Annex 1

ECF's Roadmap 2050 project: Overview and key findings in ECF's *Roadmap 2050* & *Power Perspectives 2030* reports

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This annex gives a short overview on ECF's Roadmap 2050 project, and provides more details on the methodology and key findings of the ECF reports *Roadmap 2050* and *Power Perspectives 2030*. These technical reports form the analytical basis for the deliberations in the *From Roadmaps to Reality* report.

The mission of Roadmap 2050 project is to provide a practical, independent and objective analysis of pathways to achieve a low-carbon economy in Europe, in line with the energy security, environmental and economic goals of the European Union.

Over the years, ECF has involved a wide range of companies, consultancy firms, research centres and NGOs to provide various forms of assistance during the different phases of ECF's Roadmap 2050 project. Their willingness to consult and to be consulted in the course of the years has ensured the credibility, objectivity and quality of the different outputs throughout the project.

The Roadmap 2050 project is an initiative of the European Climate Foundation (ECF). The content of the studies are the exclusive responsibility of ECF.

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

- *Background information*

The *Roadmap 2050 - A practical guide to a prosperous, low-carbon Europe* study was published in April 2010. It provides a technical and economic assessment of a series of decarbonisation pathways for achieving a pre-defined decarbonisation goal in 2050 in line with the energy security, environmental and economic goals of the EU. The study investigates the technical and economic feasibility of achieving an 80% reduction in GHG emissions (compared to 1990) by 2050 under the constraint that today's levels of electricity supply reliability, energy security, and economic growth are maintained or improved.

- *Modeling Approach*

The study applies a back-casting approach by stipulating an end-state of the energy system in 2050 (80% GHG reduction compared to 1990 levels and the energy system delivering at least as much as today, no dependency on international carbon offsets). It then derives plausible pathways on how to achieve this goal. These pathways comprise different shares of a range of low to zero carbon supply technologies, which are already commercially available, or in a late stage of development. The pathways have been defined based on these assumptions: 1) at least 95% power sector decarbonisation in 2050 (compared to 1990), 2) provision of electricity supply reliability, and 3) to be credible and plausible, not necessarily optimised.

Baseline assumptions are based on data from the International Energy Agency (WEO 2009, 2030 data extrapolated to 2050), CGE model provided by Oxford Economics 2007, and PRIMES (shares of energy and power demand, and supply by region). The transmission system is modeled by a power system analysis framework developed by the Imperial College London and KEMA to minimise total system costs while maintaining system reliability and respecting operating constraints.

- *Scenarios and key assumptions*

The study considers three decarbonisation scenarios which all have different mixes of electricity generating sources to achieve a low-carbon energy system in 2050, against a baseline Business-As-Usual. The share of RES in 2050 in the three scenarios is 40%, 60% and 80% respectively, with the remaining percentage equally split between CCS and nuclear. Generation technologies include hydro, coal and gas plants with CCS, solar PV and CSP, wind turbines on- and offshore, biomass plants and geothermal plants.

The baseline scenario assumes overall **GDP** to grow from 10 to 22 EUR trillion. **Energy demand** is projected to grow by 10% (delinking it from the GDP growth); power demand increases by 40% over 45 years with efficiency improvements of about 1-1,5% year-on-year, reaching a level of 4,800 - 4,900TWh in 2050; **GHG emissions**, which have decreased by about 10% since 1990 until 2010, are assumed to stay flat until 2050, with significant emission intensity improvements. The 2050 power demand (4800-4900TWh) is similar in both the baseline and the decarbonisation pathways. This is due to the fact that the additional energy efficiency assumed in the decarbonisation pathways offsets higher power demand from fuel shifts to power[1]. In terms of **technologies, a learning rate** of 12% is assumed for every doubling of installed CCS capacity through 2050, which is expected to bring CCS abatement costs down to 30-45$ per tCO_2. For nuclear, cost reduction of less than 10% over 40 years is assumed. **Fossil fuel price** projections are based on the IEA WEO 2009 and are as follows for 2030: oil/barrel is $115, coal/ton $109, gas/Mmbtu – $14, and uranium/MWh $8. This study assumes that fossil fuel prices remain flat beyond 2030. In the baseline modeling, the CO_2 price increases to $43 per tCO_2e in 2015 and $54 in 2030.

All of the decarbonisation scenarios are **technologically agnostic**, use multiple technologies and reflect a wide range of technologically and economically plausible inputs. The costs of fuel are assumed to be same in the decarbonised pathways as in the baseline. In the decarbonized pathways, a global carbon market is assumed from 2020 onwards, assuming $50 per tCO_2e in 2020 and $110 beyond 2030 for the EU and OECD. For other major economies (which includes China, Russia, Brazil, South Africa and the Middle East) the CO_2price is assumed to be $65/t beyond 2030. The rest of the world (ROW) power sector decarbonises less than Europe and builds 30% renewables by 2030.

- *Key findings*

The *Roadmap 2050* report demonstrates that by 2050, Europe could achieve an economy-wide reduction of GHG emissions of at least 80% compared to 1990 levels. This level of reduction is only possible with a zero-carbon power supply (power sector which emits not more than 5% or less of baseline GHG emissions level), which can be realized by deploying technologies that are already commercially available. Assuming industry consensus learning rates for these technologies, marked demand for low-carbon investment, IEA projections on fossil fuel prices and significant expansion of grid interconnection between and across regions in Europe and an average carbon prices of at least 20-30EUR per tCO_2e over 40 years, the cost of electricity and overall economic growth would be comparable to the baseline over the period 2010-2050.

The report demonstrates that the **levelised cost of electricity (LCoE)** is roughly the same in the three decarbonisation pathways. The weighted average on the three pathways is 10-15% higher that the LCoE for the baseline over a period of 40 years, prior to applying any price of carbon emission. After application, such a price (20-30EUR) would bring the baseline and the three decarbonisation pathways roughly into equivalence with each other. The LCoE deceases by the end of the period reflecting cost reductions due to technology learning and reducing use of fuel. The full costs of energy for the end-to-end energy system is lower in the decarbonisation pathways due to energy efficiency improvements, and the use of less oil, a relatively costly primary energy course.

Potential positive impact on **GDP** of 0,5 to 1% increase is possible due to technology developments but the overall effect on GDP growth is assessed to be negligible[2].
Compared to baseline, **capital costs** will increase significantly over the next 40 years and

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[1] Power demand will go down due to higher efficiency and up due to additional demand from transport and building heating.

[2] Indirectly GDP growth can be expected from increased productivity of the economy as a whole in the longer term due to lower cost of energy per unit of GDP, plus reduced impact of high carbon prices in the decarbonised pathways. Also shall Europe builds and maintains a strong global position in clean tech, European exports of clean tech will add as much as 250EUR billion to the GDP just in the period of 2010-2020.

operational costs will come down. The capital costs for the power sector are about 70% higher than in the baseline, with an additional €25 billion per year of investment on average over the 2010- 2050 period compared to the baseline. The study shows that operational costs are highest in the baseline and lowest in the 80% RES pathway. The new effect is a reduction in full cost to society of 80EUR billion per year in 2020, rising to 350EUR billion per year in 2050 or 1500EUR per year per household, henceforth the cost of the decarbonised pathways and the baseline are likely to differ less than 250EUR per year per household.

Using the time available will be of essence. Implementation of new policies and regulations, orderly construction of new plants, and a smooth build up of the new technology supply chains requires the full period of about forty years. In the decarbonisation pathways the capital spent in the power sector goes up from about 30EUR billion in 2010 to about 65EUR billion a year in 2025. When delayed by ten years, the required annual capital spent goes up to 90EUR billion in 2035. The transformation requires closer transnational cooperation in transmission infrastructure, resource planning, energy market regulation, and systems operation.

An important result appearing in all of the decarbonisation pathways is that installed **generation capacity** is larger with increasing wind and solar PV penetration due to their variable output (for the 60% RES pathway the increase is threefold); transmission capacity and backup generation requirements are significant in all decarbonisation pathways (50 to 170GW). The impact of **demand response** can reduce transmission investment costs and backup generation requirements by 20 to 30% in the higher RES pathways. Reserve sharing across EU-27 reduces **total reserve requirements** by almost 40%. The decarbonisation pathways will reduce direct emissions from the power sector by 35 to 40% in 2020, compared to 20% in the baseline.

- *Conclusions*

Priority areas of action for the next 5-10 years are stated as energy efficiency, low carbon technology, grids and integrated market operation, fuel shift in transport and buildings, markets (investments in low carbon technologies). Increasing interconnections between power systems, optimising the use of resources amongst Member States, and improving demand response through smart grid applications also emerge as key prerequisites for successful decarbonisation.

Particular attention should be paid to implementation. The magnitude of change required in the sectors affected is substantial in all of the decarbonisation pathways tested. Also, funding requirements shift substantially. Within the power sector, about € 30-50 billion per year of additional funds are required for more capital-intensive generation capacity and grid investments. Capital for oil, gas and coal supply in Europe may come down by 30%. Funding is required for new investments in energy efficiency measures, heat pumps and alternative drive trains, which may add up to over € 2-3 trillion over 40 years.

Delivery risks exist for most technologies. Nuclear and to some extent CCS carry public acceptance risks. Onshore wind also faces local public acceptance issues, while offshore environments make the construction and maintenance of offshore wind installations challenging. For biomass, the development of a reliable logistics infrastructure is challenging, as is avoiding competition with food and water and negative effects on biodiversity.

Arguably the toughest challenge of all is to obtain broad, active public support for the transformation, across countries, sectors and political parties. Transnational cooperation is required for regulation, funding, R&D, infrastructure investments and operation.

II. **European Climate Foundation Power Perspectives 2030: on the road to a decarbonised power sector**

- *Background information*

Power Perspectives 2030 builds on the *Roadmap 2050* report, and provides an analysis of the next steps required in the development of the European power sector towards 2030 in order to remain on track to full decarbonisation by 2050. Based on extensive analysis conducted by the ECF, McKinsey, KEMA, Imperial College London, RAP and E3G.

The ambition with *Power Perspectives 2030* is to analyse what it will take to decarbonise the power sector and what needs to happen in the coming 20 years based on today's knowledge of the options and choices to be made.

- *Modeling approach*

Power Perspectives 2030 is a projection analysis built around the core *On Track* case, which up to 2020 is based on the full implementation of the existing plans for the power sector. The analysis models several sensitivity scenarios that alter key parameters of the power system and compares these against the *On Track* case. All scenarios are based on generation mixes consisting of technologies that are already commercially available today or in late development stage, and each country is expected to be self-sufficient in the 2020 and 2030 timeframe.

Power demand is an input based on the Reference scenario in PRIMES report *EU energy trends to 2030* (2009, assuming the 20% energy saving target is met), and adjusted upwards to reflect electrification from transport, industry and heating sectors based on *Roadmap 2050* estimates. Production mix in 2030 is built by the model, and not back-cast as in *Roadmap 2050.* Up to 2020 both capacity and production are based on NREAPs. Beyond 2020 the modeling of the EU-27 production mix uses this 2020 RES deployment pattern as a starting point, extrapolated to 2030 and leading to a share of 50% in the *On Track* case.

- *Scenarios and key assumptions*

The main scenario – the *On Track case* – is based on the full implementation of the existing renewable and grid plans up to 2020 and further projects a power production mix towards 2030 in line with the around 60% emission reduction trajectory set by the European Commission in the *Low Carbon Economy 2050 Roadmap*.

The **carbon prices** used in the modeling are €38/ton for 2020 and €85/ton for 2030 and beyond, based on IEA WEO 2009 - 450 scenario. The carbon price is not a variable in the model and hence does not reflect the trading nature of the ETS. Fuel prices are updated according to IEA WEO 2009, same as *Roadmap 2050* (i.e. for 2030: oil/barrel is $115, coal/ton $109, gas/Mmbtu – $14, and uranium/MWh $8)[3].

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[3] The fuel and carbon price assumptions are used in the KEMA/ICL hour-by-hour dispatch model, influencing the dispatch of technologies based on short-run marginal costs.

In terms of **technologies**, a 15% learning rate cost reduction for each doubling of capacity for solar PV is assumed, leading to a 32% decrease in the capex required for 2010-2020 whereas, for offshore wind - a 4.5% learning rate for each doubling of capacity is assumed, leading to a 19% decrease in capex required for 2010-2020.

CCS demonstration plants of 250-300 MW are expected to come on line around 2015 and to ramp it up for larger plants of 500-600MW. Capital costs will come down by the time of commercialisation (currently standing at 3-4EUR million per MW) to make the technology competitive with other low-carbon solutions.

The analysis models several sensitivity scenarios that alter key parameters of the power system (with alternative modeling for RES, nuclear, CCS deployment and demand response activation) and compares these against the *On Track*. The *Higher RES* scenario assumes 60% renewables in 2030*.* In *Less Transmission* a 50% undershooting of ENTSO-E plans is modeled. In *Less Coordinated RES Deployment,* the generation mix is based on the country-lead RES deployment in line with current trends up to 2020.

The *On Track* case projects the need of major investment for both new low-carbon generation and transmission grids, up to 2020 around 628EUR billion for the former, and 68EUR billion between 2020 and 2030 for the later to enable 109GW of additional transmission capacity – near doubling of today's existing capacity.

- *Key findings*

Power Perspectives 2030 finds that existing plans for renewables, and transmission grids up to 2020, if fully implemented, constitute an adequate first step to decarbonisation but that the transition needs to accelerate towards 2030 in order to remain on track to the 2050 CO_2 abatement goal for the power sector. This acceleration implies a near doubling of investments in low-carbon generation and a near doubling of electricity grid capacity in the decade after 2020.

Hence, in the current decade, the European Union, its Member States and the relevant commercial undertakings need both to ensure the implementation of current commitments and to establish an adequate policy and legal framework to steer the decarbonisation of the power sector beyond 2020.

For new low-carbon generation the **investment** required up to 2020 in the *On Track* case is around 628EUR billion (of which 567EUR billion for generation, 15EUR billion for back-up capacity and 46EUR billion for transmission expansion). The deployment of low carbon technologies beyond 2020 would require 1,153 EUR billion capital expenditure **(Capex**), which brings the total capex for the next two decades together to 1,781EUR billion or 0.5% of EU-27 GDP[4].

For grids, the amount beyond 2020 is an estimated 68EUR billion for 109 GW of additional transmission capacity (*On Track* case)[5]. The additional interconnections are projected across

[4] Capex for 2010-2030 in PP2030 is approximately 550EUR billion higher than estimated for this period in *Roadmap 2050*. More than half of the difference is due to higher power demand assumptions w/o inclusion of extra Energy Efficiency measures and 20% to increased scope.
[5] The ENTSO-E have a ten-year network development plan requiring an increase in transmission lines

borders: e.g. UK-Ireland – 13GW; France-Spain – 9GW but inter-country transmission upgrades are also needed: NW-W Germany – 10GW; N-S UK – 8GW[6]. Grid transmission also enables sharing of reserve and response, less reserve sharing reduces opex by 24EUR billion for 2020-2030 at no additional capex costs. Sticking to national provisions of reserve and response increases the reserve requirements from 86GW to 122GW in 2030.

In all scenarios, **gas-fired generation** will play an important role going forward both as a flexible baseload and as a back-up resource. In the *On Track* case, gas-fired plans provide 22% of the annual power demand in 2010, 25% in 2020 and 28% in 2030 (3% of which gas-with-CCS).

The analysis shows **back up and flexible load capacity** of total of 42GW by 2020 and 206GW by 2030 is needed on the *On Track* case. Other options for back-up than building new plants could be preferred, for example decommissioning CCGT plants. The analysis also demonstrates that **demand side** resources reduce the balancing challenges in a decarbonised power system. A realistic DR potential in 2030, shifting up to 10% of daily load in response to availability or supply, decreases the need for grid capacity by 10% and back-up capacity by 35% and thus helps in managing the risk of insufficient grid transmission and saving respectively 7EUR billion and 25EUR billion. This lowers the need for transmission infrastructure of approximately 23GW. DR also reduces the volatility of prices by 10-30% compared to the *On Track* case and by more than 50% compared to a scenario with less transmission capacity. Also, in terms of **energy efficiency**, reducing overall demand to 2030 along similar lines as the energy savings targets for 2020 would stabilize demand at +0.3% per year. This differs from +1.8% demand growth in the *On Track* case and resulting in a 50% decrease in transmission investment and a 31% decrease in back-up investment, saving 299EUR billion in investment (30% lower capex).

Towards 2030 the **levelised cost of electricity (LCoE)** for new builds is similar to the LCoE in this decade: 89EUR/MWh (2020) and 85EUR/MWh (2030), including CO_2 prices which is only a small increase compared to the estimated 82EUR/MWh prior to application of such price. This shows that it is feasible to keep LCoE under control through the decades of transition to a fully decarbonised power sector. The increase in upfront investment will have to be incentivized appropriately but will pay off through decreased operating costs.

- *Conclusions*

Power Perspectives 2030 shows that to remain on track to achieve the 2020 and 2050 energy and climate objectives, existing instruments and targets represent a sound and adequate first step and the EU and its Member States must first fully implement them.

According to the study, beyond 2020, the decarbonisation of the European power sector will need to accelerate to remain on track (to achieve the goal set for 2050). Hence, already in this decade, a stronger sense of the direction towards 2030 is needed to support

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of 64 GW from 2010 to 2020 – a 30% capacity increase over the existing network

[6] The extent of the required grid enhancement will depend on the generation deployment in the scenario, with the low case of an additional 30EUR billion assuming energy efficiency improvements reduce total energy demand from 4,800 TWh to 4,100 TWh by 2030, and the high case of an additional 138EUR billion assuming a higher share of RES (60% versus 50% by 2030 in the *On Track* case).

investments and enable markets to support the transformation to a decarbonised power sector.

A new stable policy framework aiming at 2030 is required, fit to ensure investments in challenging areas:

1. Building more and improved transmission grid infrastructure is essential to balance a decarbonised power system cost-effectively. Beyond 2020, the rate of construction has to double compared to the rate needed in the current decade.

2. Demand side resources like energy efficiency and demand response (despite stalling political commitment and on-the-ground progress at present); demand response and energy efficiency are attractive levers to reduce backup needs as well as grid requirements.

3. Flexible generation and back up. How renewables and gas based generation capacity can interplay will be of importance for the decarbonisation process. Re-purposing some older plants can minimize required investments.

4. The way forward for different sorts of renewables beyond 2020 needs to be sorted out. Deployment is complicated by a number of factors, costs are difficult to predict and in some cases incentive schemes have tended to be inefficient to drive down the costs. By deploying renewables across the EU, rather than follow a country-by-country approach, it will be possible to achieve substantial gains from a power system perspective.

5. If the CCS option (mainly beyond 2030) is to be kept open more need to be done to drive technological development.

A physically and commercially integrated European electricity market combined with a sufficiently restrictive carbon price can achieve far-reaching emission reductions (60% around 2030 compared to 1990 levels) affordably, reliably and securely. The ETS trajectory needs to be aligned to reach consistence with these decarbonisation objectives.

The current wholesale electricity market model can continue to remunerate conventional generation adequately even with high shares of variable and low-marginal-cost resources. For the market to work, however, a number of critical conditions must be satisfied, progress on several of which is well short of what is needed.

Decarbonisation is to a big extent about investments, and will not happen without society having a strong influence on investments made by market players over a long time period. The overall challenge is to run a step-wise transformation and gradually build a stronger platform to reach the objective. There are no simple choices. Public support and acceptance will be of decisive importance.