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Battle of the Grids

Report 2011

How Europe can go 100 % renewable and phase out dirty energy

GREENPEACE

Climate change

cover image Wind turbine with pile of coal on the foreground, Vlissingen, the Netherlands.

image Aerial photo of the PS10 Concentrating Solar Thermal Power Plant. The solar radiation, mirror design plant is capable of producing 23 GWh of electricity which is enough to supply power to a population of 10,000.

Battle of the Grids report 2011

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www.energyblueprint.info

This report is based on research by Energynautics GmbH and publised in a technical report 'European Grid Study 2030/2050', commissioned by Greenpeace International. Authors: Dr.-Ing. Eckehard Tröster, MSc. Rena Kuwahata, Dr.-Ing. Thomas Ackermann. For info and contact: www.energynautics.com

Introduction

The energy and transport systems that power the industrialised world are fuelling dangerous climate change. Extreme weather, decline in agricultural production and sea-level rise will be felt by everyone, rich and poor. We can avert the worst impacts, but only if we rethink our energy system.

Today, Europe's electricity grid is characterised by big, polluting power stations pumping out constant energy, regardless of consumer need, along a wasteful, aging A/C (alternating current) network. The patchwork of national grids stitched together over the years is an uncomfortable, uneconomical fit.

Climate policy and consumer demand are hurtling us towards a smarter, more efficient Europe-wide grid that is already opening up vast new technological, business and consumer opportunities. Such a grid could guarantee supply despite extreme weather conditions, delivering green energy around Europe via efficient, largely below ground DC (direct current) cables. However, the report's title, *Battle of the Grids*, hints at the fact that we are at a political crossroads.

Despite the remarkable growth in renewables, last year they generated more investment than any other sector, we are fast reaching a showdown between green and dirty energy. Thousands of wind turbines delivering near free energy were turned off in 2010 to allow polluting and heavily subsidised nuclear and coal plants to carry on business as usual. It is estimated Spain had to ditch around 200GWh of energy last year. The buzz on the lips of industry specialists, lobbyists and in boardrooms is about system clash and the costs of building and running what is increasingly becoming a dual system. This groundbreaking report demonstrates the problem on a European scale. It also proves that Europe is capable of moving smoothly to a system that delivers nearly 100 percent renewable power around the clock.

Taken with Greenpeace's 2010 *Energy [R]evolution* report, *Battle of the Grids* builds on Greenpeace's earlier *Renewables 24/7* study. It is a 'how to' manual for the kind of system we need to deliver 68 percent renewable energy by 2030 and nearly 100 percent by 2050.

Industry leader Energynautics was commissioned to carry out extensive modelling and has delivered a working proposition for Europe based on electricity consumption and production patterns for every hour 365 days a year at 224 nodes of electricity interconnections across all 27 EU countries, plus Norway, Switzerland and non-EU Balkan States.

The main feature is the centre-spread map which shows precisely how much of each renewable power technology is feasible and how much needs to be spent on infrastructure to deliver electricity to where it is needed across Europe. The map is the first of its kind - no other study has attempted to seriously chart a future European grid of any kind.

To be able to realise this new approach to energy delivery requires a new way of approaching the problem and in effect a new vocabulary. The box of key terms summarises the concepts dealt with in the *Battle of the Grids*.

Box 1

Baseload is the concept that there must be a minimum, uninterruptible supply of power to the grid at all times, traditionally provided by coal or nuclear power. This report challenges that idea by showing how a variety of 'flexible' energy sources combined over a large area can also keep the lights on by being sent to the areas of high demand. Currently, 'baseload' is part of the business model for nuclear and coal power plants, where the operator can produce electricity around the clock whether or not it is actually needed.

Constrained power refers to when there is a local oversupply of free wind and solar power which has to be shut down, either because it cannot be transferred to other locations (bottlenecks) or because it is competing with inflexible nuclear or coal power that has been given priority access to the grid. Constrained power is also available for storage once the technology is available.

Variable power is electricity produced by wind or solar power depending on the weather. Some technologies can make variable power dispatchable, eg by adding heat storage to concentrated solar power.

Dispatchable is a type of power that can be stored and 'dispatched' when needed to areas of high demand, e.g. gas-fired power plants or power generated from biofuels.

Interconnector is a transmission line that connects different parts of the electricity grid.

Load curve is the typical pattern of electricity through the day, which has a predictable peak and trough that can be anticipated from outside temperatures and historical data.

Node is a point of connection in the electricity grid between regions or countries, where there can be local supply feeding into the grid as well.

image Electricity Station Pylons.

Key findings

After extensive computer modelling[1], including detailed predictions of how much electricity can come from solar and wind power plants every hour of the year, the *Battle of the Grids* shows that:

1. Large-scale integration of renewable electricity in the European grid (68 percent by 2030 and 99.5 percent by 2050) is both technically and economically feasible with a high level of security of supply, even under the most extreme climatic conditions with low wind and low solar radiation. This further confirms the feasibility of a 100 percent renewable electricity vision. It also strengthens the findings of Greenpeace's Energy [R]evolution[2], which demonstrates that meeting the demand in 2050 with 97 percent renewable electricity would cost 34 percent less than under the IEA's Reference scenario and that by 2030, 68 percent renewable electricity would generate 1.2 million jobs, 780,000 more than under the Reference scenario.

2. This requires significant changes in the energy mix:

- in 2030, gas plants provide most of the non-renewable electricity and serve as a flexible backup for wind and solar power. Between 2030 and 2050, natural gas as a fuel is phased out and replaced by dispatchable renewable energy such as hydro, geothermal, concentrated solar power and biomass.
- because coal and nuclear plants are too inflexible and cannot sufficiently respond to variations in wind or solar generation, 90 percent of the existing coal and nuclear plants have to be phased out by 2030 and by 2050 they are completely phased out.

3. By 2030, some 70bn€ investment in grid infrastructure is required to secure electricity supply 24 hours a day, 7days a week with 68 percent renewable power in the mix. By investing another 28bn€ on expanding the grids by 2030, the constraining of renewable sources could be reduced to 1 percent. The total grid cost is limited to less than 1 percent of the electricity bill.

4. Between 2030 and 2050, two different scenarios have been analysed in this report. In a 'High Grid' scenario, the European grid could be connected to North Africa to take advantage of the intense solar radiation. This would lower the cost to produce electricity, but increase investments required in transmission to 581bn€ between 2030 and 2050. In the 'Low Grid' scenario, more renewable energy is produced closer to regions with a high demand (large cities and heavy industry). This lowers the investment in transmission to only 74bn€ for 2030-50, but increases the costs to produce electricity because more solar panels will be installed in less sunny regions. In between those two very distinct High and Low Grid scenarios, many intermediate combinations are possible.

5. At the moment, wind turbines are often switched off during periods of high electricity supply, to give priority to nuclear or coal-fired power. To win the *Battle of the Grids* renewable energy will need priority dispatching on the European grids, including priority on the interconnections between countries, because their surplus production can be exported to other regions with a net demand.

6. Economic consequences for nuclear, coal and gas plants:

- even if technical adaptations could enable coal and nuclear plants to become more flexible and 'fit in' the renewable mix, they would be needed for only 46 percent of the year by 2030 and further decreasing afterwards, making investments in a nuclear reactor of some 6bn€ highly uneconomic. Building a new nuclear reactor is a very high risk for investors.
- in a 'Dirty scenario', of the future with a share of inflexible coal and nuclear plants in 2030 close to what is installed today, the renewable sources will have to be switched off more often and the cost of this lost renewable production will raise to 32bn€/year.
- flexible gas plants are less capital intensive than nuclear plants and could still economically produce at a load factor of 54 percent by 2030, functioning as a backup for variable renewable power. After 2030, gas plants can be converted progressively to use biogas, avoiding stranded investments in both production plants and gas grids.

1 This analysis is based on "*Renewables 24/7 – Infrastructure needed to save the climate*", Feb. 2010.
2 Energy [R]evolution. Towards a fully renewable energy supply in the EU-27. http://energyblueprint.info/1233.0.html

The Energy [R]evolution in Europe

We can shape the future

The world knows that we are heading for severe, global climate impacts because of over two centuries of industrial development based on burning fossil fuels. We also know the solution: it is nothing short of a revolution in how we provide and share energy. The Energy [R]evolution, now in its third edition, is created by Greenpeace together with the Institute of Technical Thermodynamics at the German Aerospace Centre (DLR) and more than 30 scientists and engineers from universities, institutes and the renewable energy industry around the world. It is a blueprint to provide clean and equitable power that meets the targets for greenhouse gas emissions set by science, rather than politics.

The situation in Europe today is:

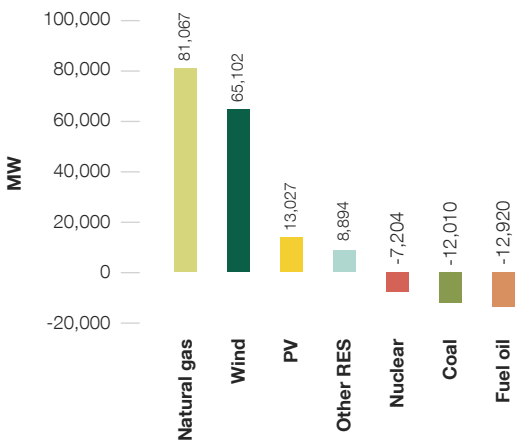
- renewable energy is booming. Over the last decade, more than half of all new installed capacity was renewable power, not fossil fuel-based generation.
- renewable energy continued to grow through 2009 despite the economic crisis.
- wind power is now the undisputed leading technology in Europe, with gas in second position and solar PV in third – investment in new European wind farms in 2009 reached 13bn€ for 10,163 MW of wind power capacity - 23 percent higher than the year before.
- wind turbines built in 2009 will produce as much electricity as 3 to 4 large nuclear or coal power plants running at baseload every year[3].
- meanwhile, both nuclear and coal are declining; more plants were closed than new ones added to the mix over the last decade.

A long way to grow

We can use current trends in the electricity market to make reliable projections on what the energy mix could be with the right support and policies. Greenpeace has published future market scenarios for a decade, based on detailed studies of industry capability. In this time, the real growth of wind energy and solar PV has consistently surpassed our own projections.

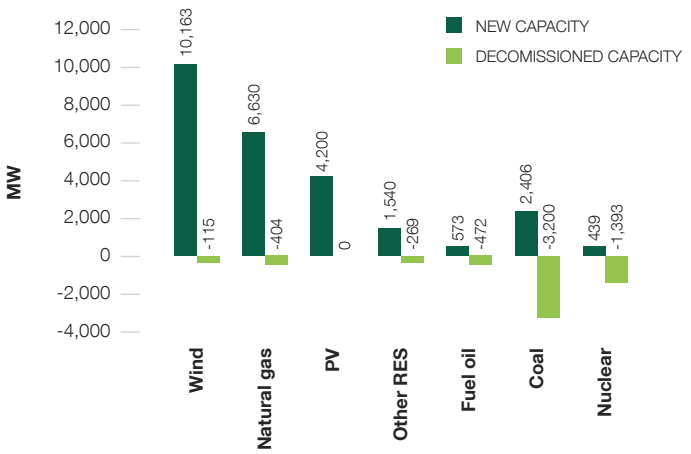
The reports provide a detailed scenario for Europe that is conservatively based only on proven and existing technologies.

Figure 1 Net installed production capacity 2000-2009 in EU 27



Source: EWEA, Platts.

Figure 2 Installed and decommissioned production capacity in 2009 in EU-27



Source: EWEA, Platts.

3 10,160MW of wind turbines at an average load factor of 0.29 will generate about 26TWh, comparable with 3.5 large thermal plants of 1000MW each running at a load factor of 0.85.

image Stockpiles of coal unloaded from bulk carriers in the port of Gijon.

The report uses top-down analysis of the overall energy supply at European level, plus bottom-up studies on technology development and growth rates, learning curves, cost analyses and resource potentials of renewable energy sources. The *Energy [R]evolution* comes in basic and advanced scenarios, based on population and GDP predicted by the International Energy Agency's World Energy Outlook of 2009.

The advanced scenario gives a CO_2 reduction of 95 percent by 2050 for the overall energy sector. It includes a phase-out of coal and nuclear power for electricity by 90 percent by 2030 and entirely by 2050. Renewable electricity sources would supply 43 percent by 2020, 68 percent by 2030 and 98 percent by 2050 under these conditions. The study shows that a transition towards a fully renewable energy supply by 2050 is technically and economically feasible.

A real Energy [R]evolution would tap into Europe's massive potential for energy savings and renewable energy and put it on a pathway to provide clean, secure and affordable energy and create millions of jobs.

Table 1 What happens in the EU with an Energy [R]evolution

Efficiency	• Primary Energy demand drops from78,880 PJ/a in 2007 to 46,030 PJ/a in 2050	• Total energy demand reduced by one third
Energy	• In 2050 fossil fuels will be replaced by biomass, solar collectors and geothermal. • Geothermal heat pumps and solar thermal power will provide industrial heat production.	• Renewable sources will cover 92 percent of final energy demand, including heat supply and transport.
Electricity	• 1,520 GW of power capacity, producing 4,110 TWh of renewable electricity per year by 2050. • Total electricity demand rises from 2900 TWh in 2007 to almost 4300 TWh in 2050, due to more use in transport and geothermal heat pumps.	• Renewable energy forms 97 percent of supply.
Transport	• More public transport systems also use electricity and there is a shift to transporting freight from road to rail.	• Electric vehicles make up 14 percent of mix by 2030 and up to 62 percent by 2050.
Costs	• In 2050, one kWh will cost 6.7 euro cent in the Advanced scenario, compared to 9.5 euro cent in the Reference • Compared to the IEA Reference scenario, fuel cost savings of average 62bn€/year in the electricity sector make up for the added investment cost of average 43bn€/year (2007-2050).	• Electricity costs 1.2 cent/kWh more in 2030 than under IEA scenario • Electricity costs 2.8 cents/kWh less in 2050 than IEA Reference scenario
Jobs	• Advanced Energy [R]evolution creates about 1.2 million jobs in the power sector in 2050	• 780,000 more jobs in the power sector than IEA Reference scenario.

How the electricity system works

The 'grid' means all the wires, transformers and infrastructure that transport electricity from power plants to users. Currently we run on a model of centralised grid that was designed and planned up to 60 years ago. The systems supported massive industrialisation in cities and brought electricity to rural areas in most developed parts of the world. But now we have to re-think and re-work the grid to deliver a clean energy system. It is a change that will take us to the next stage of society's technological evolution.

The old way

All grids have been built with large power plants in the middle connected by high voltage alternating current (AC) power lines. A smaller distribution network carries power to final consumers. The system is very wasteful, with much energy lost in transition.

The new way

The major difference in producing clean energy is that it requires lots of smaller generators, some with variable amounts of power output. A big advantage is that they can be located inside the grid, close to where power is used. Small generators include wind turbines, solar panels, micro turbines, fuel cells and co-generation (combined heat and power).

The challenge ahead is to integrate new decentralised and renewable power generation sources while phasing out most large-scale, outdated power plants. This will need a new power system architecture.

The overall concept balances fluctuations in energy demand and supply to share out power effectively among users. New measures, such as managing the demand from big users or forecasting the weather and using energy storage to cover times with less wind or sun, enable this. Advanced communication and control technologies further help deliver electricity effectively,

The key elements of the new power system architecture are **micro grids, smart grids** and a number of interconnectors for an effective **super grid**. The three types of systems support each other and interconnect with each other.

Technological opportunities

By 2050, the power system needs to look a lot different to today's. This creates huge business opportunities for the information, communication and technology (ICT) sector to help redefine the power network. Because a smart grid has power supplied from a diverse range of sources and places, it relies on the gathering and analysis of a lot of data. Smart grids require software, hardware and data networks capable of delivering data quickly, and of responding to the information that they contain. Several important ICT players are racing to smarten up energy grids across the globe and hundreds of companies could be involved with smart grids.

Box 2 Definitions

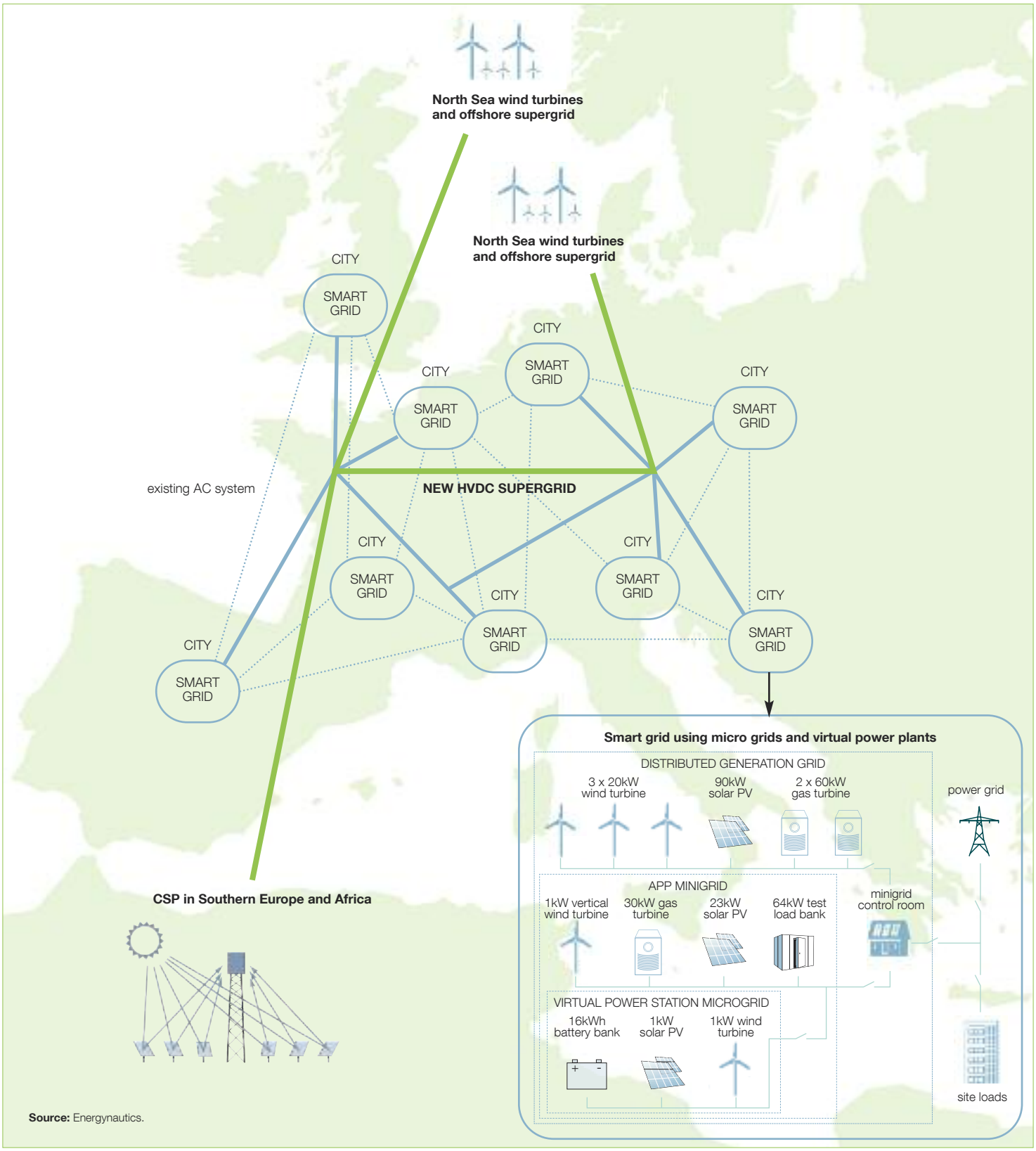
Micro grids supply local power needs. The term refers to places where monitoring and control infrastructure are embedded inside distribution networks and use local energy generation resources. They can supply islands, small rural towns or districts. An example would be a combination of solar panels, micro turbines, fuel cells, energy efficiency and information/communication technology to manage loads and make sure the lights stay on.

Smart grids balance demand out over a region. A 'smart' electricity grid connects decentralised renewable energy sources and co-generation and distributes power highly efficiently. Smart grids are a way to get massive amounts of renewable energy with no greenhouse emissions into the system, and to allow decommissioning of older, centralised power sources. Advanced types of control and management technologies for the electricity grid can also make it run more efficiently overall. An example would be smart electricity meters that show real-time use and costs, allowing big energy users to switch off or down on a signal from the grid operator, and avoid high power prices.

Super grids transport large energy loads between regions. This refers to a large interconnection - typically based on HVDC technology - between countries or areas with large supply and large demand. An example would be the interconnection of all the large renewable based power plants in the North Sea or a connection between Southern Europe and Africa where renewable energy could be exported to bigger cities and towns, from places with large locally available resources.

image Construction of offshore wind turbines.

Figure 3 Overview of the future power system with high percentage of renewable power



Source: Energynautics.

Battle of the Grids: what's the big barrier?

Power from some renewable plants, such as wind and solar, varies during the day and week. Some see this as an insurmountable problem, because up until now we have relied on coal or nuclear to provide a fixed amount of power at all times. The title of this report refers to the struggle to determine which type of infrastructure or management we choose and which energy mix to favour as we move away from a polluting, carbon intensive energy system.

Some important facts include:

- electricity demand fluctuates in a predictable way.
- smart management can work with big electricity users, so their peak demand moves to a different part of the day, evening out the load on the overall system.
- electricity from renewable sources can be stored and 'dispatched' to where it is needed in a number of ways, using advanced grid technologies.

Wind-rich countries in Europe are already experiencing conflict between renewable and conventional power. In Spain, where a lot of wind and solar is now connected to the grid, gas power is stepping in to bridge the gap between demand and supply. This is because gas plants can be switched off or run at reduced power, for example when there is low electricity demand or high wind production. As we move to a mostly renewable electricity sector, gas plants will be needed as backup for times of high demand and low renewable production. Effectively, a kWh from a wind turbine effectively displaces a kWh from a gas plant, avoiding carbon dioxide emissions. Renewable electricity sources such as thermal solar plants (CSP), geothermal, hydro, biomass and biogas can gradually phase out the need for natural gas. (See Case Studies for more). The gas plants and pipelines would then progressively be converted for transporting biogas.

Baseload blocks progress

Generally, coal and nuclear plants run as so-called baseload, meaning they work most of the time at maximum capacity regardless of how much electricity consumers need. When demand is low the power is wasted. When demand is high additional gas is needed as a backup. Coal and nuclear cannot be turned down on windy days. Instead, wind turbines will get switched off to prevent overloading the system.

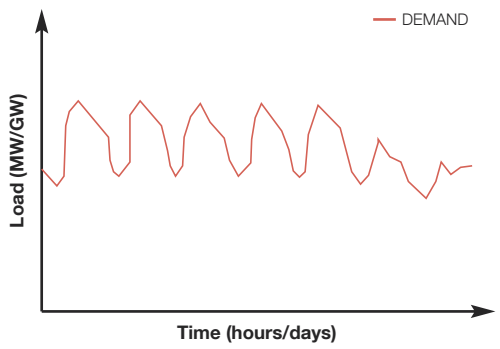
The fall in electricity demand that accompanied the recent global economic crisis revealed system conflict between inflexible baseload power, especially nuclear, and variable renewable sources, especially wind power, with wind operators told to shut off their generators. In Northern Spain and Germany, this uncomfortable mix is already exposing the limits of the grid capacity. If Europe continues to support nuclear and coal power alongside a growth in renewables, clashes will occur more and more, creating a bloated, inefficient grid.

Despite the disadvantages stacked against renewables, they have begun to challenge the profitability of older plants. After construction costs, a wind turbine is generating electricity almost for free and without burning any fuel. Meanwhile, coal and nuclear plants use expensive and highly polluting fuels.

Even where nuclear plants are kept running and wind turbines are switched off, conventional energy providers are concerned. Like any commodity, oversupply reduces price across the market. In energy markets, this affects nuclear and coal too. We can expect more intense conflicts over access to the grids over the coming years. One example is the tension in Germany over whether to extend the lifetime of nuclear reactors by 8-14 years. The German renewable energy federation (BEE) has warned its government that this would seriously damage the further expansion of renewable energy. It predicts that renewable energy could provide half of Germany's supply by 2020, but this would only make economic sense if half the nuclear and coal plants were phase-out by that date[4].

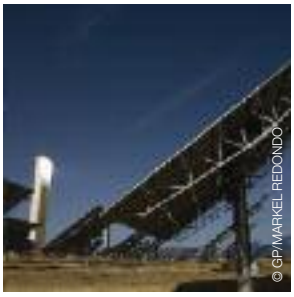
This explains why conventional utilities are growing increasingly critical of a continued and stable growth of renewables beyond 2020[5].

Figure 4 A typical load curve throughout Europe, shows electricity use peaking and falling on a daily basis



4 Fraunhofer-IWES, Dynamische Simulation der Stromversorgung in Deutschland. http://www.bee-ev.de/_downloads/publikationen/studien/2010/100119_BEE_IWES-Simulation_Stromversorgung2020_Endbericht.pdf
5 Reference to Eurelectric's energy scenario. http://www2.eurelectric.org/DocShareNoFrame/Docs/1/PMFLMPLBJHEBKNOMIEDGELBEKHYDYC5K46SD6CFGI4OJ/Eurelectric/docs/DLS/Power_Choices_FINALREPORTCORRECTIONS-2010-402-0001-01-E-2010-402-0001-01-E-2010-402-0001-01-E.pdf

image The PS10 Concentrating Solar Tower Plant in Sevilla, Spain.



The battleground for the grid

Figure 5 Current supply system with low shares of fluctuating renewable energy

This graph summarises the way we currently supply power. The 'baseload' power is at the bottom of the graph. The renewable-energy contribution forms a 'variable' layer – reflecting the way sun and wind levels changes throughout the day. The top of the graph is filled by gas and hydro power which can be switched on and off in response to demand. This is sustainable using weather forecasting and clever grid management.

Current supply with baseload nuclear and coal has room for about 25 percent variable renewable energy.

However, to combat climate change a lot more than 25 percent renewable electricity is needed.

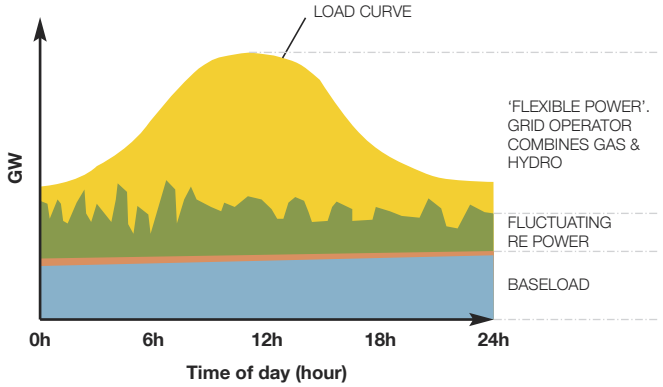


Figure 6 Supply system with more than 25 percent fluctuating renewable energy – baseload priority

Approach: More renewable energy with priority for baseload?

As renewable energy supplies grow they will exceed the demand at some times of the day, creating surplus power. To a point, this can be overcome by storing power, moving power between areas, shifting demand during the day or shutting down the renewable generators at peak times. It does not work when renewables exceed 50 percent of the mix.

Not sustainable for 90-100 percent renewable electricity.

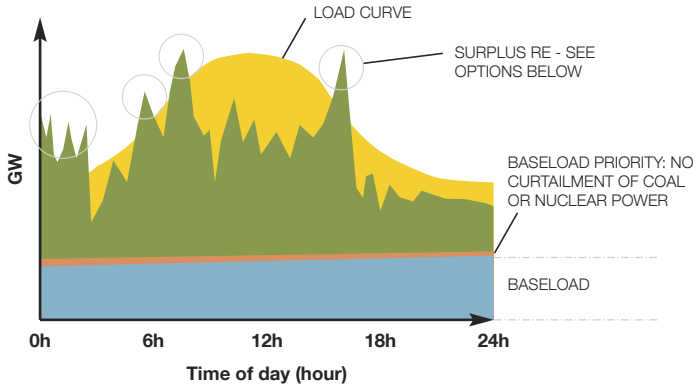
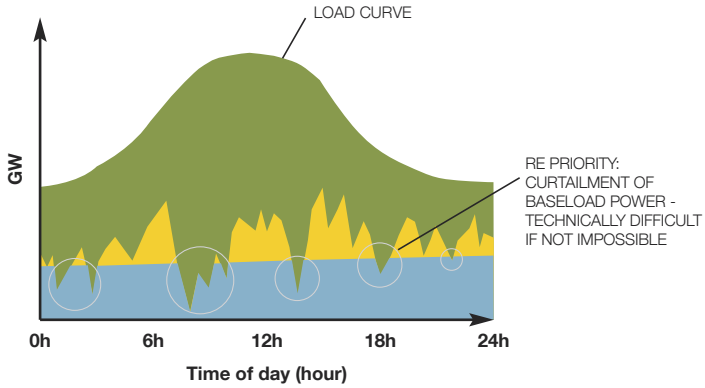


Figure 7 Supply system with more than 25 percent fluctuating renewable energy – renewable energy priority

Approach: More renewables with priority for clean energy?

If renewable energy is given priority to the grid, it "cuts into" the baseload power. This theoretically means that nuclear and coal need to run at reduced capacity or be entirely turned off in peak supply times (very sunny or windy). Since there are technical and safety limitations to the speed, scale and frequency of changes in power output for nuclear and coal-CCS plants, this is not a solution.

Technically difficult.



Battle of the grids: what's the big barrier? - continued

Planned phase out of nuclear and coal

If we want to reap the benefits of a continued and speedy growth of renewable energy technologies, they need priority access to the grid and we urgently have to phase out inflexible nuclear.

The *Energy [R]evolution* is a detailed market analysis which shows that we can reach 68 percent renewable electricity by 2030 and almost 100 percent by 2050. It also lays out a future scenario where electricity demand keeps growing, even with large-scale efficiency, because of electric vehicles displacing cars. This 2030 renewables target requires:

- an almost entire (90 percent) phaseout of coal and nuclear power by 2030.
- continued use of gas plants, which emit about half the CO_2 per kWh compared to a coal plant.

The result: CO_2 emissions in the electricity sector can fall by 65 percent in 2030 compared to 2007 levels. Between 2030 and 2050 gas can be phased out and we reach an almost 100 percent renewable and CO_2-free electricity supply.

Switching off wind turbines and giving priority to nuclear or coal is a fundamental economic and ecological mistake

image Off shore windfarm, Middelgrunden, Copenhagen, Denmark.

image Geo-thermal research drilling in the Schorfheide done by the Geoforschungszentrum Potsdam, Germany.

New research: renewable Europe 24/7

A whole-system approach is required to solve the problems of competing types of electricity supply. To find a solution Greenpeace commissioned ground-breaking research that models the whole of the European grid, running entirely on the renewable energy capacity in 2050 combined with predicted weather patterns based on 30 years of detailed records. The following pages show how it can be done.

Implications of the European electricity system

The European electricity grid is at least 50 years old. Over time it has connected more and more countries to the point where most of the grid runs as if national electricity systems do not exist anymore[6]. Integrated markets are now commonplace, like the Central Western European region (CWE) composed of Germany, France, Netherlands, Belgium and Luxemburg. Investors, namely the large European utilities, make decisions based on their European sales strategies and not national energy policies. Investments in a new plant are not linked to sales in that country, but are marketed at least regionally.

From an ecological perspective, the grid should work to help us meet strong international targets to halt climate change. The *Energy [R]evolution* scenario provides an economically and technically feasible blueprint for phasing out nuclear power and fossil fuel plants, based on European climate targets. It combines top-down policy objectives required with information from 'bottom-up' projections of what industries can deliver.

This report provides detailed steps to shift the existing electricity delivery system to one based on 100 percent renewable sources. It defines the European grid extensions required to make this possible.

Greenpeace is not the only organization advocating a European, 'top-down' approach. The recent draft communication on infrastructure from the European Commission,[7] focuses on grid requirements and policy measures in order to support three policy objectives:

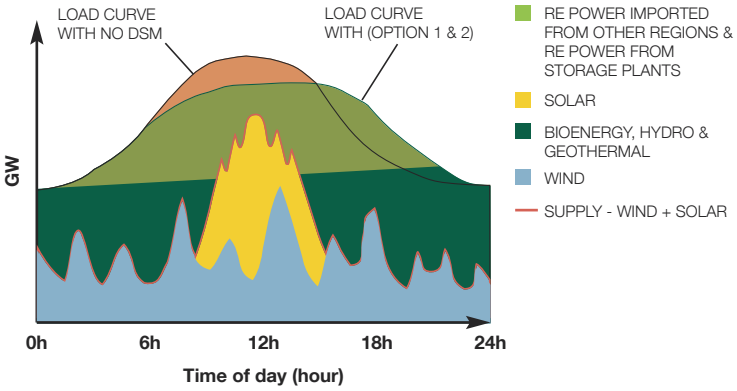
- the European-wide integration of renewable sources,
- secure supply of electricity, and
- further integrate the electricity market.

This report is an in-depth study into how to deliver the first two objectives.

Figure 8 The solution: an optimised system with over 90% renewable energy supply

The solution

A fully optimised grid, where 100 percent renewables operate with storage, transmission of electricity to other regions, demand management and curtailment only when required. Demand management is a technique that effectively moves the highest peak and 'flattens out' the curve of electricity use over a day.



6 With some exceptions, like the Iberian peninsula.
7 Energy Infrastructure Priorities. November 2010.
http://ec.europa.eu/energy/infrastructure/strategy/2020_en.htm

New research: renewable Europe 24/7 - continued

A model for Europe's energy future

Energynautics set out to model the fluctuations in energy produced from renewables in the electricity grid in 2030 and 2050. First, they constructed a model of *supply*, with the following inputs:

- the European grid consisting of 224 nodes in EU, Norway, Switzerland and Balkan countries, represented by dots on the map (centre spread).
- historical weather data at each of those nodes for solar radiation and wind, for every hour over a period of 30 years.
- the renewable and non-renewable capacities at each node, estimated for 2030 and 2050, based on the *Energy [R]evolution* scenario[8].

The model was used to calculate the renewable electricity production for each hour of the year at each node and to show dynamically the electricity production in peaks and troughs over a whole year.

Secondly, they constructed a model of *demand*, based on data from grid operators[9]. The two models were combined to calculate:

- whether supply matches demand for each hour and for each node.
- when 'dispatchable' renewables such as biomass or hydro plants should be started as backup.
- times of oversupply, e.g. when wind turbines have to be switched off because its electricity cannot be integrated in the grid due to bottlenecks (limited capacity to transport the electricity to areas with a net demand).

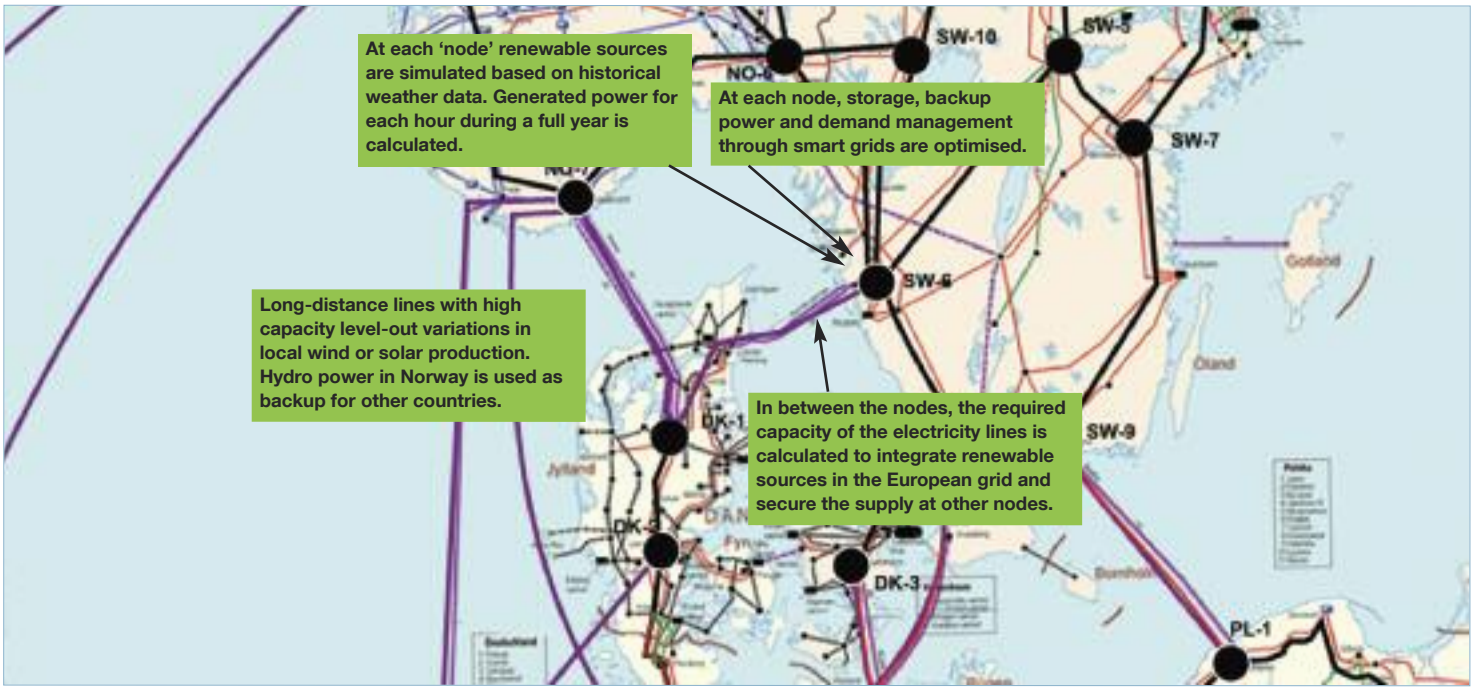
Optimisation

Greenpeace calls for a grid supporting around 68 percent renewable electricity by 2030 and 100 percent by 2050.

To do this, the researchers took an optimisation approach, which compares the costs of new grid capacity with making the production mix more flexible, improving the mix of renewable and using storage and demand management. Optimisation means both securing energy supply 24/7, even with a high penetration of variable sources and also limiting curtailment. Curtailment is when local oversupply of free wind and solar power has to be shut down because it cannot be transferred to other locations.

Optimising the system will require more grid capacity be added than strictly needed to secure supply, in order to avoid curtailment of wind and solar electricity. In the simulations, extra electricity lines were added step by step as long as the cost of new infrastructure is lower than the cost of curtailing electricity (see illustration). This will create a robust electricity grid with higher security of supply.

Figure 9 Sample illustration of nodes and interconnectors in Northern Europe



Source: Energynautics, Greenpeace.

8 Greenpeace, EU-27 *Energy [R]evolution*. http://www.energyblueprint.info/1233.0.html
9 ENTSO-E statistics. https://www.entsoe.eu/index.php?id=67

image Loading sea cables.

The optimisation process is:

- make the non-renewable capacity more flexible by phasing out nuclear and coal plants, and relying instead on gas plants as backup for variable renewable production.
- add grid capacity to avoid curtailment of wind and solar energy sources.
- improve the mix of renewable sources that complement each other.
- improve the geographical spread of renewable sources, either to locate renewables in areas with high output (e.g. windy or sunny areas) or close to electricity users to minimise transmission cost.

Pathways to 100 percent renewable energy 2050

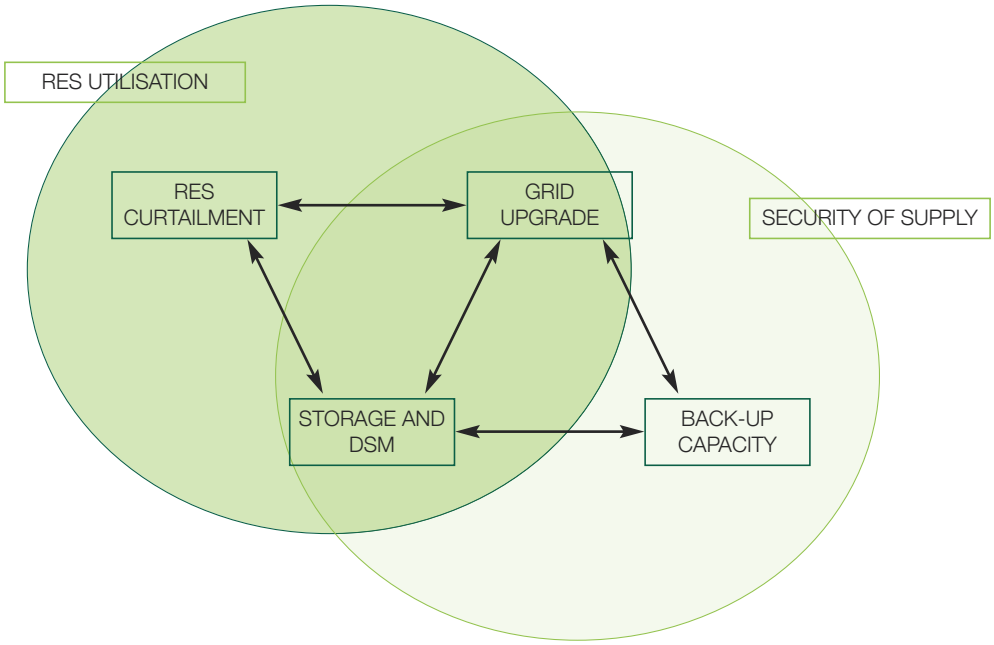
Up to 2030, following this optimisation process, this study defines a clear pathway to get to 68 percent renewables integration, a 100bn€ investment in grids and a 90 percent phase-out of nuclear and coal plants (see illustration).

The ultimate approach (2050) will depend on further technological developments, political preferences and further research. Infrastructure investments, especially electricity grids, have long lead-times for investment decisions, so at least a decade is required for implementation.

Between 2030 and 2050, we have defined two different pathways for future development:

- **'Low Grid'- Central Europe**. This pathway would seek to produce as much renewable energy close to areas with high electricity demand as possible. It is particularly focused on the centre of Europe; Germany, Netherlands, Belgium and France. Solar PV capacity in these areas is increased, even if those solar panels could supply more electricity if installed in the south of Europe. This approach would increase the generation cost per kWh, but lowers the grid investment, which is limited to 74bn€ between 2030 and 2050. Security of supply relies less on the electricity grid and long distance transmission. Instead the gas pipelines are used more intensively to transfer gasified biomass from one region to the other, thereby optimising the use of biomass as a balancing source. By gasifying biomass, the former gas plants can be converted from natural gas to biogas, thereby avoiding stranded investments in the gas sector.
- '**High Grid' – North Africa.** This approach would install a maximum of renewable energy sources in areas with the highest output, especially solar power in the South of Europe and interconnections between Europe with North Africa. This pathway would minimise the cost to produce electricity while increasing the amount of electricity to be transferred over long distances through the grid. The result is a higher interconnection cost (an investment of 581bn€ between 2030 and 2050), and strong security of supply 24/7 because the super grid capacity exceeds demand. It also balances solar production in the south and wind production in the north of Europe.

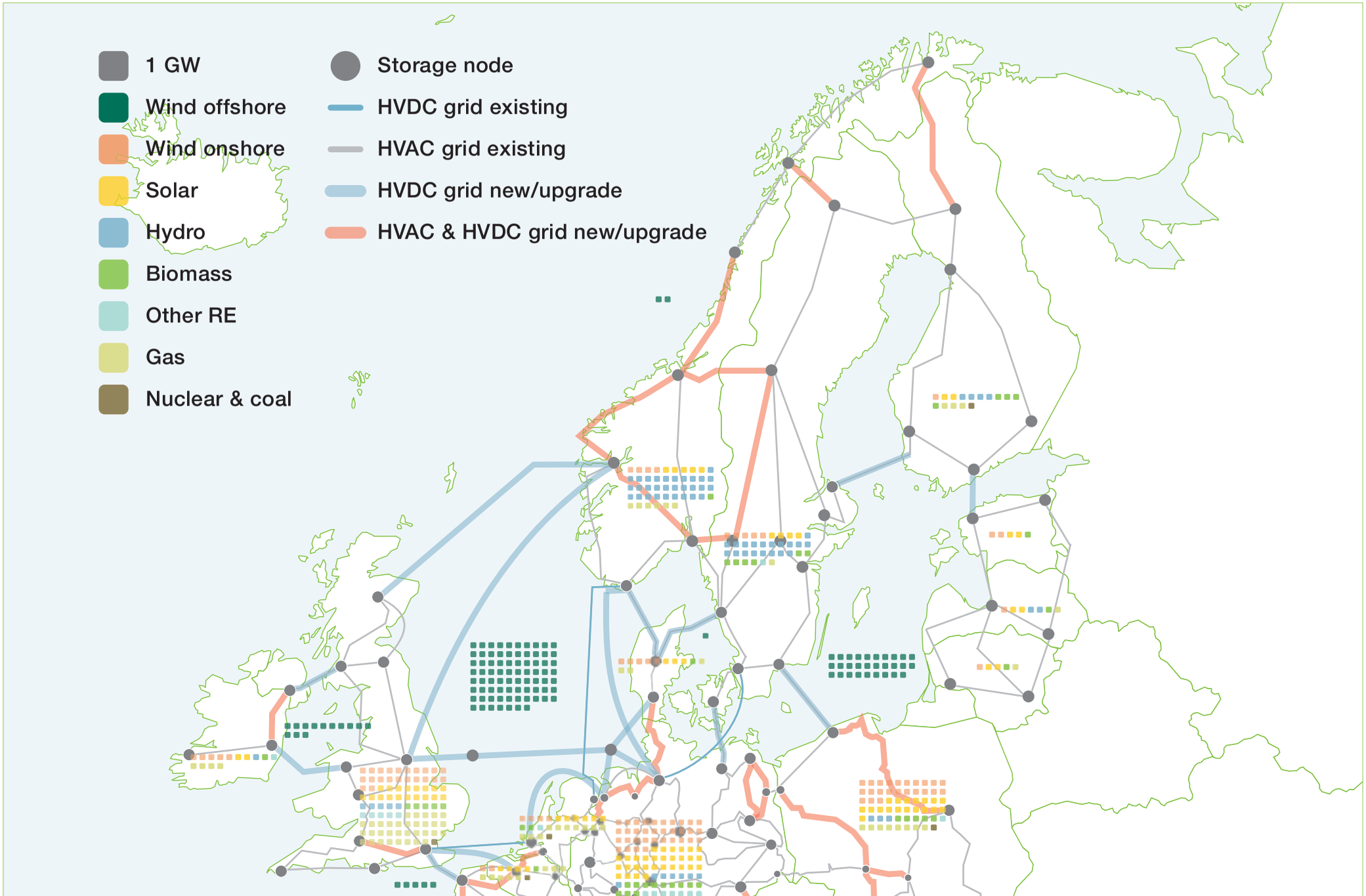
Figure 10 Optimisation process



Source: Energynautics.

The new energy map for Europe

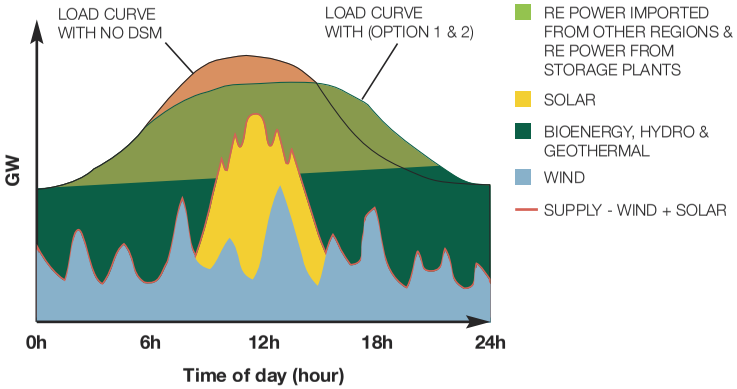
Figure 13 Overview of the future power system with 68% renewable electricity in 2030



This map represents a 68% renewable electricity system in 2030 as an intermediate step towards 100% renewable electricity in 2050

The solution

A fully optimised grid, where 100 percent renewables operate with storage, transmission of electricity to other regions, demand management and curtailment only when required. Demand management is a technique that effectively moves the highest peak and 'flattens out' the curve of electricity use over a day.



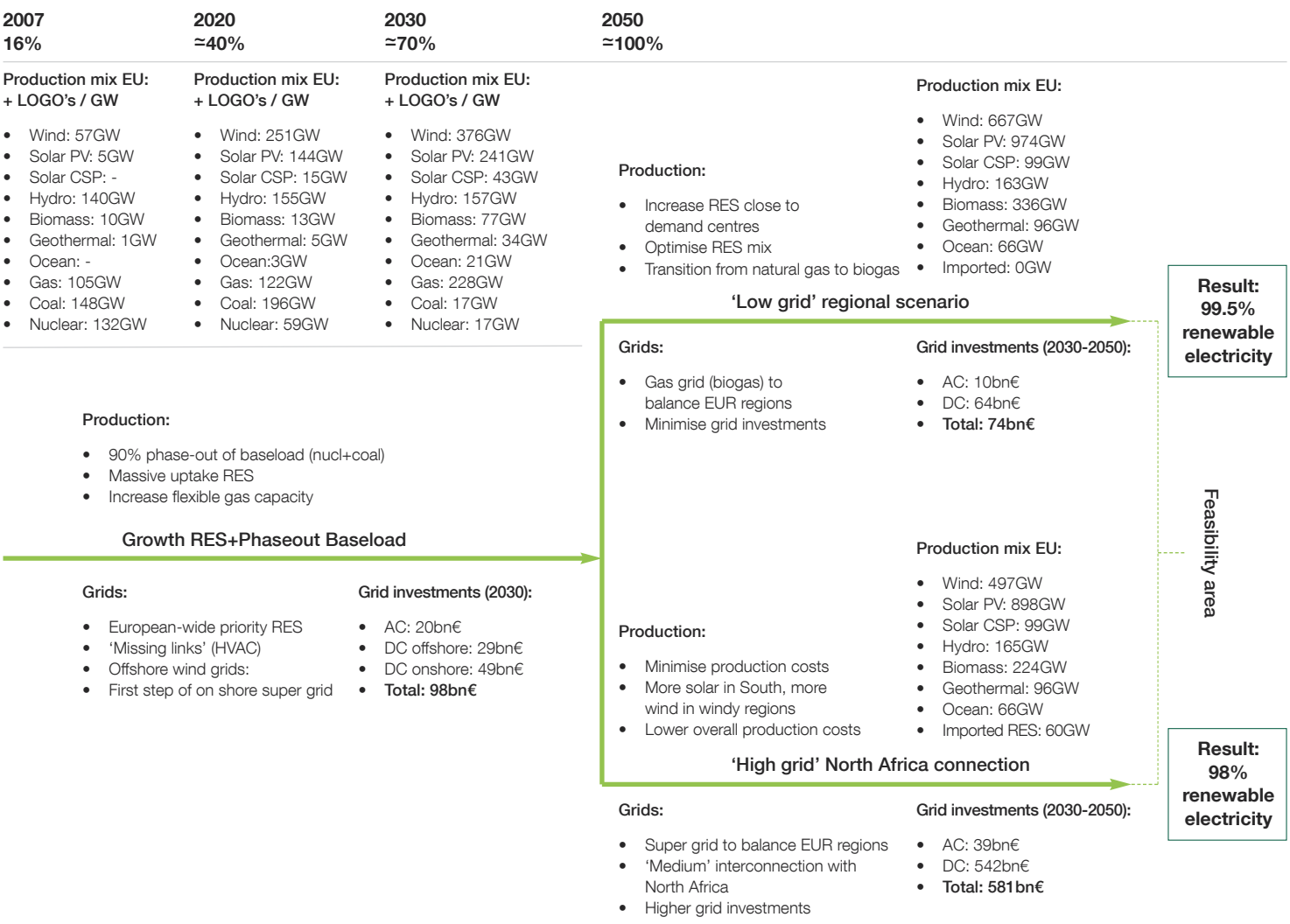
Source: Greenpeace International.

New research: renewable Europe 24/7 - continued

It should be stressed that between these 'Low Grid' and 'High Grid' scenarios after 2030, there is a large area of feasibility to combine different levels of grid development and renewable capacities. Over the next decade, European policy needs to be better formulated to provide a clearer vision for the energy mix after 2030 period.

Both 2050 scenarios confirm the single scenario for 2030. In either the Low or High Grid scenarios for post-2030, the 100bn€ grid investment before 2030 is required anyway, even though the timing might differ slightly and some of the grid investments planned in the period 2010-30 might be delayed after 2030 in the Low Grid scenario. In terms of investments in production capacity, the capacities planned by 2030 are required in both post-2030 scenarios. The Low Grid scenario will require a continued strong growth of renewables within Europe after 2030, while in the High Grid scenario, growth after 2030 will slow down in Europe due to increasing imports of renewable electricity from North Africa.

Figure 11 Pathways to 100 percent renewable electricity in 2050[10]



Source: Energynautics, Greenpeace.

10 The generation capacities for Norway, Switzerland and the Balkan countries are included in the model, but are omitted in this graph to make the data more comparable with other studies. Grid investments are for Europe.

image Close up of underwater sea cable.

Parameters of this study

This simulation of electricity production within the entire European grid has some limitations due to the complexity of calculations required in developing the concepts put forward here. In particular, extra study is recommended in the following areas, which were outside the boundaries of this research:

- Ideally, the results from the three scenarios described in this report should be fed back into the *Energy [R]evolution* scenario, in order to define overall economic costs, job creation and the interaction with the other energy sectors such as transport, heating and industry. Further integration between dynamic modelling as in this report and market scenarios such as in the *Energy [R]evolution*, would optimise overall economic costs.
- The 2030 scenario does not include an optimisation of generation capacity close to demand. It is thus more in line with the 2050 High Grid scenario. We can assume it actually underestimates the potential renewable investments for 2030 in the centre of Europe where there is high net demand over the year and resulting net imports of electricity from both Northern and Southern Europe. Further, the renewable capacities allocated to each country, or each node, in the 2030 model should not be regarded as national targets. More research is required to define a more optimal allocation of renewable capacities to each node for 2030.

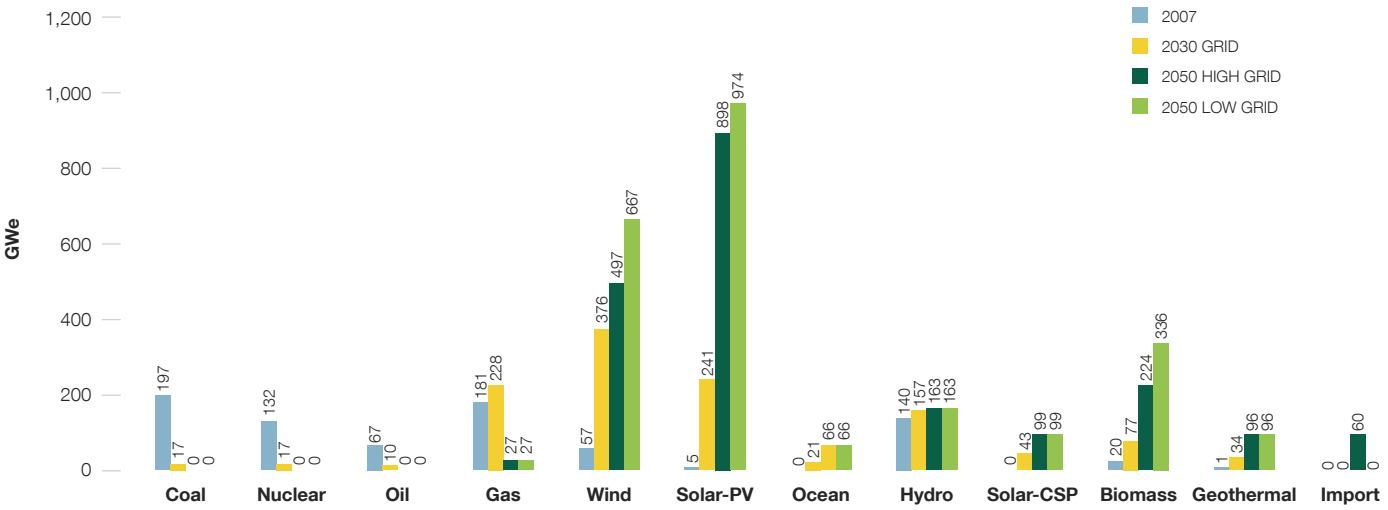
Power capacities used to model the European grid

In the *Energy [R]evolution* advanced scenario in 2030 there is 949GWe installed renewable energy capacity producing 68 percent of all electricity. By 2050, the installed capacity further increases to 1,518GWe, supplying 97 percent of the electricity.

These EU-27 capacities, which are used as input for this report, are European-wide and not allocated to each EU member state. To create our model based on 224 nodes in the EU-27, Norway, Switzerland and the Balkan states, the *Energy [R]evolution* results were allocated to each node and extended to the non-EU countries. This was done based on literature study[11] and further modelling by Energynautics.

The 2050 'Low Grid' scenario, applies some alternative dimensions to the *Energy [R]evolution* outcomes. In particular, an increase of PV and wind capacities, and an increase of the capacity of biomass plants, while keeping the annual available sustainable biomass constant.

Figure 12 Power capacities for EU-27 used for simulations in this report[12]



Note: These capacities are used to simulate electricity production at each node in the computer model of the European Grid for each hour in the year based on historical weather data (solar radiation, wind speeds). By 2030 90 percent of the nuclear and coal plants have been phased out. After 2030, gas plants are gradually converted from natural gas to biogas, so the biomass capacity mentioned for 2050 consists for a large part converted gas plants.
Source: Greenpeace, Energynautics.

11 DLR, Trans-CSP. http://www.dlr.de/tt/desktopdefault.aspx/
12 The capacities for Norway, Switzerland and the Balkan countries, which are included in the model, are omitted in this graph to make the data more comparable with other studies on the EU-27.

Six steps to build the grid for renewable Europe 24/7

STEP 1 More lines to deliver renewable electricity where it is needed:

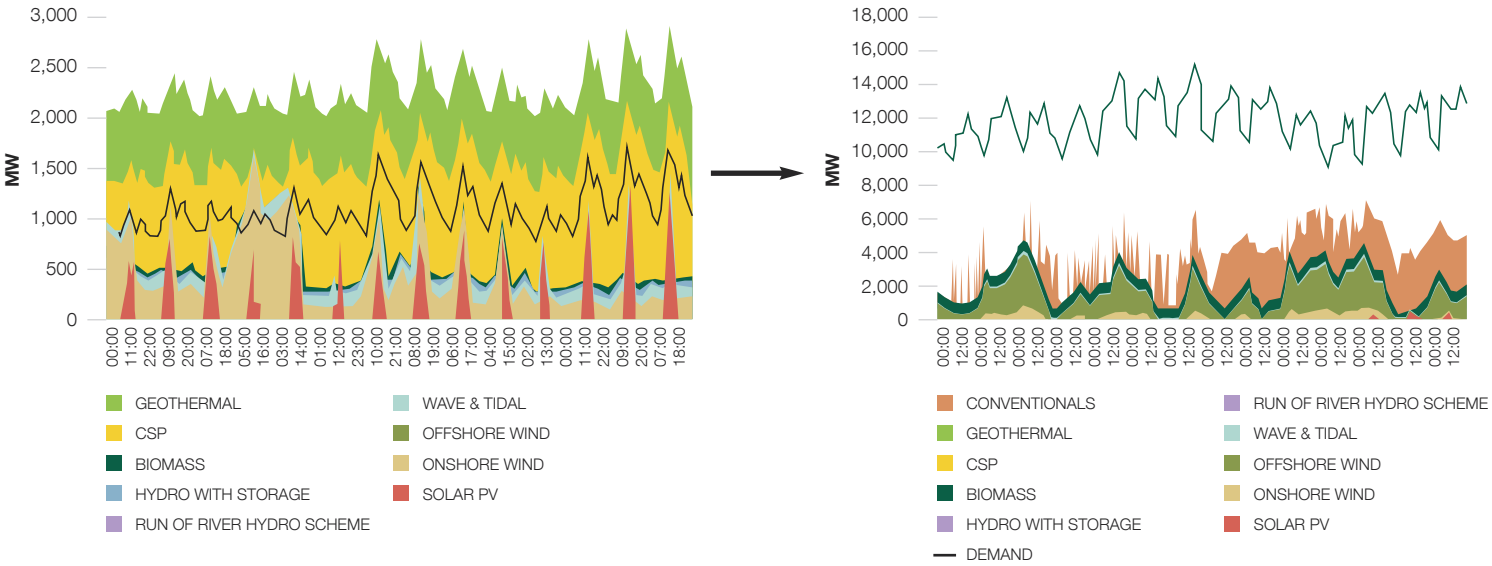
The first step in our methodology to develop a 100 percent renewable electricity system is to add more electricity lines to the base-line of the existing high-voltage grid of 2010. Lines will be needed especially from areas with overproduction, e.g. south of Europe in the summer, to areas with a high demand like Germany. This allows a more efficient use of the installed solar power. In winter months, the opposite could happen, when a large oversupply of wind power is transported from the north of Europe south to population centres. It is common for both wind speeds and solar radiation to vary across Europe concurrently, so interconnecting the variable renewables in effect 'smoothes out' the variations at any one location. Adding more grid infrastructure increases security of supply and makes better use of renewable energy sources. It also means backup capacity in Europe can be used more economically because biomass, hydro or gas plants in one region can be transferred to another region.

In this first step, lines are added to a point that is called the Base Model, electricity supply is secured in the whole of Europe 24 hours a day, seven days a week.

Box 3 High Voltage Direct Current (HVDC)

This technology can be used as an overlaying network structure to transmit bulk power, i.e. large capacity, over long distances to the areas where energy is needed. The lines have roughly half the transmission losses of more conventional High Voltage Alternating Current (HVAC). Over longer distances (more than 500km) the HVDC lines are more economic but the cost of converters goes up.[13] Another advantage of HVDC cables is that they make it easier to move the entire super grid underground. While this approach will be more costly, following existing transporting routes,laying the cables along motorways or railway tracks can allow a fast roll-out of the HVDC super grid infrastructure and reduce the visual impact of the installation.

Figure 14 Renewable energy supply and demand in an Italian town and UK during the same period



Source: Energynautics.

13 *Renewables 24/7: Infrastructure needed to save the Climate*. Greenpeace 2010. http://www.greenpeace.org/international/en/publications/reports/renewables-24-7/

image Wave power technology using a column of water to drive a turbine.

Long distance transport to stop energy loss

The Base Model focuses only on securing the supply of electricity around the clock. Our model revealed the unexpected problem that very large amounts of variable renewable sources cannot always be delivered because of bottlenecks in the grid. This problem occurs when periods of high wind or sun combine with low demand locally. Because this oversupply cannot be used in the same region, wind turbines or solar plants have to be shut down.

In the Base Model, renewable losses total 346TWh per year, or 12 percent of what these energy sources could have produced without any constraints in the grid. This represents economic losses of 34.6bn€/year.

However, renewable losses can be reduced by transporting electricity over longer distances in Europe from areas of oversupply to those with a net demand for electricity. The illustration below shows a large oversupply of renewable sources at an Italian node, while there is an undersupply in the UK over the same period. Electricity transmission from the Italian node to the UK will smooth the differences and make better economic use of the installed renewable sources.

STEP 2 Priority for renewable energy on the European grid to reduce losses

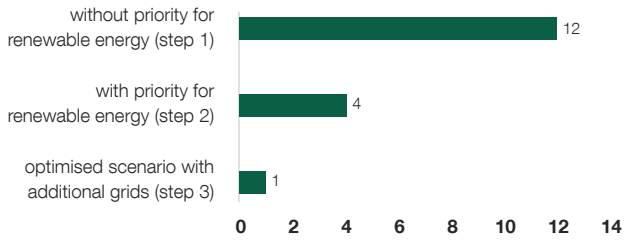
The Base Model assumes a clear priority access for renewable energy at each of the nodes. This reflects the situation in many European countries which give some level of priority at the national level. However, there are no clear priority rules at the European level, including on the interconnections between countries. For example, wind turbines in Germany currently do not have a priority over nuclear power plants in France in providing energy to the European grid.

This study also examines the effect of changing the rules to give priority to renewable sources throughout Europe, including on all interconnections, which does not require any additional investment. Under this scenario, the use of renewable sources would increase dramatically and constraining losses would be massively reduced (see Figure 15). Just by improving regulation this way, without putting security of supply at risk, renewable losses can be reduced from 12 to 4 percent, which would mean an annual saving of 248TWh of electricity or 24.8bn€/year.

Under such a new dispatch method, energy production from solar PV and wind would increase by 10 percent and 32 percent in 2030 over the base scenario without priority dispatch. And with increased generation from clean sources, generation from fossil-fuel sources will drop even more. This is particularly noticeable for power generated by gas, which would be 5 percent lower than in the Base Scenario.

For a 100 percent renewable 2050, priority rules are needed between renewable sources. Variable renewables such as wind and solar PV will get priority over dispatchable renewables such as stored hydro or biomass, which will serve as back-up.

Figure 15 Level of constrained electricity from renewable sources in 2030 (%)



Source: Energynautics 2011.

STEP 3 Additional lines to allow renewable energy through the bottlenecks

Even with a clear priority dispatch of renewable sources at the European level, there is still a significant level of renewable losses, especially for offshore wind which loses 17 percent of what could be produced without any bottlenecks in the grid. For all renewable sources this loss represents 98TWh, 4 percent of total, and an economic loss of almost 10bn€ per year.

To channel these oversupplies out of their regions would require further grid extension, in particular strengthening lines between the north and the south of Europe. There is also a need for more lines between large cities, such as London, and the offshore wind grid.

To deal with this effect, Energynautics studied what level grids should be upgraded to in order to limit the losses of renewable electricity production due to bottlenecks. By 2030, an upgrade of 28bn€, assuming the most expensive option) would reduce the losses from 4 to 1 percent, or a net saving of 66TWh per year or 6.5bn€ per year. This level of additional investment in the grid would be recovered in just a few years. Offshore wind losses would be most significantly reduced, from 17 percent to only 4 percent. A similar approach is followed for 2050.

Total investment required would be around 98bn€ up to 2030 and an additional 74bn€ or 581bn€ up to 2050 under the Low and High Grid scenarios. This allow for the more expensive approach of underground lines and new technologies such as high-voltage direct current (HVDC, see box). Infrastructure like this has a 40 year lifetime, so for 2030 this investment equates to less than 1 percent of the total electricity cost[14].

14 Calculations, based on 3553TWh/y in 2030, 98bn€ grid cost and an electricity cost of 100€/MWh.

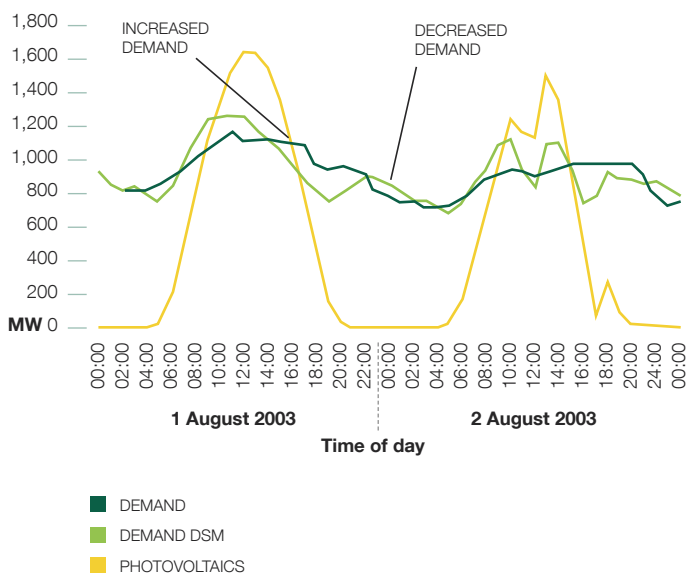
STEP 4 Demand management and smart grids to reduce transmission losses (2030 only)

Demand management and storage (step 5) have a very similar impact on the electricity system. Demand-management shifts some demand from periods with a low supply of variable renewables to periods with a higher supply, while storage can store electricity from oversupply of variable renewables to be used during periods with an undersupply.

Also referred to as demand-side management (DSM), this approach makes use of the range of technology in a smart grid (see definition list in introduction). Demand management is already common practice in many areas of industry, but could be further extended to households through grids management technologies. For example, it is possible to communicate with refrigerators so they don't run compressors during the typical peak demand of 6pm. Across whole districts this can make a difference to the demand or load curve. Demand-side management also helps to limit the losses in transporting electricity over long distances (which escapes as heat).

Demand management simulations in this study are only done for 2030. For 2050, storage simulations are used to study different levels of demand management. Given the similarities between simulations for demand-management and storage, this simplification is legitimate.

Figure 16 A typical load curve throughout Europe, shows electricity use peaking and falling on a daily basis



Source: Energynautics.

image Off shore windfarm, Middelgrunden, Copenhagen, Denmark.

image Wind turbines and electricity cables.

STEP 5 Adding storage in the system (2030 and 2050)

Another essential way to even supply and demand is to add storage capacity, for example through pumped hydro plants, batteries from electric vehicles or molten salt storage for concentrating solar power. While storage is relatively expensive, this study optimised the cost balance between investing in storage and extending the grids. There needs be a balance between extending the grid and adding more storage. This study used cost optimisation to determine that point.

As mentioned under step four, storage simulations are also used to study the impact of demand-management in 2050. Storage is factored at the European level, thus oversupply at one node can be stored at another, and this stored electricity can then be used as backup at any node in the European grid, a long as transport capacity is available.

Storage and demand-management combined have a rather limited impact on the 2030 high-voltage grid. We can assume some impact at the distribution level (the more local grid), but this is not studied in this report. This relatively low impact by 2030 is a consequence of the 98bn€ investment in grids, as modelled in this report, which allows the smooth integration of up to 68 percent renewables, as long as 90 percent of 'baseload' coal and nuclear are phased out.

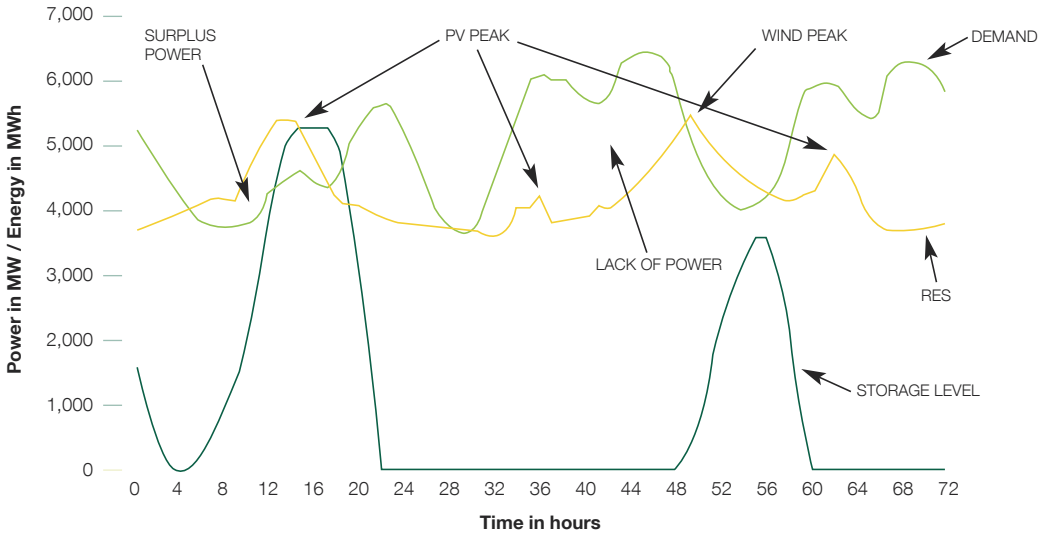
However for 2050, integration of close to 100 percent renewable power is far more challenging for the electricity system than 68 percent in 2030, and storage and demand-management play a substantial role in balancing supply and demand. Especially in the Low Grid scenario, which emphases a high regional production close to demand centres, storage and demand-management can decrease the curtailment of renewable electricity from 13 percent to 6 percent. We assume that by 2050, it will be possible to use a significant part of this curtailed electricity either for storage or other electricity use.

STEP 6 Security of supply: electricity 24/7 even if the wind doesn't blow

Adding lines, storage and demand management all increase security of supply because even under an extreme weather event of low wind combined with low solar during winter, excess wind power from another region can be imported. To test the modelled system, the most extreme weather events over the last 30 years were identified and applied to the calculation. This is typically a winter period with low wind, when solar radiation is also low and demand is typically high. The model can then tell if the optimal system can withstand the test or if more electricity lines would have to be added.

For the 2030 and 2050 models, the simulations prove that the optimised model is robust enough to withstand even the most extreme climatic events.

Figure 17 Utilization of storage at a location in Spain



Source: Energynautics.

The inflexible, dirty energy model for 2030

As part of this study, Energynautics was asked to also develop a 'Dirty Model', to find out what would happen if we try to maintain the electricity system with coal and nuclear plants running in a baseload mode.

This model assumes half of the gas capacity in the *Energy [R]evolution* scenario has been displaced by inflexible coal and nuclear plants or an additional 114GW. This represents the equivalent of some 114 large coal or nuclear plants of 1,000MW. The total inflexible baseload capacity is thus 148GW, close to today's 158GW (2007).

As previously discussed, running the inflexible coal and nuclear plants as 'baseload' poses problems for the large-scale integration of variable renewable sources. This part of the research was done to investigate claims by some nuclear utilities that nuclear and coal can perfectly complement renewable sources.

It is argued by some nuclear utilities that technical adaptations of nuclear reactors could improve their flexibility[15]. However, increasing nuclear flexibility decreases the safety of the reactor and there are technical limitations to the speed and frequency of changes in its power output. Furthermore, assuming that nuclear and coal plants would theoretically fully 'fit in' and complement variable renewables, as argued by E.ON, the economics of nuclear and coal would deteriorate dramatically. The average load factor for a hypothetical flexible nuclear power plant would be around 50 percent by 2030. This means that investing today in a new nuclear power plant with a price tag of some 6bn€ would result in major economic losses (see more details in the chapter Implications for investors). The inflexibility of a very expensive nuclear reactor or coal plant with carbon capture is therefore not only a technical and safety issue, but also a financial problem.

The study found that even by keeping nuclear and coal close to today's levels would have a significant negative economic impact on the overall electricity system. Due to their inflexibility, more renewable electricity would be lost, because the electricity system cannot effectively respond to variations in the supply of renewable electricity. Losses are estimated at 316TWh per year or 32bn€ per year. The system cost of more coal and nuclear power in just four years would be higher than the total cost for grid upgrades of 98bn€ in the *Energy [R]evolution* scenario until 2030.

The prospect of a steadily growing renewable energy share in the production mix is therefore increasing the investment risks for nuclear power. Even if nuclear utilities would succeed in slowing down the further growth of renewables, in order to protect their vested interests in nuclear and coal, a high load factor remains highly unlikely. Only reckless investors will trust estimations of a load factor of 85 percent over the reactor's whole lifetime, as presented by nuclear project developers.

Even though the industry may claim that nuclear energy has a role to play in Europe, this is far from reality. Two "flagship" nuclear power projects being built in Finland and France are facing severe technical problems, causing major delays and cost overruns of some 3bn€ each. Large nuclear utilities such as RWE and E.ON are now calling for massive subsidies in the UK before engaging in another expensive nuclear reactor project.

15 IER, Verträglichkeit von erneuerbaren Energien und Kernenergie im Erzugungsportfolio. Commissioned by E.ON, 2009.

image Wind turbine construction yard, UK.

Case studies

German case study

Germany produced 16.1 percent of its electricity demand from renewable sources in 2009, with wind power providing 6.5 percent of the demand. As such Germany more than doubled its renewable energy share in only six years, up from 7.5 percent in 2003[16].

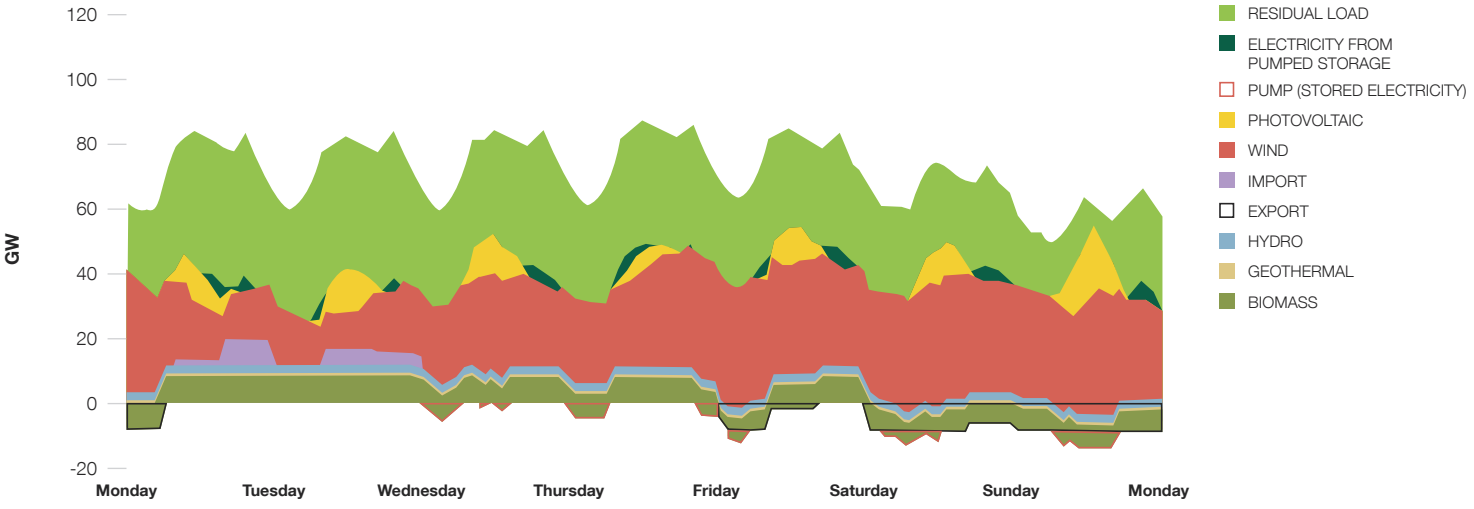
The German Federation of Renewable Energy (BEE) projects that a continuation of this strong renewable growth in Germany would further increase its share from 16.1 percent to 47 percent in 2020, or almost half of all electricity demand[17]. Due to the high share of variable wind and solar PV in the 2020 renewables mix (68 percent), its integration requires adaptations to the electricity system.

Simulations by the German research institute Fraunhofer-IWES, commissioned by BEE, demonstrate that by 2020 electricity production from renewable sources could exceed total demand in Germany during periods with high winds or solar radiation. An impressive 47% of the annual out-put would come from renewable sources; production could thus rise to 70GW, while total demand would only be 58GW. The 12GW extra power could be stored in pumping stations or be exported to other countries (See Figure 18)[18].

Fraunhofer also calculated that by 2020, about half of the existing baseload capacity (nuclear and coal) in Germany would have to be shut down in order to enable the smooth integration of the renewable electricity.

These findings are in sharp contradiction with the decision by the German government of September 2010 to extend the lifetime of Germany's nuclear reactors by an average of 12 years (eight years for reactors commissioned up to 1980, and 14 years for the younger plants). This lifetime extension is however not yet set in stone and will be legally challenged by Greenpeace and several German states at the country's Constitutional Court.

Figure 18 Simulation of the electricity generation from renewable sources in Germany in 2020 for one week. On Sunday, total renewable production exceeds total demand, and is used for storage and export



Source: Fraunhofer-IWES, 2009.

16 Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), Renewable Energy Sources in Figures - National and International Development. June 2010. http://www.erneuerbare-energien.de/files/english/pdf/application/pdf/broschuere_ee_zahlen_en_bf.pdf
17 Fraunhofer-IWES, Dynamische Simulation der Stromversorgung in Deutschland. Im Auftrag des BEE. December 2009. http://www.bee-ev.de/_downloads/publikationen/studien/2010/100119_BEE_IWES-Simulation_Stromversorgung2020_Endbericht.pdf
18 Ibid.

Spanish case study

The Spanish renewable electricity sector has grown impressively in recent years. Wind power capacity more than doubled in four years from 8.7GW in 2005 to 18.7GW by the end of 2009[19]. Wind produced 16% in 2010, and all renewables together produced more electricity (35%)[20] than nuclear power (21%) and coal (8%) together. It is projected that if renewable sources continue this growth rate, they would supply 50 percent by 2020.

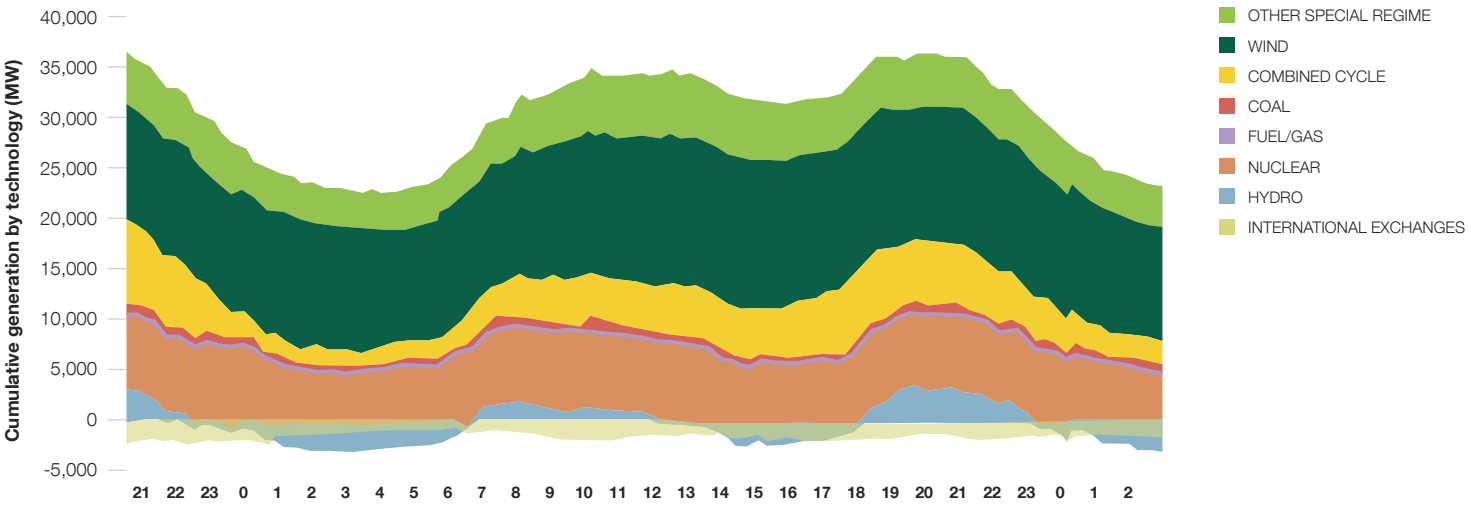
However, while the market still showed a very dynamic growth over 2005 and 2006 with around 3GW of wind power installed each year, growth since has slowed down. For 2010, it is expected to remain at around 1GW[21]. A combination of government caps on new installations and high uncertainty of regulation is to blame.

The actions of the Spanish government to slow the growth of renewables came after criticism from the large utilities. These companies have experienced a drop in profits of their coal and gas plants through a combination of a decreasing electricity demand due to the economic crisis, growth of new renewable supply and an inflexible nuclear baseload production. While gas plants capacity increased by 6 percent in 2009, their annual output was reduced by 14 percent, thereby lowering their average load factor to 38 percent.

The inflexibility of nuclear power output is clearly illustrated by the Nov. 9th 2010 event with a record-high wind production reaching almost 15GW of power and covering almost half of all Spanish electricity demand. As can be seen in the graph representing the electricity production of that day, the strong increase of renewable energy production was confronted with an inflexible (unchanged) nuclear baseload production which forced gas plants to constrain almost all of their energy output. Repeating similar events over the last two years, wind turbines had to be stopped, not because of grid limitations to transport wind power to demand centres, but because of oversupply caused by the 'must run' status of Spain's nuclear plants[22]. It is estimated that for 2010, some 200GWh of wind electricity will be curtailed by giving priority to nuclear power[23].

This problem caused by the inflexibility of nuclear plants will inevitably increase over the next years with the further growth of wind and solar power. As demonstrated in our simulations for 2030 in this report, a swift phase out of baseload power is needed to avoid economic losses in the electricity system. If this does not happen, it is the free, clean renewable electricity which has to be constrained.

Figure 19 Electricity supply on 9 November 2010 in the spanish system showing over 50% of demand covered by wind power



Source: Red Electrica, 2009.

19 Red Electrica, The Spanish Electricity System 2009.
20 Red Electrica, The Spanish Electricity System, Preliminary report 2010.
21 Power In Europe 588, Nov. 15th 2010.
22 In the early hours of Dec. 30th 2009, wind power covered 54.1 percent of electricity demand and wind power had to be curtailed by 600MW, giving priority to nuclear production.
23 Red Electrica, Dificultades de integración eólica. Noviembre 2010.

image Cooling Towers at Didcot Power Station, UK.

Implications for investors

One of the key conclusions from this research is that in the coming decades, traditional power plants will have less and less space to run in baseload mode. With increasing penetration of variable generation from wind and photovoltaics in the electricity grid, the remaining part of the system will have to run in more 'load following' mode, filling the immediate gap between demand and production.

This means the economics of baseload plants like nuclear and coal will change fundamentally as more variable generation is introduced to the electricity grid.

Gas-fired power plants have relatively low fixed costs (construction represents about 15 percent to 20 percent of power generation cost) and high marginal costs, about 60 percent of generating cost is defined by the cost of fuel, i.e. natural gas. This means that gas plants can remain economic even at lower capacity factors below 50 percent.

Very much opposite is the situation of nuclear reactors, and to some extent also coal (lignite, or any coal run with carbon capture and storage). With nuclear power plants, the fixed costs are high and represent 65 percent to 80 percent of the generation costs, whereas the marginal costs are around 15 percent to 20 percent. The immediate implication is that while it may be profitable to operate a nuclear reactor at baseload mode 85 percent or more time of the year, its economic performance dramatically deteriorates if the load drops even by several percent, not to mention bellow 50 percent.

The 2030 simulations in this report show that with 68 percent renewable electricity, the average annual load factor of flexible gas plants is 46 percent. Inflexible nuclear and coal are phased out by 90 percent. If hypothetically, nuclear or coal plants could be made as flexible as gas plants, they would still have to fit in the system and their load factor would be limited to less than 50 percent by 2030 and further decreasing afterwards. This means that any profitability of new nuclear or coal plants would completely evaporate.

An investment model developed by PwC, commissioned by Greenpeace in 2008, based on standard parameters of electricity market in Europe, clearly shows this effect. The net present value (NPV) of a new reactor is minus 2.3 bn€ for a typical power plant of 1,000MW and a capacity factor of 85 percent. This means an investor would lose more than 2 bn€ building this new reactor. If the capacity factor drops to 33 percent, operating for one third of the year, this would more than double the financial loss, the net present value reaches minus 5 bn€.

The assumption of this calculation is a 1,000MW power plant with a 4,000 Euro per kW overnight capital cost. By comparison, the financial risk for this size of power generator running on other types of fossil fuels are shown in the table below.

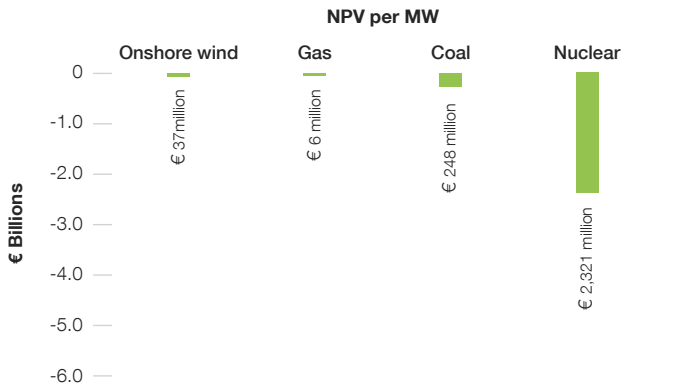
Table 2 Financial risk for this size of power generator running on other types of fossil fuels

Gas at 85% capacity	NPV: zero
Gas at 33% capacity	NPV: -708 million €
Coal at 85% capacity	NPV: - 240 million €
Coal at 33% capacity	NPV: - 1,065 million €

Source: Own calculation using the investment model and parameters by [PWC 2008].

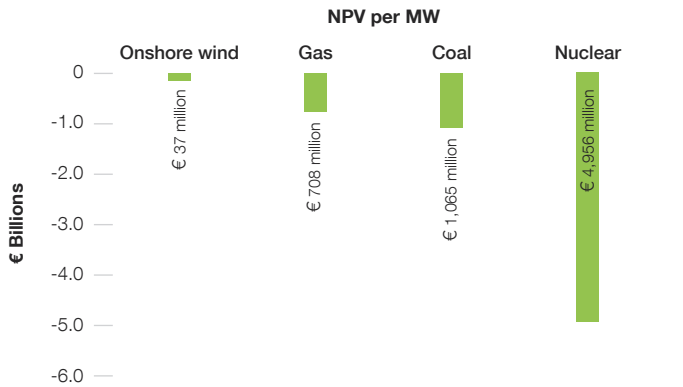
This is a big warning to any investors considering construction of new nuclear power plants. Net present value is based on a lifetime of 40 or 50 years and it is clear that if load factors drop significantly in 2020 or 2030, there would be massive stranded assets and the investment would never be paid back.

Figure 20 Net Present Value of an investment to a new 1,000 MW power plant, based on different technologies, assuming 85 % load factors (and 25 % for wind)



Source: Greenpeace calculation using the investment model and parameters by [PWC 2008].

Figure 21 Net Present Value of an investment to a new 1,000 MW power plant, based on different technologies, assuming 33 % load factor (and 25 % for wind)



Source: Greenpeace calculation using the investment model and parameters by [PWC 2008].

Policy recommendations

To drive a sustainable, robust and cost-effective power system, the EU policy framework should aim to usher in the maximum share of renewable energy possible by 2050. The transition of the power system should be guided by overarching principles of flexibility, system efficiency and transparency.

Greenpeace calls for the following steps to modernise Europe's electricity system.

1. Promote new renewable energy and a flexible power generation mix

A balanced regional spread of renewable power

The EU has already adopted a Renewable Energy Directive. An effective implementation of this is required to create a more sustainable power system. Stable, long-term national support policies are required to encourage renewable energy generation across all European countries.

A flexible generation mix

To complement variable renewable energy sources, Europe's energy policy should focus on the development of flexible power generation capacities, including the dispatchable renewable power sources and natural gas, as well as cost-effective storage technologies. In order to support the investment in more flexible (gas) power plants, Greenpeace recommends introducing a capacity bonus system.

The intra-day rescheduling of power generation should take into account all power generators, including the less flexible ones. Congestion charges should reflect the system inefficiencies that inflexible generation (nuclear and coal) cause in the network.

2. A truly European network and market management

Network development to anticipate growing shares of renewable energy

The planning and development of Europe's power system should be done with an overall view to integrating increasing shares of renewable energy sources.

The European Transmission System Operators' (ENTSO-E) Ten Year Network Development Plans should reflect the renewable energy forecasts in line with the Renewable Energy Directive.

At the same time, an independent European body should be created to oversee and coordinate European grid planning and developments. Its tasks should include also the development and analysis of long-term scenarios and network development options.

A European-wide legal framework and regulation

A European-wide legal framework is required to build and operate a cross-border transmission system. It should include a regulatory approach for international transmission and continue to harmonise network codes. Europe also requires accelerated standardisation of transmission technology to move towards a truly international power system.

Cross-border markets for the day-ahead and intra-day trading of power should be introduced to allow for a truly integrated market capable of exploiting efficiencies. At the same time, European energy regulators should allow for the international exchange and accounting of reserve capacity.

Financing tools to overcome bottlenecks

As a first priority, national and European regulators should create appropriate framework conditions to enable network upgrades and developments.

In addition, to overcome bottlenecks to international transmission, the European Commission should propose financing mechanisms for international transmission projects where the individual business case does not sufficiently reflect the wider economic benefit.

Demonstration projects for innovative approaches to onshore grid upgrades and the construction of offshore grids should be supported on the European and national level. These ground-breaking projects are necessary to help develop cross-border networks and test the technical and regulatory conditions.

3. Smart and efficient infrastructure

Support smart grid technology and demand side management

The European Union should focus on the development of smart grid technology and demand management measures through research and development support, streamlining and standardising technology, and the support of demonstration projects.

Incentives to optimise existing infrastructure

Energy regulators should give priority to the optimisation of existing grid infrastructure over the construction of new power lines. Examples of the many technical and operational methods to optimise existing power lines are 'dynamic power line rating' or replacement of existing lines with improved transmission technology.

4. Transparency and public acceptability

Respecting environmental and public concerns

Energy regulators should have a wider mandate to include environmental consideration and public acceptance as a criterion for the authorisation of new power lines, alongside economic deliberations. The optimisation of existing power infrastructure should have the first priority. Where it can speed up the process, cables should be given preference over overhead power lines, and where possible, new power lines should be constructed along existing infrastructure corridors.

Transparency of network and market data

Transmission system operators should release data underlying network development plans to allow for fair market conditions and public scrutiny.

Regulatory authorities should have full access to all relevant information concerning the power network and market operation and should have sufficient resources to monitor and verify the potential abuse of power by different market players. The Agency for the Cooperation of Energy Regulators should develop transparent criteria to establish an acceptable return on infrastructure investments.

Appendix A Installed capacity and maximum demand (both in GW) for the import 'High Grid' scenario for 2050

Country	Wind	Photo-voltaics	Geo-thermal	Biomass	CSP plants	Wave/ tidal	Hydro-power	Gas	Coal	Nuclear	Total	Max demand
Europe	**510,51**	**805,86**	**97,13**	**226,41**	**99,1**	**67,48**	**220,68**	**28,93**	**0,00**	**0,00**	**2056,10**	**931,36**
Albania	0,26	2,06	0,00	1,43	0,00	0,00	1,56	0,17	0,00	0,00	**5,48**	3,07
Austria	6,83	10,98	2,57	4,72	0,00	0,00	13,90	0,45	0,00	0,00	**39,45**	10,43
Bosnia-Herzegovina	1,07	3,58	0,00	0,86	0,00	0,00	3,25	0,00	0,00	0,00	**8,76**	3,89
Belgium	7,84	7,32	0,00	5,83	0,00	0,00	0,13	0,92	0,00	0,00	**22,03**	22,04
Bulgaria	3,43	10,73	0,51	1,13	0,00	0,00	2,95	0,11	0,00	0,00	**18,87**	12,91
Switzerland	0,79	16,52	0,00	2,03	0,00	0,00	13,72	0,16	0,00	0,00	**33,22**	15,03
Czech Republic	2,38	8,54	0,00	3,39	0,00	0,00	2,58	0,34	0,00	0,00	**17,24**	17,52
Germany	88,89	60,98	19,13	32,87	0,00	3,04	7,52	3,74	0,00	0,00	**216,16**	120,10
Denmark	11,57	5,63	0,00	3,44	0,00	0,75	0,01	0,41	0,00	0,00	**21,81**	11,08
Estonia	2,05	3,17	0,00	1,32	0,00	0,76	0,00	0,05	0,00	0,00	**7,36**	2,65
Spain	66,67	149,30	15,30	20,65	57,09	12,15	24,00	4,01	0,00	0,00	**349,17**	85,87
Finland	5,08	3,66	0,00	6,86	0,00	0,68	3,88	0,38	0,00	0,00	**20,54**	19,31
France	71,43	76,80	9,50	27,41	5,00	11,39	28,62	3,05	0,00	0,00	**233,19**	137,56
United Kingdom	77,37	37,17	0,17	24,60	0,00	16,71	4,78	3,94	0,00	0,00	**164,74**	89,42
Greece	8,94	58,96	3,98	3,78	7,76	2,28	5,49	0,68	0,00	0,00	**91,87**	20,57
Croatia	2,97	4,94	0,31	1,04	0,00	0,31	2,51	0,02	0,00	0,00	**12,11**	5,68
Hungary	1,43	11,79	11,92	4,12	0,00	0,00	0,53	0,54	0,00	0,00	**30,33**	13,53
Ireland	7,94	5,02	0,00	3,06	0,00	1,90	0,61	0,43	0,00	0,00	**18,96**	8,21
Italy	29,37	161,15	23,20	27,19	15,55	10,63	24,90	4,78	0,00	0,00	**296,77**	120,64
Lithuania	1,76	3,66	0,00	1,42	0,00	0,38	0,22	0,07	0,00	0,00	**7,51**	3,36
Luxembourg	0,29	2,44	0,00	0,24	0,00	0,00	1,31	0,03	0,00	0,00	**4,31**	1,86
Latvia	1,19	3,66	0,00	1,59	0,00	0,76	1,84	0,11	0,00	0,00	**9,15**	2,31
Montenegro	0,13	0,62	0,00	0,55	0,00	0,63	0,93	0,04	0,00	0,00	**2,90**	1,24
Macedonia	0,07	3,10	0,00	0,74	0,00	0,00	0,83	0,09	0,00	0,00	**4,83**	3,19
Netherlands	11,19	12,20	0,84	8,07	0,00	0,61	0,04	1,14	0,00	0,00	**34,09**	24,60
Norway	7,93	10,18	0,00	4,52	0,00	0,63	31,48	0,68	0,00	0,00	**55,42**	36,70
Poland	54,77	36,59	1,10	10,85	0,00	0,34	2,99	0,97	0,00	0,00	**107,61**	45,16
Portugal	14,29	56,99	3,79	4,17	13,70	2,39	6,11	0,57	0,00	0,00	**102,01**	13,43
Romania	5,24	13,41	0,43	4,88	0,00	0,00	6,56	0,36	0,00	0,00	**30,88**	16,55
Serbia	0,13	4,96	1,13	2,67	0,00	0,00	3,53	0,36	0,00	0,00	**12,78**	11,70
Slovakia	0,48	7,15	2,16	1,54	0,00	0,00	3,06	0,14	0,00	0,00	**14,53**	9,23
Slovenia	0,86	4,09	0,25	1,09	0,00	0,00	1,42	0,11	0,00	0,00	**7,81**	4,28
Sweden	15,87	8,54	0,84	8,34	0,00	1,14	19,42	0,06	0,00	0,00	**54,21**	38,24

Source: energynautics.

Appendix B Installed capacity and maximum demand (both in GW) for the regional 'Low Grid' scenario for 2050

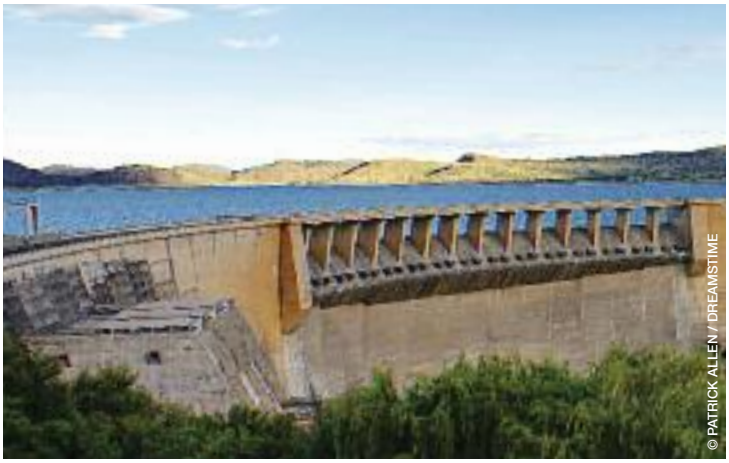
Country	Wind	Photo-voltaics	Geo-thermal	Biomass	CSP plants	Wave/ tidal	Hydro-power	Gas	Coal	Nuclear	Total	Max demand
Europe	**689,24**	**1089,25**	**97,13**	**360,50**	**99,1**	**67,48**	**220,68**	**28,93**	**0,00**	**0,00**	**2652,31**	**886,03**
Albania	0,30	2,62	0,00	0,94	0,00	0,00	1,56	0,17	0,00	0,00	**5,60**	2,77
Austria	6,83	8,78	2,57	4,51	0,00	0,00	13,90	0,45	0,00	0,00	**37,04**	9,49
Bosnia-Herzegovina	1,18	5,07	0,00	1,38	0,00	0,00	3,25	0,00	0,00	0,00	**10,87**	3,49
Belgium	24,00	33,36	0,00	13,44	0,00	0,00	0,13	0,92	0,00	0,00	**71,84**	22,58
Bulgaria	5,81	25,55	0,51	4,41	0,00	0,00	2,95	0,11	0,00	0,00	**39,34**	11,83
Switzerland	1,38	37,19	0,00	5,89	0,00	0,00	13,72	0,16	0,00	0,00	**58,34**	13,74
Czech Republic	8,82	42,21	0,00	10,15	0,00	0,00	2,58	0,34	0,00	0,00	**64,11**	17,87
Germany	115,76	146,51	19,13	62,26	0,00	3,04	7,52	3,74	0,00	0,00	**357,96**	119,67
Denmark	13,76	8,47	0,00	3,62	0,00	0,75	0,01	0,41	0,00	0,00	**27,03**	10,32
Estonia	2,17	3,51	0,00	1,58	0,00	0,76	0,00	0,05	0,00	0,00	**8,08**	2,42
Spain	66,67	48,78	15,30	7,70	57,09	12,15	24,00	4,01	0,00	0,00	**235,70**	73,82
Finland	10,31	12,93	0,00	7,51	0,00	0,68	3,88	0,38	0,00	0,00	**35,69**	20,29
France	100,36	184,52	9,50	65,28	5,00	11,39	28,62	3,05	0,00	0,00	**407,72**	136,71
United Kingdom	114,98	114,55	0,17	45,43	0,00	16,71	4,78	3,94	0,00	0,00	**300,56**	90,88
Greece	8,94	19,51	3,98	1,77	7,76	2,28	5,49	0,68	0,00	0,00	**50,41**	18,11
Croatia	3,71	8,80	0,31	1,87	0,00	0,31	2,51	0,02	0,00	0,00	**17,54**	5,16
Hungary	1,47	13,46	11,92	2,62	0,00	0,00	0,53	0,54	0,00	0,00	**30,55**	12,14
Ireland	10,72	7,97	0,00	3,95	0,00	1,90	0,61	0,43	0,00	0,00	**25,57**	7,77
Italy	36,26	114,42	23,20	32,25	15,55	10,63	24,90	4,78	0,00	0,00	**262,00**	107,01
Lithuania	2,14	5,09	0,00	1,91	0,00	0,38	0,22	0,07	0,00	0,00	**9,81**	3,02
Luxembourg	0,41	3,42	0,00	0,78	0,00	0,00	1,31	0,03	0,00	0,00	**5,94**	1,64
Latvia	1,19	2,93	0,00	1,17	0,00	0,76	1,84	0,11	0,00	0,00	**7,99**	2,06
Montenegro	0,13	0,62	0,00	0,39	0,00	0,63	0,93	0,04	0,00	0,00	**2,74**	1,15
Macedonia	0,09	5,29	0,00	1,23	0,00	0,00	0,83	0,09	0,00	0,00	**7,54**	2,94
Netherlands	20,84	29,14	0,84	14,18	0,00	0,61	0,04	1,14	0,00	0,00	**66,79**	24,69
Norway	14,94	34,12	0,00	8,53	0,00	0,63	31,48	0,68	0,00	0,00	**90,38**	34,53
Poland	64,73	60,15	1,10	23,70	0,00	0,34	2,99	0,97	0,00	0,00	**153,98**	40,43
Portugal	14,29	19,51	3,79	2,62	13,70	2,39	6,11	0,57	0,00	0,00	**62,98**	11,88
Romania	8,82	21,58	0,43	6,55	0,00	0,00	6,56	0,36	0,00	0,00	**44,31**	15,14
Serbia	0,45	21,25	1,13	4,18	0,00	0,00	3,53	0,36	0,00	0,00	**30,90**	11,34
Slovakia	0,76	16,53	2,16	3,85	0,00	0,00	3,06	0,14	0,00	0,00	**26,50**	8,54
Slovenia	1,07	6,56	0,25	1,34	0,00	0,00	1,42	0,11	0,00	0,00	**10,75**	3,79
Sweden	25,95	24,85	0,84	13,51	0,00	1,14	19,42	0,06	0,00	0,00	**85,77**	38,78

Source: energynautics.

Types of renewable electricity generation technologies

Controllable or dispatchable renewable energy

Hydro power from stocked reservoirs is fully controllable and very flexible, it can be switched on and off very quickly. Some plants can function in reverse (pumping stations) which use excess electricity to pump water up when there is a oversupply, then lets the water down again to produce power when there is a high demand.


© PATRICK ALLEN / DREAMSTIME

Biomass energy comes from burning or gasifying a variety of organic sources to generate electricity. Some plants use gasified biomass and can run in the same way as traditional fossil fuel gas plants. Biomass can be used as a backup for variable renewables.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Concentrated Solar Power (CSP) uses the heat of the sun to drive turbines or an engine. This requires direct sunlight, and CSP is only viable in very sunny regions such as the south of Spain. These plants can supply electricity on demand, even during the night when they include heat storage (e.g. molten salt).


© MARKEL REDONDO / GREENPEACE

Geothermal energy uses heat from the earth above 100°C to produce electricity with steam turbines. They typically run as baseload, but could also be more flexible.


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Variable renewable energy

Wind power is variable, but over larger areas there is an evening out effect. Essentially, the wind is always blowing somewhere.

Solar photovolatic has no electricity output during the night, but daily output is highly predictable. Solar PV is mostly decentralised, with installation on rooftops. By 2030, it is assumed that solar PV will be an ideal combination with electric vehicles that can be charged with surplus solar electricity.

Predictable renewable energy

Ocean energy from the tides or waves is not controllable. It cannot be switched on and off, but is both highly predictable and allows, network operators to plan their contribution.

Non-renewable

Nuclear power is generated in very large power plants, usually several reactors are grouped, it is highly centralised and requires large transmission networks. It is costly and dangerous to increase and decrease the power output, particularly when this is done rapidly. Therefore, nuclear reactors must be considered as inflexible (baseload).

Coal power plants are somewhat more flexible than nuclear but their efficiency decreases and CO_2 emissions rise when they are used in a more flexible mode. If carbon capture technology is ever developed – which is unlikely – coal plants would be inflexible for technical reasons.

Gas plants, especially modern combined cycle ones are highly flexible and can reduce their output or be switched off when there is a high supply of renewable energy. Gas plants emit less than half of the CO_2 for each kWh produced coal plants and are thus an ideal bridging fuel to a 100 percent renewable electricity by 2050.

image Andasol 1 solar power station is Europe's first commercial parabolic trough solar power plant. Andasol 1 will supply up to 200.000 people with climate-friendly electricity and save about 149,000 tons of carbon dioxide per year compared with a modern coal power plant.

Greenpeace is an independent global campaigning organisation that acts to change attitudes and behaviour, to protect and conserve the environment and to promote peace.

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