Roadmap 2050: A practical guide to a prosperous, low-carbon Europe

A project of the European Climate Foundation

Presentation to the U.S. Department of Energy
Electricity Advisory Committee
Michael Hogan, Senior Advisor, RAP
12 July 2011
The objective was to develop a fact based report - supported by key stakeholders and feeding directly into EU decision making.

<table>
<thead>
<tr>
<th>Key deliverables</th>
<th>Overarching objective</th>
<th>Political agenda</th>
</tr>
</thead>
</table>
| ▪ A set of plausible and visionary emissions pathways with an 80% reduction across the EU-27 below 1990 levels by 2050  
▪ Deep dive on the decarbonization of the power sector  
▪ Implications on strategic options for the EU  
▪ A related set of policy options highlighting potential decisions for the next 5 years | Develop a fact based report to support the European Commission and Member State policy-makers to chart an energy strategy for 2010-2014 consistent with the EU’s 2050 climate and energy security commitments | Post-Copenhagen political agenda for the new European Commission  
▪ November 2010  
  ▪ Commission to present European Infrastructure Package  
▪ 2011  
  ▪ Commission to present Communication on 2050 Energy Strategy  
  ▪ Commission to present Energy Action Plan 2011-2014 |
Roadmap 2050 project team

ROADMAP 2050 PARTNERS

- ECF (Philanthropic European Climate Foundation)
  - Overall sponsor and funder

- McKinsey & Company (Strategic Consultancy)
  - Overall content analysis, project management, data collection
  - Reach out to industries, workshop facilitation

- EEMA (Technical Unit Consultancy)
  - Grid design and investments, production capacity and costs associated with providing a plausible, secure electricity system for each of the pathways

- Imperial College London
  - In-depth modelling of system balancing requirements, reliability, optimization of transmission and back-up investment

- Oxford Economics (Macro-Economic Consultancy)
  - Provide analysis of macro-economic impacts of decarbonization scenarios

- E3G
  - Coauthor of policy volume 2
  - Policy insights based on the analytics

- ECN (Energy Research Center of the Netherlands)
  - Support on assumptions for technologies
  - Policy development and recommendations based on analytics

- Office for Metropolitan Architecture
  - Provide creative participation in the development of narrative, provide conceptual framing and visual communication
  - Spatial planning and visualization of the grid

Energy solutions
for a changing world
Key stakeholders are involved by providing input and reviewing results

Core Working Group participants

- Utilities
  - CEZ Group
  - edp
  - RWE
  - Enel
  - e.on
  - Iberdrola
  - Vattenfall
  - ENERGINET/DK
  - nationalgrid
  - TenneT
  - Terna
  - ENTSO-E
  - Acciona
  - Siemens
  - Vestas

- Transmission System Operators

- Manufacturers
  - Siemens

- NGOs
  - E3G
  - GERMANWATCH
  - WWF

Further outreach

- Plus 40 more companies, NGOs and research institutes

- NIO
  - First Solar
  - DESERTES
  - SCHOTT solar
  - Q celleS
80% by 2050 only possible with zero-carbon power supply
Pathways must be reliable, technically feasible, have a positive impact on the economy... & be nearly zero carbon.
Efficiency flattens demand growth, ‘fuel shift’ drives it back up to the same level as ‘BaU’, but far less energy intensive.

EU-27 power demand, TWh per year

- **Electricity demand 2005**: 3,275
- **Extrapolated power demand 2050**: 4,500
- **Buildings**: 870
- **Industry**: 420
- **Power generation before fuel shift**: 3,210
- **EVs in transport**: 740
- **Buildings**: 500
- **Industry**: 200
- **Net power demand 2050**: ~4650

1. Assumption: electrification of 100% LDVs and MDVs (partially plug-in hybrids); HDVs remain emitting ~10% while switching largely to biofuel or hydrogen fuel cells.
2. Assumption: 90% of remaining primary energy demand converted to electricity usage in buildings for heating/cooling from heat pumps; assumed to be 4 times as efficient as primary fuel usage.
3. Assumption: 10% fuel switch of remaining combustion primary energy demand converted to electricity in industry for heating from heat pumps; assumed to be 2.5 times as efficient as primary fuel usage.
The decarbonized pathways assume a mix of electric vehicles, biofuels and fuel cell vehicles

Billions of Km driven\(^1\) by type of energy sources

1 Kilometers for heavy trucks normalized for a factor 4 higher fuel consumption per km
The objective was to develop a fact based report - supported by key stakeholders and feeding directly into EU decision making.

### Decarbonization Pathways

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>40% RES(^1)</td>
<td>30% Nuclear, 30% CCS</td>
</tr>
<tr>
<td>60% RES</td>
<td>20% Nuclear, 20% CCS</td>
</tr>
<tr>
<td>80% RES</td>
<td>10% Nuclear, 10% CCS</td>
</tr>
</tbody>
</table>

- RES share close to currently legally committed by the EU and the IEA baseline
- Sensitivities on a high nuclear share and a high thermal / CCS share are included
- RES mix based on current deployment (minimum), aim for a broad mix of technologies and theoretical deployment (maximum)
- Equal shares for nuclear and thermal / CCS

**Additional sensitivities**
- Fuel prices (coal, gas, uranium)
- Cost of capital
- Learning rates
- Grid solutions
- Electricity demand
- 100% RES supply

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\(^1\) Renewable energy sources
<table>
<thead>
<tr>
<th>Technology</th>
<th>80% RES 10% CCS 10% nuclear</th>
<th>60% RES 20% CCS 20% nuclear</th>
<th>40% RES 30% CCS 30% nuclear</th>
<th>(Baseline) 34% RES 49% coal/gas 17% nuclear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>Gas CCS retrofit 1</td>
<td>3</td>
<td>7</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Gas CCS</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>28</td>
</tr>
<tr>
<td>Gas CCS retrofit</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nuclear</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>Wind On-shore</td>
<td>10</td>
<td>20</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Wind Off-shore</td>
<td>15</td>
<td>11</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Solar PV</td>
<td>19</td>
<td>12</td>
<td>12</td>
<td>21</td>
</tr>
<tr>
<td>Solar CSP</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Solar Biomass</td>
<td>12</td>
<td>8</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Solar Geothermal</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Solar Large Hydro</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

1 Only on "CCS ready" plants
2 5% from Europe and 15% from North Africa
All pathways can deliver power with roughly the same cost and reliability as the baseline with carbon price ≤ €50/tCO₂

1 Weighted average based on the CoE in each 10-year time frame (2010, 2020, 2030, 2040, 2050)
2 Generation only
3 Cost related to non-optimal plant use, system dispatch cost for secure operation, running backup plants, storage losses, reserve and response cost
4 Transmission and additional generation capex as well as fixed opex for transmission and backup
Confidence ranges for assumptions: likely outcomes are within 10-15% of each other across all pathways

Likely ranges over time in the cost of electricity of new builds$^1$ EUR/MWh (real terms)

Baseline and average of decarbonized pathways

Baseline and 60% RES pathway

Baseline and 40% RES pathway

Baseline and 80% RES pathway

NOTE This is excluding a price for CO2. A price of ~€50 per tCO2e would be equivalent to the range shown in the baseline

$^1$ Based on a WACC of 7% (real after tax), computed by technology and weighted across technologies based on their production; including grid
The cost of the decarbonized pathways and the baseline are likely to differ less than €250 per year per household

Cost impact of the decarbonized power pathways per year per household

- Coal $109/t
- Gas $14.8/mmBtu
- Oil $115/bbl
- CO2 price €20/tCO2e

Superimposing 25% lower fuel prices, 50% lower learning rates plus €500 billion cost of change would cost €300/yr

1 Assuming all power costs get passed through to households
2 CO2 price assumed of €40/tCO2e
3 IEA WEO 2009 ‘450 Scenario’ assumptions for 2030, kept constant up to 2050
4 No carbon price
5 For all technologies, learning rate defined as capex improvement per doubling of cumulative installed capacity
Most of the non-hydro capacity will be retired by 2040.

Production from new power plants that need to be built in order to meet 2020 demand.

1 Existing RES mainly hydro; remains in operation until 2050.
Power generation technologies that are at least in late stage development are included

<table>
<thead>
<tr>
<th>Type of generation</th>
<th>Generation technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-intermittent RES</td>
<td>Large hydro, Geothermal, Biomass dedicated, Solar CSP with storage</td>
</tr>
<tr>
<td>Intermittent Fossil</td>
<td>Wind onshore, Wind offshore, Solar PV, Hydro run of river</td>
</tr>
<tr>
<td>Fossil</td>
<td>Coal conventional, Coal CCS, Coal CCS retrofit, Gas conventional, Gas CCS, Gas CCS retrofit, Oil</td>
</tr>
<tr>
<td>Nuclear</td>
<td>Nuclear III</td>
</tr>
</tbody>
</table>

Regional clustering of EU-27 countries (including Switzerland and Norway)

- **Nordic**
  - Denmark
  - Finland
  - Sweden
  - (Norway)
- **Poland and Baltic**
  - Estonia
  - Latvia
  - Lithuania
  - Poland
- **Benelux and Germany**
  - Belgium
  - Germany
  - Luxembourg
  - Netherlands
- **UK and Ireland**
  - UK
  - Ireland
- **France**
  - France
- **Iberia**
  - Portugal
  - Spain
- **Central Europe**
  - Austria
  - Czech Republic
  - Slovakia
  - Slovenia
  - (Switzerland)
- **South East Europe**
  - Bulgaria
  - Cyprus
  - Greece
  - Hungary
  - Romania
- **Italy & Malta**
  - Italy
  - Malta

Energy solutions for a changing world
New inter-regional transfer capacity required (60% RES)
Increased interconnectivity across regions exploits natural counter-cyclicality of primary European RE resources

Overview of yearly energy balance, 60% RES pathway, TWh per week

Higher wind in winter
Higher solar in summer
Overall system peak demand in winter

1 Storage included in the model relates to the existing hydro storage available across the regions
Increased transmission cancels out both daily and seasonal fluctuations

Example: Regional demand variation from average per hour during one day

Regional demand variation from average over the year

NOTE Excluding additional seasonality demand from heat pumps and extreme weather cases
Reserve sharing between regions reduces total reserve requirements by ~40%  

Maximal reserve requirement\(^1\), GW  

<table>
<thead>
<tr>
<th>Region</th>
<th>Baseline</th>
<th>80% RES</th>
<th>60% RES</th>
<th>40% RES</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK &amp; Ireland</td>
<td>8</td>
<td>42</td>
<td>28</td>
<td>15</td>
</tr>
<tr>
<td>France</td>
<td>2</td>
<td>31</td>
<td>21</td>
<td>9</td>
</tr>
<tr>
<td>Iberia</td>
<td>7</td>
<td>40</td>
<td>27</td>
<td>10</td>
</tr>
<tr>
<td>Nordic</td>
<td>3</td>
<td>20</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Benelux &amp; Germany</td>
<td>13</td>
<td>44</td>
<td>28</td>
<td>10</td>
</tr>
<tr>
<td>Central-Europe</td>
<td>2</td>
<td>29</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>Poland &amp; Baltic</td>
<td>2</td>
<td>18</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>South East Europe</td>
<td>2</td>
<td>18</td>
<td>12</td>
<td>4</td>
</tr>
<tr>
<td>Italy &amp; Malta</td>
<td>2</td>
<td>40</td>
<td>27</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total EU27</strong></td>
<td>42</td>
<td>281</td>
<td>191</td>
<td>80</td>
</tr>
<tr>
<td><strong>Benefit of reserve sharing</strong></td>
<td>20</td>
<td>98</td>
<td>66</td>
<td>32</td>
</tr>
<tr>
<td><strong>Total with reserve sharing between regions</strong></td>
<td>22</td>
<td>183</td>
<td>125</td>
<td>48</td>
</tr>
</tbody>
</table>

-47%  

-35%  

-35%  

-40%  

1 Reserve refers to reserve required at four hour ahead of real-time. This is required to manage the larger changes in generation (due to plant outages and expected uncertainty in intermittent output) expected over that four hour period that could require starting additional (or switching off) generation.
Increased demand flexibility through ‘smart’ grid investments is a cost-effective alternative to curtailing low-carbon sources.

- DR also reduces the need for additional OCGT plants.
- The graph shows how the original demand line (purple) is shifted to earlier during the day (red line) when more power is available to match supply.
Demand flexibility reduces grid and related investments, minimizes low-carbon resource curtailment, minimizes cost

2050, GW

<table>
<thead>
<tr>
<th>Pathways</th>
<th>DSM</th>
<th>Transmission</th>
<th>Back-up and balancing</th>
<th>RES curtailment² %</th>
</tr>
</thead>
<tbody>
<tr>
<td>80% RES, 10% CCS, 10% nuclear</td>
<td>0%</td>
<td>166</td>
<td>255</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>127</td>
<td>160</td>
<td>2</td>
</tr>
<tr>
<td>60% RES, 20% CCS, 20% nuclear</td>
<td>0%</td>
<td>103</td>
<td>205</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>87</td>
<td>140</td>
<td>1</td>
</tr>
<tr>
<td>40% RES, 30% CCS, 30% nuclear</td>
<td>0%</td>
<td>56</td>
<td>150</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>55</td>
<td>110</td>
<td>2</td>
</tr>
</tbody>
</table>
More balance between wind & solar investment as PV technology matures

Number plants built per decade

Wind turbines¹

<table>
<thead>
<tr>
<th>Decade</th>
<th>Wind onshore</th>
<th>Wind offshore</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990-2000</td>
<td>25,000</td>
<td></td>
</tr>
<tr>
<td>2000-2010</td>
<td>40,000</td>
<td></td>
</tr>
<tr>
<td>2010-2020</td>
<td>37,000</td>
<td>6,000</td>
</tr>
<tr>
<td>2020-2030</td>
<td>31,000</td>
<td>9,000</td>
</tr>
<tr>
<td>2030-2040</td>
<td>28,000</td>
<td>4,000</td>
</tr>
<tr>
<td>2040-2050</td>
<td>23,000</td>
<td>4,000</td>
</tr>
</tbody>
</table>

Solar²

<table>
<thead>
<tr>
<th>Decade</th>
<th>Actual</th>
<th>60% RES pathway</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990-2000</td>
<td>0</td>
<td>1,000</td>
</tr>
<tr>
<td>2000-2010</td>
<td>1,000</td>
<td></td>
</tr>
<tr>
<td>2010-2020</td>
<td>3,300</td>
<td></td>
</tr>
<tr>
<td>2020-2030</td>
<td>8,100</td>
<td></td>
</tr>
<tr>
<td>2030-2040</td>
<td>10,000</td>
<td></td>
</tr>
<tr>
<td>2040-2050</td>
<td>10,000</td>
<td></td>
</tr>
</tbody>
</table>

¹ 1990 to 2010 actual data taken from BTM Consult ApS; average size of new wind turbines for wind onshore: 2.5 MW until 2020 and 3.0 MW thereafter; for wind offshore: 5.0 MW until 2020, 7 MW 2020 to 2030 and 10 MW thereafter

² Average size of 20 MW per plant; buildup of 500 plants between 2005 and 2010 which leads to 1,000 plants for 2000 to 2010

3 In line with assumption of maximum annual growth per technology of 20%

However, the new wind turbines are much larger and partly off shore
A doubling of capex would be required over the next 15 years

Annual capex development per pathway, € billions per year

| GENERATION ONLY |
Annual capital compared to total EU capital investment
Despite slightly higher initial unit costs for power, impact on overall economic performance is neutral to positive.
Energy cost decreases in the baseline, but even more so in the decarbonized pathways

Lower energy cost in the decarbonized pathways due to improved productivity and less GHG emissions which reduce the impact of the carbon price

NOTE: Energy prices are a weighted average of prices faced by consumers weighted by the shares of consumption of different fuels
In the “high RES” pathways, European imports of coal and gas decline from 35% of final consumption to 7%

Availabilities 2050: biomass: 90% EU-27, 10% Non-OECD; nuclear: 2% EU-27, 43% OECD, 55% Non-OECD; coal: 50% EU-27; 10% OECD, 40% Non-OECD; gas: 16% EU-27, 0% OECD, 84% Non-OECD
Key emerging challenges for the EU

- Step change in energy efficiency
- Technology commercialisation
- Creating strategic EU power network (wide-area integration + demand-side activation)
- The future of ETS, complementary measures and market reform
What real energy security looks like...
About RAP

The Regulatory Assistance Project (RAP) is a global, non-profit team of experts that focuses on the long-term economic and environmental sustainability of the power and natural gas sectors. RAP has deep expertise in regulatory and market policies that:

- Promote economic efficiency
- Protect the environment
- Ensure system reliability
- Allocate system benefits fairly among all consumers

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