.4799</td>
<td>...</td>
<td>3.0336</td>
<td>2.113</td>
<td>-0.74%</td>
</tr>
<tr>
<td>People’s Republic of China</td>
<td>0.8948</td>
<td>...</td>
<td>2.1649</td>
<td>2.1683</td>
<td>6.08%</td>
</tr>
<tr>
<td>World</td>
<td>1.6415</td>
<td>...</td>
<td>1.8772</td>
<td>1.6609</td>
<td>0.84%</td>
</tr>
<tr>
<td>India</td>
<td>0.4185</td>
<td>...</td>
<td>0.6378</td>
<td>0.6492</td>
<td>2.97%</td>
</tr>
</tbody>
</table>


Change in primary energy demand, 2016-40 (Mtoe)