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Perspectives for low-carbon electricity production until 2030: Lessons learned from the comparison of local contexts in Poland and Portugal

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ABSTRACT

This paper compares perspectives for low-carbon electricity production in two EU member states – Poland and Portugal until 2030. Electricity production capacities, carbon emissions of electricity production, and production cost of electricity (COE) of Poland and Portugal are analyzed. The dilemmas of investments into low-carbon electricity production technologies relying on: (i) renewable energy sources (RES), (ii) nuclear fuel, and (iii) fossil fuels integrated with carbon capture and sequestration (CCS) are discussed. Roadmap 2050 recommends about 40% decarbonization of electricity generation by 2030 and 100% by 2050. Based on electricity production mix forecast for 2030, carbon emissions of electricity are estimated at 163 GgC TWh$^{-1}$ in Poland and at 93.2 GgC TWh$^{-1}$ in Portugal. Therefore, both compared countries must implement energy policies aimed at carbon emissions reduction through expanded utilization of RES (Poland – bioenergy, wind; Portugal – hydro, wind, solar), advanced CCS options (using local synergy opportunities), and optionally nuclear power (Poland).

KEYWORDS

CO$_2$; electricity; local context; Poland; Portugal

1. Introduction

In recent years electricity is becoming an increasingly important form of energy. The main challenge facing many countries today is how to produce more cheap electricity in order to satisfy the increasing demands and to reduce dependence on imports while, at the same time, reducing CO$_2$ emissions to the atmosphere. Although the Kyoto Protocol ceases to bind states by the end of 2012 and the future shape of the Post-Kyoto Protocol climate protection legislation is still unclear today, all developed economies well understand the need for carbon emissions reductions and are developing their own climate protection policies. In Europe, European Climate Foundation (ECF) has recently presented Roadmap 2050, a practical guide to a prosperous, low-carbon Europe. Roadmap 2050 emphasizes that full decarbonization of the power sector by 2050 is a prerequisite for the required overall 80% carbon reduction (ECF, 2011). According to ECF, 80% carbon reduction by 2050 means at least 40% carbon reduction by 2030 (ECF, 2011). Energy strategy studies clearly show that between 2030 and 2050 a major shift in electricity production toward sophisticated low-carbon generating technologies can be expected (McCollum et al., 2012). Therefore, energy policies enabling massive investments in renewables, nuclear fission, energy efficiency, and carbon capture and sequestration (CCS) (Lund and Mathiesen, 2012) must be urgently adopted.

The object of this study is the systematic comparison of perspectives for low-carbon electricity production in Poland and Portugal until 2030. This study seeks important and novel insights needed for policymakers in the two compared EU-27 countries. The study emphasizes that local contexts are
central for shaping national energy policy aimed at achieving a low-carbon electricity production structure under climate protection constraints. Furthermore, this study analyzes the capacity potentials of low-carbon-generating technologies, and provides carbon emissions forecasts and costs of electricity (COEs). Finally, it discusses the main dilemmas of investments in low-carbon electricity and formulate essential energy policy recommendations for Poland and Portugal consistent with decarbonization targets.

2. Comparison of power sectors

2.1. Similarities and differences

Polish and Portuguese economies exhibit numerous similarities. They: (i) have similar electricity consumption per GDP and per capita, (ii) are dependent on imported fossil fuels in power generation, while Portugal is also among the 10 largest electricity importers in the world (9 TWh in 2008 (IEA, 2010)), and (iii) have no nuclear power today.

Major differences between Poland and Portugal relate to: (i) the potentials for electricity production from renewable energy sources (RES) (larger in Portugal) (Gomes, 2008), (ii) fossil fuel reserves (large coal reserves in Poland and almost no coal in Portugal, possible reserves of shale gas in Poland), (iii) electricity production mix (95% of electricity is produced from coal in Poland while Portugal is one of the EU-27 leaders in the share of electricity produced from RES), and (iv) CO₂ intensity of electricity production (larger in Poland).

2.2. Electricity production capacity

Tables 1 and 2 compare the electricity production capacities from various electricity production technologies by 2010, their quantitative forecasts until 2030, and their maximal economical potentials by 2030 in Poland and Portugal. The capacities from low-carbon electricity production technologies are contrasted with those obtained from conventional fossil fuel-fired technologies.

Key observations from Table 1 are such that Polish 2030 projections assume that coal-firing will remain at the same dominating level (114.1 TWhₑ), while natural gas use will grow by 305% to 13.4 TWhₑ.
The large increase will relate to biogas-derived electricity (by 1,650%) (Budzianowski, 2011a, b), wind onshore (330%), wind offshore, and solid biomass (180%). Hydro will remain almost constant due to the limited capacity available in Poland. The forecasts also assume the deployment of 31.6 TWhₑ of nuclear electricity during the 2022–2030 period, but the deployment of this technology is still debated by policymakers. The largest economical potential for low-carbon electricity in Poland by 2030 is related to wind electricity (~124 TWhₑ), biomass (~60 TWhₑ), and coal/CCS electricity (large).

The Portugal electricity production sector is analyzed in Table 2. Portuguese 2030 projections assume a rapid increase of all existing in 2010 electricity production technologies except coal-firing. Natural gas electricity is projected to grow by 85%. Among the low-carbon technologies, large hydroelectricity will be the dominant one after the increase by 77%, followed by wind (235%). The large increase will relate to concentrated solar power (solar CSP), geothermal, ocean, solid biomass, and biogas-derived electricity, but their share in total electricity production will remain negligible in the 2030 Portuguese electricity production mix. Interestingly, Portugal projects no involvement in nuclear electricity until 2030. Moreover, large Portuguese potential for solar-derived electricity will not be exploited until 2030. Recalling that Portugal is a large importer of electricity (9 TWhₑ by 2008 (IEA, 2010)), the country could benefit from the increase in low-carbon electricity production capacity in terms of both energy supply safety and GDP growth. The largest economical potentials for low-carbon electricity production in Portugal by 2030 are related to wind electricity (~124 TWhₑ), biomass (~60 TWhₑ), and coal/CCS electricity (large).

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The evolution of electricity production technologies and their capacities are summarized in Figure 1.

**2.3. Carbon emissions from electricity production**

Poland’s carbon emissions from electricity production relate mainly to coal-firing (97% and 94% in 2010 and 2030, respectively). Portugal’s carbon emissions are more differentiated and relate to coal-firing (62% and 53% in 2010 and 2030, respectively) with relatively significant carbon emissions originating from oil and natural gas firing. **Table 3**.
These carbon emissions from electricity production can be suitably evaluated using carbon intensity of electricity (CIE). From Figure 2 it can be observed that coal-firing will remain a major contributor to carbon emissions, thus necessitating the importance of clean coal CCS technologies. CCS is expected to be globally deployed on a large scale during the 2030–2050 period. Clean coal CCS technologies are of particular interest for the Polish electricity production sector because coal-firing will generate 94% of the overall carbon emissions from electricity production in Poland by 2030. For Poland it is clear that the deployment of nuclear fission will have a rather minor impact on the decarbonization of the entire power sector. RES will develop much more slowly than in Portugal. Therefore, CIE will achieve in Poland by 2030 163 vs. 93.2 GgC TWh$^{-1}$ in Portugal, i.e. Poland’s CIE will be 75% greater. Additionally, the goals of Poland’s energy policy for 2030 seem very challenging if not unrealistic because of problems with RES development. This emphasizes that CCS and other advanced carbon management technologies (Budzianowski, 2012) will be necessary in Poland around 2030. With regard to Portugal’s CIE Figure 2 emphasizes that 20% reduction from 2010 to 2030 is too small and does not ensure full electricity decarbonization by 2050. Significantly,

![Figure 1. Electricity production mix of Poland and Portugal by 2010 and projection for 2030.](image)

### Table 3. Carbon emissions by 2010 and forecasts for 2030.

<table>
<thead>
<tr>
<th>Electricity production technology</th>
<th>Carbon emissions (Gg C)</th>
<th>2010</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Poland</td>
<td>Portugal</td>
</tr>
<tr>
<td>Coal</td>
<td>33,900</td>
<td>30,800</td>
<td></td>
</tr>
<tr>
<td>Oil</td>
<td>364</td>
<td>576</td>
<td></td>
</tr>
<tr>
<td>Natural gas</td>
<td>445</td>
<td>1,350</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>34,700</td>
<td>32,800</td>
<td></td>
</tr>
<tr>
<td>Portugal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>3,890</td>
<td>4,500</td>
<td></td>
</tr>
<tr>
<td>Oil</td>
<td>993</td>
<td>1,530</td>
<td></td>
</tr>
<tr>
<td>Natural gas</td>
<td>1,360</td>
<td>2,520</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>6,240</td>
<td>8,550</td>
<td></td>
</tr>
</tbody>
</table>
Portugal’s emissions from natural gas emphasize the importance of combined cycle gas turbine-CCS (CCGT-CCS) technologies. Besides, the expected RES development toward wind and solar can result in an unstable electrical system in Portugal, which will need stabilization, e.g. through the inclusion of fuel-based RES technologies such as biogas and solid biomass or fossil fuel-CCS.

2.4. Production COE

Production COE is a central factor for investments in electricity production technologies. Table 4 provides quantitative forecasts for COEs from different electricity production technologies by 2020. Table 4 displays a range of projected COEs for all EU-27 countries while referent values are provided for the two studied countries. From Table 4 it can be observed that for EU-27 the lowest 2020 COE characterizes large-scale hydro, biogas, nuclear fission, and onshore wind electricity with 2020 COE ranging from 50 to €70 MWh\(^{-1}\).
For Poland the lowest COEs will relate to large hydro, wind, and biogas while for Portugal to large hydro and wind. Also nuclear and partly CCS technologies might fall within the acceptable range of COEs being of interest for Poland and Portugal.

According to ECF carbon sequestration costs by conventional CCS can be estimated at: abatement - €30–45 per tCO₂ abated, transport and storage - €10–15 per tCO₂ transported and stored (ECF, 2011). This totals to €40–60 per tCO₂ avoided. Assuming average CO₂ intensity of electricity of 0.8 tCO₂ MWh⁻¹ it translates to €32–48 MWh⁻¹. Interestingly, by implementing value-added carbon management technologies (Budzianowski, 2012) overall costs of carbon avoidance can be further reduced. These value-added technologies make use of existing synergies between technologies, but their capacity is dependent on local contexts. For Poland reasonable examples of value-added carbon management technologies include carbon-based energy vectors such as carbon-negative biofuels and carbon capture and recycling-derived fuels (Budzianowski, 2012). For Portugal, value-added carbon management might relate to technological options such as CO₂-enhanced oil and gas recovery in North Africa and solar CO₂-to-fuel.

3. Key recommendations for national energy policies

The presented analyses show that local contexts of electricity production are major factors impacting national energy policies in Poland and Portugal. The impact of the Post-Kyoto Protocol climate protection regulation will become a major external factor shaping the national energy policy of Poland (to less extent of Portugal) because Poland has a more CO₂-intensive electricity production system than Portugal. Due to differences in local contexts between Poland and Portugal, the national energy policy must differ. Based on the analyses in this study, essentially the following recommendations were found for Polish and Portugal national energy policies:

**RES technologies**

- Support RES technologies having the most significant capacity potentials at acceptable COEs. Poland’s RES promotion system based on tradable certificates needs to be urgently amended to become technology specific, to promote distributed power systems with small-scale electricity generation sources, and to encourage a shift toward the best available technologies. Poland must focus on bioenergy and wind energy. Portugal must focus on wind (offshore), hydro, and possibly on solar electricity, which might offer new large capacities in the near term.

- Consider the need for deployment targets beyond 2020 for key RES technologies such as offshore wind and solar PV. Prioritize RES development in R&D and early deployment financial supporting programs.

<table>
<thead>
<tr>
<th>Low-carbon electricity production technology</th>
<th>COE by 2020 (€ MWh⁻¹)</th>
<th>range EU-27</th>
<th>referent value EU-27</th>
<th>referent value Poland</th>
<th>referent value Portugal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro: large</td>
<td>30–140</td>
<td>50</td>
<td>70</td>
<td>60</td>
<td>85</td>
</tr>
<tr>
<td>Biogas</td>
<td>50–200</td>
<td>60</td>
<td>75</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>Nuclear fission</td>
<td>45–80</td>
<td>65</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Wind: onshore</td>
<td>55–90</td>
<td>70</td>
<td>80</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>Hydro: small</td>
<td>55–160</td>
<td>70</td>
<td>110</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Wind: offshore</td>
<td>65–120</td>
<td>75</td>
<td>90</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>Coal: IGCC-CCS</td>
<td>80–90</td>
<td>85</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Coal: PC-CCS</td>
<td>80–110</td>
<td>90</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Natural gas: CCGT-CCS</td>
<td>85–95</td>
<td>90</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Solid biomass</td>
<td>80–200</td>
<td>95</td>
<td>100</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>Solar: CSP</td>
<td>20–170</td>
<td>145</td>
<td>n/a</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>Solar: PV</td>
<td>270–460</td>
<td>320</td>
<td>400</td>
<td>270</td>
<td>270</td>
</tr>
</tbody>
</table>

Note: 2020 referent values for Poland and Portugal were estimated by the authors based on local contexts. n/a – source not available yet.
• Ensure smart grids development, which can accommodate a greater share of RES in distributed generation. Simultaneously support fuel-based RES (biogas and solid biomass) as energy storage technologies, which can stabilize RES-rich power systems.

CCS technologies

• Adopt a consistent decarbonization strategy with particular focus on synergies obtained through value-added CO$_2$ sequestration, e.g. CO$_2$ recycling and other negative emission technologies.

Poland – Promote carbon-negative bioenergy technologies and CO$_2$ recycling technologies (Budzianowski, 2012).

Portugal – Invest in global CCS solutions such as CO$_2$ recycling technologies and CO$_2$ transmission pipelines with focus on the North Africa region. Explore the provision of CCS services for neighboring countries.

Nuclear technologies

Poland – Nuclear power station must be in operation during 40–60 years and, thus, the plants build by 2030 must operate until 2070–2090, which implies risks of shortages in uranium supply.

Portugal – Enrichment of existing domestic uranium reserves offers a reserve for future nuclear electricity.

Other recommendations

• The switch from carbon-intensive to low-carbon electricity generation needs the commercialization of a variety of emerging low-carbon generation options. They will thus need financial incentives and regulatory frameworks that could ensure timely disinvestment and retirement of carbon-intensive assets and investment in sufficient replacement of low-carbon assets. Financial incentives must be stable in the long term, thus minimizing risks for investors.

Conclusions

During the period 2010–2030 Poland and Portugal will be interested in increasing domestic electricity production capacities in order to meet sharply rising electricity demands, decreasing the dependence on imported fossil fuels and ensuring energy supply safety. The Post-Kyoto Protocol climate protection legislation will be the central external factor shaping national energy decarbonization policies. According to Roadmap 2050, electricity production will require 100% decarbonization by 2050 and about 40% by 2030, hence emphasizing the importance of relevant energy policy solutions. Therefore, both compared countries must implement energy policies aimed at carbon emissions reduction through expanded utilization of RES (Poland – bioenergy, wind; Portugal – hydro, wind, solar), advanced CCS (using local synergy opportunities), and optionally nuclear power (Poland).

The paper suggested how to select the future generation technologies to meet the target of low-carbon electricity production. It was shown that local contexts impacted national energy policies. Portugal had greater local potential for RES electricity from hydro, wind, and solar, while Poland from wind and biomass; thus these RES technologies must be promoted in each country. The financial incentives for renewable electricity must be more attractive in Poland than in Portugal because of the limited renewable resource in Poland. Fuel-based bioelectricity was capable of stabilizing RES-rich power systems and thus it needed additional support.

Policymakers must take into account the fact that involvement into nuclear fission technology implied risks such as possible shortages of uranium, technologically unresolved environmental impacts of nuclear wastes, the problem with public acceptance, and relatively high investment costs.

CCS technologies might be indispensable under future stringent climate protection policy and could be treated as a technological bridge between 2030 and 2050. Carbon emissions of electricity were estimated for 2030 at 163 GgC TWh$_e^{-1}$ in Poland and at 93.2 GgC TWh$_e^{-1}$ in Portugal.
Therefore, CCS was found of particular interest for Poland while Portugal might be involved in the transmission of CO₂ and in developing RES-driven CO₂ recycling technologies on its territory or in North Africa as a service for some other European countries. CCS must be designed with particular focus on locally available synergies obtained through the use of value-added CO₂ sequestration and negative emission technologies.

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