European Turbine Network A.I.S.B.L.

Enabling the Increasing Share of Renewable Energy in the Grid

Technological Challenges for Power Generation, Grid Stability and the role of Gas Turbines

POSITION PAPER - KEY MESSAGES

To reach the 2020 energy and climate change goals, and to realise the EU's low carbon energy roadmap[1], ETN foresees a number of technological and infrastructural challenges where further Research and Technology Development (RTD) is required to ensure safe, secure, sustainable and low-carbon energy at affordable and competitive prices[2].

ETN welcomes the European Commission's Communication on Energy infrastructure priorities for 2020 and beyond[3]. It correctly recognises that new infrastructure is required to integrate an increasing amount of renewables into the grid, and highlights the key role that natural gas will play in the EU's energy mix in the upcoming decades.

Enhanced RTD is Key to reach the 2020 and 2050 Energy and Climate Goals

This ETN position paper discusses the technological impact of incorporating large volumes of variable renewable energy into the electricity grid, examining the problems that will spring from this, as well as possible solutions. In particular, it will focus on the need for back-up power to balance intermittent renewable energy sources, to ensure grid stabilisation, and the impact this new mode of operation will have on gas turbine and CCS operation when used in this capacity.

"Growing shares of variable renewables will require modifications to the operation of the system and market, and eventually additional flexible reserves, in order to ensure system security is not impaired"[4].

When a large volume of intermittent and unpredictable energy is incorporated into the electricity grid the following challenges will arise:

Highly flexible power production units need to be added to the grid
The variability of renewable energy sources will require highly flexible power production units as a back-up to balance any short-falls in production;

CCS incompatibility with flexible operation
Flexible operation requires that power plants operate in cyclic mode, which hampers the application of current Carbon Capture Storage (CCS) technologies, therefore new carbon capture technologies need to be developed for cyclic mode.

Efficiency, emissions and cost penalties
CO_2 reduction by renewables is partly off-set by the lower efficiency and higher emissions of power stations maintaining a spinning reserve to provide back-up in case of reduced renewables production. This may also result in a higher price for CO_2 reduction.

[1] http://ec.europa.eu/clima/policies/roadmap/index_en.htm
[2] http://ec.europa.eu/energy/strategies/2010/2020_en.htm
[3] http://ec.europa.eu/energy/infrastructure/strategy/2020_en.htm
[4] IEA, World Energy Outlook 2010, p321

Contribution of Gas Turbines to Grid Stability

Gas turbines can play a key role in ensuring flexibility in the electricity system, to match the intermittency of the renewable energy sources, both directly and indirectly[5]. Significant changes in the design and operation will be needed to enhance their usefulness in future grid operations. Combined Cycle Gas Turbine power plant technology will have to change radically in the coming decades to become more flexible and to encompass faster start up and shut down. Today's design technology is not optimized for this, except at very high costs per produced product (kWh) and with lower lifetimes. Increased investments and R&D in the following areas will be required to adapt the technology to meet these requirements:

CCS for Cyclic Operation

Developing carbon capture processes which are also applicable during highly variable cyclic operation.

Flexible Power Generation with Low Emissions

Enabling high flexibility and low part-load power plant operation incorporating combustion systems optimised for reduced NO_X and CO_2 emissions, under cyclic and part load conditions.

Reliable Power Generation designed for Cyclic Operations

New gas turbine design, components and materials with improved fatigue behaviour, thus mitigating failures due to cyclic operation.

Skills & Knowledge

Developing skills and increasing education of engineers is crucial and must be dealt with today, to face the above future technological challenges.

Framework for studies, necessary R&D actions, demonstrations and education programmes

ETN calls for a policy framework that incentivises further research and development of environmentally sound and reliable gas turbine based power stations, which allow for highly flexible cyclic operation, to be available within the next 10 years. It is crucial to address this challenge today, in order to have solutions in place that can meet the impending problems when large amounts of intermittent, renewable energy are added to the grid.

The paper especially focuses on wind power and its effect on the operation and efficiency of gas-fired power plants (combined cycle gas turbines – CCGT). However, other large scale intermittent electricity production sources (for example solar sources) result in similar difficulties, and also necessitate fast reacting back-up systems of gas turbine driven power plants.

The paper describes the situation as it stands today, with a relatively limited amount of renewables in the power grid already having a significant operational impact. Thereafter, based on the EU's energy policies and future energy mix scenarios, the paper examines the expected impact on power plant operation and efficiency when a very high share of renewables is added to the grid. Finally, the paper highlights the importance of investment in the knowledge, research and technology development required to reach emission reduction targets by 2050, outlining specific research and educational needs.

[5] Gas turbine technology can also play an important role in associated areas under development such as Compressed Air Energy Storage (CAES) and hybrid systems between gas turbine and Concentrated Solar Power (CSP).

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The European Turbine Network (ETN) is a non-profit European association which brings together the gas turbine (GT) technology community for power generation and mechanical drive applications in Europe, representing 76 members from 17 European countries. ETN addresses the main challenges and concerns of the GT users in technical committees and project groups, composed of experts from the whole value chain (Power Generation and Oil & Gas, OEMs, R&D Institutes, Suppliers and Service Providers, Technology Consultancies and Industry Associations).

Through cooperative efforts and by optimizing gas turbine Research and Technology Development (RTD), ETN promotes environmentally sound gas turbine technology with reliable and low cost operation. In addition to facilitating and coordinating the research efforts of different parties and bringing together key stakeholders in the GT community, ETN also acts as a solid platform for the exchange of knowledge and experiences, performs technology watch, identifies research gaps and contributes to the EU research effort.

Introduction

Variable sources of renewable energy are increasingly being used in the production of electric power, and this will continue to increase as industry adapts to the European Union's goal of reaching 20% renewables in the total primary energy mix by 2020. Scenarios for 2050 by the European Commission and the International Energy Agency predict as much as 50% of future power generation being provided by renewables, primarily consisting of wind and solar energy and to a lesser extent, biomass and hydro power.

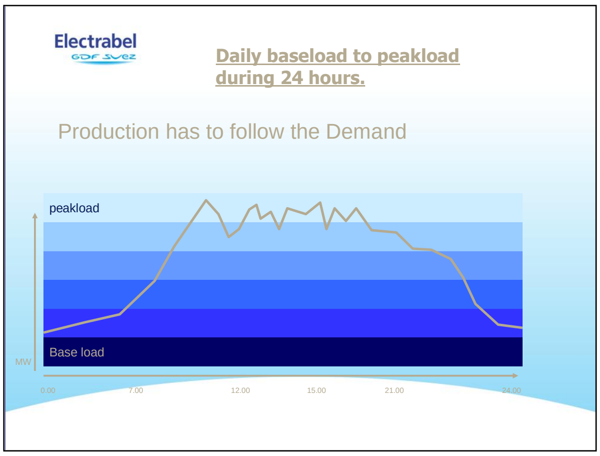

Figure 1: Normal daily demand profile

The increasing share of solar and wind in electricity production is challenging the reliability of the electric grid and the security of supply. In the production of electricity there is limited buffer or storage[6]. Therefore production must follow demand instantaneously and be in full balance. Variations in demand between day and night time (Figure 1) are predictable and can be balanced by the electricity producers.

However, wind, and to a lesser extent solar power, which will make up a bigger share of primary energy in the future, have an intermittent and to somewhat unpredictable nature.

To avoid a gap between demand and production, renewables require a fast-reacting back-up system, to balance against their intermittent nature and to prevent an unstable grid. If a grid is unstable, it can lead to a black-out in a large area due to a 'domino effect'; this can occur when 1 or 2 failing power units decrease the grid frequency to such a level that even more power units stop production. Grid companies try to avoid this

[6] Available **storage technologies** (e.g. hydro-power, compressed air energy storage and batteries) have a high cost and low efficiency. There is no short-term prospect of them being able to cope with the storage demand posed by the integration of a high share of renewables into the grid.

occurring by cutting the electricity demand of larger consumers or areas from the grid, but if this happens more often it can cause negative economic, social and political effects.

Smart grids could act as a buffer in the future by allowing bi-directional transmission, and can isolate regional black-outs to prevent larger black-outs. However, it is highly unlikely that smart grids alone will be able to accommodate the rapid increase in renewable energy. Moreover, the European Commission wrote in a recent communication that “the EU is still in the early stages of the actual deployment of Smart Grids”[7].

It is generally agreed that in cases where high capacity hydro reserve power is unavailable, gas turbine power plants running on natural gas provide the best means to balance power production[8]. This is because it is fast reacting and has the ability to be turned on and off within minutes. Nuclear and coal power generation can follow electric demand to some extent, however are not flexible enough to accommodate large and fast fluctuations.

Current Challenges

Wind energy production is only partly predictable and very intermittent (see Figure 2). Periods of stable wind will be followed by periods of no wind or intermittent wind and as a result the wind turbine’s full load capacity is seldom achieved. The yearly production is dependent on its location, but usually reaches only around 25% of the theoretical maximum. During very cold and hot days there is often little wind, resulting in no wind electricity production. In addition, the wind flow can be very unstable, so there are large fluctuations in short periods of time, resulting in similar fluctuations in the production of electricity.

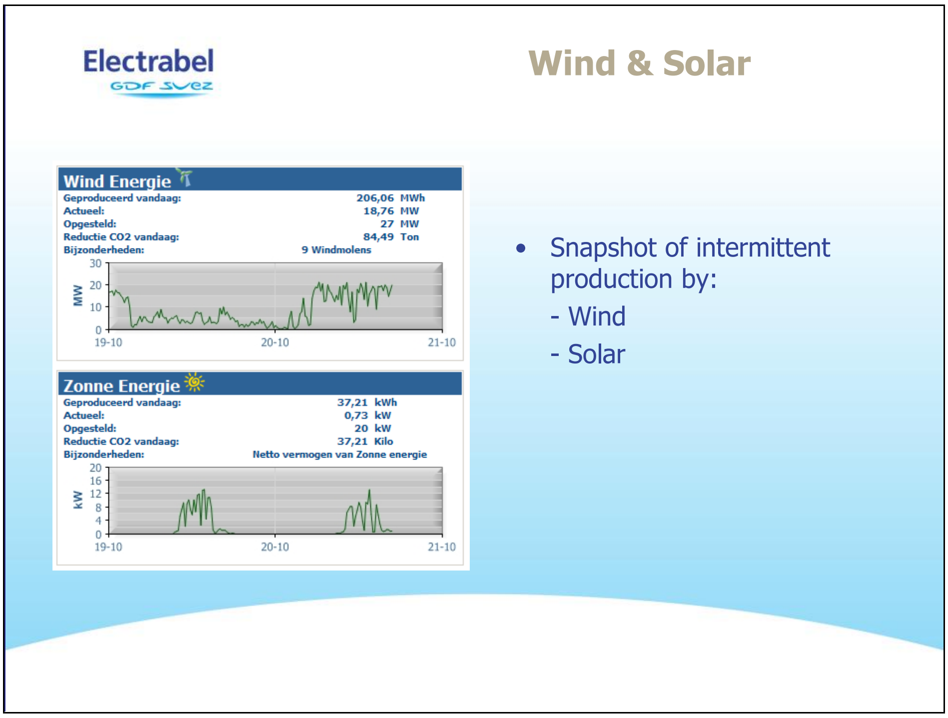

Figure 2: Snapshot of intermittent electricity production by wind and solar

As long as the amount of wind electricity production is less than approximately 25% of the total electricity production at that time, the regular non-fluctuating power units will balance the wind fluctuations by setting a production level with a higher spinning reserve[9]. However, at very low load demand there could be a problem

[7] Communication from the Commission on ‘Smart Grids: from innovation to deployment’, http://ec.europa.eu/energy/gas_electricity/smartgrids/doc/20110412_act_en.pdf, page 3.

[8] The intermittent production of electricity from renewables can be partially compensated by countries with large amounts of hydro power (especially hydro reserve capacity), however not in the required expected future quantities.

[9] Note: the production of electricity at part load will result in lower plant efficiency. As such 20% wind production is less than 20% CO_2 reduction.

in balancing the wind power, for example on a Sunday morning at 6.00 AM when power demand is low (30%) and wind power production is high and unstable at the same time.

Future Challenges

When the share of wind power production reaches 50% or even 75% of the total electricity production, as is foreseen in the National Renewable Action Plans of the EU Member States future scenarios[10], this will have a serious impact, because the thermal plants will have to respond to those high load differences. The 50% or 75% is related to the maximum daytime load; during the night and at the weekend it can be even more extreme. The key questions are: will power stations be flexible enough to allow for this? At what cost? And crucially: who is prepared to invest in new power plants with such large uncertainties?

Today, in Spain, examples of this future scenario are already being witnessed. Power units sometimes run at full-speed-no-load to act as a back-up for wind variations. CO_2 is emitted, although there is no electricity production. Consequently reduced emission levels will be more difficult to achieve.

In the UK, a modelling study was recently performed on the effect of incorporating large shares of wind energy in the grid. This Pöyry model study showed how the current grid power capacity (natural gas, nuclear and coal) would have to react if wind energy variations had to be balanced. This was done for two scenarios: a relatively minor wind generating capacity of 3.5 GW for 2010 and a major wind generating capacity of 45 GW for 2030.

The results of the study (see Figures 3 and 4) show that in the 2030 scenario high-efficiency gas fired power plants will operate only in cyclic mode and very intermittently to incorporate the wind variation.

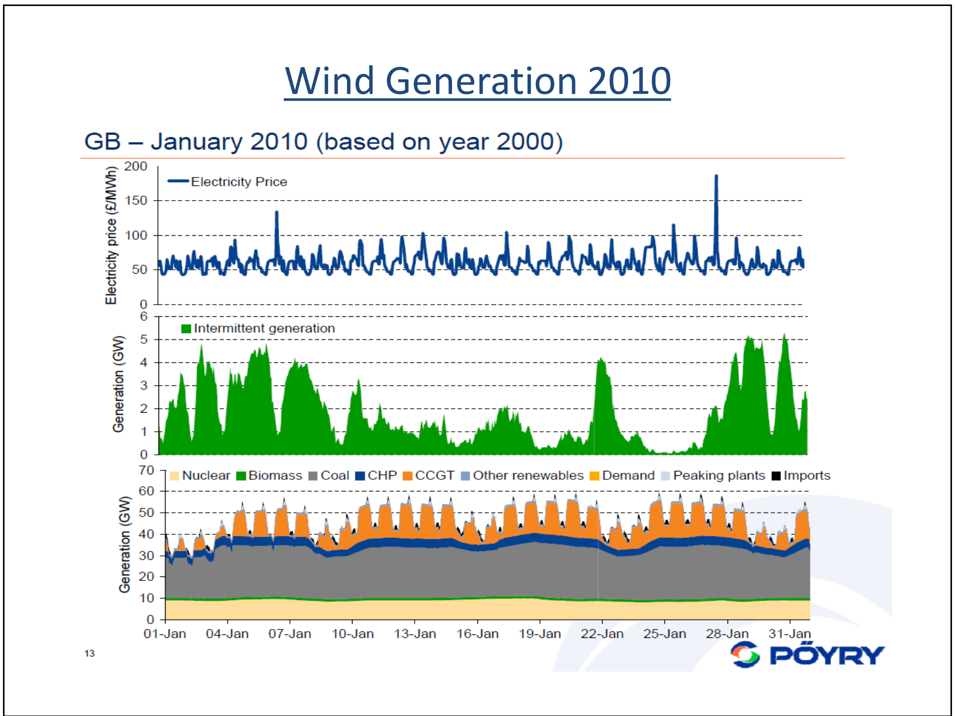

Figure 3: Simulation of wind energy production on grid (2010); relatively minor wind generating capacity of 3.5 GW (Pöyry study for wind generation 2010)

[10] http://www.ecn.nl/docs/library/report/2010/e10069.pdf

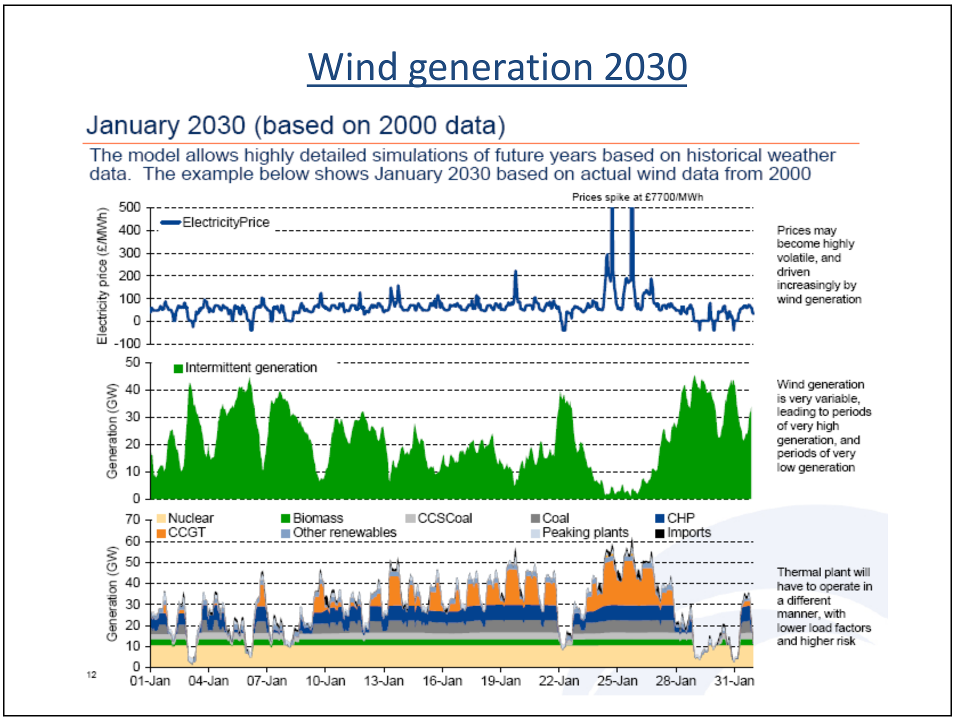

Figure 4: Simulation of wind energy production on grid (2030); major wind generating capacity of 45 GW (Pöyry study for wind generation 2010)

Even nuclear plants and conventional coal plants will sometimes have to cut production if wind production is very high. This would require an enormous change to current operating modes (Figure 5).

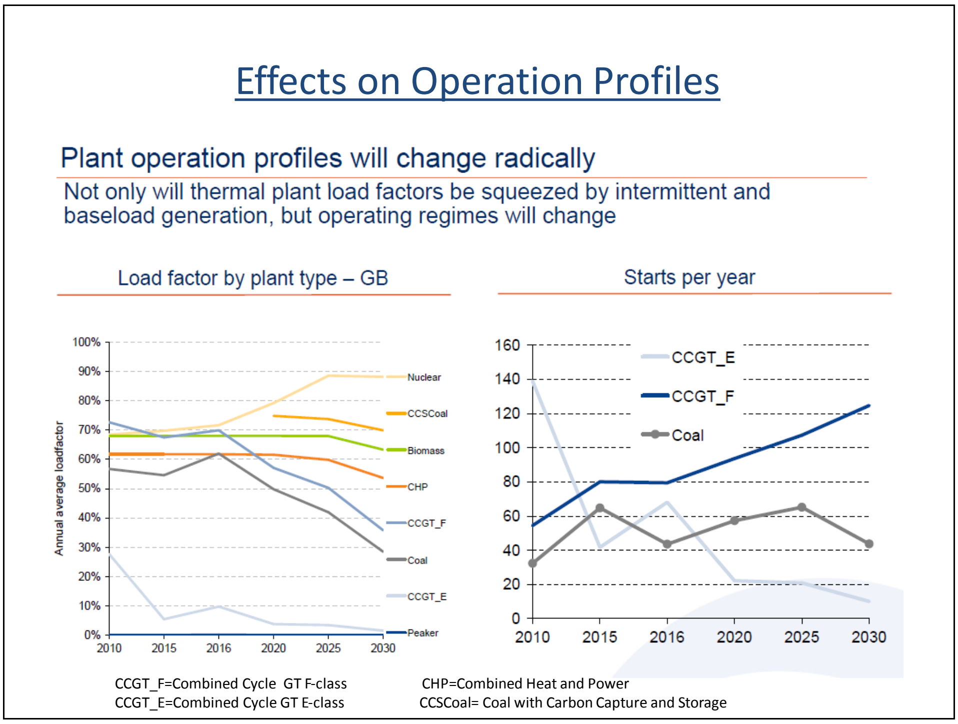

Figure 5: Plant operation will be seriously affected when large wind capacity is to be incorporated (Pöyry study for wind generation 2010)

Additionally, incorporating large amounts of wind energy has an enormous effect on other factors, for example on Carbon Capture and Storage (CCS). Because CCS is nowadays a chemical process which - with the current technology - requires uninterrupted operation, CCS can only be applied on those plants which run continuously. However, the Pöyry study[11] indicates that gas powered plants, and even conventional coal plants, will operate in cyclic mode in the future (incorporating the wind variation), hence CCS will not be easily applicable.

The Pöyry study for wind generation shows that the incorporation of large amounts of wind energy in the future will lead to uncertainty and risks, an investment conundrum and extremes in prices, both positive and negative. In addition, the risk of power interruptions or even a black-out in a large area will increase significantly.

Expected impact on power plant operation

The scenario, as outlined above, will change the mode of electricity production of Combined Cycle Gas Turbine Power Plants (CCGT) dramatically in the coming years (and in some countries, such as Spain, already today). From a base load of 12 starts per year and 8000 hours of operation, operation will be cyclic, with as many as 250 (or more) starts with only 3000 hours (or less) of operation per year at part load. Furthermore, as a result of the multiple starts and lower efficiency, the power station will face higher emissions of CO_2 and NO_x per produced kWh.

Power stations will also face an increased risk of failure due to low-cycle fatigue problems[12], caused by the components and materials being subjected to repeated loading and unloading. These damages will lead to lower availability and reliability. In addition, maintenance of gas-fired power plants will be more costly and more uncertain, due to the fact that the fatigue limits of gas turbine parts are less well known and flexible than the limits for creep behaviour[13].

It is not only wind power which is causing the problems described above. Other large scale applications of intermittent electricity production (such as solar sources) cause the same type of problems, with a similar requirement for fast reacting back-up systems of gas turbine driven power plants.

Policy framework to incentivise further and increased research investments

Power plant technologies will have to change radically in the coming decades to become more flexible and to encompass faster start-up and shut-down. Today’s design technology is not optimised for this, except at very high costs per produced product (kWh) and lower lifetimes.

ETN therefore calls for a policy framework to incentivise further research and development of environmentally sound and reliable power stations, which allow highly flexible cyclic operation, to be made available within the next ten years. It is crucial to address this today for solutions to be in place that meet the challenges affecting the grids when the share of renewables is increased.

To develop skills and knowledge of engineers is also crucial and must be dealt with today. This is key to face the above future technological challenges and in order for Europe to keep its position as a leading innovation society.

The technological challenges, investment needs and research opportunities identified by ETN are summarized on the next page.

[11] http://www.poyry.com/linked/group/study
[12] Fatigue is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading.
[13] Creep is the tendency of a solid material to slowly move or deform permanently under the influence of stress.

A Summary of the Technological Impact, Challenges and Research Needs

When large volumes of intermittent energy are incorporated into the electricity grid the following challenges will arise:

- The variability of renewable energy sources will require highly flexible power production units as a back-up to balance any short-falls in production;
- CCS will become incompatible with the flexible operation of gas turbines, hence new carbon capture technologies need to be developed suitable for cyclic operation;
- Power stations will have to maintain a spinning reserve to provide back-up during periods of reduced renewables production**,** resulting in lower efficiency, higher costs and an off-set of the CO_2 reduction achieved by renewables.

For Combined Cycle Gas Turbines (CCGT) operating under this future scenario the following challenges will arise:

- operation and maintenance costs per kWh will increase;
- overall efficiency will decrease;
- emissions of CO_2 and NO_x per kWh will increase; and
- the risk of power interruptions will increase.

The above mentioned challenges will require investments in R&D to:

- Develop carbon capture processes which are also applicable during highly variable cyclic operation;
- Enable high flexibility and low part-load power plant operation incorporating combustion systems optimised for reduced NO_x and CO_2 emissions, under these conditions;
- Develop new gas turbine design, components and materials with improved fatigue behaviour, thus mitigating failures due to cyclic operation;
- Develop skills and knowledge of engineers is crucial and must be dealt with today, to face the above future technological challenges.

ETN calls for a policy framework which incentivises further R&D in environmentally sound and reliable gas turbine based power stations that permit highly flexible cyclic operation to be made available within the next 10 years. As part of this effort, it is of paramount importance to initiate a broad study on the specific future requirements of power plants operating mainly in cyclic mode. By applying Technoeconomic Environmental Risk Analysis (TERA) the most promising investments and operation patterns could be identified. The study should provide insight into the design, development and manufacturing options that are required for different future scenarios and operational modes. It must address all the major systems of future power plants, such as the gas turbine, the steam turbine, the boiler, the generator and the power transmission.

ETN welcomes the opportunity to present more specific proposals for studies and projects that would contribute to the knowledge and technology development required to reach the emission reduction targets by 2050.

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