energy

[r]evolution

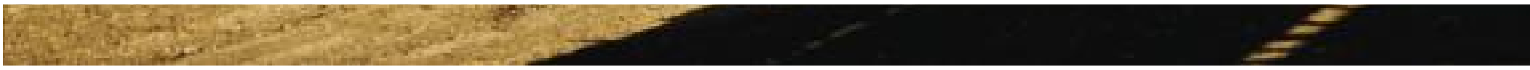
TOWARDS A FULLY RENEWABLE ENERGY SUPPLY IN THE EU 27

EREC
EUROPEAN RENEWABLE ENERGY COUNCIL

GREENPEACE

report 2010 eu 27 energy scenario

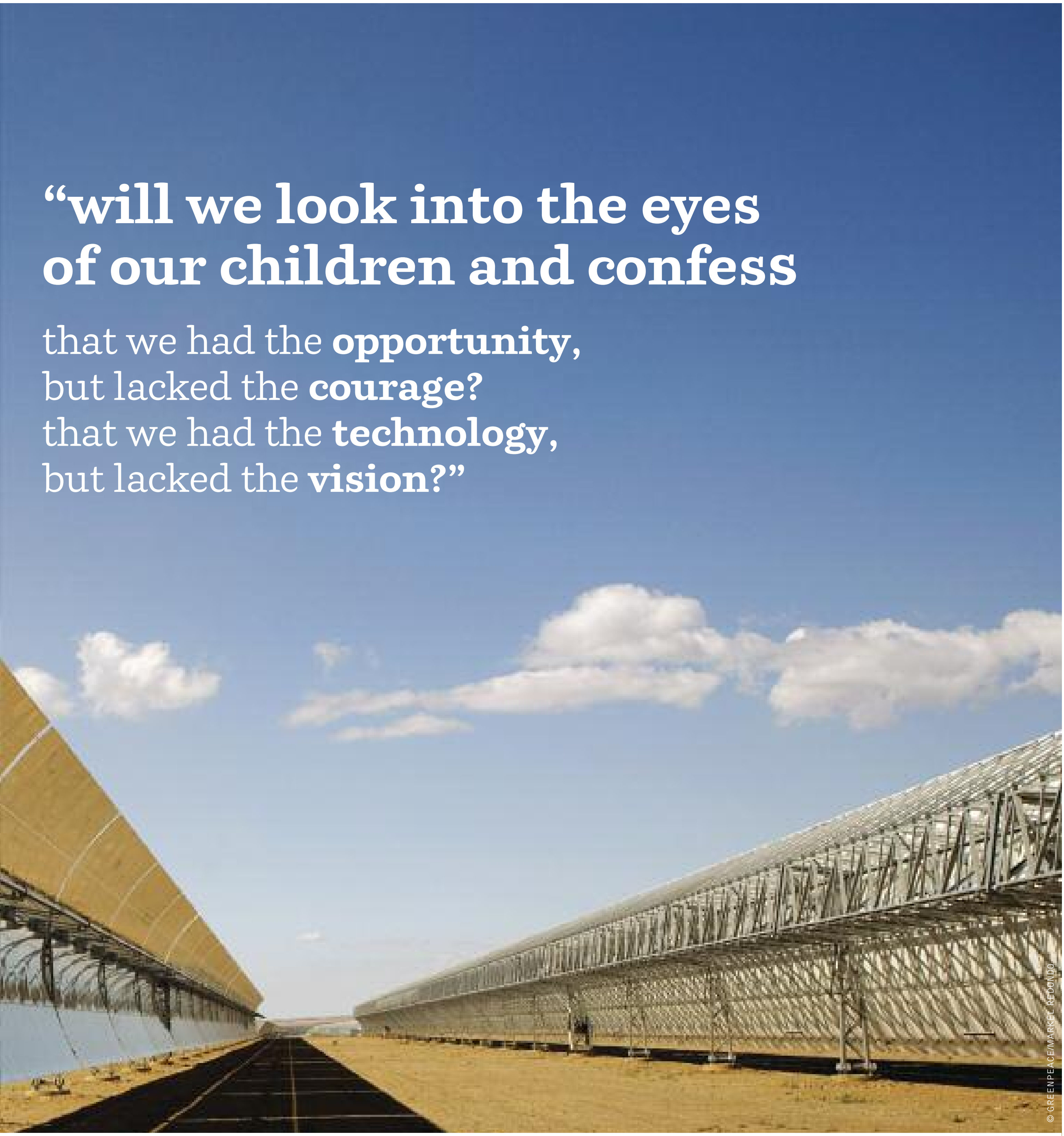
contents



ANDASOL 1 SOLAR POWER STATION SUPPLIES UP TO 200,000 PEOPLE WITH CLIMATE-FRIENDLY ELECTRICITY AND SAVES ABOUT 149,000 TONNES OF CARBON DIOXIDE PER YEAR COMPARED WITH A MODERN COAL POWER PLANT.

“will we look into the eyes of our children and confess

that we had the **opportunity**,
but lacked the **courage**?
that we had the **technology**,
but lacked the **vision**?”



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introduction

"WE NEED TO MAKE SURE WE COME OUT OF THIS RECESSION WITH A REBALANCED AND GREEN ECONOMY."
NICK CLEGG, DEPUTY PRIME MINISTER, UK

image A WORKER ENTERS A TURBINE TOWER FOR MAINTENANCE AT DABANCHENG WIND FARM. CHINA'S BEST WIND RESOURCES ARE MADE POSSIBLE BY THE NATURAL BREACH IN TIANSHAN (TIAN MOUNTAIN).

The energy debate has moved to the top of the agenda across the social, political and economic spectrum. Energy is the lifeblood of the economy, but Europe's current energy model fails to guarantee a secure, sustainable and affordable supply into the future. Insecure and expensive fuel supplies, persistent safety risks and the urgent threat of climate change call for an Energy [R]evolution.

fuel dependency and soaring prices

Europe's energy system is characterised by increasing energy consumption, increasing costs, and an increasing dependence on fossil and nuclear fuel imports. The price of fossil fuels has tripled over the last decade and become more and more volatile. At the same time, our dependency on imported oil, coal and gas has risen to more than half our energy needs.[1]

According to the European Commission, the price of fuel imports totalled an estimated € 350 billion in 2008[2] – money spent on the exploitation of finite natural resources, rather than sustainable jobs and economic development.

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image NORTH HOYLE WIND FARM, UK'S FIRST WIND FARM IN THE IRISH SEA WHICH WILL SUPPLY 50,000 HOMES WITH POWER.

The picture for nuclear energy is no more attractive. Finland's Olkiluoto 3 nuclear reactor project, heralded as the nuclear industry's poster child, is already three years behind schedule and 50% over-budget. Ratings agency Moody's has made it abundantly clear that, even with massive government subsidy, nuclear power is not a sound investment.[3] What is more, the world's proven and reasonably assured uranium resources would only be able to cover current consumption levels for a few more decades.

safety risks

BP's Deepwater Horizon catastrophe is only the most recent reminder of the hazards of our energy system. The blight of tar sands extraction threatens to be the next major oil disaster. Environmental damage and major risks to companies and shareholders will continue to exist as long as our economy depends on fossil and nuclear fuels.

climate change

Looming large behind the daily risks of our energy system is the urgent need to combat climate change. If Europe and the world fail to slash greenhouse gas emissions urgently, we risk crossing a tipping point in the climate system that could bring about runaway climate change with devastating droughts, floods, sea level rise, storms and wildfires. In October 2009, European leaders set a greenhouse gas emission reduction target of 80-95% below 1990 levels in 2050, though credible action on this commitment is yet to come.

high time for a switch

To keep the lights on, major investment decisions to modernise Europe's energy system are unavoidable. Energy infrastructure is outdated, and much of the European Union's power generation capacity is nearing the end of its life. Now is the time for an energy revolution.

> **"for the second year running, renewable energy technologies accounted for more than half of the power production capacity added in Europe in 2009."**

towards a 100% renewable energy system

The challenges for Europe's energy system are enormous. But solutions are within reach. Using technologies that already exist today, from wind turbines to super-efficient appliances and electric cars, the Energy [R]evolution scenarios demonstrate how Europe can move into a sustainable energy future based on cost-effective, clean and stable supplies.

The uptake of renewable energy technologies has grown exponentially over the last years. For the second year running, renewable energy technologies accounted for more than half of the power production capacity added in Europe in 2009.[4] Already today, businesses active in resource-efficient and renewable energy technologies form a significant part of the economy, providing millions of sustainable jobs in Europe.[5]

The economic case for renewable energy sources and energy efficiency is expected to further improve as they develop technically, as the price of fossil fuels continues to rise and as their saving of carbon dioxide emissions is given a more realistic monetary value.

A number of European cities and regions have already committed to generating 100% renewable energy in electricity, heating and/or transport. Theisland of Samso in Denmarkis already demonstrating that a fully renewable power supply is possible. The region of Navarre in Northern Spain and the town of Beckerich in Luxembourg are expected to achieve the same objective in the near future. This Energy [R]evolution study demonstrates how the entire continent can follow their example.

Christine Lins
SECRETARY GENERAL
EUROPEAN RENEWABLE
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executive summary

"EUROPE HAS A GOLDEN OPPORTUNITY TO DEVELOP A GREEN ECONOMY WHICH WILL BOOST THE ECONOMY OVERALL AND BUILD NEW JOBS."
MAUD OLOFFSON, ENERGY MINISTER, SWEDEN

image THE PS10 CONCENTRATING SOLAR THERMAL POWER PLANT IN SEVILLA, SPAIN. THE 11 MEGAWATT SOLAR POWER TOWER PRODUCES ELECTRICITY WITH 624 LARGE MOVABLE MIRRORS CALLED HELIOSTATS. 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.

moving towards 100% renewable energy in europe

Europe's energy policy is at a crossroads. Many of its power stations are nearing the end of their working lives and its infrastructure is aging. Important issues are at stake; energy security, stability of supply, growing demand, the employment of thousands and the urgent need to cut emissions and head off climate change. But an answer is within reach: energy savings and renewable energy, with zero fuel costs, zero reliance on scarce resources, and zero climate damaging emissions, is an increasingly attractive option. This study shows that investing in green energy will nudge up the cost of electricity in the short to medium term. But it will save trillions of Euros in fuel costs alone from 2030 and represents an immediate investment in jobs and energy security. It presents a revolution that will give Europe a global competitive advantage and act as a beacon to other regions looking to steer a course away from the dangerous climate change approaching from the horizon. The revolution is feasible, as calculations done by the Systems Analysis and Technology Assessment department of the German Aerospace Center show. But it is going to rely on supportive policies at European and member state level.

basic and advanced energy [r]evolutions

This study outlines two energy development pathways, a basic and an advanced scenario. Both are based on proven, existing technologies, rather than future unknowns. Both offer a broad mix of technologies and efficiency options to allow for a good diversification of investment risks and energy resources. The general framework parameters for population and GDP are based on the Reference scenario of the International Energy Agency's World Energy Outlook of 2009 (WEO 2009).[6] The work of the German Aerospace Center (DLR) combines a top-down analysis of the overall energy supply at European level together with technology-oriented, bottom up studies in relevant areas like learning curves and growth rates of technologies, cost analyses and assessment of resource potentials of renewable energies.

references
6 THE WORLD ENERGY OUTLOOK 2009 INCLUDES DIFFERENT ENERGY DEVELOPMENT SCENARIOS FOR 2030. THE ENERGY [R]EVOLUTION REPORT USES AS A BASELINE THE REFERENCE SCENARIO OF THE WORLD ENERGY OUTLOOK 2009. THIS SCENARIO HAS BEEN EXTRAPOLATED BY DLR TO 2050.

image WELDER WORKING AT VESTAS WIND TURBINE FACTORY, CAMPBELLTOWN, SCOTLAND.

A **basic Energy [R]evolution** reduces EU-wide carbon dioxide emissions by 80% compared to 1990 levels by 2050, while phasing out expensive nuclear power production and its dangerous radioactive waste. To achieve this, the scenario exploits Europe's large potential for energy efficiency. At the same time, available cost-effective renewable energy sources are used for heat and electricity generation, and transport.

An **advanced Energy [R]evolution** dramatically improves energy security, boosts green technology leadership and pulls the emergency brake on greenhouse gas emissions, achieving close to a fully renewable energy system by 2050. The advanced scenario reduces EU-wide carbon dioxide emissions by 95% by 2050, matching the upper range of the emissions reduction target adopted by EU leaders in October 2009. This scenario requires the rapid phasing out of nuclear power generation and assumes a maximum lifetime of 20 years for coal-fired power plants, half the technical lifetime of such plants.

The scenario uses the same energy efficiency developments as the basic Energy [R]evolution scenario. However, it projects less driving and a faster uptake of efficient combustion vehicles. For the heating sector, it projects a faster expansion of combined heat and power (CHP) for industry and more electrification of process heating.

A faster uptake of electric vehicles, combined with the speedy implementation of smart grids and super grids, about ten years earlier than under the basic Energy [R]evolution, would allow a higher share of fluctuating renewable electricity from wind and solar generation in the EU's energy system. Furthermore, the scenario entails a faster growth of solar and geothermal heating systems, in line with the latest renewable energy industry market developments.[7]

six characteristics of the advanced energy [r]evolution

1. Exploitation of the large existing energy efficiency potential will ensure that primary energy demand is reduced by more than a third, from the current 73,880 PJ/a (2007) to 46,030 PJ/a in 2050, compared to 75,920 PJ/a in the Reference scenario. This dramatic reduction is a crucial prerequisite for achieving a significant share of renewable energy sources in the overall energy supply system, compensating for the phasing out of nuclear energy and reducing the consumption of fossil fuels.
2. Electric vehicles pick up in the transport sector and hydrogen produced from electrolysis plays an increasingly important role. After 2020, the final energy share of electric vehicles increases to 14% by 2030 and to 62% by 2050. More public transport systems also use electricity and there is a greater shift in transporting freight from road to rail. With biomass mainly committed to stationary applications for heat and power generation, the production of biofuels is limited by the availability of sustainable raw materials.
3. The increased use of CHP generation additionally improves the supply system's energy conversion efficiency, increasingly using natural gas and biomass. In the long term, improved energy efficiency and a decreasing demand for heat, as well as a large potential for producing heat directly from renewable energy sources, limits the further expansion of CHP.
4. The electricity sector will be the pioneer of renewable energy utilisation. By 2050, around 97% of electricity will be produced from renewable sources. A capacity of 1,520 GW will produce 4,110 TWh of renewable electricity per year by 2050. A significant share of the fluctuating power generation from wind and solar photovoltaics will be used to supply electricity for vehicle batteries and produce hydrogen as a secondary fuel in transport and industry. By using load management strategies, excess electricity generation will be reduced and more balancing power made available.
5. In the heat supply sector, the contribution of renewables will increase to 92% by 2050. Fossil fuels will be increasingly replaced by more efficient modern technologies, in particular biomass, solar collectors and geothermal. Geothermal heat pumps and solar thermal power will play a growing part in industrial heat production.
6. By 2050, 92% of final energy demand will be covered by renewable energy sources. To achieve an economically attractive growth of these sources, a balanced and timely mobilisation of all technologies is of great importance. Such mobilisation depends on technical potentials, actual costs, cost reduction potentials and technical maturity.

investing in the future – the costs and savings

The Energy [R]evolution will require initial investment higher than in the Reference case. The resulting slightly higher electricity generation costs under the advanced Energy [R]evolution scenario will, however, be compensated by reduced requirement for fuels in other sectors such as heating and transport. Assuming average costs of three cents per kWh for implementing energy efficiency measures, the additional cost for electricity supply under the advanced Energy [R]evolution scenario will amount to €82 billion per year in 2020 and €73 billion per year in 2030, compared to the Reference scenario. These additional costs, which represent society's investment in an environmentally benign, secure and affordable energy supply, decrease after 2030. By 2050, the annual cost of electricity supply will be €85 billion per year below those in the Reference scenario.

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7 SEE EREC, RE-THINKING 2050, GWEC, EPIA ET AL.

It would require €3.8 trillion of EU investment to implement the advanced scenario - approximately 90% higher than the Reference scenario (€2.0 trillion). Under the Reference version, levels of investment in renewable energy account for less than two thirds of total investment until 2030, €780 billion, whereas conventional fuels represent about one third. Under the advanced scenario, however, the EU shifts about 80% of investment towards renewables. By 2030, the remaining fossil fuel share of power sector investment would be focused mainly on combined heat and power and efficient gas-fired power plants. The average annual additional investment in the power sector under the advanced Energy [R]evolution between 2007 and 2030 would be approximately €30 billion.

Because renewable energy has no fuel costs, however, the fuel cost savings in the basic Energy [R]evolution scenario reach a total of €2.1 trillion by 2050, or €49 billion per year. The advanced Energy [R]evolution has even higher fuel cost savings of €2.6 trillion, or €62 billion per year.

Under the Reference scenario, the average annual additional fuel costs compared to the advanced Energy [R]evolution are almost twice as high as the additional investment requirements of the advanced scenario. In fact, from 2040 onwards, the fuel savings are enough to fund the entire additional investment needs for renewable, cogeneration and back-up capacity under the advanced scenario. The renewable energy sources would then go on to produce electricity without any further fuel costs, while the costs for coal and gas will continue to be a burden on national economies.

job creation

The EU would see more direct jobs created in the energy sector if it shifted to either of the Energy [R]evolution scenarios. The Energy [R]evolution scenarios lead to more energy sector jobs in EU 27 at every stage.

- By 2015, renewable power sector jobs in the advanced Energy [R]evolution scenario are estimated to reach about 830,00, 260,000 more than in the Reference scenario. The basic version will lead to 720,000 jobs in the renewable power industry.
- By 2020, the advanced Energy [R]evolution scenario has created about 940,000 jobs in the renewable power industry, 410,000 more than the Reference scenario. The job losses in the fossil fuel sector due to a reduced coal generation capacity are overcompensated by the growing renewable power generation.
- By 2030, the advanced Energy [R]evolution scenario has created about 1,2 million jobs in the renewable power industry, 780,000 more than the Reference scenario. Approximately 280,000 new renewable energy jobs are created between 2020 and 2030, compared to the reference with a slight decrease of renewable energy jobs in the same time frame.

emissions cuts of 95%

While CO_2 emissions EU-wide will only decrease by 16% under the Reference scenario by 2050, an unsustainable development path, under the advanced scenario they will decrease from 3,890 million tonnes in 2007 to 195 million tonnes in 2050. Annual per capita emissions will drop from 7.9 tonnes/capita to 0.4 t/capita. In spite of the phasing out of nuclear energy and a growing electricity demand, CO_2 emissions will decrease enormously in the electricity sector. In the long run, efficiency gains and the increased use of renewable electric vehicles, as well as a sharp expansion in public transport, will even reduce CO_2 emissions in the transport sector. With a share of 9% of total emissions in 2050, the power sector will reduce significantly its emissions.

"fuel cost savings in the advanced energy [r]evolution reach € 2.6 trillion by 2050, or € 62 billion per year."

image CONSTRUCTION OF THE OFFSHORE WINDFARM AT MIDDELGRUNDEN NEAR COPENHAGEN, DENMARK.

five policy asks to start the energy [r]evolution

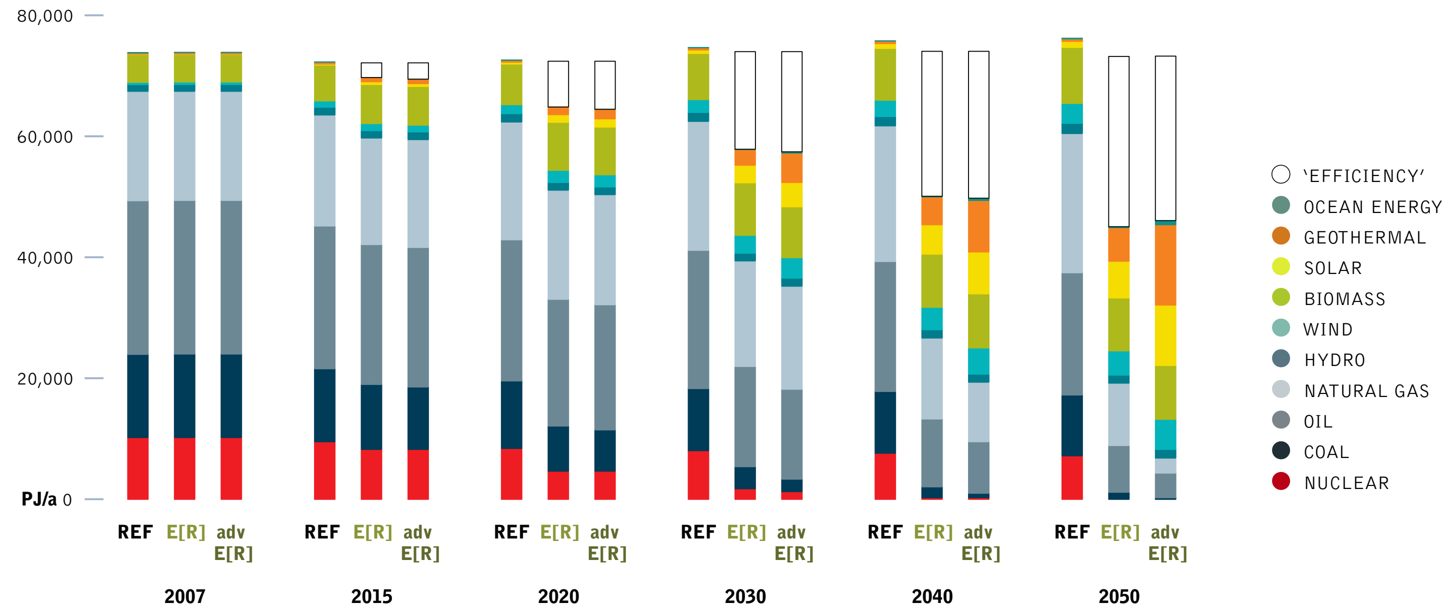
The central challenge to achieving an Energy [R]evolution is one of implementation. Today, three quarters of primary energy supply comes from fossil fuels. To achieve large scale and cost effective growth of renewable energy and resource-efficient technologies, a balanced and timely mobilisation of private and public investment is needed. This mobilisation will rely on policy mechanisms to ensure that conventional power sources are replaced by clean ones.

The European Union and its member states are urged to make rapid progress in five areas.

1. **Develop a vision for a truly sustainable energy economy for 2050 that guides European climate and energy policy** This should include commitment to a fully renewable energy system as well as the development of a credible emissions reduction pathway.
2. **Adopt and implement ambitious targets for emissions reductions, energy savings and renewable energy** Legally binding emission reductions of 30% by 2020, mandatory energy savings targets and the implementation of the 20% renewable energy target are important foundations for energy development in the years to come.
3. **Remove barriers** The electricity market and network management practices should be subject to a thorough reform. All subsidies and support measures for nuclear power, fossil fuels, inefficient plants, appliances, vehicles and buildings should be removed. Energy prices should reflect the genuine costs of fossil fuel and nuclear energy use.
4. **Implement effective policies to promote a clean economy** An update of the European Emissions Trading Scheme, the effective implementation of the Renewable Energy Directive and ambitious energy efficiency standards for vehicles, consumer appliances, buildings and power production should be part of a clean energy strategy.
5. **Redirect public finance** Structural and Cohesion Funds should be re-directed towards renewable energy and energy savings. At the same time, targeted support for innovation and research in energy saving technologies will be essential to hasten the Energy [R]evolution.

figure 0.1: development of primary energy consumption under the three scenarios

('EFFICIENCY' = REDUCTION COMPARED TO THE REFERENCE SCENARIO)



the energy [r]evolution

GLOBAL

KEY PRINCIPLES
A DEVELOPMENT PATHWAY
NEW BUSINESS MODEL

THE NEW ELECTRICITY GRID
HYBRID SYSTEMS
SMART GRIDS

1

DECOUPLE GROWTH FROM FOSSIL FUEL USE. © G. POROPAT/DREAMSTIME

“for some in the EU, energy policy is the fight against climate change, for others it is about energy security. it is both.”

JERZY BUZEK
PRESIDENT OF THE EUROPEAN PARLIAMENT

image WANG WAN YI, AGE 76, ADJUSTS THE SUNLIGHT POINT ON A SOLAR DEVICE USED TO BOIL HIS KETTLE. HE LIVES WITH HIS WIFE IN ONE ROOM CARVED OUT OF THE SANDSTONE, A TYPICAL DWELLING FOR LOCAL PEOPLE IN THE REGION. DROUGHT IS ONE OF THE MOST HARMFUL NATURAL HAZARDS IN NORTHWEST CHINA. CLIMATE CHANGE HAS A SIGNIFICANT IMPACT ON CHINA'S ENVIRONMENT AND ECONOMY.

The climate change imperative demands nothing short of an energy revolution. The expert consensus is that this fundamental shift must begin immediately and be well underway within the next ten years in order to avert the worst impacts. What is needed is a complete transformation of the way we produce, consume and distribute energy, and at the same time maintain economic growth. Nothing short of such a revolution will enable us to limit global warming to less than a rise in temperature of well below 2° Celsius, above which the impacts become devastating.

Current electricity generation relies mainly on burning fossil fuels, with their associated CO_2 emissions, in very large power stations which waste much of their primary input energy. More energy is lost as the power is moved around the electricity grid network and converted from high transmission voltage down to a supply suitable for domestic or commercial consumers. The system is innately vulnerable to disruption: localised technical, weather-related or even deliberately caused faults can quickly cascade, resulting in widespread blackouts. Whichever technology is used to generate electricity within this old fashioned configuration, it will inevitably be subject to some, or all, of these problems. At the core of the Energy [R]evolution there therefore needs to be a change in the way that energy is both produced and distributed.

key principles

the energy [r]evolution can be achieved by adhering to five key principles:

1. **respect natural limits – phase out fossil fuels by the end of this century on the global level and by 2050 on the European level** We must learn to respect natural limits. There is only so much carbon that the atmosphere can absorb. Each year the global population emits over 25 billion tonnes of carbon equivalent; we are literally filling up the sky. Geological resources of coal could provide several hundred years of fuel, but we cannot burn them and keep within safe limits. Oil and coal development must be ended.

   While the basic Energy [R]evolution scenario has a reduction target for energy related CO_2 emissions of 50% from 1990 levels by 2050 and 75% on the European level, the advanced case goes one step further and aims for a reduction target of over 80% globally and 95% on the European level.

2. **equity and fairness** As long as there are natural limits there needs to be a fair distribution of benefits and costs within societies, between nations and between present and future generations. At one extreme, a third of the world's population has no access to electricity, whilst the most industrialised countries consume much more than their fair share.

   The effects of climate change on the poorest communities are exacerbated by massive global energy inequality. If we are to address climate change, one of the principles must be equity and fairness, so that the benefits of energy services – such as light, heat, power and transport – are available for all: north and south, rich and poor. Only in this way can we create true energy security, as well as the conditions for genuine human wellbeing.

   The Energy [R]evolution scenarios have a target to achieve energy equity as soon as technically possible. By 2050 the average per capita emission should be between 1 and 2 tonnes of CO_2.

3. **implement clean, renewable solutions and decentralise energy systems** There is no energy shortage. All we need to do is use existing technologies to harness energy effectively and efficiently. Renewable energy and energy efficiency measures are ready, viable and increasingly competitive. Wind, solar and other renewable energy technologies have experienced double digit market growth for the past decade.

   Just as climate change is real, so is the renewable energy sector. Sustainable decentralised energy systems produce less carbon emissions, are cheaper and involve less dependence on imported fuel. They create more jobs and empower local communities. Decentralised systems are more secure and more efficient. This is what the Energy [R]evolution must aim to create.

"THE STONE AGE DID NOT END FOR LACK OF STONE, AND THE OIL AGE WILL END LONG BEFORE THE WORLD RUNS OUT OF OIL."

Sheikh Zaki Yamani, former Saudi Arabian oil minister

   To stop the earth's climate spinning out of control, most of the world's fossil fuel reserves – coal, oil and gas – must remain in the ground. Our goal is for humans to live within the natural limits of our small planet.

4. **decouple growth from fossil fuel use** Starting in the developed countries, economic growth must be fully decoupled from fossil fuel usage. It is a fallacy to suggest that economic growth must be predicated on their increased combustion.

   We need to use the energy we produce much more efficiently, and we need to make the transition to renewable energy and away from fossil fuels quickly in order to enable clean and sustainable growth.

5. **phase out dirty, unsustainable energy** We need to phase out coal and nuclear power. We cannot continue to build coal plants at a time when emissions pose a real and present danger to both ecosystems and people. And we cannot continue to fuel the myriad nuclear threats by pretending nuclear power can in any way help to combat climate change. There is no role for nuclear power in the Energy [R]evolution.

from principles to practice

In 2007, renewable energy sources accounted for 13% of the world's primary energy demand. Biomass, which is mostly used for heating, was the main renewable energy source. The share of renewable energy in electricity generation was 18%. The contribution of renewables to primary energy demand for heat supply was around 24%. About 80% of primary energy supply today still comes from fossil fuels, and 6% from nuclear power.[8]

The time is right to make substantial structural changes in the energy and power sector within the next decade. Many power plants in industrialised countries, such as the USA, Japan and the European Union, are nearing retirement; more than half of all operating power plants are over 20 years old. At the same time developing countries, such as China, India and Brazil, are looking to satisfy the growing energy demand created by their expanding economies.

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8 'ENERGY BALANCE OF NON-OECD COUNTRIES' AND 'ENERGY BALANCE OF OECD COUNTRIES', IEA, 2009

Within the next ten years, the power sector will decide how this new demand will be met, either by fossil and nuclear fuels or by the efficient use of renewable energy. The Energy [R]evolution scenario is based on a new political framework in favour of renewable energy and cogeneration combined with energy efficiency.

To make this happen both renewable energy and cogeneration – on a large scale and through decentralised, smaller units – have to grow faster than overall global energy demand. Both approaches must replace old generating technologies and deliver the additional energy required in the developing world.

As it is not possible to switch directly from the current large scale fossil and nuclear fuel based energy system to a full renewable energy supply, a transition phase is required to build up the necessary infrastructure. Whilst remaining firmly committed to the promotion of renewable sources of energy, we appreciate that gas, used in appropriately scaled cogeneration plants, is valuable as a transition fuel, and able to drive cost-effective decentralisation of the energy infrastructure. With warmer summers, tri-generation, which incorporates heat-fired absorption chillers to deliver cooling capacity in addition to heat and power, will become a particularly valuable means of achieving emissions reductions.

a development pathway

The Energy [R]evolution envisages a development pathway which turns the present energy supply structure into a sustainable system. There are three main stages to this.

step 1: energy efficiency

The Energy [R]evolution is aimed at the ambitious exploitation of the potential for energy efficiency. It focuses on current best practice and technologies that will become available in the future, assuming continuous innovation. The energy savings are fairly equally distributed over the three sectors – industry, transport and domestic/business. Intelligent use, not abstinence, is the basic philosophy for future energy conservation.

The most important energy saving options are improved heat insulation and building design, super efficient electrical machines and drives, replacement of old style electrical heating systems by renewable heat production (such as solar collectors) and a reduction in energy consumption by vehicles used for goods and passenger traffic. Industrialised countries, which currently use energy in the most inefficient way, can reduce their consumption drastically without the loss of either housing comfort or information and entertainment electronics. The Energy [R]evolution scenario uses energy saved in OECD countries as a compensation for the increasing power requirements in developing countries. The ultimate goal is stabilisation of global energy consumption within the next two decades. At the same time the aim is to create 'energy equity' – shifting the current one-sided waste of energy in the industrialised countries towards a fairer worldwide distribution of efficiently used supply.

A dramatic reduction in primary energy demand compared to the IEA's Reference scenario (see chapter 4) – but with the same GDP and population development - is a crucial prerequisite for achieving a significant share of renewable energy sources in the overall energy supply system, compensating for the phasing out of nuclear energy and reducing the consumption of fossil fuels.

step 2: the renewable energy [r]evolution

decentralised energy and large scale renewables In order to achieve higher fuel efficiencies and reduce distribution losses, the Energy [R]evolution scenario makes extensive use of Decentralised Energy (DE). This is energy generated at or near the point of use.

DE is connected to a local distribution network system, supplying homes and offices, rather than the high voltage transmission system. The proximity of electricity generating plant to consumers allows any waste heat from combustion processes to be piped to nearby buildings, a system known as cogeneration or combined heat and power. This means that nearly all the input energy is put to use, not just a fraction as with traditional centralised fossil fuel plant.

figure 1.1: centralised energy infrastructures waste more than two thirds of their energy

61.5 units LOST THROUGH INEFFICIENT GENERATION AND HEAT WASTAGE

3.5 units LOST THROUGH TRANSMISSION AND DISTRIBUTION

13 units WASTED THROUGH INEFFICIENT END USE

100 units >> ENERGY WITHIN FOSSIL FUEL

38.5 units >> OF ENERGY FED TO NATIONAL GRID

35 units >> OF ENERGY SUPPLIED

22 units OF ENERGY ACTUALLY UTILISED

image GREENPEACE OPENS A SOLAR ENERGY WORKSHOP IN BOMA. A MOBILE PHONE GETS CHARGED BY A SOLAR ENERGY POWERED CHARGER.

DE also includes stand-alone systems entirely separate from the public networks, for example heat pumps, solar thermal panels or biomass heating. These can all be commercialised at a domestic level to provide sustainable low emission heating. Although DE technologies can be considered 'disruptive' because they do not fit the existing electricity market and system, with appropriate changes they have the potential for exponential growth, promising 'creative destruction' of the existing energy sector.

A huge proportion of global energy in 2050 will be produced by decentralised energy sources, although large scale renewable energy supply will still be needed in order to achieve a fast transition to a renewables dominated system. Large offshore wind farms and concentrating solar power (CSP) plants in the sunbelt regions of the world will therefore have an important role to play.

cogeneration The increased use of combined heat and power generation (CHP) will improve the supply system's energy conversion efficiency, whether using natural gas or biomass. In the longer term, a decreasing demand for heat and the large potential for producing heat directly from renewable energy sources will limit the need for further expansion of CHP.

renewable electricity The electricity sector will be the pioneer of renewable energy utilisation. Many renewable electricity technologies have been experiencing steady growth over the past 20 to 30 years of up to 35% annually and are expected to consolidate at a high level between 2030 and 2050. By 2050, under the Energy [R]evolution scenario, the majority of electricity will be produced from renewable energy sources. The anticipated growth of electricity use in transport will further promote the effective use of renewable power generation technologies.

renewable heating In the heat supply sector, the contribution of renewables will increase significantly. Growth rates are expected to be similar to those of the renewable electricity sector. Fossil fuels will be increasingly replaced by more efficient modern technologies, in particular biomass, solar collectors and geothermal. By 2050, renewable energy technologies will satisfy the major part of heating and cooling demand.

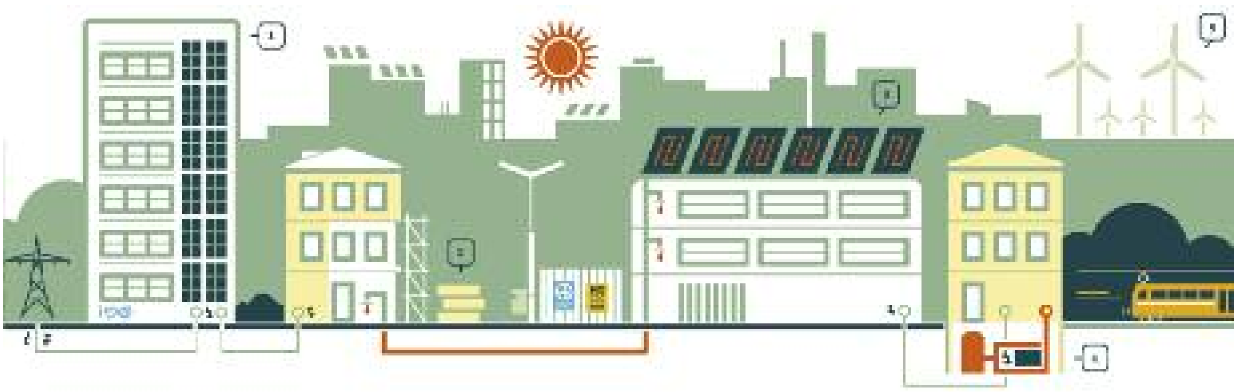
transport Before new technologies, including hybrid or electric cars and new fuels such as bio fuels, can play a substantial role in the transport sector, the existing large efficiency potentials have to be exploited. In this study, biomass is primarily committed to stationary applications; the use of bio fuels for transport is limited by the availability of sustainably grown biomass. Electric vehicles will therefore play an even more important role in improving energy efficiency in transport and substituting for fossil fuels.

Overall, to achieve an economically attractive growth of renewable energy sources, a balanced and timely mobilisation of all technologies is essential. Such a mobilisation depends on the resource availability, cost reduction potential and technological maturity. And alongside technology driven solutions, lifestyle changes - like simply driving less and using more public transport – have a huge potential to reduce greenhouse gas emissions.

figure 1.2: a decentralised energy future

EXISTING TECHNOLOGIES, APPLIED IN A DECENTRALISED WAY AND COMBINED WITH EFFICIENCY MEASURES AND ZERO EMISSION DEVELOPMENTS, CAN DELIVER LOW CARBON COMMUNITIES AS ILLUSTRATED HERE. POWER IS GENERATED USING EFFICIENT COGENERATION TECHNOLOGIES PRODUCING BOTH HEAT (AND SOMETIMES COOLING) PLUS ELECTRICITY, DISTRIBUTED VIA LOCAL NETWORKS. THIS SUPPLEMENTS THE ENERGY PRODUCED FROM BUILDING INTEGRATED GENERATION. ENERGY SOLUTIONS COME FROM LOCAL OPPORTUNITIES AT BOTH A SMALL AND COMMUNITY SCALE. THE TOWN SHOWN HERE MAKES USE OF – AMONG OTHERS – WIND, BIOMASS AND HYDRO RESOURCES. NATURAL GAS, WHERE NEEDED, CAN BE DEPLOYED IN A HIGHLY EFFICIENT MANNER.

city



1. **PHOTOVOLTAIC, SOLAR FAÇADES** WILL BE A DECORATIVE ELEMENT ON OFFICE AND APARTMENT BUILDINGS. PHOTOVOLTAIC SYSTEMS WILL BECOME MORE COMPETITIVE AND IMPROVED DESIGN WILL ENABLE ARCHITECTS TO USE THEM MORE WIDELY.
2. **RENOVATION CAN CUT ENERGY CONSUMPTION OF OLD BUILDINGS** BY AS MUCH AS 80% - WITH IMPROVED HEAT INSULATION, INSULATED WINDOWS AND MODERN VENTILATION SYSTEMS.
3. **SOLAR THERMAL COLLECTORS** PRODUCE HOT WATER FOR BOTH THEIR OWN AND NEIGHBOURING BUILDINGS.
4. **EFFICIENT THERMAL POWER (CHP) STATIONS** WILL COME IN A VARIETY OF SIZES - FITTING THE CELLAR OF A DETACHED HOUSE OR SUPPLYING WHOLE BUILDING COMPLEXES OR APARTMENT BLOCKS WITH POWER AND WARMTH WITHOUT LOSSES IN TRANSMISSION.
5. **CLEAN ELECTRICITY** FOR THE CITIES WILL ALSO COME FROM FARTHER AFIELD. OFFSHORE WIND PARKS AND SOLAR POWER STATIONS IN DESERTS HAVE ENORMOUS POTENTIAL.

new business model

The Energy [R]evolution scenario will also result in a dramatic change in the business model of energy companies, utilities, fuel suppliers and the manufacturers of energy technologies. Decentralised energy generation and large solar or offshore wind arrays which operate in remote areas, without the need for any fuel, will have a profound impact on the way utilities operate in 2020 and beyond.

While today the entire power supply value chain is broken down into clearly defined players, a global renewable power supply will inevitably change this division of roles and responsibilities. The following table provides an overview of today's value chain and how it would change in a revolutionised energy mix.

While today a relatively small number of power plants, owned and operated by utilities or their subsidiaries, are needed to generate the required electricity, the Energy [R]evolution scenario projects a future share of around 60 to 70% of small but numerous decentralised power plants performing the same task. Ownership will therefore shift towards more private investors and away from centralised utilities. In turn, the value chain for power companies will shift towards project development, equipment manufacturing and operation and maintenance.

table 1.2: utilities today

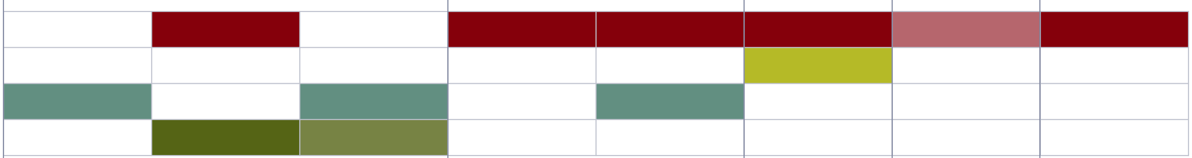
FUEL SUPPLY	(LARGE SCALE) GENERATION	TRADING	TRANS-MISSION	DISTRIBUTION	SALES
utilities					
		trader (e.g. banks)		local DSO	
	IPP		TSO		retailer
mining companies					

FUEL SUPPLY	(LARGE & SMALL SCALE) GENERATION	TRADING	TRANS-MISSION STORAGE	DISTRIBUTION RENEWABLE GENERATION	SALES RENEWABLE GENERATION
utilities					investors
		trader (e.g. banks)		local DSO	
	IPP		TSO		retailer
mining companies			IT companies		

IPP = INDEPENDEND POWER PRODUCER
TSO = TRANSMISSION SYSTEM OPERATOR
LOCAL DSO = LOCAL DISTRIBUTION SYSTEM OPERATOR

table 1.1: power plant value chain

TASK & MARKET PLAYER	(LARGE SCALE) GENERATION	PROJECT DEVELOPMENT	INSTALLATION	PLANT OWNER	OPERATION & MAINTANANCE	FUEL SUPPLY	DISTRIBUTION	SALES
STATUS QUO	Very few new power plants + central planning			large scale generation in the hand of few IPP´s & utilities		global mining operations	grid operation still in the hands of utilities	
MARKET PLAYER								
Utility								
Mining company								
Component manufacturer								
Engineering companies & project developers								



TASK & MARKET PLAYER	(LARGE SCALE) GENERATION	PROJECT DEVELOPMENT	INSTALLATION	PLANT OWNER	OPERATION & MAINTANANCE	FUEL SUPPLY	DISTRIBUTION	SALES
ENERGY [R]EVOLUTION POWER MARKET	many smaller power plants + decentralized planning			large number of players e.g. IPP´s, utilities, private consumer, building operators		no fuel needed (except biomass)	grid operation under state control	
MARKET PLAYER								
Utility								
Mining company								
Component manufacturer								
Engineering companies & project developers								

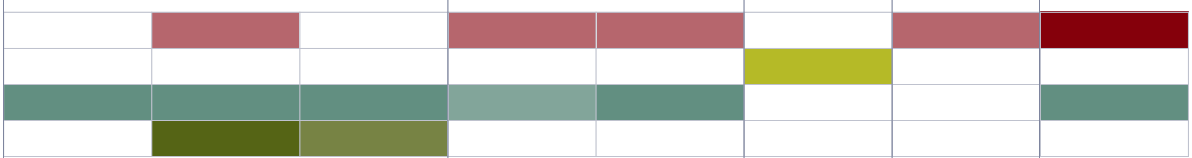


image THE TRUCK DROPS ANOTHER LOAD OF WOOD CHIPS AT THE BIOMASS POWER PLANT IN LELYSTAD, THE NETHERLANDS.

Simply selling electricity to customers will play a smaller role, as the power companies of the future will deliver a total power plant to the customer, not just electricity. They will therefore move towards becoming service suppliers for the customer. The majority of power plants will also not require any fuel supply, with the result that mining and other fuel production companies will lose their strategic importance.

The future pattern under the Energy [R]evolution will see more and more renewable energy companies, such as wind turbine manufacturers, also becoming involved in project development, installation and operation and maintenance, whilst utilities will lose their status. Those traditional energy supply companies which do not move towards renewable project development will either lose market share or drop out of the market completely.

step 3: optimised integration – renewables 24/7

A complete transformation of the energy system will be necessary to accommodate the significantly higher shares of renewable energy expected under the Energy [R]evolution scenario. The grid network of cables and sub-stations that brings electricity to our homes and factories was designed for large, centralised generators running at huge loads, usually providing what is known as 'baseload' power. Renewable energy has had to fit in to this system as an additional slice of the energy mix and adapt to the conditions under which the grid currently operates. If the Energy [R]evolution scenario is to be realised, this will have to change.

Some critics of renewable energy say it is never going to be able to provide enough power for our current energy use, let alone for the projected growth in demand. This is because it relies mostly on natural resources, such as the wind and sun, which are not available 24/7. Existing practice in a number of countries has already shown that this is wrong, and further adaptations to how the grid network operates will enable the large quantities of renewable generating capacity envisaged in this report to be successfully integrated.

We already have the sun, wind, geothermal sources and running rivers available right now, whilst ocean energy, biomass and efficient gas turbines are all set to make a massive contribution in the future. Clever technologies can track and manage energy use patterns, provide flexible power that follows demand through the day, use better storage options and group customers together to form 'virtual batteries'. With all these solutions we can secure the renewable energy future needed to avert catastrophic climate change. Renewable energy 24/7 is technically and economically possible, it just needs the right policy and the commercial investment to get things moving and 'keep the lights on'.[9]

the new electricity grid

The electricity 'grid' is the collective name for all the cables, transformers and infrastructure that transport electricity from power plants to the end users. In all networks, some energy is lost as it is travels, but moving electricity around within a localised distribution network is more efficient and results in less energy loss.

The existing electricity transmission (main grid lines) and distribution system (local network) was mainly designed and planned 40 to 60 years ago. All over the developed world, the grids were built with large power plants in the middle and high voltage alternating current (AC) transmission power lines connecting up to the areas where the power is used. A lower voltage distribution network then carries the current to the final consumers. This is known as a centralised grid system, with a relatively small number of large power stations mostly fuelled by coal or gas.

references
9 THE ARGUMENTS AND TECHNICAL SOLUTIONS OUTLINED HERE ARE EXPLAINED IN MORE DETAIL IN THE EUROPEAN RENEWABLE ENERGY COUNCIL/GREENPEACE REPORT, "[R]ENEWABLES 24/7: INFRASTRUCTURE NEEDED TO SAVE THE CLIMATE", NOVEMBER 2009.

In the future we need to change the grid network so that it does not rely on large conventional power plants but instead on clean energy from a range of renewable sources. These will typically be smaller scale power generators distributed throughout the grid. A localised distribution network is more efficient and avoids energy losses during long distance transmission. There will also be some concentrated supply from large renewable power plants. Examples of these large generators of the future are the massive wind farms already being built in Europe's North Sea and the plan for large areas of concentrating solar mirrors to generate energy in Southern Europe or Northern Africa.

The challenge ahead is to integrate new generation sources and at the same time phase out most of the large scale conventional power plants, while still keeping the lights on. This will need novel types of grids and an innovative power system architecture involving both new technologies and new ways of managing the network to ensure a balance between fluctuations in energy demand and supply.

The key elements of this new power system architecture are micro grids, smart grids and an efficient large scale super grid. The three types of system will support and interconnect with each other (see Figure 1.3).

A major role in the construction and operation of this new system architecture will be played by the IT sector. Because a smart grid has power supplied from a diverse range of sources and locations it relies on the gathering and analysis of a large quantity of data. This requires software, hardware and networks that are capable of delivering data quickly, and responding to the information that they contain. Providing energy users with real time data about their energy consumption patterns and the appliances in their buildings, for example, helps them to improve their energy efficiency, and will allow appliances to be used at a time when a local renewable supply is plentiful, for example when the wind is blowing.

There are numerous IT companies offering products and services to manage and monitor energy. These include IBM, Fujitsu, Google, Microsoft and Cisco. These and other giants of the telecommunications and technology sector have the power to make the grid smarter, and to move us faster towards a clean energy future. Greenpeace has initiated the 'Cool IT' campaign to put pressure on the IT sector to make such technologies a reality.

hybrid systems

The developed world has extensive electricity grids supplying power to nearly 100% of the population. In parts of the developing world, however, many rural areas get by with unreliable grids or polluting electricity, for example from stand-alone diesel generators. This is also very expensive for small communities.

The electrification of rural areas that currently have no access to any power system cannot go ahead as it has in the past. A standard approach in developed countries has been to extend the grid by installing high or medium voltage lines, new substations and a low voltage distribution grid. But when there is low potential electricity demand, and long distances between the existing grid and rural areas, this method is often not economically feasible.

Electrification based on renewable energy systems with a hybrid mix of sources is often the cheapest as well as the least polluting alternative. Hybrid systems connect renewable energy sources such as wind and solar power to a battery via a charge controller, which stores the generated electricity and acts as the main power supply. Back-up supply typically comes from a fossil fuel, for example in a wind-battery-diesel or PV-battery-diesel system. Such decentralised hybrid systems are more reliable, consumers can be involved in their operation through innovative technologies and they can make best use of local resources. They are also less dependent on large scale infrastructure and can be constructed and connected faster, especially in rural areas.

Finance can often be an issue for relatively poor rural communities wanting to install such hybrid renewable systems. Greenpeace has therefore developed a model in which projects are bundled together in order to make the financial package large enough to be eligible for international investment support. In the Pacific region, for example, power generation projects from a number of islands, an entire island state such as the Maldives or even several island states could be bundled into one project package. This would make it large enough for funding as an international project by OECD countries. Funding could come from a mixture of a feed-in tariff and a fund which covers the extra costs, as proposed in the "[R]enewables 24/7" report, and known as a Feed-in Tariff Support Mechanism. In terms of project planning, it is essential that the communities themselves are directly involved in the process.

elements in the new power system architecture

A **hybrid system** based on more than one generating source, for example solar and wind power, is a method of providing a secure supply in remote rural areas or islands, especially where there is no grid-connected electricity. This is particularly appropriate in developing countries. In the future, several hybrid systems could be connected together to form a **micro grid** in which the supply is managed using smart grid techniques.

A **smart grid** is an electricity grid that connects decentralised renewable energy sources and cogeneration and distributes power highly efficiently. Advanced communication and control technologies such as smart electricity meters are used to deliver electricity more cost effectively, with lower greenhouse intensity and in response to consumer needs. Typically, small generators such as wind turbines, solar panels or fuels cells are combined with energy management to balance out the load of all the users on the system. Smart grids are a way to integrate massive amounts of renewable energy into the system and enable the decommissioning of older centralised power stations.

A **super grid** is a large scale electricity grid network linking together a number of countries, or connecting areas with a large supply of renewable electricity to an area with a large demand - ideally based on more efficient HVDC (High Voltage Direct Current) cables. An example of the former would be the interconnection of all the large renewable based power plants in the North Sea. An example of the latter would be a connection between Southern Europe and Africa so that renewable energy could be exported from an area with a large renewable resource to urban centres where there is high demand.

image THE WIND TURBINES ARE GOING TO BE USED FOR THE CONSTRUCTION OF AN OFFSHORE WINDFARM AT MIDDELGRUNDEN WHICH IS CLOSE TO COPENHAGEN, DENMARK.

smart grids

The task of integrating renewable energy technologies into existing power systems is similar in all power systems around the world, whether they are large centralised networks or island systems. The main aim of power system operation is to balance electricity consumption and generation.

Thorough forward planning is needed to ensure that the available production can match demand at all times. In addition to balancing supply and demand, the power system must also be able to:

- Fulfil defined power quality standards – voltage/frequency - which may require additional technical equipment, and
- Survive extreme situations such as sudden interruptions of supply, for example from a fault at a generation unit or a breakdown in the transmission system.

Integrating renewable energy by using a smart grid means moving away from the issue of baseload power towards the question as to whether the supply is flexible or inflexible. In a smart grid a portfolio of flexible energy providers can follow the load during both day and night (for example, solar plus gas, geothermal, wind and demand management) without blackouts.

A number of European countries have already shown that it is possible to integrate large quantities of variable renewable power generation into the grid network and achieve a high percentage of the total supply. In Denmark, for example, the average supplied by wind power is about 20%, with peaks of more than 100% of demand. On those occasions surplus electricity is exported to neighbouring countries. In Spain, a much larger country with a higher demand, the average supplied by wind power is 14%, with peaks of more than 50%.

Until now renewable power technology development has put most effort into adjusting its technical performance to the needs of the existing network, mainly by complying with grid codes, which cover such issues as voltage frequency and reactive power. However, the time has come for the power systems themselves to better adjust to the needs of variable generation. This means that they must become flexible enough to follow the fluctuations of variable renewable power, for example by adjusting demand via demand-side management and/or deploying storage systems.

The future power system will no longer consist of a few centralised power plants but instead of tens of thousands of generation units such as solar panels, wind turbines and other renewable generation, partly distributed in the distribution network, partly concentrated in large power plants such as offshore wind parks.

The trade off is that power system planning will become more complex due to the larger number of generation assets and the significant share of variable power generation causing constantly changing power flows. Smart grid technology will be needed to support power system planning. This will operate by actively supporting day-ahead forecasts and system balancing, providing real-time information about the status of the network and the generation units, in combination with weather forecasts. It will also play a significant role in making sure systems can meet the peak demand at all times and make better use of distribution and transmission assets, thereby keeping the need for network extensions to the absolute minimum.

To develop a power system based almost entirely on renewable energy sources will require a new overall power system architecture, including smart grid technology. This concept will need substantial amounts of further work to fully emerge.[10] Figure 1.3 shows a simplified graphic representation of the key elements in future renewable-based power systems using smart grid technology.

A range of options are available to enable the large-scale integration of variable renewable energy resources into the power supply system. These include demand side management, the concept of a Virtual Power Plant and a number of choices for the storage of power.

The level and timing of **demand for electricity** can be managed by providing consumers with financial incentives to reduce or shut off their supply at periods of peak consumption. This system is already used for some large industrial customers. A Norwegian power supplier even involves private household customers by sending them a text message with a signal to shut down. Each household can decide in advance whether or not they want to participate. In Germany, experiments are being conducted with time flexible tariffs so that washing machines operate at night and refrigerators turn off temporarily during periods of high demand.

This type of demand side management has been simplified by advances in communications technology. In Italy, for example, 30 million innovative electricity counters have been installed to allow remote meter reading and control of consumer and service information. Many household electrical products or systems, such as refrigerators, dishwashers, washing machines, storage heaters, water pumps and air conditioning, can be managed either by temporary shut-off or by rescheduling their time of operation, thus freeing up electricity load for other uses and dovetailing it with variations in renewable supply.

A **Virtual Power Plant** (VPP) interconnects a range of real power plants (for example solar, wind and hydro) as well as storage options distributed in the power system using information technology. A real life example of a VPP is the Combined Renewable Energy Power Plant developed by three German companies.[11] This system interconnects and controls 11 wind power plants, 20 solar power plants, four CHP plants based on biomass and a pumped storage unit, all geographically spread around Germany. The VPP combines the advantages of the various renewable energy sources by carefully monitoring (and anticipating through weather forecasts) when the wind turbines and solar modules will be generating electricity. Biogas and pumped storage units are then used to make up the difference, either delivering electricity as needed in order to balance short term fluctuations or temporarily storing it.[12] Together the combination ensures sufficient electricity supply to cover demand.

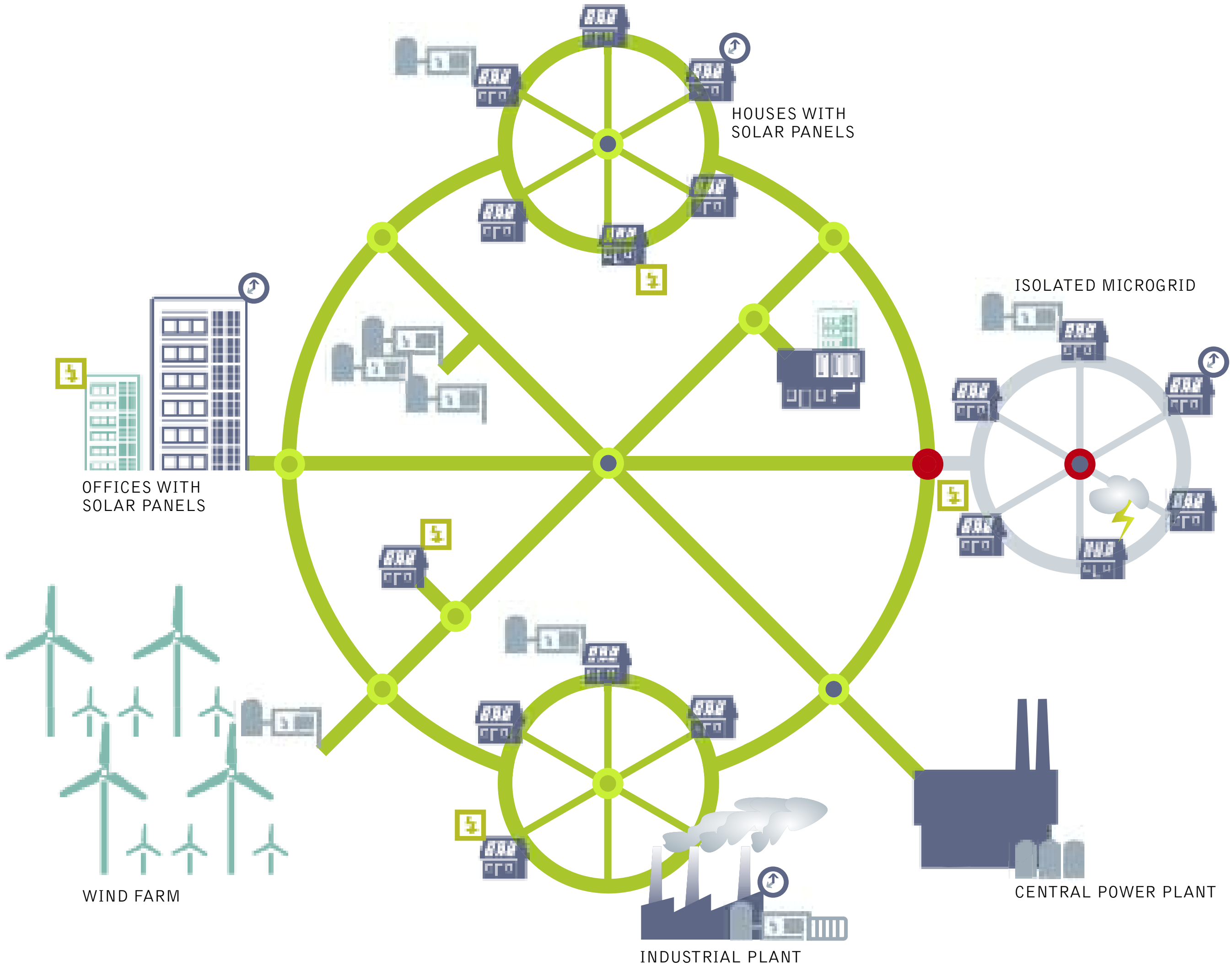
A number of mature and emerging technologies are viable options for **storing electricity**. Of these, pumped storage can be considered the most established technology. Pumped storage is a type of hydroelectric power station that can store energy. Water is pumped from a lower elevation reservoir to a higher elevation during times of low cost, off-peak electricity. During periods of high electrical demand, the stored water is released through turbines. Taking into account evaporation losses from the exposed water surface and conversion losses, roughly 70 to 85% of the electrical energy used to pump the water into the elevated reservoir can be regained when it is released. Pumped storage plants can also respond to changes in the power system load demand within seconds.

references

10 SEE ALSO ECOGRID PHASE 1 SUMMARY REPORT, AVAILABLE AT: HTTP://WWW.ENERGINET.DK/NR/RDONLYRES/8B1A4A06-CBA3-41DA-9402-B56C2C288FB0/0/ECOGRIDDK_PHASE1_SUMMARYREPORT.PDF
11 SEE ALSO HTTP://WWW.KOMBIKRAFTWERK.DE/INDEX.PHP?ID=27
12 SEE ALSO HTTP://WWW.SOLARSERVER.DE/SOLARMAGAZIN/ANLAGEJANUAR2008_E.HTML

figure 1.3: the smart-grid vision for the energy [r]evolution

A VISION FOR THE FUTURE – A NETWORK OF INTEGRATED MICROGRIDS THAT CAN MONITOR AND HEAL ITSELF.



- **PROCESSORS** EXECUTE SPECIAL PROTECTION SCHEMES IN MICROSECONDS
- **SENSORS** ON 'STANDBY' – DETECT FLUCTUATIONS AND DISTURBANCES, AND CAN SIGNAL FOR AREAS TO BE ISOLATED
- **SENSORS** 'ACTIVATED' – DETECT FLUCTUATIONS AND DISTURBANCES, AND CAN SIGNAL FOR AREAS TO BE ISOLATED

SMART APPLIANCES CAN SHUT OFF IN RESPONSE TO FREQUENCY FLUCTUATIONS

DEMAND MANAGEMENT USE CAN BE SHIFTED TO OFF-PEAK TIMES TO SAVE MONEY

GENERATORS ENERGY FROM SMALL GENERATORS AND SOLAR PANELS CAN REDUCE OVERALL DEMAND ON THE GRID

STORAGE ENERGY GENERATED AT OFF-PEAK TIMES COULD BE STORED IN BATTERIES FOR LATER USE

DISTURBANCE IN THE GRID

Another way of 'storing' electricity is to use it to directly meet the demand from electric vehicles. The number of electric cars and trucks is expected to increase dramatically under the Energy [R]evolution scenario. The Vehicle-to-Grid (V2G) concept, for example, is based on electric cars equipped with batteries that can be charged during times when there is surplus renewable generation and then discharged to supply peaking capacity or ancillary services to the power system while they are parked. During peak demand times cars are often parked close to main load centres, for instance outside factories, so there would be no network issues. Within the V2G concept a Virtual Power Plant would be built using ICT technology to aggregate the electric cars participating in the relevant electricity markets and to meter the charging/de-charging activities. In 2009 the EDISON demonstration project was launched to develop and test the infrastructure for integrating electric cars into the power system of the Danish island of Bornholm.

energy resources & security of supply

GLOBAL | STATUS OF GLOBAL FUEL SUPPLIES | GLOBAL POTENTIAL FOR SUSTAINABLE BIOMASS | POTENTIAL OF ENERGY CROPS

2

AROUND 80% OF GLOBAL ENERGY DEMAND IS MET BY FINITE FOSSIL FUELS. © R. KASPRZAK/DREAMSTIME

“the energy revolution in france will be through energy savings and the development of renewable energies.”

JEAN-LOUIS BORLOO
FRENCH MINISTER FOR ECOLOGY, ENERGY, SUSTAINABLE DEVELOPMENT AND TOWN AND COUNTRY PLANNING

The issue of security of supply is now at the top of the energy policy agenda. Concern is focused both on price security and the security of physical supply. At present around 80% of global energy demand is met by fossil fuels. The unrelenting increase in energy demand is matched by the finite nature of these resources. At the same time, the global distribution of oil and gas resources does not match the distribution of demand. Some countries have to rely almost entirely on fossil fuel imports. The maps on the following pages provide an overview of the availability of different fuels and their regional distribution. Information in this chapter is based partly on the report 'Plugging the Gap'[13], as well as information from the International Energy Agency's World Energy Outlook 2008 and 2009 reports.

status of global fuel supplies

Oil is the lifeblood of the modern global economy, as the effects of the supply disruptions of the 1970s made clear. It is the number one source of energy, providing 32% of the world's needs and the fuel employed almost exclusively for essential uses such as transportation. However, a passionate debate has developed over the ability of supply to meet increasing consumption, a debate obscured by poor information and stirred by recent soaring prices.

the reserves chaos

Public data about oil and gas reserves is strikingly inconsistent, and potentially unreliable for legal, commercial, historical and sometimes political reasons. The most widely available and quoted figures, those from the industry journals *Oil & Gas Journal and World Oil*, have limited value as they report the reserve figures provided by companies and governments without analysis or verification. Moreover, as there is no agreed definition of reserves or standard reporting practice, these figures usually stand for different physical and conceptual magnitudes. Confusing terminology - 'proved', 'probable', 'possible', 'recoverable', 'reasonable certainty' - only adds to the problem.

Historically, private oil companies have consistently underestimated their reserves to comply with conservative stock exchange rules and through natural commercial caution. Whenever a discovery was made, only a portion of the geologist's estimate of recoverable resources was reported; subsequent revisions would then increase the reserves from that same oil field over time. National oil companies, mostly represented by OPEC (Organisation of Petroleum Exporting Countries), have taken a very different approach. They are not subject to any sort of accountability and their reporting practices are even less clear. In the late 1980s, the OPEC countries blatantly overstated their reserves while competing for production quotas, which were allocated as a proportion of the reserves. Although some revision was needed after the companies were nationalised, between 1985 and 1990, OPEC countries increased their apparent joint reserves by 82%. Not only were these dubious revisions never corrected, but many of these countries have reported untouched reserves for years, even if no sizeable discoveries were made and production continued at the same pace. Additionally, the Former Soviet Union's oil and gas reserves have been overestimated by about 30% because the original assessments were later misinterpreted.

Whilst private companies are now becoming more realistic about the extent of their resources, the OPEC countries hold by far the majority of the reported reserves, and their information is as unsatisfactory as ever. Their conclusions should therefore be treated with considerable caution. To fairly estimate the world's oil resources a regional assessment of the mean backdated (i.e. 'technical') discoveries would need to be performed.

non-conventional oil reserves

A large share of the world's remaining oil resources is classified as 'non-conventional'. Potential fuel sources such as oil sands, extra heavy oil and oil shale are generally more costly to exploit and their recovery involves enormous environmental damage. The reserves of oil sands and extra heavy oil in existence worldwide are estimated to amount to around 6 trillion barrels, of which between 1 and 2 trillion barrels are believed to be recoverable if the oil price is high enough and the environmental standards low enough.

One of the worst examples of environmental degradation resulting from the exploitation of unconventional oil reserves is the oil sands that lie beneath the Canadian province of Alberta and form the world's second-largest proven oil reserves after Saudi Arabia. Producing crude oil from these 'tar sands' - a heavy mixture of bitumen, water, sand and clay found beneath more than 54,000 square miles[14] of prime forest in northern Alberta, an area the size of England and Wales - generates up to four times more carbon dioxide, the principal global warming gas, than conventional drilling. The booming oil sands industry will produce 100 million tonnes of CO_2 a year (equivalent to a fifth of the UK's entire annual emissions) by 2012, ensuring that Canada will miss its emission targets under the Kyoto treaty. The oil rush is also scarring a wilderness landscape: millions of tonnes of plant life and top soil are scooped away in vast opencast mines and millions of litres of water diverted from rivers. Up to five barrels of water are needed to produce a single barrel of crude and the process requires huge amounts of natural gas. It takes two tonnes of the raw sands to produce a single barrel of oil.

gas

Natural gas has been the fastest growing fossil energy source over the last two decades, boosted by its increasing share in the electricity generation mix. Gas is generally regarded as an abundant resource and public concerns about depletion are limited to oil, even though few in-depth studies address the subject. Gas resources are more concentrated, and a few massive fields make up most of the reserves. The largest gas field in the world holds 15% of the Ultimate Recoverable Resources (URR), compared to 6% for oil. Unfortunately, information about gas resources suffers from the same bad practices as oil data because gas mostly comes from the same geological formations, and the same stakeholders are involved.

13 'PLUGGING THE GAP - A SURVEY OF WORLD FUEL RESOURCES AND THEIR IMPACT ON THE DEVELOPMENT OF WIND ENERGY', GLOBAL WIND ENERGY COUNCIL/RENEWABLE ENERGY SYSTEMS, 2006.
14 *THE INDEPENDENT*, 10 DECEMBER 2007

image THE BIOENERGY VILLAGE OF JUEHNDE WHICH WAS THE FIRST COMMUNITY IN GERMANY TO PRODUCE ALL ITS ENERGY NEEDED FOR HEATING AND ELECTRICITY, WITH CO_2 NEUTRAL BIOMASS.

image A NEWLY DEFORESTED AREA WHICH HAS BEEN CLEARED FOR AGRICULTURAL EXPANSION IN THE AMAZON, BRAZIL.

Most reserves are initially understated and then gradually revised upwards, giving an optimistic impression of growth. By contrast, Russia's reserves, the largest in the world, are considered to have been overestimated by about 30%. Owing to geological similarities, gas follows the same depletion dynamic as oil, and thus the same discovery and production cycles. In fact, existing data for gas is of worse quality than for oil, with ambiguities arising over the amount produced, partly because flared and vented gas is not always accounted for. As opposed to published reserves, the technical ones have been almost constant since 1980 because discoveries have roughly matched production.

shale gas[15]

Natural gas production, especially in the United States, has recently involved a growing contribution from non-conventional gas supplies such as shale gas. Conventional natural gas deposits have a well-defined geographical area, the reservoirs are porous and permeable, the gas is produced easily through a wellbore and does not generally require artificial stimulation. Non-conventional deposits, on the other hand, are often lower in resource concentration, more dispersed over large areas and require well stimulation or some other extraction or conversion technology. They are also usually more expensive to develop per unit of energy.

Research and investment in non-conventional gas resources has increased significantly in recent years due to the rising price of conventional natural gas. In some areas the technologies for economic production have already been developed, in others it is still at the research stage. Extracting shale gas, however, usually goes hand in hand with environmentally hazardous processes. Even so, it is expected to increase.

coal

Coal was the world's largest source of primary energy until it was overtaken by oil in the 1960s. Today, coal supplies almost one quarter of the world's energy. Despite being the most abundant of fossil fuels, coal's development is currently threatened by environmental concerns; hence its future will unfold in the context of both energy security and global warming.

Coal is abundant and more equally distributed throughout the world than oil and gas. Global recoverable reserves are the largest of all fossil fuels, and most countries have at least some. Moreover, existing and prospective big energy consumers like the US, China and India are self-sufficient in coal and will be for the foreseeable future. Coal has been exploited on a large scale for two centuries, so both the product and the available resources are well known; no substantial new deposits are expected to be discovered. Extrapolating the demand forecast forward, the world will consume 20% of its current reserves by 2030 and 40% by 2050. Hence, if current trends are maintained, coal would still last several hundred years.

table 2.1: **overview of fossil fuel reserves and resources**

RESERVES, RESOURCES AND ADDITIONAL OCCURRENCES OF FOSSIL ENERGY CARRIERS ACCORDING TO DIFFERENT AUTHORS. **C** CONVENTIONAL (PETROLEUM WITH A CERTAIN DENSITY, FREE NATURAL GAS, PETROLEUM GAS, **NC** NON-CONVENTIONAL) HEAVY FUEL OIL, VERY HEAVY OILS, TAR SANDS AND OIL SHALE, GAS IN COAL SEAMS, AQUIFER GAS, NATURAL GAS IN TIGHT FORMATIONS, GAS HYDRATES). THE PRESENCE OF ADDITIONAL OCCURRENCES IS ASSUMED BASED ON GEOLOGICAL CONDITIONS, BUT THEIR POTENTIAL FOR ECONOMIC RECOVERY IS CURRENTLY VERY UNCERTAIN. IN COMPARISON: IN 1998, THE GLOBAL PRIMARY ENERGY DEMAND WAS 402EJ (UNDP ET AL., 2000).

ENERGY CARRIER		WEO 2009, WEO 2008, WEO 2007 EJ	BROWN, 2002 EJ	IEA, 2002c EJ		IPCC, 2001a EJ		NAKICENOVIC ET AL., 2000 EJ		UNDP ET AL., 2000 EJ		BGR, 1998 EJ
Gas	reserves	182 tcm[a]	5,600	6,200	c	5,400	c	5,900	c	5,500	c	5,300
					nc	8,000	nc	8,000	nc	9,400	nc	100
	resources	405 tcm[a]	9,400	11,100	c	11,700	c	11,700	c	11,100	c	7,800
					nc	10,800	nc	10,800	nc	23,800	nc[d]	111,900
	additional occurrences	921 tcm[a]				796,000		799,700		930,000		
Oil	reserves	2,369 bb[b]	5,800	5,700	c	5,900	c	6,300	c	6,000	c	6,700
					nc	6,600	nc	8,100	nc	5,100	nc	5,900
	resources		10,200	13,400	c	7,500	c	6,100	c	6,100	c	3,300
					nc	15,500	nc	13,900	nc	15,200	nc	25,200
	additional occurrences					61,000		79,500		45,000		
Coal	reserves	847 bill tonnes[c]	23,600	22,500		42,000		25,400		20,700		16,300
	resources		26,000	165,000		100,000		117,000		179,000		179,000
	additional occurrences	921 tcm[c]				121,000		125,600				
Total	resource (reserves + resources)		**180,600**	**223,900**		**212,200**		**213,200**		**281,900**		**361,500**
Total	occurrence					**1,204,200**		**1,218,000**		**1,256,000**		

sources & notes A) WEO 2009, B) OIL WEO 2008, PAGE 205 TABLE 9.1 C) IEA WEO 2008, PAGE 127 & WEC 2007. D) INCLUDING GAS HYDRATES. SEE TABLE FOR ALL OTHER SOURCES.

15 INTERSTATE NATURAL GAS ASSOCIATION OF AMERICA (INGAA), "AVAILABILITY, ECONOMICS AND PRODUCTION POTENTIAL OF NORTH AMERICAN UNCONVENTIONAL NATURAL GAS SUPPLIES", NOVEMBER 2008

table 2.2: assumptions on world wide fossil fuel use in the energy [r]evolution scenario

Oil	2007	2015	2020	2030	2040	2050
Reference [PJ]	155,920	161,847	170,164	192,431	209,056	224,983
Reference [million barrels]	25,477	26,446	27,805	31,443	34,159	36,762
E[R] [PJ]		153,267	143,599	123,756	101,186	81,833
E[R] [million barrels]		25,044	23,464	20,222	16,534	13,371
Adv E[R] [PJ]		152,857	142,747	115,002	81,608	51,770
Adv E[R] [million barrels]		24,977	23,325	18,791	13,335	8,459
Gas	2007	2015	2020	2030	2040	2050
Reference [PJ]	104,845	112,931	121,148	141,706	155,015	166,487
Reference [billion cubic metres = 10E9m³]	2,759	2,972	3,188	3,729	4,079	4,381
E[R] [PJ]		116,974	121,646	122,337	99,450	71,383
E[R] [billion cubic metres = 10E9m³]		3,078	3,201	3,219	2,617	1,878
Adv E[R] [PJ]		118,449	119,675	114,122	79,547	34,285
Adv E[R] [billion cubic metres = 10E9m³]		3,117	3,149	3,003	2,093	902
Coal	2007	2015	2020	2030	2040	2050
Reference [PJ]	135,890	162,859	162,859	204,231	217,356	225,245
Reference [million tonnes]	7,319	8,306	8,306	9,882	10,408	10,751
E[R] [PJ]		140,862	140,862	96,846	64,285	37,563
E[R] [million tonnes]		7,217	7,217	4,407	2,810	1,631
Adv E[R] [PJ]		135,005	135,005	69,871	28,652	7,501
Adv E[R] [million tonnes]		6,829	6,829	3,126	1,250	326

nuclear

Uranium, the fuel used in nuclear power plants, is a finite resource whose economically available reserves are limited. Its distribution is almost as concentrated as oil and does not match global consumption. Five countries - Canada, Australia, Kazakhstan, Russia and Niger - control three quarters of the world's supply. As a significant user of uranium, however, Russia's reserves will be exhausted within ten years.

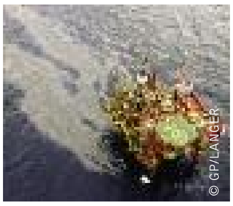
Secondary sources, such as old deposits, currently make up nearly half of worldwide uranium reserves. These will soon be used up, however. Mining capacities will have to be nearly doubled in the next few years to meet current needs.

A joint report by the OECD Nuclear Energy Agency and the International Atomic Energy Agency[16] estimates that all existing nuclear power plants will have used up their nuclear fuel, employing current technology, within less than 70 years. Given the range of scenarios for the worldwide development of nuclear power, it is likely that uranium supplies will be exhausted sometime between 2026 and 2070. This forecast includes the use of mixed oxide fuel (MOX), a mixture of uranium and plutonium.

16 'URANIUM 2003: RESOURCES, PRODUCTION AND DEMAND'

image PLATFORM/OIL RIG DUNLIN IN THE NORTH SEA SHOWING OIL POLLUTION.

image ON A LINFEN STREET, TWO MEN LOAD UP A CART WITH COAL THAT WILL BE USED FOR COOKING. LINFEN, A CITY OF ABOUT 4.3 MILLION, IS ONE OF THE MOST POLLUTED CITIES IN THE WORLD. CHINA'S INCREASINGLY POLLUTED ENVIRONMENT IS LARGELY A RESULT OF THE COUNTRY'S RAPID DEVELOPMENT AND CONSEQUENTLY A LARGE INCREASE IN PRIMARY ENERGY CONSUMPTION, WHICH IS ALMOST ENTIRELY PRODUCED BY BURNING COAL.



renewable energy

Nature offers a variety of freely available options for producing energy. Their exploitation is mainly a question of how to convert sunlight, wind, biomass or water into electricity, heat or power as efficiently, sustainably and cost-effectively as possible.

On average, the energy in the sunshine that reaches the earth is about one kilowatt per square metre worldwide. According to the Research Association for Solar Power, power is gushing from renewable energy sources at a rate of 2,850 times more energy than is needed in the world. In one day, the sunlight which reaches the earth produces enough energy to satisfy the world's current power requirements for eight years. Even though only a percentage of that potential is technically accessible, this is still enough to provide just under six times more power than the world currently requires.

Before looking at the part renewable energies can play in the range of scenarios in this report, however, it is worth understanding the upper limits of their potential. To start with, the overall technical potential of renewable energy – the amount that can be produced taking into account the primary resources, the socio-geographical constraints and the technical losses in the conversion process – is huge and several times higher than current total energy demand. Assessments of the global technical potential vary significantly from 2,477 Exajoules per annum (EJ/a) (Nitsch 2004) up to 15,857 EJ/a (UBA 2009). Based on the global primary energy demand in 2007 (IEA 2009) of 503 EJ/a, the total technical potential of renewable energy sources at the upper limit would exceed demand by a factor of 32. However, barriers to the growth of renewable energy technologies may come from economical, political and infrastructural constraints. That is why the technical potential will never be realised in total.

Assessing long term technical potentials is subject to various uncertainties. The distribution of the theoretical resources, such as the global wind speed or the productivity of energy crops, is not always well analysed. The geographical availability is subject to variations such as land use change, future planning decisions on where certain technologies are allowed, and accessibility of resources, for example underground geothermal energy. Technical performance may take longer to achieve than expected. There are also uncertainties in terms of the consistency of the data provided in studies, and underlying assumptions are often not explained in detail.

The meta study by the DLR (German Aerospace Center), Wuppertal Institute and Ecofys, commissioned by the German Federal Environment Agency, provides a comprehensive overview of the technical renewable energy potential by technologies and world region.[18] This survey analysed ten major studies of global and regional potentials by organisations such as the United Nations Development Programme and a range of academic institutions. Each of the major renewable energy sources was assessed, with special attention paid to the effect of environmental constraints on their overall potential. The study provides data for the years 2020, 2030 and 2050 (see Table 2.3).

The complexity of calculating renewable energy potentials is particularly great because these technologies are comparatively young and their exploitation involves changes to the way in which energy is both generated and distributed. Whilst a calculation of the theoretical and geographical potentials has only a few dynamic parameters, the technical potential is dependent on a number of uncertainties.

definition of types of energy resource potential[17]

theoretical potential The theoretical potential identifies the physical upper limit of the energy available from a certain source. For solar energy, for example, this would be the total solar radiation falling on a particular surface.

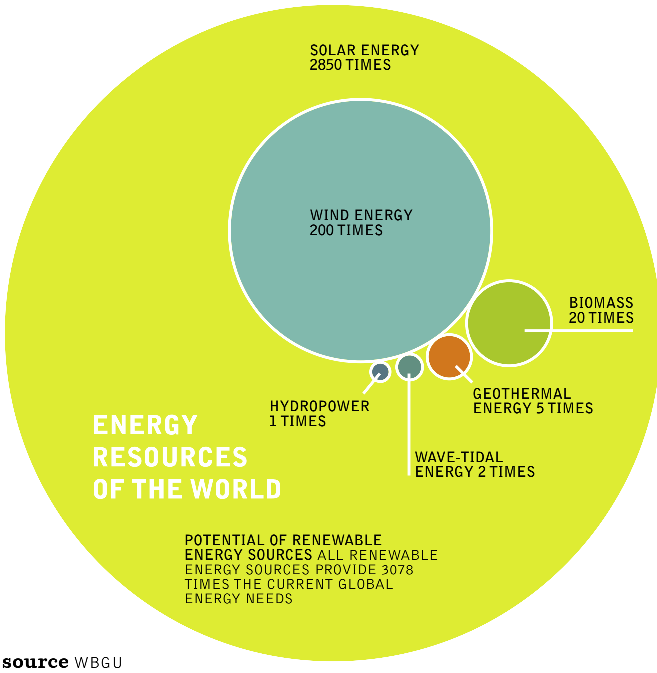
conversion potential This is derived from the annual efficiency of the respective conversion technology. It is therefore not a strictly defined value, since the efficiency of a particular technology depends on technological progress.

technical potential This takes into account additional restrictions regarding the area that is realistically available for energy generation. Technological, structural and ecological restrictions, as well as legislative requirements, are accounted for.

economic potential The proportion of the technical potential that can be utilised economically. For biomass, for example, those quantities are included that can be exploited economically in competition with other products and land uses.

sustainable potential This limits the potential of an energy source based on evaluation of ecological and socio-economic factors.

figure 2.1: **energy resources of the world**



source WBGU

17 WBGU (GERMAN ADVISORY COUNCIL ON GLOBAL CHANGE).
18 DLR, WUPPERTAL INSTITUTE, ECOFYS, 'ROLE AND POTENTIAL OF RENEWABLE ENERGY AND ENERGY EFFICIENCY FOR GLOBAL ENERGY SUPPLY', COMMISSIONED BY GERMAN FEDERAL ENVIRONMENT AGENCY, FKZ 3707 41 108, MARCH 2009;

table 2.3: technical potential by renewable energy technology for 2020, 2030 and 2050

	TECHNICAL POTENTIAL ELECTRICITY EJ/YEAR ELECTRIC POWER							TECHNICAL POTENTIAL HEAT EJ/A		TECHNICAL POTENTIAL PRIMARY ENERGY EJ/A		
	SOLAR CSP	SOLAR PV	HYDRO POWER	WIND ON-SHORE	WIND OFF-SHORE	OCEAN ENERGY	GEO-THERMAL ELECTRIC	GEO-THERMAL DIRECT USES	SOLAR WATER HEATING	BIOMASS RESIDUES	BIOMASS ENERGY CROPS	TOTAL
World 2020	1,125.9	5,156.1	47.5	368.6	25.6	66.2	4.5	498.5	113.1	58.6	43.4	7,505
World 2030	1,351.0	6,187.3	48.5	361.7	35.9	165.6	13.4	1,486.6	117.3	68.3	61.1	9,897
World 2050	1,688.8	8,043.5	50.0	378.9	57.4	331.2	44.8	4,955.2	123.4	87.6	96.5	15,857
World energy demand 2007: 502.9 EJ/a[a]												
Technical potential in 2050 versus world primary energy demand 2007.	3.4	16.0	0.1	0.8	0.1	0.7	0.1	9.9	0.2	0.2	0.2	32

source DLR, WUPPERTAL INSTITUTE, ECOFYS; ROLE AND POTENTIAL OF RENEWABLE ENERGY AND ENERGY EFFICIENCY FOR GLOBAL ENERGY SUPPLY; COMMISSIONED BY THE GERMAN FEDERAL ENVIRONMENT AGENCY FKZ 3707 41 108, MARCH 2009; POTENTIAL VERSUS ENERGY DEMAND: S. TESKE
a IEA 2009

A technology breakthrough, for example, could have a dramatic impact, changing the technical potential assessment within a very short time frame. Considering the huge dynamic of technology development, many existing studies are based on out of date information. The estimates in the DLR study could therefore be updated using more recent data, for example significantly increased average wind turbine capacity and output, which would increase the technical potentials still further.

Given the large unexploited resources which exist, even without having reached the full development limits of the various technologies, it can be concluded that the technical potential is not a limiting factor to expansion of renewable energy generation.

It will not be necessary to exploit the entire technical potential, however, nor would this be unproblematic. Implementation of renewable energies has to respect sustainability criteria in order to achieve a sound future energy supply. Public acceptance is crucial, especially bearing in mind that the decentralised character of many renewable energy technologies will move their operation closer to consumers. Without public acceptance, market expansion will be difficult or even impossible. The use of biomass, for example, has become controversial in recent years as it is seen as competing with other land uses, food production or nature conservation. Sustainability criteria will have a huge influence on whether bio-energy in particular can play a central role in future energy supply.

As important as the technical potential of worldwide renewable energy sources is their market potential. This term is often used in different ways. The general understanding is that market potential means the total amount of renewable energy that can be implemented in the market taking into account the demand for energy, competing technologies, any subsidies available as well as the current and future costs of renewable energy sources. The market potential may therefore in theory be larger than the economic potential. To be realistic, however, market potential analyses have to take into account the behaviour of private economic agents under specific prevailing conditions, which are of course partly shaped by public authorities. The energy policy framework in a particular country or region will have a profound impact on the expansion of renewable energies.

the global potential for sustainable biomass

As part of background research for the Energy [R]evolution Scenarios, Greenpeace commissioned the German Biomass Research Centre, the former Institute for Energy and Environment, to investigate the worldwide potential for energy crops up to 2050. In addition, information has been compiled from scientific studies of the global potential and from data derived from state of the art remote sensing techniques, such as satellite images. A summary of the report's findings is given below; references can be found in the full report.[19]

assessment of biomass potential studies

Various studies have looked historically at the potential for bio energy and come up with widely differing results. Comparison between them is difficult because they use different definitions of the various biomass resource fractions. This problem is particularly significant in relation to forest derived biomass. Most research has focused almost exclusively on energy crops, as their development is considered to be more significant for satisfying the demand for bio energy. The result is that the potential for using forest residues (wood left over after harvesting) is often underestimated.

Data from 18 studies has been examined, with a concentration on those which report the potential for biomass residues. Among these there were ten comprehensive assessments with more or less detailed documentation of the methodology. The majority focus on the long-term potential for 2050 and 2100. Little information is available for 2020 and 2030. Most of the studies were published within the last ten years. Figure 2.3 shows the variations in potential by biomass type from the different studies.

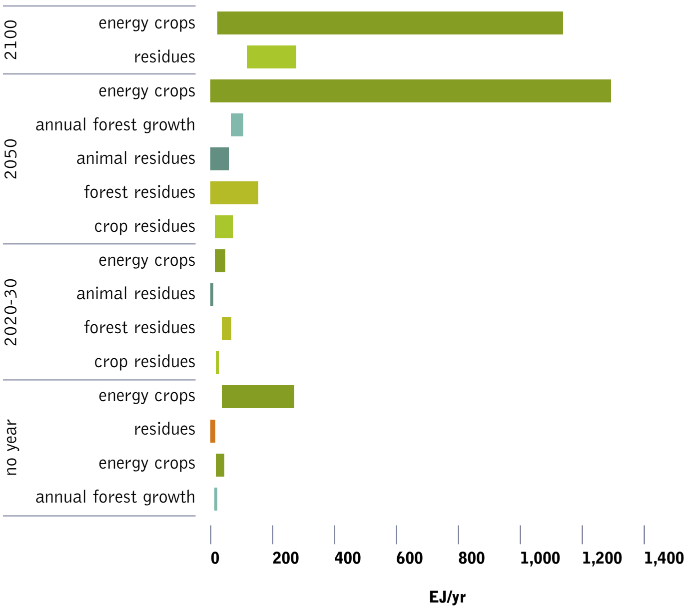
Looking at the contribution of different types of material to the total biomass potential, the majority of studies agree that the most promising resource is energy crops from dedicated plantations. Only six give a regional breakdown, however, and only a few quantify all types of residues separately. Quantifying the potential of minor fractions, such as animal residues and organic wastes, is difficult as the data is relatively poor.

19 SEIDENBERGER T., THRÄN D., OFFERMANN R., SEYFERT U., BUCHHORN M. AND ZEDDIES J. (2008). GLOBAL BIOMASS POTENTIALS. INVESTIGATION AND ASSESSMENT OF DATA. REMOTE SENSING IN BIOMASS POTENTIAL RESEARCH. COUNTRY-SPECIFIC ENERGY CROP POTENTIAL. GERMAN BIOMASS RESEARCH CENTRE (DBFZ). FOR GREENPEACE INTERNATIONAL. 137 P.

image SOLON AG PHOTOVOLTAICS FACILITY IN ARNSTEIN OPERATING 1,500 HORIZONTAL AND VERTICAL SOLAR "MOVERS". LARGEST TRACKING SOLAR FACILITY IN THE WORLD. EACH "MOVER" CAN BE BOUGHT AS A PRIVATE INVESTMENT FROM THE S.A.G. SOLARSTROM AG, BAYERN, GERMANY.

image WIND ENERGY PARK NEAR DAHME. WIND TURBINE IN THE SNOW OPERATED BY VESTAS.

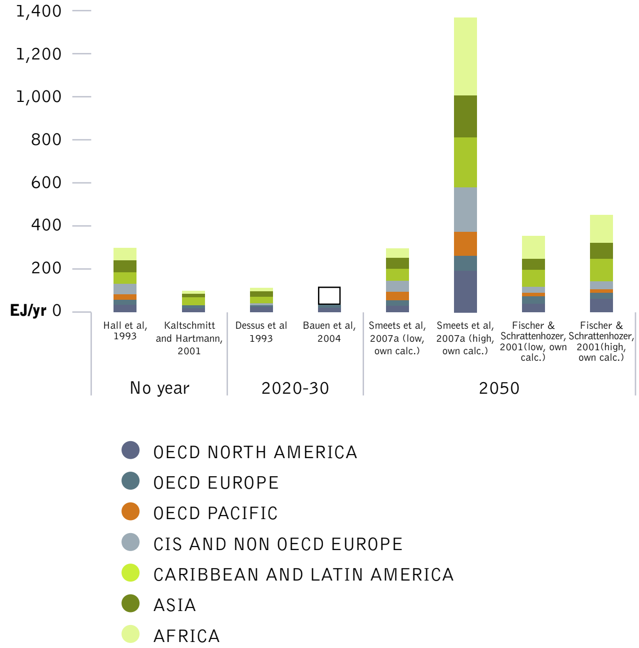
figure 2.2: ranges of potential for different biomass types



source GERMAN BIOMASS RESEARCH CENTRE (DBFZ)

figure 2.3: bio energy potential analysis from different authors

('EFFICIENCY' = REDUCTION COMPARED TO THE REFERENCE SCENARIO)



source GERMAN BIOMASS RESEARCH CENTRE (DBFZ)

potential of energy crops

Apart from the utilisation of biomass from residues, the cultivation of energy crops in agricultural production systems is of greatest significance in several regions of the world. The technical potential for growing energy crops has been calculated on the assumption that demand for food takes priority. As a first step the demand for arable and grassland for food production has been calculated for each of 133 countries in different scenarios. These scenarios are:

- Business as usual (BAU) scenario: Present agricultural activity continues for the foreseeable future
- Basic scenario: No forest clearing; reduced use of fallow areas for agriculture
- Sub-scenario 1: Basic scenario plus expanded ecological protection areas and reduced crop yields
- Sub-scenario 2: Basic scenario plus food consumption reduced in industrialised countries
- Sub-scenario 3: Combination of sub-scenarios 1 and 2

In a next step the surpluses of agricultural areas were classified either as arable land or grassland. On grassland, hay and grass silage are produced, on arable land fodder silage and Short Rotation Coppice (such as fast-growing willow or poplar) are cultivated. Silage of green fodder and grass are assumed to be used for biogas production, wood from SRC and hay from grasslands for the production of heat, electricity and synthetic fuels. Country specific yield variations were taken into consideration.

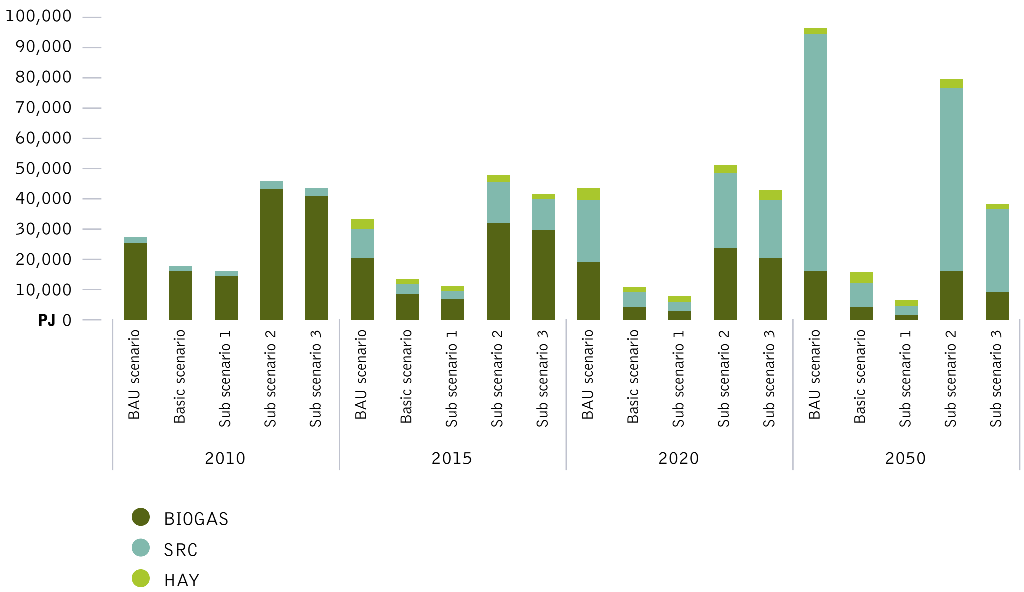
The result is that the global biomass potential from energy crops in 2050 falls within a range from 6 EJ in Sub-scenario 1 up to 97 EJ in the BAU scenario.

The best example of a country which would see a very different future under these scenarios in 2050 is Brazil. Under the BAU scenario large agricultural areas would be released by deforestation, whereas in the Basic and Sub 1 scenarios this would be forbidden, and no agricultural areas would be available for energy crops. By contrast a high potential would be available under Sub-scenario 2 as a consequence of reduced meat consumption. Because of their high populations and relatively small agricultural areas, no surplus land is available for energy crop production in Central America, Asia and Africa. The EU, North America and Australia, however, have relatively stable potentials.

The results of this exercise show that the availability of biomass resources is not only driven by the effect on global food supply but the conservation of natural forests and other biospheres. So the assessment of future biomass potential is only the starting point of a discussion about the integration of bioenergy into a renewable energy system.

The total global biomass potential (energy crops and residues) therefore ranges in 2020 from 66 EJ (Sub-scenario 1) up to 110 EJ (Sub-scenario 2) and in 2050 from 94 EJ (Sub-scenario 1) to 184 EJ (BAU scenario). These numbers are conservative and include a level of uncertainty, especially for 2050. The reasons for this uncertainty are the potential effects of climate change, possible changes in the worldwide political and economic situation, a higher yield as a result of changed agricultural techniques and/or faster development in plant breeding.

figure 2.4: world wide energy crop potentials in different scenarios



The Energy [R]evolution takes a precautionary approach to the future use of biofuels. This reflects growing concerns about the greenhouse gas balance of many biofuel sources, and also the risks posed by expanded bio fuels crop production to biodiversity (forests, wetlands and grasslands) and food security. In particular, research commissioned by Greenpeace in the development of the Energy [R]evolution suggests that there will be acute pressure on land for food production and habitat protection in 2050. As a result, the Energy [R]evolution does not include any biofuels from energy crops at 2050, restricting feedstocks to a limited quantity of forest and agricultural residues. It should be stressed, however, that this conservative approach is based on an assessment of today's technologies and their associated risks. The development of advanced forms of biofuels which do not involve significant land-take, are demonstrably sustainable in terms of their impacts on the wider environment, and have clear greenhouse gas benefits, should be an objective of public policy, and would provide additional flexibility in the renewable energy mix.

Concerns have also been raised about how countries account for the emissions associated with biofuels production and combustion. The lifecycle emissions of different biofuels can vary enormously. Rules developed under the Kyoto Protocol mean that under many circumstances, countries are not held responsible for all the emissions associated with land-use change or management. At the same time, under the Kyoto Protocol and associated instruments such as the European Emissions Trading scheme, biofuels is 'zero-rated' for emissions as an energy source. To ensure that biofuels are produced and used in ways which maximize its greenhouse gas saving potential, these accounting problems will need to be resolved in future.

scenarios for a future energy supply

3

image WIND TURBINE IN SAMUT SAKHON, THAILAND. © GP/VINAI DITHAJOHN

"we know the price of wind is not going to change between now and 2020 from its current level of zero."

EAMON RYAN
MINISTER FOR COMMUNICATIONS, ENERGY AND NATURAL RESOURCES, IRELAND

Moving from principles to action on energy supply and climate change mitigation requires a long-term perspective. Energy infrastructure takes time to build up; new energy technologies take time to develop. Policy shifts often also need many years to take effect. Any analysis that seeks to tackle energy and environmental issues therefore needs to look ahead at least half a century.

Scenarios are important in describing possible development paths, to give decision-makers an overview of future perspectives and to indicate how far they can shape the future energy system. Three different kinds of scenarios are used here to characterise the wide range of possible pathways for a future energy supply system: a Reference scenario, reflecting a continuation of current trends and policies, and two Energy [R]evolution scenarios, which are designed to achieve a set of dedicated environmental policy targets.

The **Reference scenario** is based on the reference scenario published by the International Energy Agency (IEA) in World Energy Outlook 2009 (WEO 2009).[20] This only takes existing international energy and environmental policies into account. Its assumptions include, for example, continuing progress in electricity and gas market reforms, the liberalisation of cross-border energy trade and recent policies designed to combat environmental pollution. The Reference scenario does not include additional policies to reduce greenhouse gas emissions. As the IEA's projection only covers a time horizon up to 2030, it has also been extended by extrapolating its key macroeconomic and energy indicators forward to 2050. This provides a baseline for comparison with the Energy [R]evolution scenarios.

The basic **Energy [R]evolution scenario** has a key target to reduce EU wide carbon dioxide emissions down to a level of around 970 million tonnes per year by 2050 in order to keep the increase in global temperature under +2°C. A second objective is the phasing out of nuclear energy. First published in 2007, then updated and expanded in 2008, this latest revision also serves as a baseline for the more ambitious "advanced" Energy [R]evolution scenario. To achieve its targets, the scenario is characterised by significant efforts to fully exploit the large potential for energy efficiency, using currently available best practice technology. At the same time, all cost-effective renewable energy sources are used for heat and electricity generation as well as the production of bio fuels. The general framework parameters for population and GDP growth remain unchanged from the Reference Scenario.

The **advanced Energy [R]evolution scenario** is aimed at an even stronger decrease in CO_2 emissions (195 million tonnes in 2050), especially given the uncertainty that even 970 Megatonnes might be too much to keep global temperature rises at bay. All general framework parameters such as population and economic growth remain unchanged. The efficiency pathway for industry and "other sectors" is also the same as in the basic Energy [R]evolution scenario. What is different is that the advanced scenario incorporates a stronger effort to develop better technologies to achieve CO_2 reduction. So the transport sector factors in lower demand (compared to the basic scenario), resulting from a change in driving patterns and a faster uptake of efficient combustion vehicles and – after 2025 – a larger share of electric and plug-in hybrid vehicles.

Given the enormous and diverse potential for renewable power, the advanced scenario also foresees a shift in the use of renewables from power to heat. Assumptions for the heating sector therefore include a faster expansion of the use of district heat and hydrogen and more electricity for process heat in the industry sector. More geothermal heat pumps are also used, which leads – combined with a larger share of electric drives in the transport sector – to a higher overall electricity demand. In addition a faster expansion of solar and geothermal heating systems is assumed.

In all sectors, the latest market development projections of the renewables industry[21] have been taken into account (see Table 3.12 Annual growth rates of RE energy technologies). A shorter operational lifetime for coal power plants, of 20 instead of 40 years, has been assumed in order to allow a faster uptake of renewables. The speedier introduction of electric vehicles, combined with the implementation of smart grids and faster expansion of super grids (about ten years ahead of the basic Energy [R]evolution scenario) - allows a higher share of variable renewable power generation (photovoltaics and wind) to be employed. The 60% mark for the proportion of renewables in the EU wide energy supply is therefore passed before 2040 (also ten years ahead), reaching a total share of 92% in 2050.

The available quantities of biomass and large hydro power remain the same in both Energy [R]evolution scenarios, for reasons of sustainability.

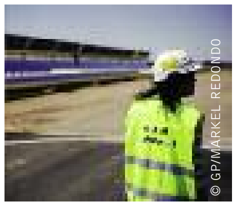
These scenarios by no means claim to predict the future; they simply describe three potential development pathways out of the broad range of possible 'futures'. The Energy [R]evolution scenarios are designed to indicate the efforts and actions required to achieve their ambitious objectives and to illustrate the options we have at hand to change our energy supply system into one that is sustainable.

scenario background

As energy is traded on global markets, a global market perspective is needed. The present report is based on the global version of the Energy [R]evolution report. The main scenario assumptions of the global energy outlook are explained in the following paragraphs.The scenarios in this report were jointly commissioned by Greenpeace and the European Renewable Energy Council from the Institute of Technical Thermodynamics, part of the German Aerospace Center (DLR). The supply scenarios were calculated using the MESAP/PlaNet simulation model adopted in the previous Energy [R]evolution studies.[22] Some detailed analyses carried out during preparation of the 2008 Energy [R]evolution study were also used as input to this update. The energy demand projections were developed for the 2008 study by Ecofys Netherlands, based on an analysis of the future potential for energy efficiency measures. The biomass potential, judged according to Greenpeace sustainability criteria, has been developed especially for this scenario by the German Biomass Research Centre. The future development pathway for car technologies is based on a special report produced in 2008 by the Institute of Vehicle Concepts, DLR for Greenpeace International. These studies are described briefly below.

references
20 INTERNATIONAL ENERGY AGENCY, 'WORLD ENERGY OUTLOOK 2007', 2007
21 SEE EREC, RE-THINKING 2050, GWEC, EPIA ET AL
22 'ENERGY [R]EVOLUTION: A SUSTAINABLE WORLD ENERGY OUTLOOK', GREENPEACE INTERNATIONAL, 2007 AND 2008

image A WORKER SURVEYS THE EQUIPMENT AT ANDASOL 1 SOLAR POWER STATION, WHICH 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 TONNES OF CARBON DIOXIDE PER YEAR COMPARED WITH A MODERN COAL POWER PLANT.



- **Energy efficiency study**. The aim of the Ecofys study was to develop a low energy demand scenario for the period 2005 to 2050 covering the world regions as defined in the IEA's World Energy Outlook report series. Calculations were made for each decade from 2010 onwards. Energy demand was split up into electricity and fuels. The sectors which were taken into account were industry, transport and 'other' consumers, including households and services. Under the low energy demand scenario, worldwide final energy demand is reduced by 38% in 2050 in comparison to the Reference scenario, resulting in a final energy demand of 376 EJ (ExaJoules). The energy savings are fairly equally distributed over the three sectors of industry, transport and other uses. The most important energy saving options are efficient passenger and freight transport and improved heat insulation and building design. The resulting demand projections of this study have been updated on the basis of the reference scenario fromIEA´s World Energy Outlook 2009.

- **The future for cars**. The Institute of Vehicle Concepts in Stuttgart, Germany has developed a global scenario for light duty vehicles (LDV) covering ten world regions. The aim was to produce a demanding but feasible scenario to lower global CO_2 emissions from LDVs within the context of the overall objectives of this report. The approach takes into account a vast range of technical measures to reduce the energy consumption of vehicles, but also considers the dramatic increase in vehicle ownership and annual mileage taking place in developing countries. The major parameters are vehicle technology, alternative fuels, changes in sales of different vehicle sizes (segment split) and changes in vehicle kilometres travelled (modal split). The scenario assumes that a large share of renewable electricity will be available in the future.

  A combination of ambitious efforts towards higher efficiency in vehicle technologies, a major switch to grid-connected electric vehicles and incentives for vehicle users to save carbon dioxide lead to the conclusion that it is possible to reduce LDV CO_2 emissions from 'well-to-wheel' in 2050 by roughly 25%[23] compared to 1990 and 40% compared to 2005. By 2050, in this scenario, 60% of the final energy used in road transport will still come from fossil sources, mainly gasoline and diesel. Renewable electricity will cover 25%, bio fuels 13% and hydrogen 2%. Total energy consumption will be reduced by 17% in 2050 compared to 2005, however, in spite of enormous increases in fuel use in some regions of the world. The peak in global CO_2 emissions from transport occurs between 2010 and 2015. From 2010 onwards, new legislation in the US and Europe will contribute to breaking the upwards trend. From 2020, the effect of introducing grid-connected electric cars can be clearly seen.

  This study still forms the basis for the LDV development pathway in the updated Energy [R]evolution scenarios, but has been modified on the basis of changed statistical data for the new reference year 2007 as well as changes in the reference scenario from IEA´s World Energy Outlook 2009.

- **The global potential for sustainable bio energy**. As part of the Energy [R]evolution scenario, Greenpeace also commissioned the German Biomass Research Centre (the former Institute for Energy and Environment) to look at the worldwide potential for energy crops up to 2050. A summary of this report can be found in Chapter 2.

main scenario assumptions

Development of a global energy scenario requires the use of a multi-region model in order to reflect the significant structural differences between different countries' energy supply systems. The International Energy Agency breakdown of world regions, as used in the ongoing series of World Energy Outlook reports, has been chosen because the IEA also provides the most comprehensive global energy statistics.[24] In line with WEO 2009, this new edition maintains the ten region approach. The definitions of the ten world regions are shown in Figure 3.1.

1. population development

One important underlying factor in energy scenario building is future population development. Population growth affects the size and composition of energy demand, directly and through its impact on economic growth and development. World Energy Outlook 2009 uses the United Nations Development Programme (UNDP) projections for population development. For this study the most recent population projections from UNDP up to 2050 are applied.[25]

Table 3.1 shows that, based on UNDP's 2009 assessment, the world's population is expected to grow by 0.86 % on average over the period 2007 to 2050, from 6.7 billion people in 2007 to more than 9.1 billion by 2050. Population growth will slow over the projection period, from 1.2% per year during 2007-2010 to 0.4% per year during 2040-2050. The updated projections show a small decrease in population by 2050 of around 19 million compared to the previous edition. This will scarcely reduce the demand for energy. The population of the developing regions will continue to grow most rapidly. The Transition Economies will face a continuous decline, followed after a short while by the OECD Pacific countries. OECD Europe and OECD North America are expected to maintain their population, with a peak in around 2020/2030 and a slight decline afterwards. The share of the population living in today's non-OECD countries will increase from the current 82% to 85% in 2050. China's contribution to world population will drop from 20% today to 16% in 2050. Africa will remain the region with the highest growth rate, leading to a share of 22% of world population in 2050.

Satisfying the energy needs of a growing population in the developing regions of the world in an environmentally friendly manner is a key challenge for achieving a global sustainable energy supply.

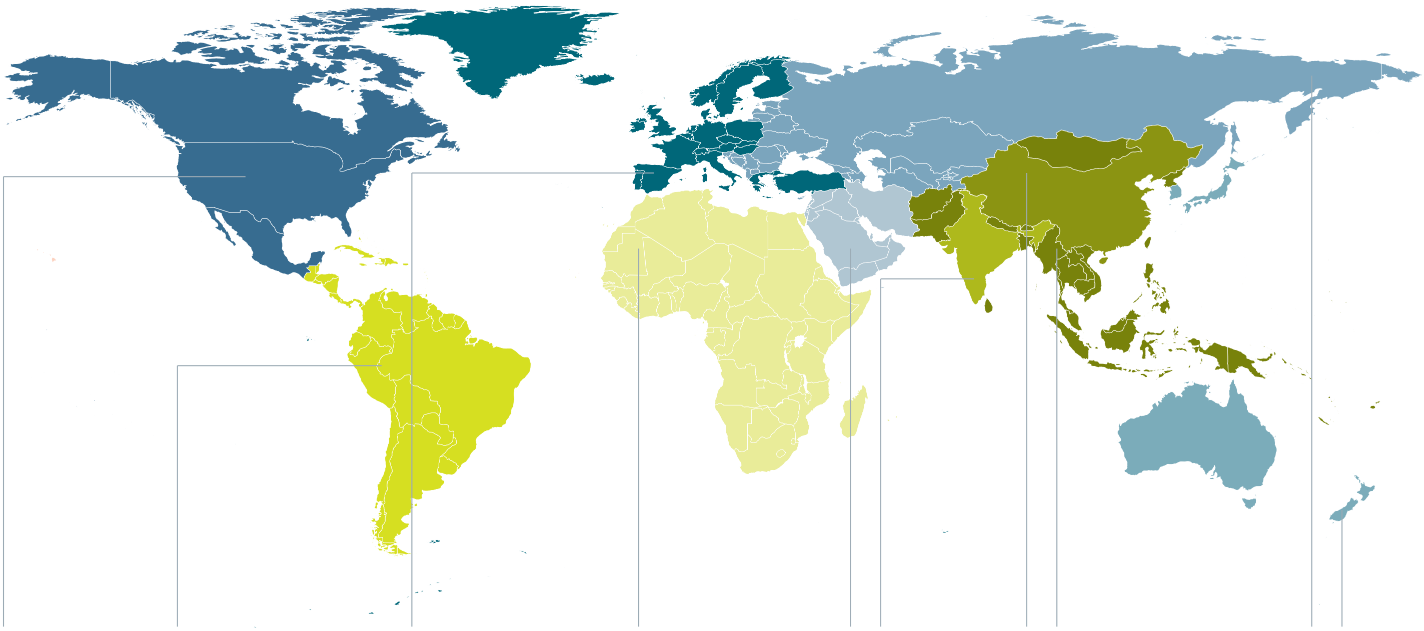
references

23 THERE IS NO RELIABLE NUMBER AVAILABLE FOR GLOBAL LDV EMISSIONS IN 1990, SO A ROUGH ESTIMATE HAS BEEN MADE.

24 'ENERGY BALANCE OF NON-OECD COUNTRIES' AND 'ENERGY BALANCE OF OECD COUNTRIES', IEA, 2009.

25 'WORLD POPULATION PROSPECTS: THE 2008 REVISION', UNITED NATIONS, POPULATION DIVISION, DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS (UNDP), 2009.

figure 3.1: world regions used in the scenarios BASED ON IEA



oecd north america

Canada, Mexico, United States

latin america

Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bermuda, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, St. Kitts-Nevis-Anguila, Saint Lucia, St. Vincent and Grenadines, Suriname, Trinidad and Tobago, Uruguay, Venezuela

oecd europe

Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom

africa

Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Democratic Republic of Congo, Cote d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, United Republic of Tanzania, Togo, Tunisia, Uganda, Zambia, Zimbabwe

middle east

Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen

india

India

china

People's Republic of China including Hong Kong

developing asia

Afghanistan, Bangladesh, Bhutan, Brunei, Cambodia, Chinese Taipei, Fiji, French Polynesia, Indonesia, Kiribati, Democratic People's Republic of Korea, Laos, Macao, Malaysia, Maldives, Mongolia, Myanmar, Nepal, New Caledonia, Pakistan, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Sri Lanka, Thailand, Vietnam, Vanuatu

transition economies

Albania, Armenia, Azerbaijan, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, Estonia, Serbia and Montenegro, former Republic of Macedonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Romania, Russia, Slovenia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan, Cyprus*, Malta*

oecd pacific

Australia, Japan, Korea (South), New Zealand

* CYPRUS AND MALTA ARE ALLOCATED TO THE TRANSITION ECONOMIES FOR STATISTICAL REASONS

image A LARGE SOLAR SYSTEM OF 63M² RISES ON THE ROOF OF A HOTEL IN CELERINA, SWITZERLAND. THE COLLECTOR IS EXPECTED TO PRODUCE HOT WATER AND HEATING SUPPORT AND CAN SAVE ABOUT 6,000 LITERS OF OIL PER YEAR. THUS, THE CO_2 EMISSIONS AND COMPANY COSTS CAN BE REDUCED.

2. economic growth

Economic growth is a key driver for energy demand. Since 1971, each 1% increase in global Gross Domestic Product (GDP) has been accompanied by a 0.6% increase in primary energy consumption. The decoupling of energy demand and GDP growth is therefore a prerequisite for reducing demand in the future. Most global energy/economic/environmental models constructed in the past have relied on market exchange rates to place countries in a common currency for estimation and calibration. This approach has been the subject of considerable discussion in recent years, and the alternative of purchasing power parity (PPP) exchange rates has been proposed. Purchasing power parities compare the costs in different currencies of a fixed basket of traded and non-traded goods and services and yield a widely-based measure of the standard of living. This is important in analysing the main drivers of energy demand or for comparing energy intensities among countries.

Although PPP assessments are still relatively imprecise compared to statistics based on national income and product trade and national price indexes, they are considered to provide a better basis for global scenario development.[26] Thus all data on economic development in WEO 2009 refers to purchasing power adjusted GDP. However, as WEO 2009 only covers the time period up to 2030, the projections for 2030-2050 are based on our own estimates.

Prospects for GDP growth have decreased considerably since the previous study, due to the financial crisis at the beginning of 2009, although underlying growth trends continue much the same. GDP growth in all regions is expected to slow gradually over the coming decades. World GDP is assumed to grow on average by 3.1% per year over the period 2007-2030, the same annual growth rate than between 1971 and 2007. China and India are expected to grow faster than other regions, followed by the Other Developing Asia countries, Africa and the Transition Economies. The Chinese economy will slow as it becomes more mature, but will nonetheless become the largest in the world in PPP terms early in the 2020s. GDP in EU 27 is assumed to grow by around 1.5% per year over the projection period until 2050. The OECD share of global PPP-adjusted GDP will decrease from 55% in 2005 to around 30% in 2050.

table 3.1: population development projections

(IN MILLIONS)

REGION	2007	2010	2015	2020	2030	2040	**2050**
World	6,671	6,909	7,302	7,675	8,309	8,801	**9,150**
OECD Europe	540	548	558	566	575	578	**575**
OECD North America	449	462	483	503	537	561	**577**
OECD Pacific	200	201	202	201	197	190	**180**
Transition Economies	340	339	339	337	331	321	**311**
India	1,165	1,214	1,294	1,367	1,485	1,565	**1,614**
China	1,336	1,361	1,403	1,439	1,471	1,464	**1,426**
Other Developing Asia	1,011	1,056	1,131	1,203	1,333	1,439	**1,516**
Latin America	462	478	503	526	563	588	**600**
Africa	965	1,033	1,153	1,276	1,524	1,770	**1,998**
Middle East	202	215	235	255	293	326	**353**

source UN WORLD POPULATION PROSPECTS - 2008 REVISION

references
26 NORDHAUS, W, 'ALTERNATIVE MEASURES OF OUTPUT IN GLOBAL ECONOMIC-ENVIRONMENTAL MODELS: PURCHASING POWER PARITY OR MARKET EXCHANGE RATES?', REPORT PREPARED FOR IPCC EXPERT MEETING ON EMISSION SCENARIOS, US-EPA WASHINGTON DC, JANUARY 12-14, 2005.

3. oil and gas price projections

The recent dramatic fluctuations in global oil prices have resulted in much higher forward price projections for fossil fuels. Under the 2004 'high oil and gas price' scenario from the European Commission, for example, an oil price of just €28.1 per barrel was assumed in 2030. More recent projections of oil prices by 2030 in the IEA's WEO 2009 range from €66/bbl in the lower prices sensitivity case up to €124/bbl in the higher prices sensitivity case. The reference scenario in WEO 2009 predicts an oil price of €95/bbl.

Since the first Energy [R]evolution study was published in 2007, however, the actual price of oil has moved over €82.7/bbl for the first time, and in July 2008 reached a record high of more than €116/bbl. Although oil prices fell back to €82.7/bbl in September 2008 and around €66/bbl in April 2010 the projections in the IEA reference scenario might still be considered too conservative. Taking into account the growing global demand for oil we have assumed a price development path for fossil fuels based on the IEA WEO 2009 higher prices sensitivity case extrapolated forward to 2050 (see Table 3.2).

As the supply of natural gas is limited by the availability of pipeline infrastructure, there is no world market price for gas. In most regions of the world the gas price is directly tied to the price of oil. Gas prices are therefore assumed to increase to €19.8-24/GJ by 2050.

4. cost of CO_2 emissions

Assuming that a CO_2 emissions trading system is established across all world regions in the longer term, the cost of CO_2 allowances needs to be included in the calculation of electricity generation costs. Projections of emissions costs are even more uncertain than energy prices, however, and available studies span a broad range of future estimates. As in the previous Energy [R]evolution study we assume CO_2 costs of €8.5/tCO_2 in 2015, rising to €41.5/tCO_2 by 2050. Additional CO_2 costs are applied in Kyoto Protocol Non-Annex B (developing) countries only after 2020.

table 3.2: development projections for fossil fuel prices in € 2005

	UNIT	2000	2005	2007	2008	2010	2015	2020	2025	2030	2040	2050
Crude oil imports												
IEA WEO 2009 "Reference"	barrel	28.39	41.38	62.07	80.43		71.73	82.76	88.96	95.17		
IEA WEO 2007 / ETP 2008	barrel			57.20			55.50			60.10		
USA EIA 2008 "Reference"	barrel							57.90		68.30		
USA EIA 2008 "High Price"	barrel							99.10		115.00		
Energy [R]evolution 2008	barrel						105.00	110.00		120.00		
Energy [R]evolution 2010	barrel						91.50	107.58	115.86	124.13		
Natural gas imports												
IEA WEO 2009 "Reference"												
United States	GJ	4.14	1.92	2.68	7.20		6.36	7.74	8.76	9.92		
Europe	GJ	3.06	3.72	5.21	9.01		9.13	10.56	11.43	12.24		
Japan LNG	GJ	5.05	3.74	5.24	11.03		10.40	12.00	12.95	13.85		
Energy [R]evolution 2010												
United States	GJ		1.92	2.68	7.20		6.93	8.85	10.26	11.90	14.98	19.64
Europe	GJ		3.72	5.21	9.01		11.62	13.71	14.89	15.96	18.21	21.54
Japan LNG	GJ		3.74	5.24	11.04		13.25	15.59	16.86	18.07	20.52	24.25
Hard coal imports												
OECD steam coal imports												
Energy [R]evolution 2010	tonne						96.12	112.06	115.45	118.09	132.41	142.59
IEA WEO 2009 "Reference"	tonne	34.11	41.05	57.47		99.80	75.35	86.20	88.65	90.54		
Biomass (solid)												
Energy [R]evolution 2010												
OECD Europe	GJ			6.2		6.4	6.8	7.6		8.3	8.5	8.7
OECD Pacific and North America	GJ			2.7		2.8	3.1	3.1		3.6	3.9	4.3
Other regions	GJ			2.2		2.3	2.9	2.9		3.3	3.8	4.1

source 2000-2030, IEA WEO 2009 HIGHER PRICES SENSITIVITY CASE FOR CRUDE OIL, GAS AND STEAM COAL; 2040-2050 AND OTHER FUELS, OWN ASSUMPTIONS.

image FIRE BOAT RESPONSE CREWS BATTLE THE BLAZING REMNANTS OF THE OFFSHORE OIL RIG DEEPWATER HORIZON APRIL 21, 2010. MULTIPLE COAST GUARD HELICOPTERS, PLANES AND CUTTERS RESPONDED TO RESCUE THE DEEPWATER HORIZON'S 126 PERSON CREW.

table 3.3: assumptions on CO_2 emissions cost development

($\$/tCO_2$)

COUNTRIES	2015	2020	2030	2040	2050
Kyoto Annex B countries	10	20	30	40	**50**
Non-Annex B countries		20	30	40	**50**

5. cost projections for efficient fossil fuel generation and carbon capture and storage (CCS)

While the fossil fuel power technologies in use today for coal, gas, lignite and oil are established and at an advanced stage of market development, further cost reduction potentials are assumed. The potential for cost reductions is limited, however, and will be achieved mainly through an increase in efficiency.[27]

There is much speculation about the potential for carbon capture and storage (CCS) to mitigate the effect of fossil fuel consumption on climate change, even though the technology is still under development.

CCS is a means of trapping CO_2 from fossil fuels, either before or after they are burned, and 'storing' (effectively disposing of) it in the sea or beneath the surface of the earth. There are currently three different methods of capturing CO_2: 'pre-combustion', 'post-combustion' and 'oxyfuel combustion'. However, development is at a very early stage and CCS will not be implemented - in the best case - before 2020 and will probably not become commercially viable as a possible effective mitigation option until 2030.

Cost estimates for CCS vary considerably, depending on factors such as power station configuration, technology, fuel costs, size of project and location. One thing is certain, however: CCS is expensive. It requires significant funds to construct the power stations and the necessary infrastructure to transport and store carbon. The IPCC assesses costs at €12-62 per ton of captured CO_2[28], while a recent US Department of Energy report found installing carbon capture systems to most modern plants resulted in a near doubling of costs.[29] These costs are estimated to increase the price of electricity in a range from 21-91%.[30]

Pipeline networks will also need to be constructed to move CO_2 to storage sites. This is likely to require a considerable outlay of capital.[31] Costs will vary depending on a number of factors, including pipeline length, diameter and manufacture from corrosion-resistant steel, as well as the volume of CO_2 to be transported. Pipelines built near population centres or on difficult terrain, such as marshy or rocky ground, are more expensive.[32]

The Intergovernmental Panel on Climate Change (IPCC) estimates a cost range for pipelines of €1-7/ton of CO_2 transported. Storage and subsequent monitoring and verification costs are estimated to range from €0.4-7/tCO_2 (for storage) and €0.1-0.25/tCO_2 (for monitoring). The overall cost of CCS could therefore serve as a major barrier to its deployment.[33]

For the above reasons, CCS power plants are not included in our financial analysis.

Table 3.4 summarises our assumptions on the technical and economic parameters of future fossil-fuelled power plant technologies. In spite of growing raw material prices, we assume that further technical innovation will result in a moderate reduction of future investment costs as well as improved power plant efficiencies. These improvements are, however, outweighed by the expected increase in fossil fuel prices, resulting in a significant rise in electricity generation costs.

table 3.4: development of efficiency and investment costs for selected power plant technologies

		2007	2015	2020	2030	2040	2050
Coal-fired condensing power plant	Efficiency (%)	45	46	48	50	52	**53**
	Investment costs (€/kW)	1,092	1,018	985	960	935	**910**
	Electricity generation costs including CO_2 emission costs (€cents/kWh)	5.5	7.4	8.9	10.3	11.8	**13.0**
	CO_2 emissions $^{a)}$(g/kWh)	744	728	697	670	644	**632**
Lignite-fired condensing power plant	Efficiency (%)	41	43	44	44.5	45	**45**
	Investment costs (€/kW)	1,299	1,192	1,142	1,117	1,092	**1,068**
	Electricity generation costs including CO_2 emission costs (€cents/kWh)	4.9	5.4	6.2	7.0	7.7	**8.5**
	CO_2 emissions $^{a)}$(g/kWh)	975	929	908	898	888	**888**
Natural gas combined cycle	Efficiency (%)	57	59	61	62	63	**64**
	Investment costs (€/kW)	807	769	751	743	735	**735**
	Electricity generation costs including CO_2 emission costs (€cents/kWh)	6.2	8.7	10.5	12.7	14.4	**15.6**
	CO_2 emissions $^{a)}$(g/kWh)	354	342	330	325	320	**315**

source DLR, 2010 **a)** CO_2 EMISSIONS REFER TO POWER STATION OUTPUTS ONLY; LIFE-CYCLE EMISSIONS ARE NOT CONSIDERED.

references

27 'GREENPEACE INTERNATIONAL BRIEFING: CARBON CAPTURE AND STORAGE', GOERNE, 2007.
28 ABANADES, J C ET AL., 2005, PG 10.
28 NATIONAL ENERGY TECHNOLOGY LABORATORIES, 2007.
30 RUBIN ET AL., 2005A, PG 40.
31 RAGDEN, P ET AL., 2006, PG 18.
32 HEDDLE, G ET AL., 2003, PG 17.
33 RUBIN ET AL., 2005B, PG 4444.

4. cost projections for renewable energy technologies

The range of renewable energy technologies available today display marked differences in terms of their technical maturity, costs and development potential. Whereas hydro power has been widely used for decades, other technologies, such as the gasification of biomass, have yet to find their way to market maturity. Some renewable sources by their very nature, including wind and solar power, provide a variable supply, requiring a revised coordination with the grid network. But although in many cases these are 'distributed' technologies - their output being generated and used locally to the consumer - the future will also see large-scale applications in the form of offshore wind parks, photovoltaic power plants or concentrating solar power stations.

By using the individual advantages of the different technologies, and linking them with each other, a wide spectrum of available options can be developed to market maturity and integrated step by step into the existing supply structures. This will eventually provide a complementary portfolio of environmentally friendly technologies for heat and power supply and the provision of transport fuels.

Many of the renewable technologies employed today are at a relatively early stage of market development. As a result, the costs of electricity, heat and fuel production are generally higher than those of competing conventional systems - a reminder that the external (environmental and social) costs of conventional power production are not included in market prices. It is expected, however, that compared with conventional technologies, large cost reductions can be achieved through technical advances, manufacturing improvements and large-scale production. Especially when developing long-term scenarios spanning periods of several decades, the dynamic trend of cost developments over time plays a crucial role in identifying economically sensible expansion strategies.

To identify long-term cost developments, learning curves have been applied which reflect the correlation between cumulative production volumes of a particular technology and a reduction in its costs. For many technologies, the learning factor (or progress ratio) falls in the range between 0.75 for less mature systems to 0.95 and higher for well-established technologies. A learning factor of 0.9 means that costs are expected to fall by 10% every time the cumulative output from the technology doubles. Empirical data shows, for example, that the learning factor for PV solar modules has been fairly constant at 0.8 over 30 years whilst that for wind energy varies from 0.75 in the UK to 0.94 in the more advanced German market.

Assumptions on future costs for renewable electricity technologies in the Energy [R]evolution scenario are derived from a review of learning curve studies, for example by Lena Neij and others[34], from the analysis of recent technology foresight and road mapping studies, including the European Commission funded NEEDS project (New Energy Externalities Developments for Sustainability)[35] or the IEA Energy Technology Perspectives 2008, projections by the European Renewable Energy Council published in April 2010 ("RE-thinking 2050") and discussions with experts from a wide range of different sectors of the renewable energy industry.

photovoltaics (pv)

The worldwide photovoltaics (PV) market has been growing at over 35% per annum in recent years and the contribution it can make to electricity generation is starting to become significant. The importance of photovoltaics comes from its decentralised/centralised character, its flexibility for use in an urban environment and huge potential for cost reduction. Development work is focused on improving existing modules and system components by increasing their energy efficiency and reducing material usage. Technologies like PV thin film (using alternative semiconductor materials) or dye sensitive solar cells are developing quickly and present a huge potential for cost reduction. The mature technology crystalline silicon, with a proven lifetime of 30 years, is continually increasing its cell and module efficiency (by 0.5% annually), whereas the cell thickness is rapidly decreasing (from 230 to 180 microns over the last five years). Commercial module efficiency varies from 14 to 21%, depending on silicon quality and fabrication process.

The learning factor for PV modules has been fairly constant over the last 30 years, with a cost reduction of 20% each time the installed capacity doubles, indicating a high rate of technical learning. Assuming a globally installed capacity of 1,600 GW by between 2030 and 2040 in the basic Energy [R]evolution scenario, and with an electricity output of 2,600 TWh, we can expect that generation costs of around 5-10 cents/kWh (depending on the region) will be achieved. During the following five to ten years, PV will become competitive with retail electricity prices in many parts of the world, and competitive with fossil fuel costs by 2030. The advanced Energy [R]evolution version shows faster growth, with PV capacity reaching 439 GW by 2020 – ten years ahead of the basic scenario.

table 3.5: photovoltaics (pv) cost assumptions

	2007	2015	2020	2030	2040	2050
Energy [R]evolution						
Global installed capacity (GW)	6	98	335	1,036	1,915	**2,968**
Investment costs (€/kWp)	3,100	2,160	1,470	850	650	**630**
Operation & maintenance costs (€/kW/a)	55	31	13	11	9	**8**
Advanced Energy [R]evolution						
Global installed capacity (GW)	6	108	439	1,330	2,959	**4,318**
Investment costs (€/kWp)	3,100	2,160	1,470	850	630	**611**
Operation & maintenance costs (€/kW/a)	55	31	13	11	9	**8**

34 NEIJ, L, 'COST DEVELOPMENT OF FUTURE TECHNOLOGIES FOR POWER GENERATION - A STUDY BASED ON EXPERIENCE CURVES AND COMPLEMENTARY BOTTOM-UP ASSESSMENTS', ENERGY POLICY 36 (2008), 2200-2211.
35 WWW.NEEDS-PROJECT.ORG

image AERIAL VIEW OF THE WORLD'S LARGEST OFFSHORE WINDPARK IN THE NORTH SEA HORNS REV IN ESBJERG, DENMARK.

concentrating solar power

Solar thermal 'concentrating' power stations (CSP) can only use direct sunlight and are therefore dependent on high irradiation locations. North Africa, for example, has a technical potential which far exceeds local demand. The various solar thermal technologies (parabolic trough, power towers and parabolic dish concentrators) offer good prospects for further development and cost reductions. Because of their more simple design, 'Fresnel' collectors are considered as an option for additional cost trimming. The efficiency of central receiver systems can be increased by producing compressed air at a temperature of up to 1,000°C, which is then used to run a combined gas and steam turbine.

Thermal storage systems are a key component for reducing CSP electricity generation costs. The Spanish Andasol 1 plant, for example, is equipped with molten salt storage with a capacity of 7.5 hours. A higher level of full load operation can be realised by using a thermal storage system and a large collector field. Although this leads to higher investment costs, it reduces the cost of electricity generation.

Depending on the level of irradiation and mode of operation, it is expected that long term future electricity generation costs of 6-10 cents/kWh can be achieved. This presupposes rapid market introduction in the next few years.

wind power

Within a short period of time, the dynamic development of wind power has resulted in the establishment of a flourishing global market. While favourable policy incentives have made Europe the main driver for the global wind market, in 2009 more than three quarters of the annual capacity installed was outside Europe. This trend is likely to continue. The boom in demand for wind power technology has nonetheless led to supply constraints. As a consequence, the cost of new systems has increased. Because of the continuous expansion of production capacities, the industry is already resolving the bottlenecks in the supply chain, however. Taking into account market development projections, learning curve analysis and industry expectations, we assume that investment costs for wind turbines will reduce by 30% for onshore and 50% for offshore installations up to 2050.

table 3.6: concentrating solar power (csp) cost assumptions

	2007	2015	2020	2030	2040	**2050**
Energy [R]evolution						
Global installed capacity (GW)	1	25	105	324	647	**1,002**
Investment costs (€/kW)*	6,000	4,615	4,174	3,528	3,476	**3,443**
Operation & maintenance costs (€/kW/a)	248	207	174	149	132	**128**
Advanced Energy [R]evolution						
Global installed capacity (GW)	1	28	225	605	1,173	**1,643**
Investment costs (€/kW)*	6,000	4,615	4,174	3,476	3,443	**3,410**
Operation & maintenance costs (€/kW/a)	248	207	174	149	132	**128**

* INCLUDING HIGH TEMPERATURE HEAT STORAGE.

table 3.7: wind power cost assumptions

	2007	2015	2020	2030	2040	**2050**
Energy [R]evolution						
Installed capacity (on+offshore)	95	407	878	1,733	2,409	**2,943**
Wind onshore						
Investment costs (€/kWp)	1,250	1,039	826	788	750	**740**
O&M costs (€/kW/a)	48	42	37	36	34	**34**
Wind offshore						
Investment costs (€/kWp)	2,400	1,821	1,274	1,208	1,101	**1,080**
O&M costs (€/kW/a)	137	127	94	80	73	**69**
Advanced Energy [R]evolution						
Installed capacity (on+offshore)	95	494	1,140	2,241	3,054	**3,754**
Wind onshore						
Investment costs (€/kWp)	1,250	1,039	826	750	740	**730**
O&M costs (€/kW/a)	48	42	37	36	34	**34**
Wind offshore						
Investment costs (€/kWp)	2,400	1,821	1,274	1,208	1,101	**1,080**
O&M costs (€/kW/a)	137	127	94	80	73	**69**

biomass

The crucial factor for the economics of biomass utilisation is the cost of the feedstock, which today ranges from a negative cost for waste wood (based on credit for waste disposal costs avoided) through inexpensive residual materials to the more expensive energy crops. The resulting spectrum of energy generation costs is correspondingly broad. One of the most economic options is the use of waste wood in steam turbine combined heat and power (CHP) plants. Gasification of solid biomass, on the other hand, which opens up a wide range of applications, is still relatively expensive. In the long term it is expected that favourable electricity production costs will be achieved by using wood gas both in micro CHP units (engines and fuel cells) and in gas-and-steam power plants. Great potential for the utilisation of solid biomass also exists for heat generation in both small and large heating centres linked to local heating networks. Converting crops into ethanol and 'bio diesel' made from rapeseed methyl ester (RME) has become increasingly important in recent years, for example in Brazil, the USA and Europe. Processes for obtaining synthetic fuels from biogenic synthesis gases will also play a larger role.

A large potential for exploiting modern technologies exists in Latin and North America, Europe and the Transition Economies, either in stationary appliances or the transport sector. In the long term Europe and the Transition Economies will realise 20-50% of the potential for biomass from energy crops, whilst biomass use in all the other regions will have to rely on forest residues, industrial wood waste and straw. In Latin America, North America and Africa in particular, an increasing residue potential will be available.

In other regions, such as the Middle East and all Asian regions, increased use of biomass is restricted, either due to a generally low availability or already high traditional use. For the latter, using modern, more efficient technologies will improve the sustainability of current usage and have positive side effects, such as reducing indoor pollution and the heavy workloads currently associated with traditional biomass use.

geothermal

Geothermal energy has long been used worldwide for supplying heat, and since the beginning of the last century for electricity generation. Geothermally generated electricity was previously limited to sites with specific geological conditions, but further intensive research and development work has enabled the potential areas to be widened. In particular the creation of large underground heat exchange surfaces - Enhanced Geothermal Systems (EGS) - and the improvement of low temperature power conversion, for example with the Organic Rankine Cycle, open up the possibility of producing geothermal electricity anywhere. Advanced heat and power cogeneration plants will also improve the economics of geothermal electricity.

As a large part of the costs for a geothermal power plant come from deep underground drilling, further development of innovative drilling technology is expected. Assuming a global average market growth for geothermal power capacity of 9% per year up to 2020, adjusting to 4% beyond 2030, the result would be a cost reduction potential of 50% by 2050:

table 3.8: biomass cost assumptions

	2007	2015	2020	2030	2040	2050
Energy [R]evolution						
Biomass (electricity only)						
Global installed capacity (GW)	28	48	62	75	87	**107**
Investment costs (€/kW)	2,332	2,029	2,015	1,967	1,944	**1,925**
O&M costs (€/kW/a)	151	137	126	122	122	**121**
Biomass (CHP)						
Global installed capacity (GW)	18	67	150	261	413	**545**
Investment costs (€/kW)	4,345	3,521	3,080	2,690	2,479	**2,355**
O&M costs (€/kW/a)	334	288	224	195	180	**171**
Advanced Energy [R]evolution						
Biomass (electricity only)						
Global installed capacity (GW)	28	50	64	78	83	**81**
Investment costs (€/kW)	2,332	2,029	2,015	1,967	1,944	**1,925**
O&M costs (€/kW/a)	151	137	126	122	122	**121**
Biomass (CHP)						
Global installed capacity (GW)	18	65	150	265	418	**540**
Investment costs (€/kW)	4,345	3,521	3,080	2,690	2,479	**2,355**
O&M costs (€/kW/a)	334	288	224	195	180	**171**

table 3.9: geothermal cost assumptions

	2007	2015	2020	2030	2040	2050
Energy [R]evolution						
Geothermal (electricity only)						
Global installed capacity (GW)	10	19	36	71	114	**144**
Investment costs (€/kW)	10,300	9,000	7,600	6,000	5,000	**4,300**
O&M costs (€/kW/a)	534	461	354	310	290	**275**
Geothermal (CHP)						
Global installed capacity (GW)	1	3	13	37	83	**134**
Investment costs (€/kW)	10,500	9,200	7,800	6,200	5,200	**4,500**
O&M costs (€/kW/a)	535	400	290	243	212	**193**
Advanced Energy [R]evolution						
Geothermal (electricity only)						
Global installed capacity (GW)	10	21	57	191	337	**459**
Investment costs (€/kW)	10,300	9,000	7,600	4,300	3,698	**3,180**
O&M costs (€/kW/a)	534	461	354	310	290	**275**
Geothermal (CHP)						
Global installed capacity (GW)	0	3	13	47	132	**234**
Investment costs (€/kW)	10,500	9,200	7,800	6,200	5,200	**4,500**
O&M costs (€/kW/a)	535	400	290	243	212	**193**

image A COW INFRONT OF A BIOREACTOR IN THE BIOENERGY VILLAGE OF JUEHNDE. IT IS THE FIRST COMMUNITY IN GERMANY THAT PRODUCES ALL OF ITS ENERGY NEEDED FOR HEATING AND ELECTRICITY, WITH CO_2 NEUTRAL BIOMASS.

- for conventional geothermal power, from 5.8 €cents/kWh to about 1.6 €cents/kWh;
- for EGS, despite the presently high figures (about 16.6 €cents/kWh), electricity production costs - depending on the payments for heat supply - are expected to come down to around 4.1 €cents/kWh in the long term.

Because of its non-fluctuating supply and a grid load operating almost 100% of the time, geothermal energy is considered to be a key element in a future supply structure based on renewable sources. Up to now we have only used a marginal part of the potential. Shallow geothermal drilling, for example, makes possible the delivery of heating and cooling at any time anywhere, and can be used for thermal energy storage.

ocean energy

Ocean energy, particularly offshore wave energy, is a significant resource, and has the potential to satisfy an important percentage of electricity supply worldwide. Globally, the potential of ocean energy has been estimated at around 90,000 TWh/year. The most significant advantages are the vast availability and high predictability of the resource and a technology with very low visual impact and no CO_2 emissions. Many different concepts and devices have been developed, including taking energy from the tides, waves, currents and both thermal and saline gradient resources. Many of these are in an advanced phase of R&D, large scale prototypes have been deployed in real sea conditions and some have reached pre-market deployment. There are a few grid connected, fully operational commercial wave and tidal generating plants.

The cost of energy from initial tidal and wave energy farms has been estimated to be in the range of 15-55 €cents/kWh, and for initial tidal stream farms in the range of 11-22 €cents/kWh. Generation costs of 10-25 €cents/kWh are expected by 2020. Key areas for development will include concept design, optimisation of the device configuration, reduction of capital costs by exploring the use of alternative structural materials, economies of scale and learning from operation. According to the latest research findings, the learning factor is estimated to be 10-15% for offshore wave and 5-10% for tidal stream. In the medium term, ocean energy has the potential to become one of the most competitive and cost effective forms of generation. In the next few years a dynamic market penetration is expected, following a similar curve to wind energy.

Because of the early development stage any future cost estimates for ocean energy systems are uncertain. Present cost estimates are based on analysis from the European NEEDS project.[36]

hydro power

Hydropower is a mature technology with a significant part of its global resource already exploited. There is still, however, some potential left both for new schemes (especially small scale run-of-river projects with little or no reservoir impoundment) and for repowering of existing sites. The significance of hydropower is also likely to be encouraged by the increasing need for flood control and the maintenance of water supply during dry periods. The future is in sustainable hydropower which makes an effort to integrate plants with river ecosystems while reconciling ecology with economically attractive power generation.

table 3.10: ocean energy cost assumptions

Energy [R]evolution	2007	2015	2020	2030	2040	**2050**
Global installed capacity (GW)	0	9	29	73	168	**303**
Investment costs (€/kW)	5,972	3,221	2,322	1,786	1,491	**1,328**
Operation & maintenance costs (€/kW/a)	298	171	97	74	62	**55**
Advanced Energy [R]evolution						
Global installed capacity (GW)	0	9	58	180	425	**748**
Investment costs (€/kW)	5,972	3,221	2,322	1,491	1,328	**1,183**
Operation & maintenance costs (€/kW/a)	298	171	97	74	62	**55**

table 3.11: hydro power cost assumptions

Energy [R]evolution	2007	2015	2020	2030	2040	**2050**
Global installed capacity (GW)	922	1,043	1,206	1,307	1,387	**1,438**
Investment costs (€/kW)	2,239	2,370	2,443	2,553	2,645	**2,726**
Operation & maintenance costs (€/kW/a)	91	95	102	106	110	**113**
Advanced Energy [R]evolution						
Global installed capacity (GW)	922	1,111	1,212	1,316	1,406	**1,451**
Investment costs (€/kW)	2,239	2,370	2,443	2,553	2,645	**2,726**
Operation & maintenance costs (€/kW/a)	91	95	102	106	110	**113**

36 WWW.NEEDS-PROJECT.ORG

summary of renewable energy cost development

Figure 3.2 summarises the cost trends for renewable energy technologies as derived from the respective learning curves. It should be emphasised that the expected cost reduction is basically not a function of time, but of cumulative capacity, so dynamic market development is required. Most of the technologies will be able to reduce their specific investment costs to between 30% and 70% of current levels by 2020, and to between 20% and 60% once they have achieved full maturity (after 2040).

Reduced investment costs for renewable energy technologies lead directly to reduced heat and electricity generation costs, as shown in Figure 3.3. Generation costs today are around 8 to 22 €cents/kWh (10-26 $cents/kWh) for the most important technologies, with the exception of photovoltaics. In the long term, costs are expected to converge at around 4 to 10 €cents/kWh (5-12 $cents/kWh). These estimates depend on site-specific conditions such as the local wind regime or solar irradiation, the availability of biomass at reasonable prices or the credit granted for heat supply in the case of combined heat and power generation.

assumed growth rates in different scenarios

In scientific literature[37] quantitative scenario modelling approaches are broadly separated into two groups: "top-down" and "bottom-up" models. While this classification might have made sense in the past, it is less appropriate today, since the transition between the two categories is continuous, and many models, while being rooted in one of the two traditions - macro-economic or energy-engineering - incorporate aspects from the other approach and thus belong to the class of so-called hybrid models.[38] In the energy-economic modelling community, macro-economic approaches are traditionally classified as top-down models and energy-engineering models as bottom-up. The Energy [R]evolution scenario is a "bottom-up" (technology driven) scenario and the assumed growth rates for renewable energy technology deployment are important drivers.

Around the world, however, energy modelling scenario tools are under constant development and in the future both approaches are likely to merge into one, with detailed tools employing both a high level of technical detail and economic optimisation. The Energy [R]evolution scenario uses a "classical" bottom-up model which has been constantly developed, and now includes calculations covering both the investment pathway and the employment effect (see Chapter 4).

figure 3.2: future development of renewable energy investment costs (NORMALISED TO CURRENT COST LEVELS) FOR RENEWABLE ENERGY TECHNOLOGIES

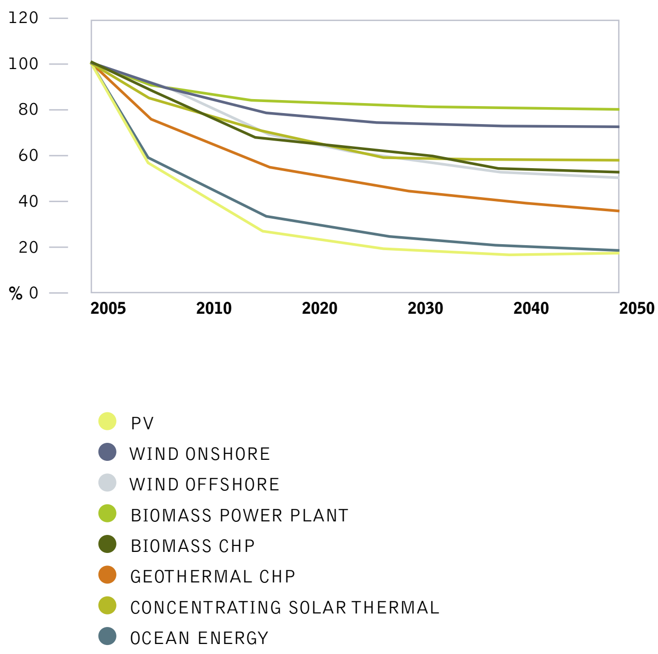
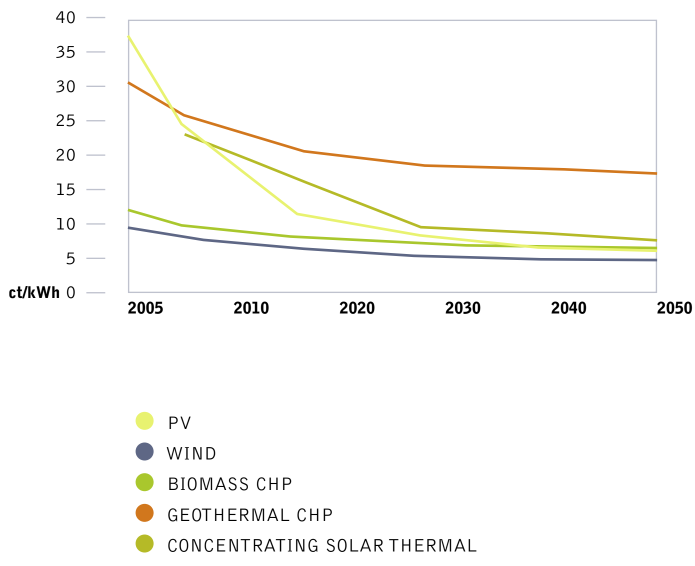


figure 3.3: expected development of electricity generation costs from fossil fuel and renewable options
EXAMPLE FOR OECD NORTH AMERICA



37 HERZOG *ET AL.*, 2005; BARKER *ET AL.*, 2007.
38 VAN VUUREN *ET AL.*; HOURCADE *ET AL.*, 2006.

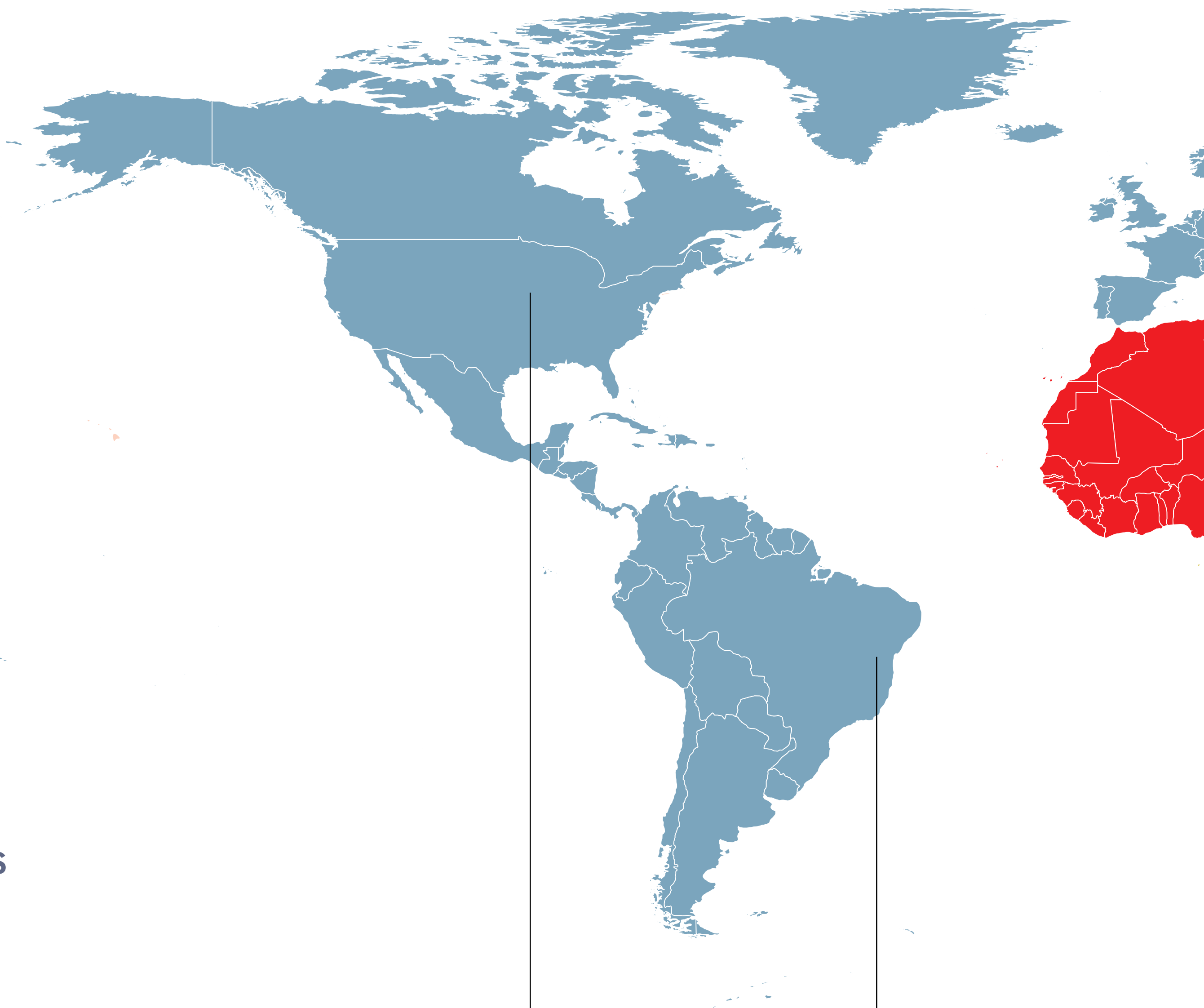
image CONSTRUCTION OF WIND TURBINES.

table 3.12: assumed global average annual growth rates for renewable technologies

	ENERGY PARAMETER GENERATION (TWh/a)					
REF	REF	E[R]	ADV E[R]	REF	E[R]	ADV E[R]
2020	27,248	25,851	25,919			
2030	34,307	30,133	30,901			
2050	46,542	37,993	43,922			
Solar						
PV-2020	108	437	594	17%	37%	42%
PV-2030	281	1,481	1,953	11%	15%	14%
PV-2050	640	4,597	6,846	10%	13%	15%
CSP-2020	38	321	689	17%	49%	62%
CSP-2030	121	1,447	2,734	14%	18%	17%
CSP-2050	254	5,917	9,012	9%	17%	14%
Wind						
On+Offshore-2020	1,009	2,168	2,849	12%	22%	26%
On+Offshore-2030	1,536	4,539	5,872	5%	9%	8%
On+Offshore-2050	2,516	8,474	10,841	6%	7%	7%
Geothermal						
2020 (power generation)	117	235	367	6%	14%	20%
2030 (power generation)	168	502	1,275	4%	9%	15%
2050 (power generation)	265	1,009	2,968	5%	8%	10%
2020 (heat&power)	6	65	66	13%	47%	47%
2030 (heat&power)	9	192	251	5%	13%	16%
2050 (heat&power)	19	719	1,263	9%	16%	20%
Bio energy						
2020 (power generation)	337	373	392	8%	9%	10%
2030 (power generation)	552	456	481	6%	2%	2%
2050 (power generation)	994	717	580	7%	5%	2%
2020 (heat&power)	186	739	742	2%	19%	19%
2030 (heat&power)	287	1,402	1,424	5%	7%	8%
2050 (heat&power)	483	3,013	2,991	6%	9%	9%
Ocean						
2020	3	53	119	15%	55%	70%
2030	11	128	420	13%	10%	15%
2050	25	678	1,943	10%	20%	19%
Hydro						
2020	4,027	4,029	4,059	2%	2%	2%
2030	4,679	4,370	4,416	2%	1%	1%
2050	5,963	5,056	5,108	3%	2%	2%

map 3.1: CO_2 emissions reference scenario and the advanced energy [r]evolution scenario

WORLDWIDE SCENARIO



EMISSIONS

CO_2

LEGEND

100-75 | 75-50 | 50-25 | 25-0 — % OF 1990 EMISSIONS IN THE 2050 ADVANCED ENERGY [R]EVOLUTION SCENARIO

REF — REFERENCE SCENARIO

E[R] — ADVANCED ENERGY [R]EVOLUTION SCENARIO

0 — 1000 KM

CO_2 — EMISSIONS TOTAL
MILLION TONNES [mio t] | % OF 1990 EMISSIONS

EMISSIONS PER PERSON TONNES [t]

H HIGHEST | M MIDDLE | L LOWEST

OECD NORTH AMERICA

		REF mio t	REF %	E[R] mio t	E[R] %
CO_2	2007	6,686H	165	6,686	165
	2050	6,822	169	215M	5
		t		**t**	
per person	2007	14.89H		14.89	
	2050	11.82H		0.37	

LATIN AMERICA

		REF mio t	REF %	E[R] mio t	E[R] %
CO_2	2007	1,010	167M	1,010	167
	2050	2,006	332M	119L	20
		t		**t**	
per person	2007	2.18		2.18	
	2050	3.34		0.20L	

OECD EUROPE

		REF		E[R]	
		mio t	%	mio t	%
CO_2	2007	4,017M	100	4,017	100
	2050	3,798	94	215	5
		t		t	
	2007	7.44		7.44	
	2050	6.61M		0.36	

MIDDLE EAST

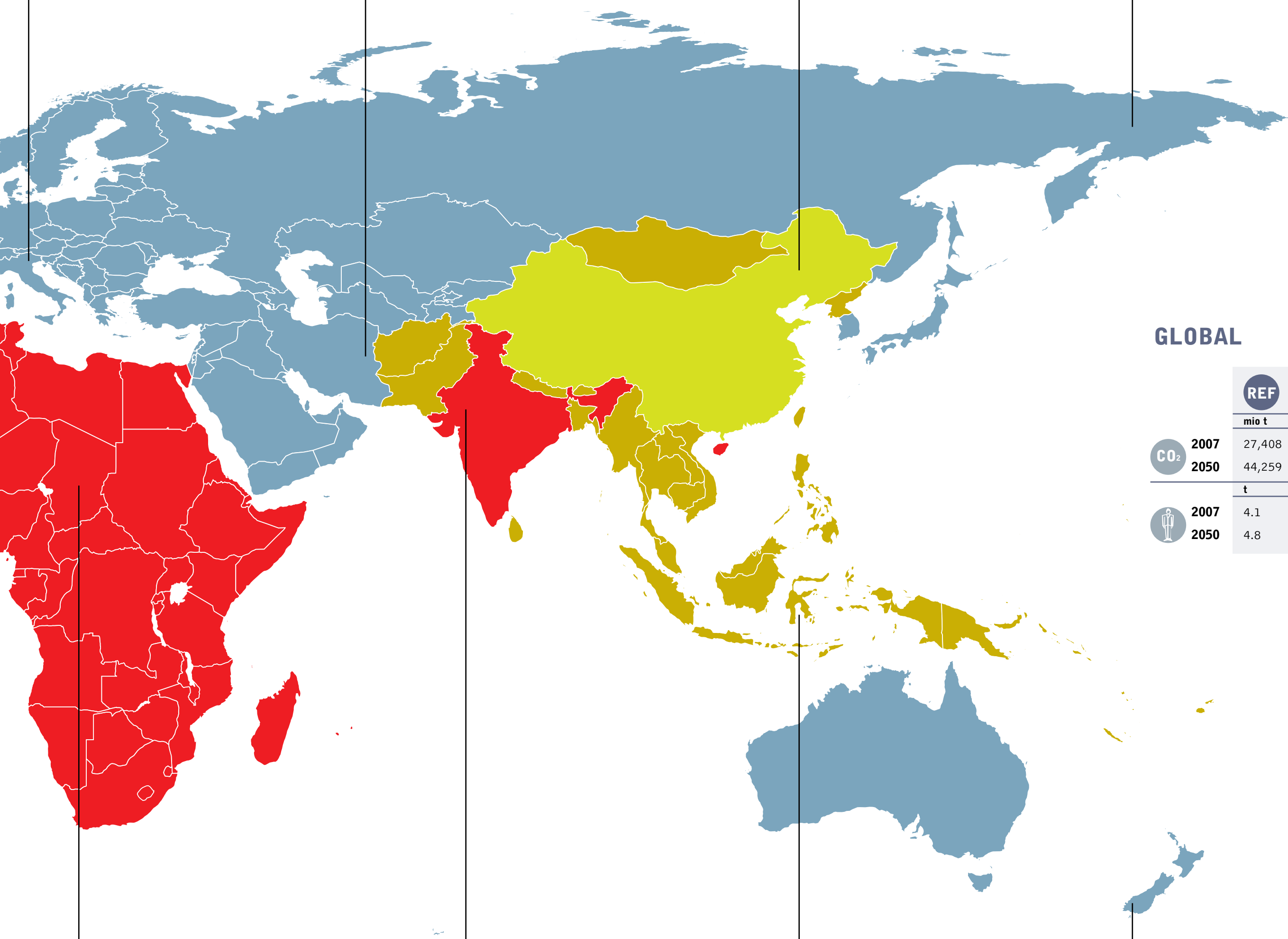
		REF		E[R]	
		mio t	%	mio t	%
CO_2	2007	1,374	234	1,374	234
	2050	3,208	546	122	21
		t		t	
	2007	6.79M		6.79	
	2050	9.08		0.35	

CHINA

		REF		E[R]	
		mio t	%	mio t	%
CO_2	2007	5,852	261	5,852	261
	2050	12,460H	555	925H	41
		t		t	
	2007	4.38		4.38	
	2050	8.74		0.65	

TRANSITION ECONOMIES

		REF		E[R]	
		mio t	%	mio t	%
CO_2	2007	2,650	66	2,650	66
	2050	3,564	88	258	6
		t		t	
	2007	7.79		7.79	
	2050	11.47		0.83H	



GLOBAL

		REF		E[R]	
		mio t	%	mio t	%
CO_2	2007	27,408	131	27,408	131
	2050	44,259	211	3,267	16
		t		t	
	2007	4.1		4.1	
	2050	4.8		0.4	

AFRICA

		REF		E[R]	
		mio t	%	mio t	%
CO_2	2007	881L	161	881	161
	2050	1,622L	297	423	77
		t		t	
	2007	0.91L		0.91	
	2050	0.81L		0.21	

INDIA

		REF		E[R]	
		mio t	%	mio t	%
CO_2	2007	1,307	222	1,307	222
	2050	5,110	868	449	85
		t		t	
	2007	1.12		1.12	
	2050	3.17		0.31	

DEVELOPING ASIA

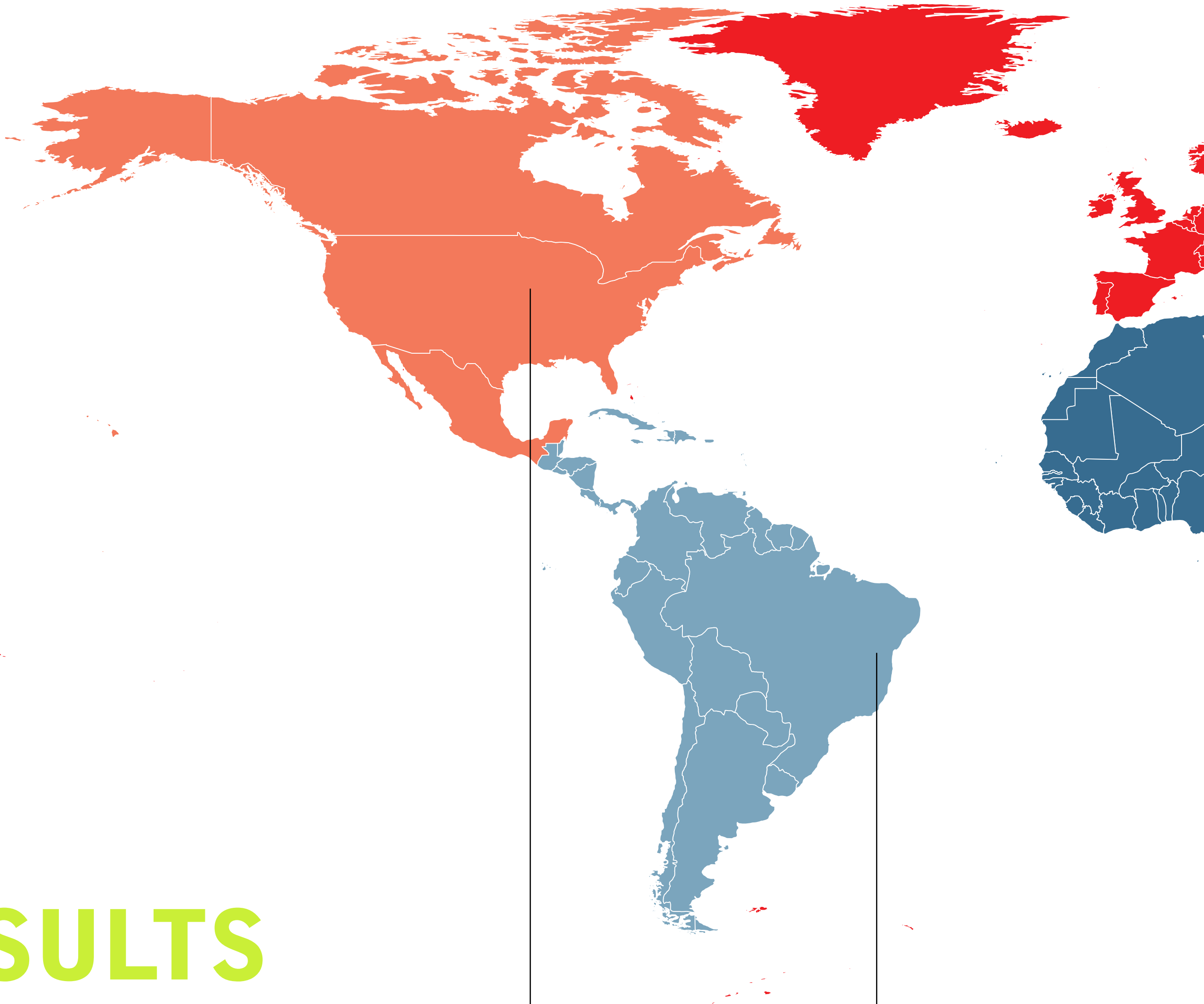
		REF		E[R]	
		mio t	%	mio t	%
CO_2	2007	1,488	216	1,488	216
	2050	3,846M	557	428	62
		t		t	
	2007	1.47		1.47	
	2050	2.54		0.28	

OECD PACIFIC

		REF		E[R]	
		mio t	%	mio t	%
CO_2	2007	2,144	136	2,144	136
	2050	1,822	116	74	5
		t		t	
	2007	10.70		10.70	
	2050	10.14		0.41M	

map 3.2: results reference scenario and the advanced energy [r]evolution scenario

WORLDWIDE SCENARIO



OECD NORTH AMERICA

		REF PE PJ	REF EL TWh	E[R] PE PJ	E[R] EL TWh
	2007	115,758H	5,221H	115,758H	5,221
	2050	129,374	7,917	70,227	7,925
		%		%	
Share of renewables	2007	7	15	7	15
	2050	15	25	85	98
		%		%	
Share of fossil fuels	2007	85	67M	85	67M
	2050	75	59M	9	2
		%		%	
Share of nuclear energy	2007	8	18	NUCLEAR POWER PHASED OUT BY 2040	
	2050	10	16		

LATIN AMERICA

		REF PE PJ	REF EL TWh	E[R] PE PJ	E[R] EL TWh
	2007	22,513L	998	22,513L	998
	2050	40,874	2,480	27,311	2,927
		%		%	
Share of renewables	2007	29	70H	29	70H
	2050	28	57H	88H	98
		%		%	
Share of fossil fuels	2007	70L	28L	70L	28L
	2050	69	40L	12L	2
		%		%	
Share of nuclear energy	2007	1	2	NUCLEAR POWER PHASED OUT BY 2030	
	2050	3	2		

SCENARIO

RESULTS

LEGEND

> -50 > -40 > -30
> -20 > -10 > 0
> +10 > +20 > +30
> +40 > +50

% CHANGE OF ENERGY CONSUMPTION IN THE ADVANCED ENERGY [R]EVOLUTION SCENARIO 2050 COMPARED TO CURRENT CONSUMPTION 2007

REF REFERENCE SCENARIO

E[R] ADVANCED ENERGY [R]EVOLUTION SCENARIO

0 1000 KM

SHARE OF RENEWABLES %

SHARE OF FOSSIL FUELS %

SHARE OF NUCLEAR ENERGY %

H HIGHEST | **M** MIDDLE | **L** LOWEST
PE PRIMARY ENERGY PRODUCTION/DEMAND IN PETA JOULE [PJ]
EL ELECTRICITY PRODUCTION/GENERATION IN TERAWATT HOURS [TWh]

OECD EUROPE

	REF PE PJ	REF EL TWh	E[R] PE PJ	E[R] EL TWh
2007	79,599	3,576	79,599	3,576
2050	82,634	5,351	46,754	4,233
	%		%	
2007	10	20	10	20
2050	21	42	85	97
	%		%	
2007	77	54	77	54
2050	71	46	16	2
	%		%	
2007	13	26H	NUCLEAR POWER PHASED OUT BY 2030	
2050	8	12		

MIDDLE EAST

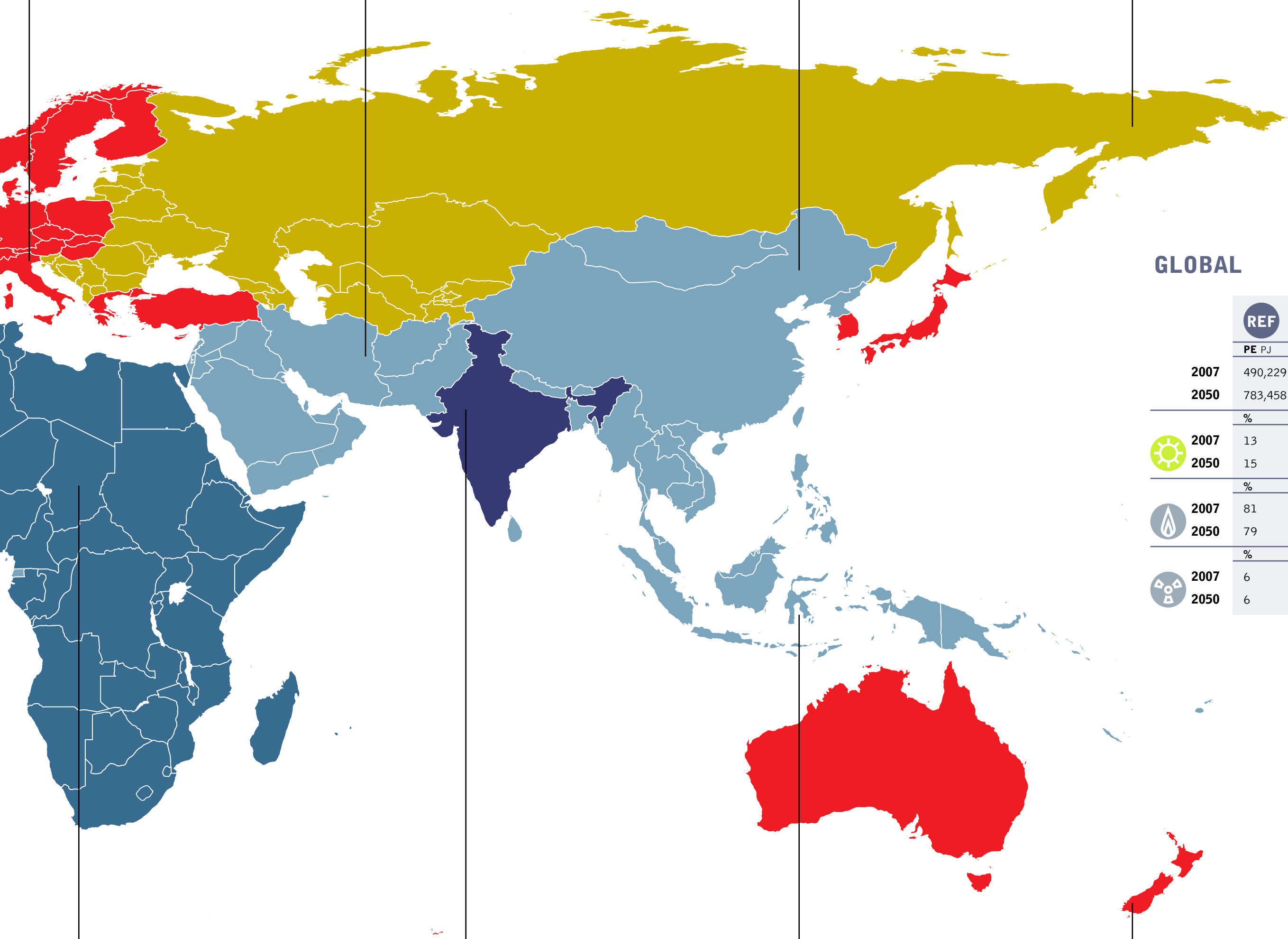
	REF PE PJ	REF EL TWh	E[R] PE PJ	E[R] EL TWh
2007	21,372	715	21,372	715
2050	51,281	2,404	27,475	2,786L
	%		%	
2007	1L	3	1L	3L
2050	2L	7	76	99H
	%		%	
2007	99H	97	99H	97H
2050	97H	92	23	1L
	%		%	
2007	0L	0	NO NUCLEAR ENERGY DEVELOPMENT	
2050	0L	0		

CHINA

	REF PE PJ	REF EL TWh	E[R] PE PJ	E[R] EL TWh
2007	83,922	3,319	83,922	3,319
2050	183,886H	12,188H	107,104H	10,190H
	%		%	
2007	12M	15	12M	15
2050	10	18	77L	90
	%		%	
2007	87	83	87	83
2050	85	75	23H	10H
	%		%	
2007	1	2	NUCLEAR POWER PHASED OUT BY 2045	
2050	5	7		

TRANSITION ECONOMIES

	REF PE PJ	REF EL TWh	E[R] PE PJ	E[R] EL TWh
2007	48,111M	1,685	48,111M	1,685
2050	64,449	3,110	34,710	2,438
	%		%	
2007	4	17M	4	17M
2050	7	22M	76	93
	%		%	
2007	89	65	89	65
2050	85	63	24	7
	%		%	
2007	7M	17	NUCLEAR POWER PHASED OUT BY 2045	
2050	8	15		



GLOBAL

	REF PE PJ	REF EL TWh	E[R] PE PJ	E[R] EL TWh
2007	490,229	19,773	490,229	19,773
2050	783,458	46,542	480,861	43,922
	%		%	
2007	13	18	13	18
2050	15	24	80	95
	%		%	
2007	81	68	81	68
2050	79	67	20	5
	%		%	
2007	6	14	NUCLEAR POWER PHASED OUT BY 2045	
2050	6	10		

AFRICA

	REF PE PJ	REF EL TWh	E[R] PE PJ	E[R] EL TWh
2007	26,355	615L	26,355	615L
2050	43,173	1,826L	35,805	2,490L
	%		%	
2007	48H	16	48H	16
2050	45H	36	79M	94
	%		%	
2007	51	82	51	82
2050	54L	62	20M	6
	%		%	
2007	0L	2	NUCLEAR POWER PHASED OUT BY 2025	
2050	0L	2		

INDIA

	REF PE PJ	REF EL TWh	E[R] PE PJ	E[R] EL TWh
2007	25,159	814	25,159	814
2050	77,7610M	4,918	52,120	5,062
	%		%	
2007	29	17	29	17
2050	13	12	78	93L
	%		%	
2007	70	81	70	81
2050	84	85	22	7
	%		%	
2007	1	2	NUCLEAR POWER PHASED OUT BY 2045	
2050	3	3		

DEVELOPING ASIA

	REF PE PJ	REF EL TWh	E[R] PE PJ	E[R] EL TWh
2007	31,903	978	31,903	978
2050	69,233	3,721	40,639	3,548
	%		%	
2007	27	16	27	16
2050	19	21	73L	94
	%		%	
2007	72	79	72	79
2050	79	77	27	6
	%		%	
2007	1	5M	NUCLEAR POWER PHASED OUT BY 2045	
2050	2	2		

OECD PACIFIC

	REF PE PJ	REF EL TWh	E[R] PE PJ	E[R] EL TWh
2007	37,588	1,851M	37,588	1,851M
2050	40,793	2,626	21,299L	2,322
	%		%	
2007	4	8	4	8
2050	10	16	84	98M
	%		%	
2007	84	70	84	70
2050	66	51	16	2M
	%		%	
2007	12H	22	NUCLEAR POWER PHASED OUT BY 2045	
2050	24H	33H		

key results of the eu 27 energy [r]evolution scenario

EU 27

4

image SOLAR PANEL. © BERND JUERGENS/DREAMSTIME

"clean and renewable energy are [...] indispensable if we are not to place an unbearable burden on our children and grandchildren in the 21st century."

ANGELA MERKEL
GERMAN FEDERAL CHANCELLOR:

image AERIAL PHOTO OF THE ANDASOL 1 SOLAR POWER STATION, 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 TONNES OF CARBON DIOXIDE PER YEAR COMPARED WITH A MODERN COAL POWER PLANT.

image image TEST WINDMILL N90 2500, BUILT BY THE GERMAN COMPANY NORDEX, IN THE HARBOUR OF ROSTOCK. THIS WINDMILL PRODUCES 2.5 MEGA WATT AND IS TESTED UNDER OFFSHORE CONDITIONS. TWO TECHNICIANS WORKING INSIDE THE TURBINE.

energy demand by sector

The future development pathways for Europe's energy demand are shown in Figure 4.1. Under the Reference scenario, total primary energy demand in EU 27 increases by 3% from the current 73,880 PJ/a to 75,920 PJ/a in 2050. The energy demand in 2050 under the basic Energy [R]evolution scenario decreases by 39%, and 38% in the advanced case, compared to current consumption. By 2050, it is expected to reach 45,040 PJ/a and 46,030 PJ/a respectively.

Under the advanced Energy [R]evolution scenario, electricity demand in the industrial, residential and service sectors are expected to decrease after 2015 (see Figure 4.2). Efficiency measures in industry and other sectors avoid the generation of about 1,335 TWh/a (1,410 TWh/a in the Energy [R]evolution scenario) compared to the Reference scenario. This reduction in energy demand can be achieved, in particular, by introducing highly efficient electronic devices using the best available technology.

The advanced Energy [R]evolution scenario introduces electric vehicles earlier and sees more freight and passenger transport shifting to electric trains and public transport. This leads to an electricity demand in the transport sector of 1,240 TWh/a in the advanced scenario and 850 TWh/a in the basic Energy [R]evolution scenario in 2050, compared to 135 TWh/a in the Reference scenario.

In the transport sector, it is assumed under the advanced Energy [R]evolution scenario that energy demand will decrease to 7,250 PJ/a by 2050, saving 52% compared to the Reference scenario. This reduction can be achieved by the introduction of highly efficient vehicles, by shifting the transport of goods from road to rail and by changes in mobility-related behaviour patterns.

Efficiency gains in the heat supply sector are higher than in the electricity sector. Under both Energy [R]evolution scenarios, final demand for heat supply can be reduced significantly (see Figure 4.3). Compared to the Reference scenario, heat consumption equivalent to 6340 PJ/a, or 25%, in the advanced case (5960 PJ/a, or 23%, in the Energy [R]evolution), is avoided through efficiency gains by 2050. As a result of energy-related renovation of the existing stock of residential buildings, as well as the introduction of low energy standards and 'passive house standards' for new buildings, it will be possible to enjoy the same comfort and energy service with a much lower future energy demand.

The increasing number of electric vehicles and quicker phase-out of fossil fuels from industrial process heat generation towards electric geothermal heat pumps and hydrogen lead to a rising electricity demand of 4,220 TWh in the advanced Energy [R]evolution by 2050. This value is still 11% lower than in the Reference case.

Further details regarding the electricity sector can be found in the next paragraph.

figure 4.1: projection of total final energy demand by sector (REF, E[R] & advanced E[R])

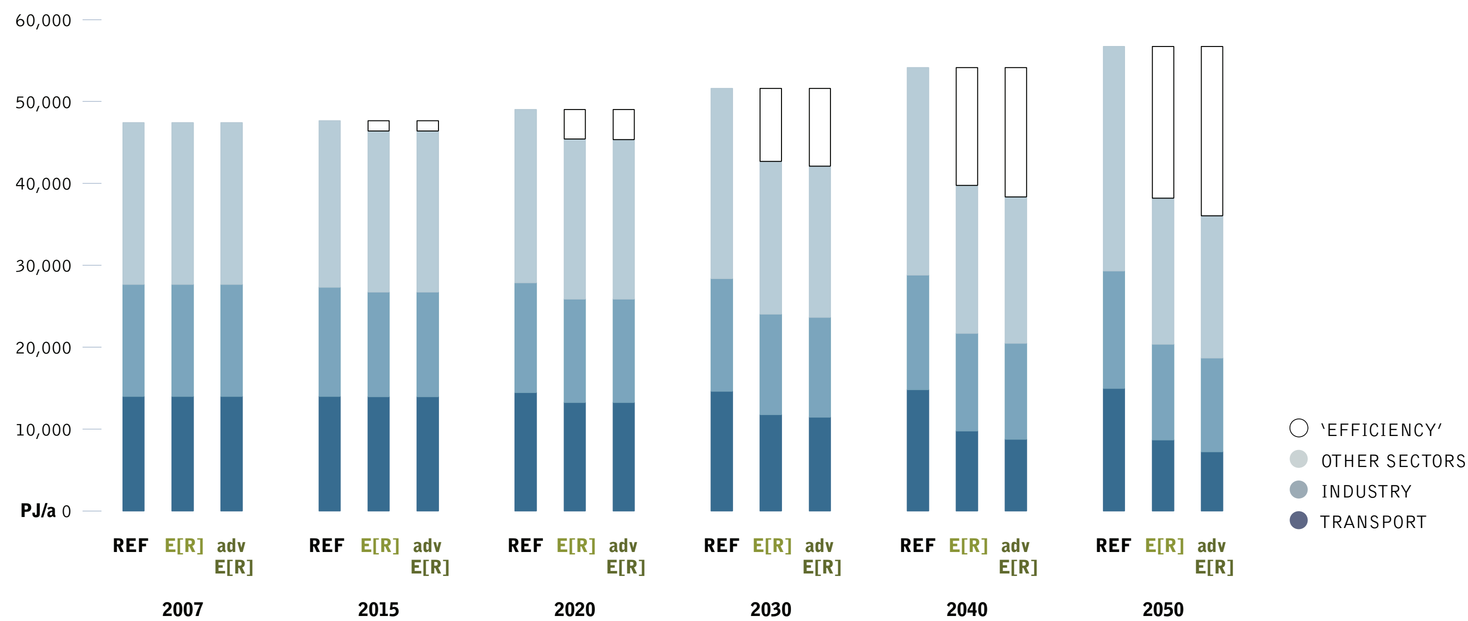
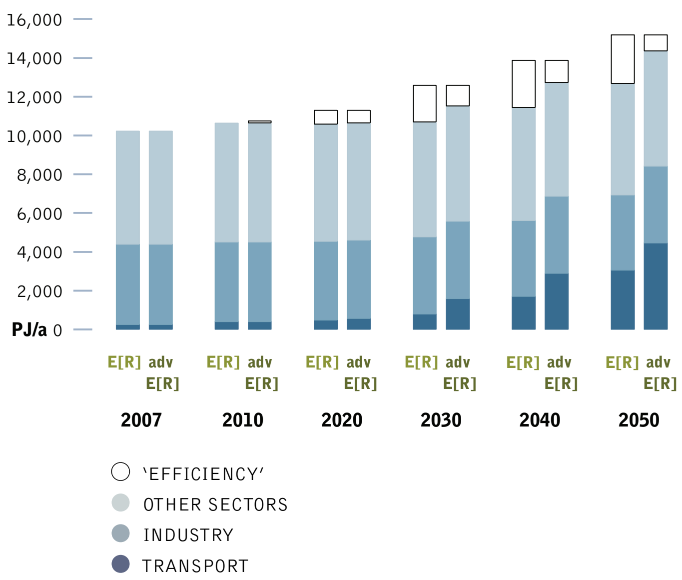


figure 4.2: development of electricity demand by sector (REF, E[R] & advanced E[R])



heating and cooling supply

Renewables currently provide 13% of EU 27 primary energy demand for heat supply, mostly through biomass. The lack of district heating networks is a severe structural barrier to the large scale utilisation of geothermal and solar thermal energy. In the advanced Energy [R]evolution scenario, renewables provide 92% of EU 27 total heating and cooling demand by 2050. This value is 36 percentage points higher than in the Energy [R]evolution scenario due to two main effects:

- Strict energy efficiency measures through tight building standards and renewable heating systems, among other things, are introduced around 5 years ahead of the Energy [R]evolution scenario. They can decrease the current demand for heat supply by 6340 PJ/a, or 25%, compared to the Reference scenario by 2050, while improving living standards.

- Solar collectors and geothermal heating systems, eclipsing fossil fuel-fired systems, achieve economies of scale via ambitious support programmes 5 to 10 years earlier than in the Energy [R]evolution scenario. This leads to a renewable share in the advanced scenario which is more than four times higher than in the Reference scenario (92%).

figure 4.3: development of heat demand by sector

figure 4.4: development of heat supply structure under 3 scenarios

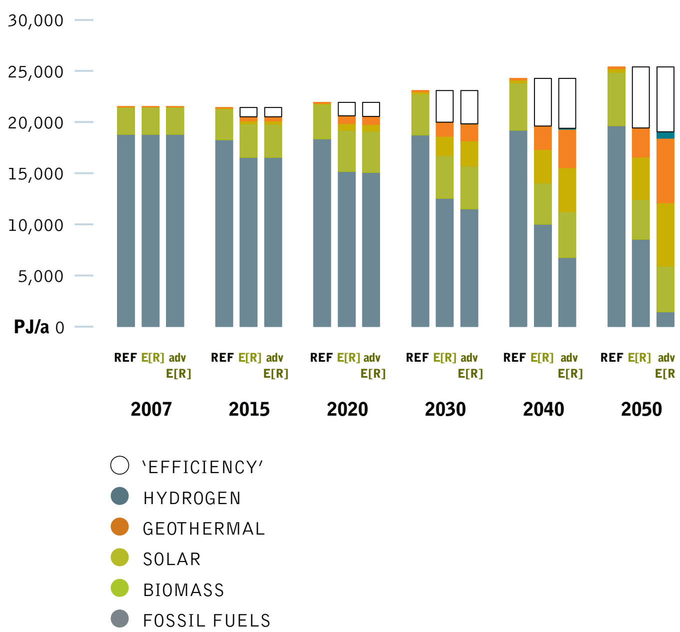


image OFFSHORE WINDFARM, MIDDELGRUNDEN, COPENHAGEN, DENMARK.

image MAN USING METAL GRINDER ON PART OF A WIND TURBINE MAST IN THE VESTAS FACTORY, CAMBELTOWN, SCOTLAND, GREAT BRITAIN.

electricity generation

The development of the electricity supply sector in the advanced Energy [R]evolution scenario is characterised by a rapidly growing renewable energy market. This will compensate for the phasing out of nuclear energy and reduce the number of fossil fuel-fired power plants required for grid stabilisation. By 2050, nearly all the electricity produced in EU 27 will come from renewable energy sources (97%). Figure 4.5 shows the evolution of the European electricity mix under the three different scenarios. Up to 2020, hydro and wind power will remain the main contributors to the growing RES market share. After 2020, the continued growth of wind will be complemented by electricity from photovoltaic, biomass, geothermal and solar thermal (CSP) energy. The advanced Energy [R]evolution scenario will lead to a higher share of variable power generation sources (photovoltaic, wind and ocean) of 36% by 2030 and 52% in 2050. Therefore, the expansion of smart grids, demand-side management (DSM) and storage capacity from an increased share of electric vehicles and pumped hydropower will be used for better grid integration and power generation management.

The installed capacity of renewable energy technologies will grow from the current 223 GW to 1,520 GW in 2050, increasing renewable capacity by a factor of almost 7 (see Table 4.1) in the advanced Energy [R]evolution scenario. Wind power and photovoltaics each cover around a third of the total installed renewable capacity, around 500 GW each. The remaining third is mainly provided by hydro power (160 GW) and equal 100 GW shares of biomass, geothermal and CSP power.

Compared to the Energy [R]evolution scenario, the advanced scenario sees more than 40% additional power from renewable energy sources to satisfy increased electricity demand. While a faster uptake of the different renewable energy technologies is assumed, only the use of biomass is kept to a lower level for sustainability reasons.

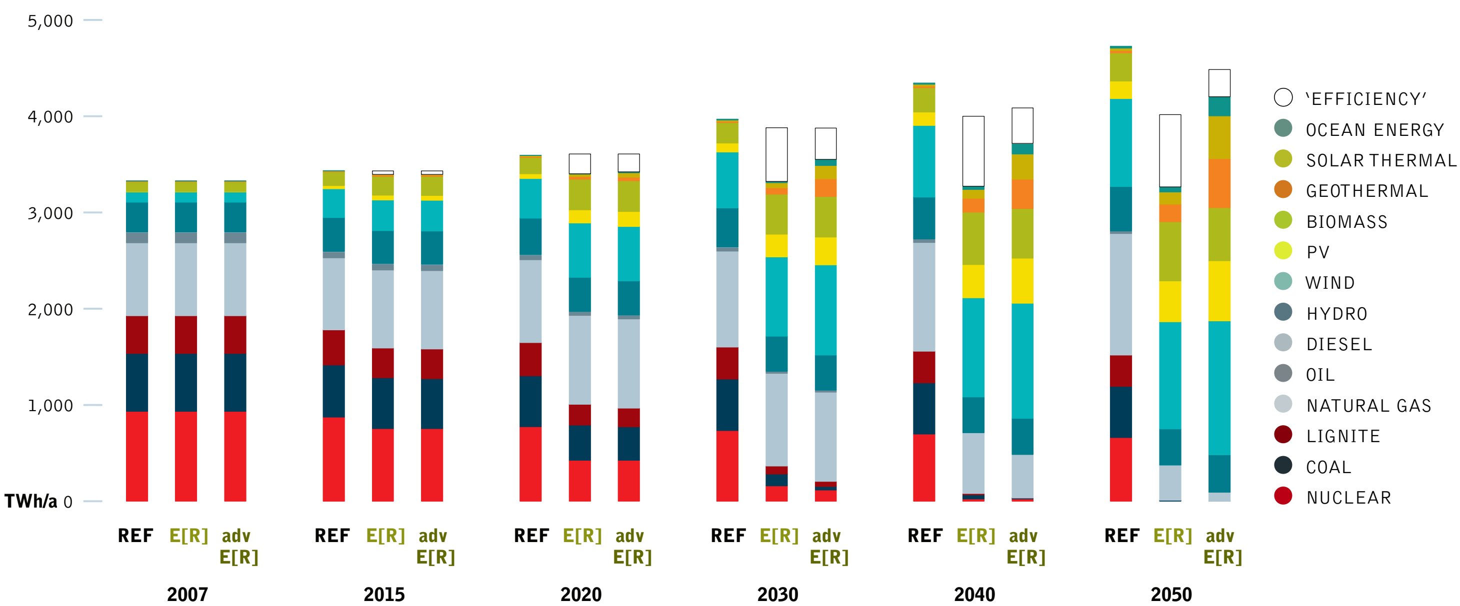
table 4.1: projection of renewable electricity generation capacity under both energy [r]evolution scenarios

IN GW

		2007	2020	2030	2040	2050
Hydro	E[R]	140	155	157	157	156
	advanced E[R]	140	155	157	159	163
Biomass	E[R]	20	59	76	98	112
	advanced E[R]	20	59	77	93	100
Wind	E[R]	57	251	330	382	398
	advanced E[R]	57	251	376	443	497
Geothermal	E[R]	1	5	13	27	35
	advanced E[R]	1	7	34	58	96
PV	E[R]	5	125	196	282	340
	advanced E[R]	5	144	241	381	498
CSP	E[R]	0	9	17	27	31
	advanced E[R]	0	15	43	73	99
Ocean energy	E[R]	0	1	4	11	18
	advanced E[R]	0	3	21	37	66
Total	**E[R]**	**223**	**605**	**792**	**985**	**1,090**
	advanced E[R]	**223**	**634**	**949**	**1,244**	**1,518**

figure 4.5: development of electricity generation structure under 3 scenarios

(REFERENCE, ENERGY [R]EVOLUTION AND ADVANCED ENERGY [R]EVOLUTION) ["EFFICIENCY" = REDUCTION COMPARED TO THE REFERENCE SCENARIO]



future costs of electricity generation

The introduction of renewable technologies under the two Energy [R]evolution scenarios slightly increases the specific costs of electricity generation compared to the Reference scenario until 2030 (see Figure 4.6). The difference will be less than 1.2 euro cent/kWh.

However, after 2030, specific electricity generation costs will become economically favourable under both Energy [R]evolution scenarios. This is due to the lower CO_2 intensity of electricity generation and the related costs for emission allowances as well as better economics of scale in the production of renewable power equipment. In 2050, the specific costs for one kWh add up to 6.7 euro cent in the advanced scenario, 7.3 euro cent in the basic Energy [R]evolution scenario and 9.5 euro cent in the Reference scenario.

Under the Reference scenario, the unchecked growth in electricity demand, the increase in fossil fuel prices and the cost of CO_2 emissions result in total electricity supply costs rising from today's €240 billion per year to €500 billion in 2050. Figure 4.6 shows that the Energy [R]evolution scenarios not only comply with Europe's CO_2 reduction targets but also help to stabilise energy costs and relieve economic pressure on society. Increasing energy efficiency and shifting energy supply to renewables result in long-term costs for electricity supply that are 34 % lower in the advanced and 43% lower in the Energy [R]evolution scenario. The higher total costs in the advanced compared to the basic Energy [R]evolution scenario result from a higher requirement for electricity due to the increasing electrification of the transport and heating sectors.

job results

The Energy [R]evolution scenarios lead to more energy sector jobs in EU 27 at every stage.

- By 2015, renewable power sector jobs in the advanced Energy [R]evolution scenario are estimated to reach about 830,00, 260,000 more than in the Reference scenario. The basic version will lead to 720,000 jobs in the renewable power industry.

- By 2020, the advanced Energy [R]evolution scenario has created about 940,000 jobs in the renewable power industry, 410,000 more than the Reference scenario. The job losses in the fossil fuel sector due to a reduced coal generation capacity are overcompensated by the growing renewable power generation.

- By 2030, the advanced Energy [R]evolution scenario has created about 1,2 million jobs in the renewable power industry, 780,000 more than the Reference scenario. Approximately 280,000 new renewable energy jobs are created between 2020 and 2030, compared to the reference with a slight decrease of renewable energy jobs in the same time frame.

Table 4.2 shows the increase in job numbers under both Energy [R]evolution scenarios for each technology up to 2030. Both scenarios show losses in coal generation, but these are outweighed by employment growth in renewable technologies and gas. Wind shows particularly strong growth in both Energy [R]evolution scenarios by 2020, but by 2030 there is significant employment across a range of renewable technologies. In both Energy [R]evolution scenarios, renewable power jobs reach over 70% of total energy sector jobs by 2020, with a share of over 80% by 2030.

figure 4.6: development of total electricity supply costs & development of specific electricity generation costs under 3 scenarios

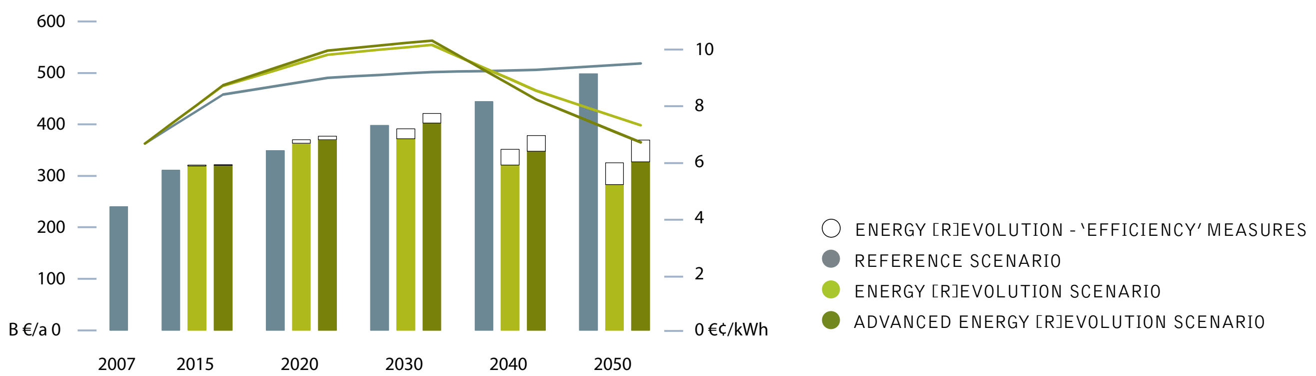


image PLANT NEAR REYKJAVIK WHERE ENERGY IS PRODUCED FROM THE GEOTHERMAL ACTIVITY.

image WORKERS EXAMINE PARABOLIC TROUGH COLLECTORS IN THE PS10 SOLAR TOWER PLANT AT SAN LUCAR LA MAYOR OUTSIDE SEVILLE, SPAIN, 2008.

table 4.2: employment & investment

	REFERENCE			ENERGY [R]EVOLUTION			ADVANCED ENERGY [R]EVOLUTION		
Jobs	2015	2020	2030	2015	2020	2030	2015	2020	2030
Construction & installation	0.12	0.08	0.06	0.18	0.09	0.13	0.20	0.14	0.20
Manufacturing	0.17	0.12	0.09	0.17	0.15	0.17	0.27	0.23	0.23
Operations & maintenance	0.34	0.36	0.42	0.40	0.56	0.68	0.40	0.56	0.73
Fuel	0.32	0.30	0.28	0.34	0.30	0.21	0.35	0.30	0.17
Coal and gas export	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Jobs	**0.94**	**0.87**	**0.85**	**1.09**	**1.11**	**1.20**	**1.22**	**1.23**	**1.33**
Coal	0.27	0.25	0.23	0.27	0.20	0.08	0.28	0.20	0.04
Gas, oil and diesel	0.06	0.05	0.04	0.07	0.07	0.07	0.07	0.07	0.07
Nuclear	0.04	0.04	0.03	0.03	0.02	0.01	0.03	0.02	0.01
Renewables	0.57	0.53	0.54	0.72	0.82	1.04	0.83	0.94	1.22
Total Jobs	**0.94**	**0.87**	**0.85**	**1.09**	**1.11**	**1.20**	**1.22**	**1.23**	**1.33**

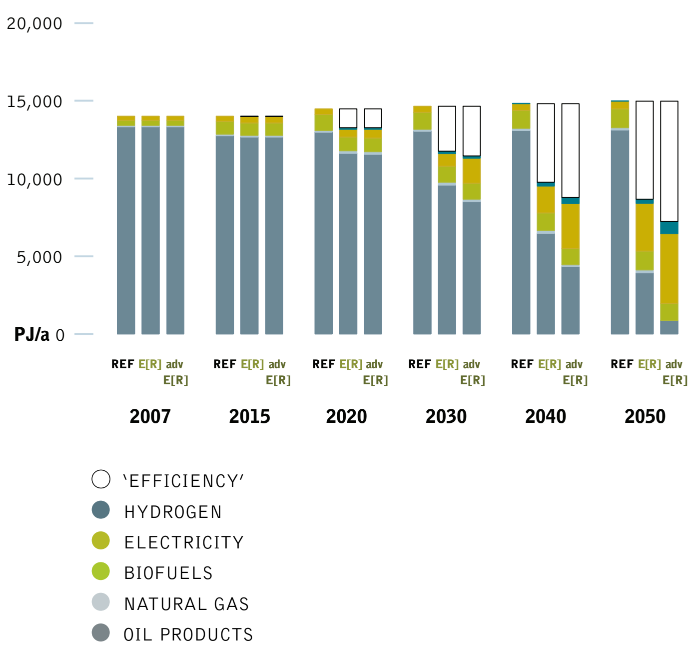
transport

For the transport sector, the advanced Energy [R]evolution scenario assumes that energy demand will decrease by more than half current level to 7,250 PJ/a by 2050 (8,700 PJ/a in the Energy [R]evolution scenario), saving 52% compared to the Reference scenario. This reduction can be achieved by the introduction of highly efficient vehicles, by shifting the transport of goods from road to rail and by changes in mobility-related behaviour patterns. Implementing attractive alternatives to individual cars would seethe car stock grow more slowly than in the Reference scenario. A shift towards smaller cars triggered by economic incentives and a significant shift in propulsion technology towards electrified trains and road vehicles will also contribute, as will a reduction of annual vehicle kilometres travelled.

19% of the final energy demand in the transport sector is covered by RES in 2030, rising to 86% in 2050. This is twice as high as the renewable share in the Energy [R]evolution case, whereas the amount of biofuels is higher in the latter case (1,220 PJ/a vs. 1,100 PJ/a in the advanced scenario).

In 2030, electricity will provide 14% of the transport sector's total energy demand in the advanced Energy [R]evolution scenario (7% in the basic Energy [R]evolution scenario) and increase to 62% (35% respectively) by 2050.

figure 4.7: transport under 3 scenarios



development of CO_2 emissions

While CO_2 emissions in EU 27 will increase by 13% in the Reference scenario by 2050, under the advanced Energy [R]evolution scenario they will decrease from 3890 million tonnes in 2007 to 195 million tonnes in 2050 (equal to a 95% emissions reduction compared to the 1990 level). Annual per capita emissions will drop from 7.9 t to 0.4 t. In spite of the phasing out of nuclear energy and increasing demand, CO_2 emissions will decrease in the electricity sector. In the long run, efficiency gains and the increased use of renewable electricity in vehicles will reduce emissions in the transport sector. With a share of 9% of total CO_2 emissions in 2050, the power sector will drop below transport as the largest source of emissions (see Figure 4.8).

The basic Energy [R]evolution scenario reduces energy related CO_2 emissions with a delay of 10 to 15 years compared to the advanced Energy [R]evolution scenario, leading to 4.3 t per capita by 2030 and 2.0 t by 2050. By 2050, EU 27´s CO_2 emissions are 76% under 1990 levels.

primary energy consumption

Taking into account the assumptions discussed above, the resulting primary energy consumption under the advanced Energy [R]evolution scenario is shown in Figure 4.9. Compared to the Reference scenario, overall energy demand will be reduced to 62% in 2050. Around 86% of the remaining primary energy demand will be covered by renewable energy sources. Compared to the basic Energy [R]evolution scenario, the absolute primary energy savings are the same, whereas the renewable energy share reaches only 60%. This gap is due to the fact that the advanced scenario phases out coal and oil about 10 to 15 years faster than the Energy [R]evolution scenario. Main reasons for this are a replacement of new coal power plants with renewables after 20 years rather than 40 year lifetime in the Energy [R]evolution scenario and a faster introduction of electric vehicles to replace combustion engines. Nuclear energy is phased out in both Energy [R]evolution scenarios just after 2030.

figure 4.8: development of CO_2 emissions by sector under both energy [r]evolution scenarios

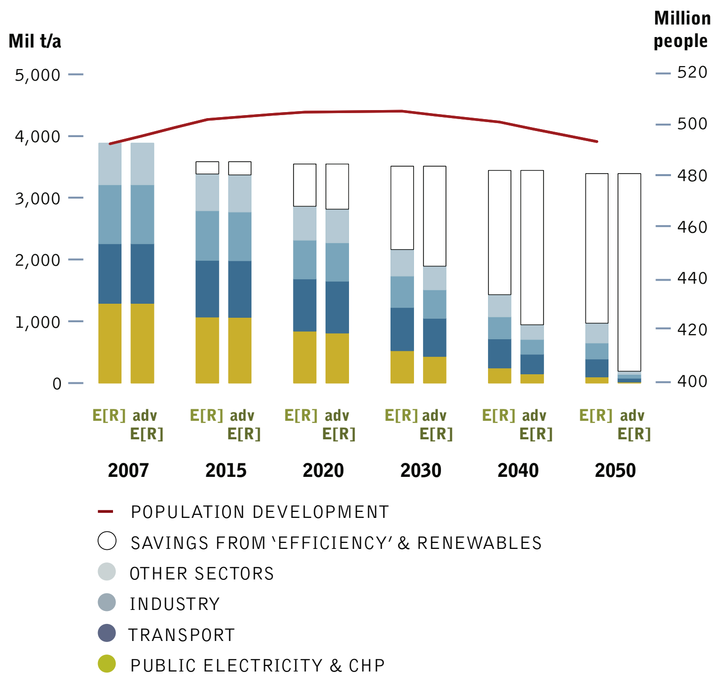


figure 4.9: development of primary energy consumption under three scenarios

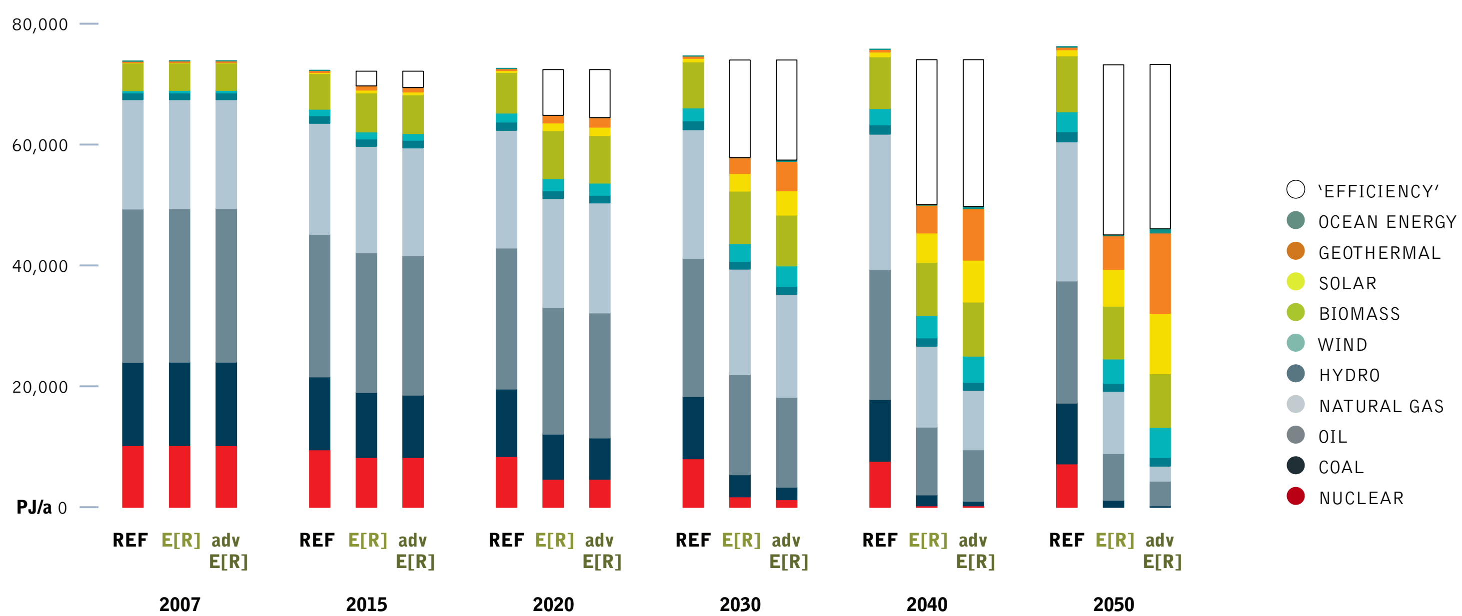


image THROUGH BURNING OF WOOD CHIPS THE POWER PLANT GENERATES ELECTRICITY, ENERGY OR HEAT. HERE WE SEE THE STOCK OF WOOD CHIPS WITH A CAPACITY OF 1000 M3 ON WHICH THE PLANT CAN RUN, UNMANNED, FOR ABOUT 4 DAYS. LELYSTAD, THE NETHERLANDS.

image THE MARANCHON WIND FARM IS THE LARGEST IN EUROPE WITH 104 GENERATORS, AND IS OPERATED BY IBERDROLA, THE LARGEST WIND ENERGY COMPANY IN THE WORLD.

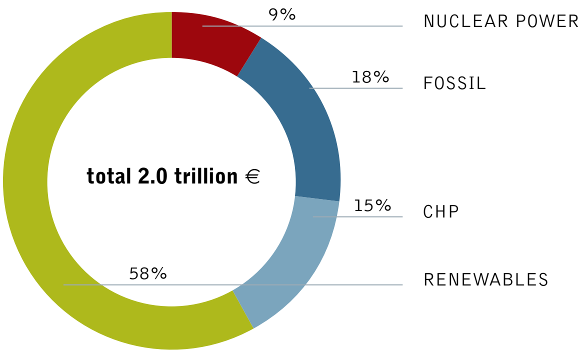
future investment

investment for new electricity production plants The overall level of investment required for new power plants in Europe until 2050 will be in the region of €2.0 to €3.8 trillion. A major driving force for investment in new generation capacity will be the ageing fleet of power plants. Utilities must choose which technologies to opt for within the next five to ten years based on national energy policies, in particular market liberalisation, renewable energy and CO_2 reduction targets. The European Emission Trading scheme (ETS) will have a major impact on whether the majority of investment goes to fossil fuelled power plants or renewable energy and co-generation. The ETS will play a major role in future technology choices, as will whether investments in renewable energy become competitive compared to investment costs for conventional power plants. In regions with a good wind regime, for example, wind farms can already produce electricity at the same cost levels as coal or gas power plants.

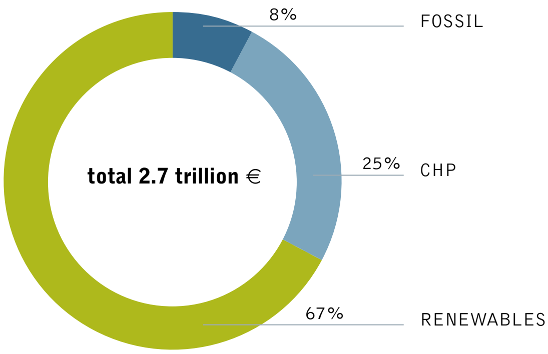
To become a reality, the Energy [R]evolution scenario would require a total investment of €2.7 trillion in power plants and combined heat and power plants – approximately 33% higher than in the Reference scenario (€2.0 trillion), see Figure 4.10. The advanced Energy [R]evolution scenario would need a €3.8 trillion investment, approximately 40% more than the basic version. While 35% of investment under the Reference scenario will go to fossil fuels and nuclear power plants, amounting to €420 billion, under the Energy [R]evolution scenarios, the EU 27 would shift over 90% of investment towards renewables and cogeneration. The remaining fossil fuel share of power sector investment would be focused mainly on combined heat and power and efficient gas-fired power plants.

figure 4.10: investment shares - reference versus energy [r]evolution

reference scenario 2007 - 2050



energy [r]evolution scenario 2007 - 2050



advanced energy [r]evolution scenario 2007 - 2050

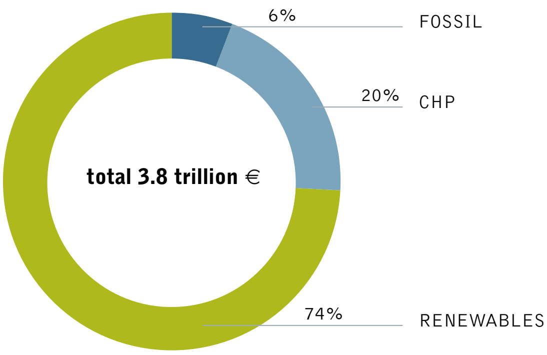
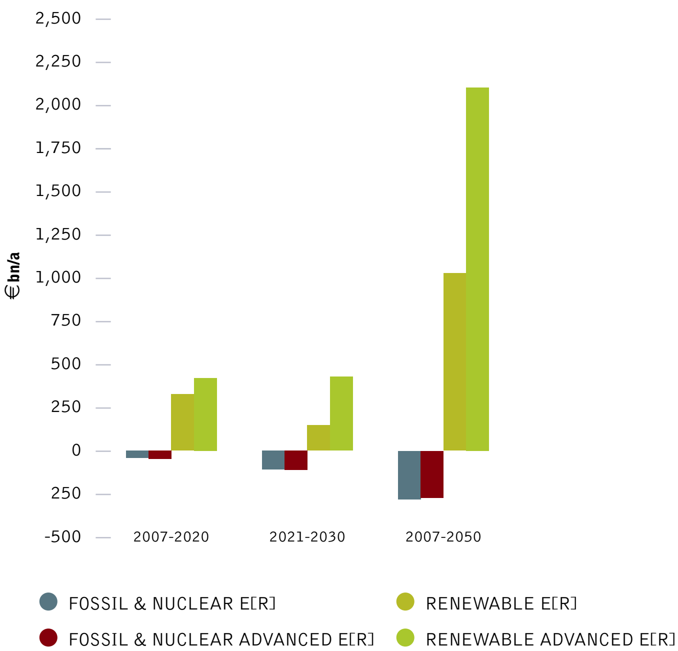


figure 4.11: change in cumulative power plant investment in both energy [r]evolution scenarios



renewable energy power generation investment "Under the Reference scenario, investment in renewable electricity generation between 2007 and 2050 will be €1.4 trillion. This compares to €3.5 trillion in the advanced Energy [R]evolution scenario. How investment is divided between the different renewable power generation technologies depends on their level of technical development and on regionally available resources. Technologies such as wind power, which in many regions is already cost-competitive with existing power plants, will take a larger investment volume and a bigger market share. The market volume attributed to different technologies also depends on local resources and policy frameworks within the EU 27. Figure 4.12 provides an overview of the investment required for each technology under the advanced Energy [R]evolution scenario including combined heat and power plants.

For solar photovoltaics, the main market will remain in Germany and Spain for some years to come, but should soon expand across other EU member states. Because solar photovoltaic energy is a highly modular and decentralised technology which can be used almost everywhere, its market will eventually spread across the entire EU. Concentrated solar power systems, on the other hand, can only operate in the most southern regions of the EU. The main investment in this technology is therefore expected to take place in Spain, France, Italy and Greece. Major developments for the wind industry are expected in northern Europe, Spain and Portugal. Offshore wind technology is expected to take a larger share from around 2015 onwards. The main offshore wind development will take place around the North Sea region. Bio energy power plants could be distributed across the whole of Europe, as there is potential almost everywhere for biomass and/or biogas (cogeneration) power plants.

figure 4.12: renewable energy investment costs

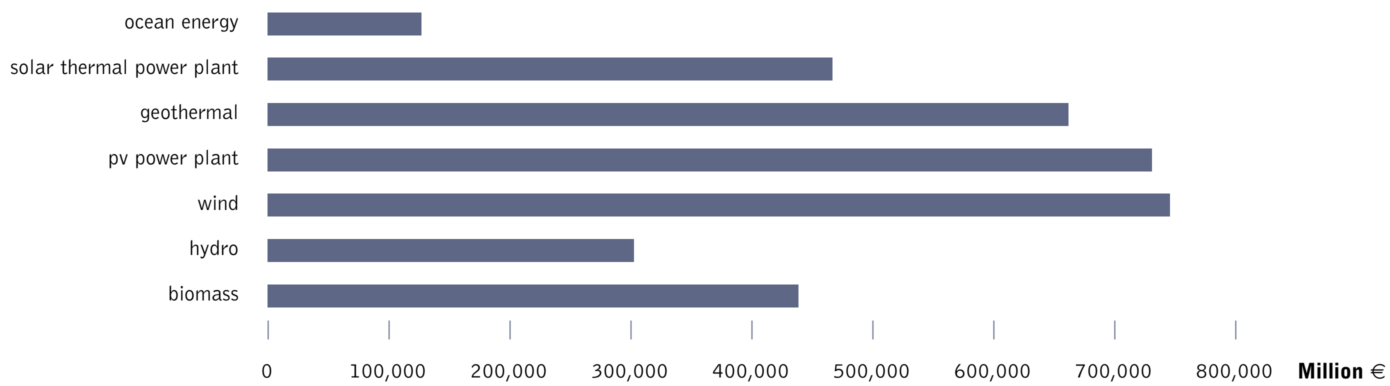


image GEOTHERMAL ACTIVITY NEAR HOLSSELSNALAR CLOSE TO REYKJAVIK, ICELAND.

fuel cost savings using renewable energy Total fuel cost savings in the basic Energy [R]evolution scenario reach a total of €2.1 trillion, or €49 billion per year. The advanced Energy [R]evolution has even higher fuel cost savings of €2.6 trillion, or €62 billion per year. This is because renewable energy has no fuel costs.

In the basic case, additional investments amount to €750 billion from today until 2050, which would be covered almost three times by fuel cost savings (see Table 4.3). In the advanced case, fuel cost savings are as well enough to compensate for the entire additional investment in renewable and cogeneration capacity required.

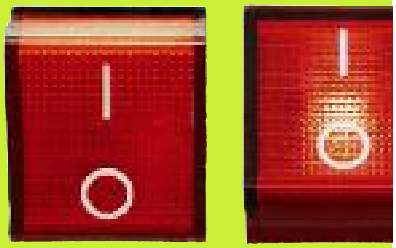
table 4.3: fuel cost savings and investment costs under the reference, energy[r]evolution and advanced energy [r]evolution

INVESTMENT COST	DOLLAR	2007-2020	2021-2030	2007-2050	2007-2050 AVERAGE PER YEAR
EU 27 (2010) DIFFERENCE E[R] VERSUS REF					
Conventional (fossil & nuclear)	billion €	-55	-111	-278	-6
Renewables (incl. CHP)	billion €	341	149	1,026	24
Total	billion €	286	38	748	17
EU 27 (2010) DIFFERENCE ADV E[R] VERSUS REF					
Conventional (fossil & nuclear)	billion €	-54	-118	-269	-6
Renewables (incl. CHP)	billion €	424	435	2,117	49
Total	billion €	371	316	1,849	43
CUMULATED FUEL COST SAVINGS					
SAVINGS E[R] CUMULATED IN €					
Fuel oil	billion €/a	28	64	220	5
Gas	billion €/a	-42	-12	1,188	28
Hard coal	billion €/a	25	126	605	14
Lignite	billion €/a	7	21	102	2
Total	billion €/a	18	200	2,116	49
SAVINGS ADV E[R] CUMULATED IN €					
Fuel oil	billion €/a	28	64	220	5
Gas	billion €/a	-43	2	1,652	38
Hard coal	billion €/a	29	149	667	16
Lignite	billion €/a	7	24	108	3
Total	billion €/a	21	239	2,647	62

policy recommendations

GLOBAL

5



STANDBY POWER IS WASTED POWER. GLOBALLY, WE HAVE 50 DIRTY POWER PLANTS RUNNING JUST FOR OUR WASTED STANDBY POWER. OR: IF WE WOULD REDUCE OUR STANDBY TO JUST 1 WATT, WE CAN AVOID THE BUILDING OF 50 NEW DIRTY POWER PLANTS.

"saving the planet is not an after-dinner drink, a 'digestif' that you take or leave. climate change does not disappear because of the financial crisis."

JOSÉ MANUEL BARROSO
PRESIDENT OF THE EUROPEAN COMMISSION

image A YOUNG INDIGENOUS NENET BOY PRACTICES WITH HIS ROPE. THE BOYS ARE GIVEN A ROPE FROM PRETTY MUCH THE MOMENT THEY ARE BORN. BY THE AGE OF SIX THEY ARE OUT HELPING LASSOING THE REINDEER. THE INDIGENOUS NENETS PEOPLE MOVE EVERY 3 OR 4 DAYS SO THAT THEIR REINDEER DO NOT OVER GRAZE THE GROUND AND THEY DO NOT OVER FISH THE LAKES. THE YAMAL PENINSULA IS UNDER HEAVY THREAT FROM GLOBAL WARMING AS TEMPERATURES INCREASE AND RUSSIAS ANCIENT PERMAFROST MELTS.

The Energy [R]evolution presents European decision-makers with a cost-effective and sustainable pathway for our economy, while tackling the challenges of climate change and the security of energy supply.

A fully renewable and efficient energy system would allow Europe to develop a sound energy economy, create high quality jobs, boost technology development, secure global competitiveness and trigger industrial leadership.

At the same time, the drive towards renewables and the smart use of energy would deliver the necessary carbon dioxide emissions cuts of 95% by 2050 compared with 1990 levels, which Europe will have to realise in the fight against climate change.

But the Energy [R]evolution will not happen without much needed political leadership: The European Union and its Member States will have to set the framework for a sustainable energy pathway.

At present, a wide range of energy-market failures still discourage the shift towards a clean energy system. It is high time to remove these barriers to increase energy savings and facilitate the replacement of fossil fuels with clean and abundant renewable energy sources.

European decision-makers should demonstrate commitment to a clean energy future, create the regulatory conditions for an efficient and renewable energy system, and stimulate governments, businesses, industries and citizens to opt for renewable energy and its smart use.

Greenpeace proposes five steps that the European Union and its Member States should take to realise the Energy [R]evolution.

1. develop a vision for a truly sustainable energy economy for 2050 to guide European climate and energy policy

Demonstrate how the EU will play its role in slashing global emissions until 2050

EU leaders committed in 2005 to the objective of keeping global mean temperature increase below two-degrees Celsius (2° C) compared to pre-industrial levels. Above this level, damage to ecosystems and disruption of the climate system would increase dramatically. In October 2009 the EU leaders also committed to reduce emissions in the EU by 80-95% in 2050 compared to 1990.

The EU should develop a credible emissions reduction pathway to achieve a 95% cut within Europe, so as to make sure that the EU does its part to keep global warming below the 2°C threshold.

Move the energy system towards 100% renewable energy and high efficiency in all sectors

Europe's energy system is outdated and substantial investments in power production capacity and infrastructure, as well as buildings and transportation, will have to take place within the next decade. These investment decisions will shape the structure of the energy system until 2050 and beyond.

A highly energy-efficient economy is a precondition for Europe's competitiveness and well-being. To power our electricity, transportation and remaining heating requirements, renewable energy sources are the truly sustainable, cost-effective and available solution.

Too much energy is still wasted in inefficient vehicles and buildings. Investments in coal production and nuclear power hinder the transition towards a clean energy economy. They divert financial resources and create economic and technical lock-in effects in conflict with the uptake of renewable energy and energy efficiency.

Europe should therefore take a strategic approach and commit to a truly sustainable vision for a fully renewable and energy efficient electricity and heat production, as well as clean transportation until 2050.

2. adopt and implement ambitious and legally binding targets for emissions reductions, energy savings and renewable energy

Commit to legally binding emissions reductions of 30% as the next step, and lead by example

The EU has only included a 20% emission reduction target for 2020 in EU legislation, and has put a conditional offer for 30% emission reductions on the table at the international climate negotiations.

Greenpeace urges EU leaders to show leadership and to commit as soon as possible to a 30% unconditional emission reduction target for the EU. This as a first step towards at least 40% emission cuts by 2020 for all industrialised countries under a global climate agreement.

Furthermore, a 30% reduction target is required to strengthen the EU's carbon price in the EU Emissions Trading Scheme (EU ETS). Due to the economic recession of 2008 and 2009 the EU ETS carbon price has collapsed, taking away an important driver for green and resource-efficient technology investments.

Internationally, the European Union will have to provide substantial additional finance to help developing countries mitigate climate change with clean energy technologies and forest protection.

Set legally binding targets for energy savings by 2020

The EU has set itself a target to reduce energy use by 20% by 2020, compared to business-as-usual. This target will not be met without additional measures. The EU should convert the non-binding 2020 EU energy savings goal into a legally binding requirement for all EU member states, whilst allowing member states some flexibility in achieving these requirements. It should accelerate the implementation of current energy savings policies and devise new policies to deliver large-scale investments into energy efficiency improvements.

Implement the binding renewable energy targets of at least 20% by 2020

With the adoption of the Renewable Energy Directive, European Member States have committed to legally binding targets, adding up to a share of at least 20% renewable energy in the EU by 2020.

The Energy [R]evolution scenarios demonstrate that even more is possible. To reap the full benefits that renewable energy offers for the economy, energy security, technological leadership and emissions reductions, governments should aim for an early achievement of their renewable energy targets and prepare for the further uptake of renewable energy sources beyond 2020.

3. remove barriers to a renewable and efficient energy system

Reform the electricity market and network management

After decades of state-subsidies to conventional energy sources, the entire electricity market structure and network system, have been developed so as to suit centralised nuclear and fossil production structures. Current ownership structures, price mechanisms, transmission and congestion management practices and technical requirements hinder the optimal integration of variable and decentralised renewable energy technologies.

As an important step to facilitate the reform of the electricity market, all European governments should secure full ownership unbundling of transmission system operations from power production and supply activities. This is the effective way to provide fair market access and overcome existing discriminatory practices against new market entrants, such as renewable energy producers.

A modernisation of the power grid system is urgently required to allow for the cost-effective connection and integration of renewable power sources. The European Union and its governments should create the necessary framework conditions and incentives for the development of grid connections for renewable energy supply, including offshore, targeted interconnection that allows for the transmission and balancing of variable supplies across regions, as well as smart grid management and technology that allows for the integration of variable and decentralised supplies and active demand side management.

To facilitate this modernisation, the Agency for the Cooperation of Energy Regulators (ACER) should be strengthened and the mandate of national energy regulators should be reviewed.

Both ACER and the European Network of Transmission System Operators for Electricity (ENTSO-E) should develop a strategic interconnection plan until 2050 which enables the development of a fully renewable electricity supply.

In parallel, electricity market regulation should ensure that investments in balancing capacity and flexible power production facilitate the integration of renewable power sources, while phasing out inflexible 'baseload' power supply.

Phase out all subsidies and other support measures for inefficient plants, appliances, vehicles and buildings, as well as for fossil fuel use and nuclear power

While the EU is striving for a liberalised market for electricity production, government support is still propping up conventional energy technologies, hindering the uptake of renewable energy sources and energy savings.

For example, the nuclear power sector in Europe still benefits from direct subsidies, government loan guarantees, export credit guarantees, government equity input and subsidised in-kind support.

In addition, the sector continues to profit from guaranteed cheap loans under the Euratom Loan Facility and related loans by the European Investment Bank.

image A WOMAN IN FRONT OF HER FLOODED HOUSE IN SATJELLIA ISLAND. DUE TO THE REMOTENESS OF THE SUNDARBANS ISLANDS, SOLAR PANELS ARE USED BY MANY VILLAGERS. AS A HIGH TIDE INVADES THE ISLAND, PEOPLE REMAIN ISOLATED SURROUNDED BY THE FLOODS.

Apart from these financial advantages, the nuclear sector profits from cost-limitations for decommissioning of power stations and radioactive waste management (e.g. in Slovakia and the UK), government bail-outs of insufficient reserves for decommissioning and waste management (in the UK), and government financing of R&D and education infrastructure (on a national level and under Euratom). Liability coverage for installations in the nuclear energy sector is so low that damage of any major accident will have to be covered almost completely by state funds. The total level of these financial advantages is estimated to be several times the financial support given to the renewable energy sector.

Also fossil fuels continue to receive large financial benefits that contradict the development of a clean power market. Spain, Germany, Poland and Romania still subsidise their coal sectors with support or at least acceptance from the side of the European Commission, although these subsidies should be phased out under the Treaty of the European Union.

New EU funds for fossil fuel technologies have been made available in recent years to promote carbon capture and storage technology. Spending money on carbon capture and storage is diverting funds away from renewable energy and energy savings. Even if some carbon capture and storage becomes technically feasible and capable of long-term storage, it would still only have a limited impact on emission reductions and would come at a high cost.

In the transport sector, the most energy intensive modes, road and aviation, receive about EUR 150 billion in subsidies and tax exemptions. About 7% of the EU's Structural and Cohesion Funds are spent on road and aviation infrastructure. Also the EIB has long favoured these modes of transportation, especially in Central and Eastern Europe, cementing Europe's high carbon transport system.

Close existing loopholes for nuclear waste

The European Union and the Member States should bring the management of nuclear waste in line with general EU waste policies in order to make the polluter pays principle fully effective. This means that loopholes under which certain forms of radioactive waste are excluded from waste rules have to be closed. This includes depleted uranium, reprocessing waste, plutonium and reprocessed uranium stockpiles, uranium mining waste as well as fluid and air-borne wastes from uranium enrichment, fuel production and spent nuclear fuel reprocessing.

It also includes clear policies for phasing out the production of radioactive waste from processes for which there are economic and environmentally viable alternatives, which is certainly the case for nuclear electricity production. Over 90% of radioactive waste is produced by the nuclear power sector – a nuclear phase out policy as proposed in the Energy [R]evolution scenario is therefore the logical step in a coherent and consequent EU waste policy.

4. implement effective policies to promote a clean energy economy

Update the EU Emission Trading Scheme

The EU should update its Emissions Trading Scheme (EU ETS) so as to move away rapidly from free allocation of emission allowances. To provide the right market signals and the economic incentives for the transition of our energy system along the whole production and consumption chain, all allowances under the Emissions Trading System should be auctioned rather than being given out for free. Auctioning reduces the total cost of European climate action because it is the most economically efficient allocation methodology, eliminating windfall profits from free allowances.

Furthermore the EU ETS should be a driver for domestic emission reductions. The required domestic reductions must not be replaced by investments in questionable projects in third countries ('offsetting'). Strict quantitative limits and strict quality criteria on offsetting should guarantee real emission cuts and investments in green technology and jobs.

Implement stable support for renewable energy and secure the successful enforcement of the Renewable Energy Directive

With the adoption of the Renewable Energy Directive, EU Member States have committed to a framework for the support of clean energy. In order to secure the realisation of the 20% renewable energy targets, governments should implement effective support policies to compensate for the existing market failures and to help maturing renewable energy technologies to realise their full economic potential.

In the electricity sector, feed-in tariffs or premium systems, if designed well, have proven to be the most successful and cost effective instruments to promote the broad uptake of renewable power technologies. Under a feed-in system, a certain price is guaranteed for the electricity produced from different renewable sources. A premium model provides for a certain premium paid on top of the market price.

For the heating sector, the Renewable Energy Directive foresees a building obligation, which establishes that a certain share of heating and cooling in new and refurbished buildings have to come from renewable energy sources. In addition, investments subsidies and tax credits are among the instruments available to support renewable heating and cooling.

The support of renewable energy in the transport sector should focus primarily on the use of renewable electricity in electric vehicles and trains, while support the development of further sustainable renewable energy options for all modes of transportation. The availability of sustainable biofuels is limited. The European Union and individual governments should ensure the effective implementation and improvement of sustainability standards for biofuels and biomass.

Alongside direct support for renewable energy sources, complex licensing procedures and bureaucratic hurdles for renewable energy should be removed and European governments and authorities should secure simple and transparent authorisation procedures. At the same time, the access to infrastructure should be facilitated and priority grid connection and access to the electricity network should be guaranteed for renewable power.

In addition, awareness-raising and training for local and regional authorities, spatial planners, architects and installers, and for the public, are important for the successful uptake of renewable energy sources.

Set energy efficiency standards for vehicles, consumer appliances, buildings and power production

A large part of energy savings can be achieved through efficiency standards for vehicles, consumer products and buildings. However, current EU legislation in this field represents and incoherent patchwork of measures, which does not add up to a clear and consistent division of responsibility and fails to deliver on the EU's energy savings potential.

Efforts should be stepped up in each area. With regard to vehicles, the EU should regulate for an average of 125 g CO_2/km for light commercial vehicles by 2020, and lower the CO_2 reduction target for passenger cars to 80 g CO_2/km by 2020.

With regard to electricity generation, the EU should set an emission performance standard for new and existing power plants of 350 grams of CO_2eq per kWh.

Initiate robust and harmonised EU green taxation

A harmonisation and strengthening of taxes on carbon emissions and energy use should be implemented in all EU member states, in particular for sectors not covered by the EU ETS (such as transport and agriculture). Taxing energy use is crucial to achieve energy security and lower the consumption of natural resources. Green taxation would also deliver more jobs, because labour-intensive production would gain a competitive advantage. This effect would even be stronger if member states used revenues of green taxation to reduce labour costs (e.g. by reducing taxes on income).

5. ensure that the transition is financed

Allocate EU Cohesion and Structural Funds to a clean energy future

Ambitious emission reductions in the EU are technically and economically feasible, and can even deliver significant net benefits for the European energy economy. However, before the Energy [R]evolution starts paying off, major investments are required. In particular for the EU member states with an economy in transition, in particular in Central and Eastern Europe, it can be difficult to mobilise the required private and public investments. In the revision of the EU budget, in 2011, including EU Cohesion and Structural Funds, decision-makers should therefore ensure funds are allocated to energy system modernisation, energy infrastructure and energy efficiency technology.

Support innovation and research in energy saving technologies and renewable energy

Innovation will play an important role in making the Energy [R]evolution more attractive. Direct public support is often necessary to speed up the deployment of new technologies.

The European Union, national governments, as well as public finance institutions should prioritise investments in research and development for more efficient appliances and building techniquies, new types of renewable energy production such as tidal and wave power, smart grid technology, as well as low-emitting transport options. These include the development of better batteries for electric vehicles, freight transport management programmes and 'tele-working'.

Alongside support to facilitate the maturing or existing renewable energy and efficiency technologies, research and innovation are required also for truly sustainable technologies for the aviation and shipping sectors, as well as heavy road-transport. While substantial efficiency improvements and a shift from air- and road-based transportation to shipping and trains can help reduce the impact of transportation, the availability of sustainable renewable energy technologies is currently limited. Innovations, such as second generation sails or hydrogen, could become part of the solution.

glossary & appendix

GLOBAL

6

"i would like to see a europe that is the most climate-friendly region in the world."

CONNIE HEDEGAARD
EUROPEAN COMMISSIONER FOR CLIMATE CHANGE

image COAL FIRED POWER PLANT.
© F. FUXA/DREAMSTIME

glossary of commonly used terms and abbreviations

CHP	Combined Heat and Power
CO_2	Carbon dioxide, the main greenhouse gas
GDP	Gross Domestic Product (means of assessing a country's wealth)
PPP	Purchasing Power Parity (adjustment to GDP assessment to reflect comparable standard of living)
IEA	International Energy Agency

J	Joule, a measure of energy:
kJ	= 1,000 Joules,
MJ	= 1 million Joules,
GJ	= 1 billion Joules,
PJ	= 10^{15} Joules,
EJ	= 10^{18} Joules

W	Watt, measure of electrical capacity:
kW	= 1,000 watts,
MW	= 1 million watts,
GW	= 1 billion watts

kWh	Kilowatt-hour, measure of electrical output: TWh = 10^{12} watt-hours
t/Gt	Tonnes, measure of weight: Gt = 1 billion tonnes

conversion factors - fossil fuels

FUEL				
Coal	23.03	MJ/t	1 cubic	0.0283 m^3
Lignite	8.45	MJ/t	1 barrel	159 liter
Oil	6.12	GJ/barrel	1 US gallon	3.785 liter
Gas	38000.00	kJ/m^3	1 UK gallon	4.546 liter

conversion factors - different energy units

FROM / TO: MULTIPLY BY	TJ	Gcal	Mtoe	Mbtu	GWh
TJ	1	238.8	2.388×10^{-5}	947.8	0.2778
Gcal	4.1868×10^{-3}	1	$10^{(-7)}$	3.968	1.163×10^{-3}
Mtoe	4.1868×10^{4}	10^{7}	1	3968×10^{7}	11630
Mbtu	1.0551×10^{-3}	0.252	2.52×10^{-8}	1	2.931×10^{-4}
GWh	3.6	860	8.6×10^{-5}	3412	1

image MINOTI SINGH AND HER SON AWAIT FOR CLEAN WATER SUPPLY BY THE RIVERBANK IN DAYAPUR VILLAGE IN SATJELLIA ISLAND: "WE DO NOT HAVE CLEAN WATER AT THE MOMENT AND ONLY ONE TIME WE WERE LUCKY TO BE GIVEN SOME RELIEF. WE ARE NOW WAITING FOR THE GOVERNMENT TO SUPPLY US WITH WATER TANKS".

definition of sectors

The definition of different sectors below is the same as the sectoral breakdown in the IEA World Energy Outlook series.

All definitions below are from the IEA Key World Energy Statistics

Industry sector: Consumption in the industry sector includes the following subsectors (energy used for transport by industry is not included -> see under "Transport")

- Iron and steel industry
- Chemical industry
- Non-metallic mineral products e.g. glass, ceramic, cement etc.
- Transport equipment
- Machinery
- Mining
- Food and tobacco
- Paper, pulp and print
- Wood and wood products (other than pulp and paper)
- Construction
- Textile and Leather

Transport sector: The Transport sector includes all fuels from transport such as road, railway, domestic aviation and domestic navigation. Fuel used for ocean, costal and inland fishing is included in "Other Sectors".

Other sectors: 'Other sectors' covers agriculture, forestry, fishing, residential, commercial and public services.

Non-energy use: Covers use of other petroleum products such as paraffin waxes, lubricants, bitumen etc.

eu 27: reference scenario

table 6.1: eu 27: electricity generation

TWh/a	2007	2015	2020	2030	2040	2050
Power plants	**2,664**	**2,728**	**2,852**	**3,158**	**3,464**	**3,774**
Coal	446	382	364	353	343	334
Lignite	294	280	260	250	240	231
Gas	443	403	498	602	700	800
Oil	59	22	13	10	8	4
Diesel	8	7	6	5	4	3
Nuclear	935	874	773	736	699	662
Biomass	55	67	78	86	101	114
Hydro	309	351	381	408	435	462
Wind	104	300	412	581	746	915
PV	4	32	48	93	138	182
Geothermal	6	7	8	12	16	20
Solar thermal power plants	0	2	8	14	20	27
Ocean energy	1	1	2	9	15	21
Combined heat & power production	**663**	**706**	**741**	**812**	**883**	**954**
Coal	155	160	166	179	189	198
Lignite	95	86	85	84	89	93
Gas	317	343	363	393	429	463
Oil	45	40	32	28	23	20
Biomass	51	76	94	126	151	178
Geothermal	0	1	1	2	2	2
Hydrogen	0	0	0	0	0	0
CHP by producer						
Main activity producers	477	505	530	580	630	688
Autoproducers	186	201	211	232	253	266
Total generation	**3,327**	**3,433**	**3,593**	**3,970**	**4,347**	**4,728**
Fossil	1863	1722	1787	1904	2,025	2,146
Coal	601	542	531	532	531	532
Lignite	390	366	345	334	329	324
Gas	760	746	861	995	1,129	1,263
Oil	104	62	45	38	31	24
Diesel	8	7	6	5	4	3
Nuclear	935	874	773	736	699	662
Hydrogen	0	0	0	0	0	0
Renewables	**529**	**837**	**1,033**	**1,330**	**1,623**	**1,921**
Hydro	309	351	381	408	435	462
Wind	104	300	412	581	746	915
PV	4	32	48	93	138	182
Biomass	105	143	172	212	252	292
Geothermal	6	8	9	13	18	22
Solar thermal	0	2	8	14	20	27
Ocean energy	1	1	2	9	15	21
Distribution losses	204	183	179	181	182	182
Own consumption electricity	294	287	293	308	323	339
Electricity for hydrogen production	0	0	0	0	0	0
Final energy consumption (electricity)	**2,840**	**2,989**	**3,138**	**3,497**	**3,857**	**4,220**
Fluctuating RES (PV, Wind, Ocean)	109	333	462	683	899	1,118
Share of fluctuating RES	3.3%	9.7%	12.9%	17.2%	20.7%	23.6%
RES share	**15.9%**	**24.4%**	**28.7%**	**33.5%**	**37.3%**	**40.6%**

table 6.2: eu 27: heat supply

PJ/A	2007	2015	2020	2030	2040	2050
District heating plants	**1,302**	**1,406**	**1,364**	**1,186**	**1,006**	**814**
Fossil fuels	1,005	1,085	1,052	916	777	628
Biomass	293	316	306	267	226	183
Solar collectors	0	0	0	0	0	0
Geothermal	4	5	5	4	3	3
Heat from CHP	**2,315**	**2,398**	**2,499**	**2,877**	**3,239**	**3,646**
Fossil fuels	2,037	2,063	2,111	2,430	2,730	3,104
Biomass	278	330	375	433	494	526
Geothermal	0	6	12	14	15	16
Direct heating[1)]	**17,936**	**17,649**	**18,089**	**19,048**	**20,042**	**20,956**
Fossil fuels	15,792	15,139	15,220	15,424	15,723	15,919
Biomass	2,066	2,376	2,683	3,297	3,913	4,531
Solar collectors	39	77	115	228	278	346
Geothermal	39	57	70	98	128	160
Total heat supply[1)]	**21,553**	**21,454**	**21,952**	**23,111**	**24,287**	**25,416**
Fossil fuels	18,834	18,288	18,384	18,770	19,230	19,651
Biomass	2,636	3,022	3,365	3,997	4,633	5,241
Solar collectors	39	77	115	229	278	346
Geothermal	43	67	87	116	146	179
RES share (including RES electricity)	**12.6%**	**14.8%**	**16.3%**	**18.8%**	**20.8%**	**22.7%**

1) heat from electricity (direct and from electric heat pumps) not included; covered in the model under 'electric appliances'

table 6.3: eu 27: CO_2 emissions

MILL t/a	2007	2015	2020	2030	2040	2050
Condensation power plants	**925**	**773**	**739**	**744**	**749**	**736**
Coal	388	312	280	262	255	248
Lignite	305	273	239	222	213	205
Gas	181	166	205	248	271	278
Oil	43	16	10	7	6	3
Diesel	8	7	6	4	3	2
Combined heat & power production	**530**	**468**	**446**	**437**	**457**	**469**
Coal	161	155	155	135	154	161
Lignite	119	78	65	70	77	85
Gas	154	164	178	198	204	210
Oil	95	70	49	34	21	13
CO_2 emissions electricity & steam generation	**1,455**	**1,241**	**1,186**	**1,181**	**1,205**	**1,205**
Coal	549	466	435	398	409	409
Lignite	425	351	303	292	290	290
Gas	335	330	382	445	476	488
Oil & diesel	146	93	65	46	30	18
CO_2 emissions by sector	**3,886**	**3,585**	**3,549**	**3,511**	**3,444**	**3,393**
% of 1990 emissions	96%	89%	88%	87%	85%	84%
Industry	619	550	527	496	461	426
Other sectors	678	654	653	664	682	697
Transport	962	922	937	942	946	949
Electricity & steam generation	1,293	1,106	1,066	1,072	1,110	1,124
District heating & others	334	352	364	337	245	197
Population (Mill.)	492.9	502.5	505.3	505.6	501.4	493.9
CO_2 emissions per capita (t/capita)	**7.9**	**7.1**	**7.0**	**6.9**	**6.9**	**6.9**

table 6.4: eu 27: installed capacity

GW	2007	2015	2020	2030	2040	2050
Power plants	**647**	**751**	**788**	**880**	**979**	**1,079**
Coal	91	87	76	65	63	61
Lignite	57	61	54	46	42	39
Gas	105	115	120	146	163	178
Oil	39	20	12	6	5	2
Diesel	8	7	6	5	5	4
Nuclear	132	123	108	103	98	93
Biomass	10	13	15	16	18	21
Hydro	140	156	166	175	184	193
Wind	57	138	183	232	276	326
PV	5	29	44	78	113	146
Geothermal	1	1	1	2	3	4
Solar thermal power plants	0	1	3	4	6	7
Ocean energy	0	0	1	3	5	7
Combined heat & power production	**162**	**191**	**185**	**185**	**198**	**212**
Coal	30	37	35	33	35	36
Lignite	19	20	18	15	16	17
Gas	75	87	88	95	104	112
Oil	28	33	28	18	15	13
Biomass	10	14	17	23	28	34
Geothermal	0	0	0	0	0	0
Hydrogen	0	0	0	0	0	0
CHP by producer						
Main activity producers	107	125	124	125	136	149
Autoproducers	54	66	62	60	62	63
Total generation	**808**	**942**	**974**	**1,065**	**1,177**	**1,291**
Fossil	453	466	436	430	446	462
Coal	121	124	111	98	97	97
Lignite	76	80	72	61	59	56
Gas	181	202	208	242	266	289
Oil	67	53	39	24	20	16
Diesel	8	7	6	5	5	4
Nuclear	132	123	108	103	98	93
Hydrogen	0	0	0	0	0	0
Renewables	**223**	**352**	**430**	**533**	**633**	**736**
Hydro	140	156	166	175	184	193
Wind	57	138	183	232	276	326
PV	5	29	44	78	113	146
Biomass	20	27	32	39	47	54
Geothermal	1	1	2	2	3	4
Solar thermal	0	1	3	4	6	7
Ocean energy	0	0	1	3	5	7
Fluctuating RES (PV, Wind, Ocean)	62	167	227	312	393	479
Share of fluctuating RES	7.7%	17.8%	23.3%	29.3%	33.4%	37.1%
RES share	**27.6%**	**37.4%**	**44.1%**	**50.0%**	**53.7%**	**57.0%**

table 6.5: eu 27: primary energy demand

PJ/A	2007	2015	2020	2030	2040	2050
Total	**73,876**	**72,111**	**72,457**	**74,516**	**75,564**	**75,918**
Fossil	**57,286**	**53,876**	**53,834**	**54,306**	**53,825**	**52,875**
Hard coal	9,995	8,769	8,285	7,504	7,329	7,001
Lignite	3,826	3,165	2,733	2,631	2,617	2,613
Natural gas	18,054	18,354	19,450	21,352	22,397	23,019
Crude oil	25,410	23,588	23,365	22,819	21,482	20,242
Nuclear	**10,205**	**9,535**	**8,433**	**8,029**	**7,625**	**7,222**
Renewables	**6,385**	**8,700**	**10,190**	**12,181**	**14,114**	**15,821**
Hydro	1,114	1,264	1,372	1,469	1,566	1,663
Wind	375	1,080	1,483	2,092	2,686	3,294
Solar	53	199	317	614	847	1,099
Biomass	4,594	5,888	6,722	7,635	8,576	9,261
Geothermal	247	266	287	342	386	428
Ocean Energy	2	3	9	31	53	76
RES share	**8.7%**	**12.1%**	**14.1%**	**16.3%**	**18.6%**	**20.6%**

table 6.6: eu 27: final energy demand

PJ/a	2007	2015	2020	2030	2040	2050
Total (incl. non-energy use)	**52,228**	**52,013**	**53,286**	**55,642**	**57,982**	**60,350**
Total (energy use)	**47,418**	**47,659**	**49,058**	**51,623**	**54,172**	**56,750**
Transport	**14,010**	**14,026**	**14,486**	**14,654**	**14,821**	**14,989**
Oil products	13,331	12,773	12,981	13,045	13,099	13,133
Natural gas	85	103	113	123	134	144
Biofuels	331	820	1,030	1,088	1,153	1,225
Electricity	263	330	363	398	435	486
RES electricity	42	80	104	133	163	197
Hydrogen	0	0	0	0	0	0
RES share Transport	**2.7%**	**6.4%**	**7.8%**	**8.3%**	**8.9%**	**9.5%**
Industry	**13,686**	**13,329**	**13,421**	**13,731**	**14,020**	**14,339**
Electricity	4,142	4,229	4,354	4,606	4,857	5,108
RES electricity	659	1,031	1,252	1,543	1,814	2,075
District heat	1,660	1,626	1,533	1,509	1,468	1,456
RES district heat	289	295	282	255	229	202
Coal	951	666	592	427	261	92
Oil products	1,869	1,660	1,589	1,429	1,266	1,102
Gas	4,234	4,193	4,265	4,372	4,478	4,585
Solar	0	0	0	0	0	0
Biomass and waste	830	954	1,087	1,387	1,690	1,995
Geothermal	0	0	0	0	0	0
Hydrogen	0	0	0	0	0	0
RES share Industry	**13.0%**	**17.1%**	**19.5%**	**23.2%**	**26.6%**	**29.8%**
Other Sectors	**19,722**	**20,304**	**21,150**	**23,238**	**25,331**	**27,422**
Electricity	5,820	6,202	6,580	7,586	8,592	9,599
RES electricity	926	1,512	1,891	2,541	3,208	3,899
District heat	1,761	1,915	2,061	2,271	2,481	2,692
RES district heat	306	347	380	384	388	373
Coal	462	389	335	205	147	64
Oil products	3,187	2,894	2,766	2,603	2,437	2,271
Gas	6,952	7,090	7,335	7,979	8,620	9,261
Solar	39	76	115	228	278	346
Biomass and waste	1,467	1,687	1,895	2,277	2,658	3,040
Geothermal	35	51	63	90	119	148
RES share Other Sectors	**14.1%**	**18.1%**	**20.5%**	**23.8%**	**26.3%**	**28.5%**
Total RES	**4,924**	**6,855**	**8,101**	**9,928**	**11,700**	**13,502**
RES share	**10.4%**	**14.4%**	**16.5%**	**19.2%**	**21.6%**	**23.8%**
Non energy use	**4,810**	**4,354**	**4,229**	**4,019**	**3,810**	**3,601**
Oil	4,127	3,736	3,628	3,449	3,269	3,089
Gas	628	569	552	525	498	470
Coal	55	49	48	46	43	41

eu 27: energy [r]evolution scenario

table 6.7: eu 27: electricity generation

TWh/a	2007	2015	2020	2030	2040	2050
Power plants	**2,664**	**2,687**	**2,622**	**2,497**	**2,383**	**2,410**
Coal	446	396	311	123	45	9
Lignite	294	273	187	76	14	0
Gas	443	439	496	514	265	128
Oil	59	28	22	10	0	0
Diesel	8	7	5	3	1	0
Nuclear	935	755	425	158	22	0
Biomass	55	65	71	79	80	81
Hydro	309	340	355	365	372	375
Wind	104	320	564	825	1,032	1,115
PV	4	49	138	235	345	425
Geothermal	6	8	18	42	79	97
Solar thermal power plants	0	5	26	54	93	125
Ocean energy	1	1	3	13	34	55
Combined heat & power production	**663**	**709**	**780**	**825**	**890**	**858**
Coal	155	133	55	2	0	0
Lignite	95	35	28	6	0	0
Gas	317	371	429	451	363	239
Oil	45	32	14	7	0	0
Biomass	51	134	247	336	464	534
Geothermal	0	4	8	25	64	85
Hydrogen	0	0	0	0	0	0
CHP by producer						
Main activity producers	477	505	550	570	583	540
Autoproducers	186	204	230	255	307	318
Total generation	**3,327**	**3,396**	**3,402**	**3,322**	**3,273**	**3,268**
Fossil	1863	1,714	1,546	1,191	688	376
Coal	601	529	366	125	45	9
Lignite	390	308	215	82	14	0
Gas	760	810	925	965	628	367
Oil	104	60	36	17	0	0
Diesel	8	7	5	3	1	0
Nuclear	935	755	425	158	22	0
Hydrogen	0	0	0	0	0	0
Renewables	**529**	**926**	**1,431**	**1,973**	**2,563**	**2,892**
Hydro	309	340	355	365	372	375
Wind	104	320	564	825	1,032	1,115
PV	4	49	138	235	345	425
Biomass	105	199	318	415	544	615
Geothermal	6	12	26	66	143	182
Solar thermal	0	5	26	54	93	125
Ocean energy	1	1	3	13	34	55
Distribution losses	204	183	185	185	195	210
Own consumption electricity	294	280	275	270	260	255
Electricity for hydrogen production	0	3	40	62	99	101
Final energy consumption (electricity)	**2,840**	**2,958**	**2,942**	**2,973**	**3,180**	**3,527**
Fluctuating RES (PV, Wind, Ocean)	109	370	705	1,073	1,411	1,595
Share of fluctuating RES	3.3%	10.9%	20.7%	32.3%	43.1%	48.8%
RES share	**15.9%**	**27.3%**	**42.1%**	**59.4%**	**78.3%**	**88.5%**
'Efficiency' savings (compared to Ref.)	**0**	**52**	**232**	**637**	**1,032**	**1,411**

table 6.8: eu 27: heat supply

PJ/A	2007	2015	2020	2030	2040	2050
District heating plants	**1,302**	**1,401**	**1,501**	**1,621**	**1,886**	**2,265**
Fossil fuels	1,005	967	938	632	226	0
Biomass	293	336	375	438	472	521
Solar collectors	0	56	105	373	868	1,291
Geothermal	4	42	83	178	321	453
Heat from CHP	**2,315**	**2,534**	**2,856**	**3,026**	**3,244**	**3,214**
Fossil fuels	2,037	1,889	1,746	1,612	1,292	882
Biomass	278	614	1,037	1,192	1,379	1,568
Geothermal	0	32	73	222	573	764
Direct heating[1]	**17,936**	**16,606**	**16,287**	**15,364**	**14,512**	**13,980**
Fossil fuels	15,792	13,710	12,506	10,326	8,513	7,694
Biomass	2,066	2,329	2,618	2,556	2,198	1,822
Solar collectors	39	236	561	1,507	2,419	2,832
Geothermal	39	331	602	976	1,382	1,632
Total heat supply[1]	**21,553**	**20,541**	**20,645**	**20,011**	**19,642**	**19,459**
Fossil fuels	18,834	16,565	15,191	12,570	10,031	8,576
Biomass	2,636	3,279	4,031	4,186	4,048	3,911
Solar collectors	39	292	666	1,879	3,287	4,123
Geothermal	43	405	757	1,375	2,276	2,849
RES share (including RES electricity)	**12.6%**	**19.4%**	**26.4%**	**37.2%**	**48.9%**	**55.9%**
'Efficiency' savings (compared to Ref.)	**0**	**913**	**1,307**	**3,100**	**4,645**	**5,958**

1) heat from electricity (direct and from electric heat pumps) not included; covered in the model under 'electric appliances'

table 6.9: eu 27: CO_2 emissions

MILL t/a	2007	2015	2020	2030	2040	2050
Condensation power plants	**925**	**797**	**636**	**381**	**150**	**51**
Coal	388	323	239	91	34	6
Lignite	305	266	172	67	12	0
Gas	181	181	204	212	103	44
Oil	43	20	16	7	0	0
Diesel	8	7	5	3	1	0
Combined heat & power production	**530**	**394**	**301**	**232**	**171**	**105**
Coal	161	130	51	1	0	0
Lignite	119	32	21	4	0	0
Gas	154	178	210	219	171	105
Oil	95	54	19	7	0	0
CO_2 emissions electricity & steam generation	**1,455**	**1,190**	**937**	**613**	**321**	**155**
Coal	549	453	290	93	34	6
Lignite	425	298	193	72	12	0
Gas	335	358	414	431	274	149
Oil & diesel	146	81	40	18	1	0
CO_2 emissions by sector	**3,886**	**3,387**	**2,862**	**2,163**	**1,431**	**972**
% of 1990 emissions	96%	84%	71%	54%	35%	24%
Industry	619	505	432	360	271	227
Other sectors	678	599	546	432	359	323
Transport	962	916	843	697	473	291
Electricity & steam generation	1,293	1,071	841	527	246	100
District heating & others	334	296	199	148	82	31
Population (Mill.)	492.9	502	505	506	501	494
CO_2 emissions per capita (t/capita)	**7.9**	**6.7**	**5.7**	**4.3**	**2.9**	**2.0**

table 6.10: eu 27: installed capacity

GW	2007	2015	2020	2030	2040	2050
Power plants	**647**	**756**	**861**	**916**	**991**	**1,040**
Coal	91	90	65	25	10	3
Lignite	57	59	39	14	2	0
Gas	105	110	115	121	88	64
Oil	39	25	20	6	0	0
Diesel	8	7	5	3	1	0
Nuclear	132	106	59	22	3	0
Biomass	10	12	13	14	12	12
Hydro	140	151	155	157	157	156
Wind	57	147	251	330	382	398
PV	5	45	125	196	282	340
Geothermal	1	2	3	8	15	18
Solar thermal power plants	0	2	9	17	27	31
Ocean energy	0	0	1	4	11	18
Combined heat & power production	**162**	**185**	**180**	**182**	**185**	**173**
Coal	30	30	12	0	0	0
Lignite	19	8	6	1	0	0
Gas	75	94	103	109	87	56
Oil	28	27	12	4	0	0
Biomass	10	25	46	62	86	100
Geothermal	0	1	2	5	13	17
Hydrogen	0	0	0	0	0	0
CHP by producer						
Main activity producers	107	122	123	123	120	107
Autoproducers	54	63	57	58	65	66
Total generation	**808**	**942**	**1,041**	**1,097**	**1,176**	**1,213**
Fossil	453	450	377	283	189	123
Coal	121	121	77	25	10	3
Lignite	76	67	45	15	2	0
Gas	181	204	219	230	175	120
Oil	67	51	32	10	0	0
Diesel	8	7	5	3	1	0
Nuclear	132	106	59	22	3	0
Hydrogen	0	0	0	0	0	0
Renewables	**223**	**385**	**605**	**792**	**985**	**1,090**
Hydro	140	151	155	157	157	156
Wind	57	147	251	330	382	398
PV	5	45	125	196	282	340
Biomass	20	38	59	76	98	112
Geothermal	1	2	5	13	27	35
Solar thermal	0	2	9	17	27	31
Ocean energy	0	0	1	4	11	18
Fluctuating RES (PV, Wind, Ocean)	62	192	377	530	675	757
Share of fluctuating RES	7.7%	20.4%	36.2%	48.3%	57.4%	62.4%
RES share	**27.6%**	**40.9%**	**58.1%**	**72.2%**	**83.7%**	**89.9%**

table 6.11: eu 27: primary energy demand

PJ/A	2007	2015	2020	2030	2040	2050
Total	**73,876**	**69,673**	**64,853**	**57,792**	**50,018**	**45,039**
Fossil	**57,286**	**51,462**	**46,420**	**37,605**	**26,363**	**19,139**
Hard coal	9,995	8,063	5,769	3,008	1,733	1,178
Lignite	3,826	2,688	1,736	647	112	0
Natural gas	18,054	17,588	17,963	17,367	13,333	10,247
Crude oil	25,410	23,122	20,952	16,582	11,185	7,715
Nuclear	**10,205**	**8,236**	**4,636**	**1,724**	**240**	**0**
Renewables	**6,385**	**9,975**	**13,797**	**18,463**	**23,415**	**25,899**
Hydro	1,114	1,224	1,278	1,314	1,339	1,350
Wind	375	1,152	2,030	2,970	3,715	4,014
Solar	53	486	1,257	2,920	4,864	6,103
Biomass	4,594	6,430	7,929	8,660	8,799	8,712
Geothermal	247	678	1,290	2,553	4,575	5,522
Ocean Energy	2	4	12	47	122	198
RES share	**8.7%**	**14.4%**	**21.4%**	**32.5%**	**48.2%**	**59.9%**
'Efficiency' savings (compared to Ref.)	**0**	**2,424**	**7,536**	**16,168**	**23,967**	**28,101**

table 6.12: eu 27: final energy demand

PJ/A	2007	2015	2020	2030	2040	2050
Total (incl. non-energy use)	**52,228**	**50,788**	**49,681**	**46,721**	**43,577**	**41,815**
Total (energy use)	**47,418**	**46,433**	**45,453**	**42,702**	**39,767**	**38,215**
Transport	**14,010**	**13,996**	**13,281**	**11,773**	**9,781**	**8,695**
Oil products	13,331	12,682	11,621	9,595	6,483	3,958
Natural gas	85	111	174	175	175	171
Biofuels	331	789	895	1,041	1,151	1,224
Electricity	263	407	494	802	1,713	3,070
RES electricity	42	111	208	476	1,341	2,717
Hydrogen	0	6	97	160	259	272
RES share Transport	**2.7%**	**6.4%**	**8.6%**	**13.7%**	**27.6%**	**48.1%**
Industry	**13,686**	**12,773**	**12,620**	**12,270**	**11,925**	**11,698**
Electricity	4,142	4,117	4,054	3,977	3,912	3,883
RES electricity	659	1,123	1,705	2,362	3,063	3,437
District heat	1,660	1,534	1,522	1,670	1,898	2,000
RES district heat	289	459	622	920	1,429	1,797
Coal	951	759	584	546	376	332
Oil products	1,869	1,374	1,032	588	165	82
Gas	4,234	3,903	3,790	3,326	2,869	2,602
Solar	0	102	255	568	972	1,140
Biomass and waste	830	889	1,132	1,143	1,049	820
Geothermal	0	96	251	453	685	838
Hydrogen	0	0	0	0	0	0
RES share Industry	**13.0%**	**20.9%**	**31.4%**	**44.4%**	**60.4%**	**68.7%**
Other Sectors	**19,722**	**19,665**	**19,552**	**18,659**	**18,061**	**17,822**
Electricity	5,820	6,125	6,044	5,922	5,822	5,743
RES electricity	926	1,671	2,541	3,517	4,558	5,083
District heat	1,761	2,128	2,544	2,679	2,916	3,156
RES district heat	306	636	1,040	1,477	2,196	2,836
Coal	462	289	108	57	0	0
Oil products	3,187	3,060	2,866	1,635	848	492
Gas	6,952	6,028	5,622	5,319	5,103	4,942
Solar	39	134	307	939	1,447	1,692
Biomass and waste	1,467	1,700	1,778	1,697	1,393	1,204
Geothermal	35	201	284	411	531	592
RES share Other Sectors	**14.1%**	**22.1%**	**30.4%**	**43.1%**	**56.1%**	**64.0%**
Total RES	**4,924**	**7,912**	**11,057**	**15,099**	**20,019**	**23,620**
RES share	**10.4%**	**17.0%**	**24.3%**	**35.4%**	**50.3%**	**61.8%**
Non energy use	**4,810**	**4,354**	**4,229**	**4,019**	**3,810**	**3,601**
Oil	4,127	3,736	3,628	3,449	3,269	3,089
Gas	628	569	552	525	498	470
Coal	55	49	48	46	43	41

eu 27: advanced energy [r]evolution scenario

table 6.13: eu 27: electricity generation

TWh/a	2007	2015	2020	2030	2040	2050
Power plants	**2,664**	**2,688**	**2,642**	**2,728**	**2,925**	**3,477**
Coal	446	385	289	32	10	0
Lignite	294	272	172	51	2	0
Gas	443	444	496	498	203	14
Oil	59	28	22	10	0	0
Diesel	8	7	5	3	1	0
Nuclear	935	755	425	118	22	0
Biomass	55	65	71	75	76	81
Hydro	309	345	355	365	377	391
Wind	104	320	564	939	1,196	1,392
PV	4	50	158	289	467	622
Geothermal	6	9	30	143	198	333
Solar thermal power plants	0	6	45	141	262	446
Ocean energy	1	1	10	63	110	198
Combined heat & power production	**663**	**709**	**780**	**825**	**795**	**745**
Coal	155	133	60	3	0	0
Lignite	95	35	22	3	0	0
Gas	317	371	429	428	247	78
Oil	45	32	14	7	0	0
Biomass	51	134	247	345	439	474
Geothermal	0	4	8	40	109	174
Hydrogen	0	0	0	0	1	20
CHP by producer						
Main activity producers	477	505	550	570	545	515
Autoproducers	186	204	230	255	250	230
Total generation	**3,327**	**3,397**	**3,422**	**3,553**	**3,720**	**4,222**
Fossil	1863	1,707	1,509	1,035	463	92
Coal	601	518	349	35	10	0
Lignite	390	307	194	54	2	0
Gas	760	815	925	926	450	92
Oil	104	60	36	17	0	0
Diesel	8	7	5	3	1	0
Nuclear	935	755	425	118	22	0
Hydrogen	0	0	0	0	1	20
Renewables	**529**	**934**	**1,488**	**2,400**	**3,234**	**4,110**
Hydro	309	345	355	365	377	391
Wind	104	320	564	939	1,196	1,392
PV	4	50	158	289	467	622
Biomass	105	199	318	420	515	554
Geothermal	6	13	38	183	307	507
Solar thermal	0	6	45	141	262	446
Ocean energy	1	1	10	63	110	198
Distribution losses	204	183	185	185	195	210
Own consumption electricity	294	280	275	270	260	255
Electricity for hydrogen production	0	3	40	60	144	289
Final energy consumption (electricity)	**2,840**	**2,959**	**2,963**	**3,206**	**3,581**	**4,274**
Fluctuating RES (PV, Wind, Ocean)	109	371	732	1,291	1,773	2,212
Share of fluctuating RES	3.3%	10.9%	21.4%	36.3%	47.7%	52.4%
RES share	**15.9%**	**27.5%**	**43.5%**	**67.6%**	**86.9%**	**97.3%**
'Efficiency' savings (compared to Ref.)	**0**	**52**	**232**	**627**	**1,001**	**1,335**

table 6.14: eu 27: heat supply

PJ/A	2007	2015	2020	2030	2040	2050
District heating plants	**1,302**	**1,400**	**1,595**	**1,720**	**2,453**	**3,103**
Fossil fuels	1,005	966	997	671	294	0
Biomass	293	336	399	464	589	683
Solar collectors	0	56	112	396	1,153	1,800
Geothermal	4	42	88	189	417	621
Heat from CHP	**2,315**	**2,534**	**2,860**	**3,134**	**3,286**	**3,288**
Fossil fuels	2,037	1,889	1,750	1,586	871	280
Biomass	278	614	1,037	1,187	1,433	1,384
Geothermal	0	32	73	360	978	1,563
Direct heating[1]	**17,936**	**16,600**	**16,113**	**14,993**	**13,582**	**12,125**
Fossil fuels	15,792	13,705	12,342	9,288	5,622	1,196
Biomass	2,066	2,328	2,607	2,530	2,456	2,404
Solar collectors	39	236	559	2,072	3,151	4,384
Geothermal	39	331	605	1,102	2,352	4,142
Hydrogen	0	0	0	0	95	562
Total heat supply[1]	**21,553**	**20,534**	**20,569**	**19,847**	**19,415**	**19,079**
Fossil fuels	18,834	16,560	15,089	11,545	6,788	1,476
Biomass	2,636	3,278	4,043	4,182	4,478	4,470
Solar collectors	39	292	671	2,468	4,304	6,184
Geothermal	43	405	765	1,651	3,747	6,325
RES share (including RES electricity)	**12.6%**	**19.4%**	**26.6%**	**41.8%**	**65.0%**	**92.2%**
'Efficiency' savings (compared to Ref.)	**0**	**920**	**1,383**	**3,264**	**4,872**	**6,338**

1) heat from electricity (direct and from electric heat pumps) not included; covered in the model under 'electric appliances'

table 6.15: eu 27: CO_2 emissions

MILL t/a	2007	2015	2020	2030	2040	2050
Condensation power plants	**925**	**789**	**605**	**284**	**89**	**5**
Coal	388	314	222	24	8	0
Lignite	305	265	158	45	2	0
Gas	181	183	204	205	79	5
Oil	43	20	16	7	0	0
Diesel	8	7	5	3	1	0
Combined heat & power production	**530**	**394**	**302**	**227**	**116**	**33**
Coal	161	130	56	2	0	0
Lignite	119	32	17	2	0	0
Gas	154	178	210	215	116	33
Oil	95	54	19	8	0	0
CO_2 emissions electricity & steam generation	**1,455**	**1,182**	**907**	**511**	**205**	**39**
Coal	549	444	279	26	8	0
Lignite	425	297	175	48	2	0
Gas	335	360	414	420	195	38
Oil & diesel	146	81	40	18	1	0
CO_2 emissions by sector	**3,886**	**3,370**	**2,818**	**1,894**	**946**	**195**
% of 1990 emissions	96%	83%	70%	47%	23%	5%
Industry	619	505	422	327	187	54
Other sectors	678	601	546	382	240	54
Transport	962	916	838	619	317	63
Electricity & steam generation	1,293	1,063	811	431	151	18
District heating & others	334	285	200	135	50	5
Population (Mill.)	492.9	502	505	506	501	494
CO_2 emissions per capita (t/capita)	**7.9**	**6.7**	**5.6**	**3.7**	**1.9**	**0.4**

table 6.16: eu 27: installed capacity

GW	2007	2015	2020	2030	2040	2050
Power plants	**647**	**759**	**889**	**1,043**	**1,217**	**1,405**
Coal	91	88	60	6	3	0
Lignite	57	59	36	9	0	0
Gas	105	111	122	125	68	9
Oil	39	25	20	6	0	0
Diesel	8	7	5	3	1	0
Nuclear	132	106	59	17	3	0
Biomass	10	12	13	14	12	12
Hydro	140	153	155	157	159	163
Wind	57	147	251	376	443	497
PV	5	45	144	241	381	498
Geothermal	1	2	5	26	36	61
Solar thermal power plants	0	2	15	43	73	99
Ocean energy	0	0	3	21	37	66
Combined heat & power production	**162**	**185**	**180**	**180**	**162**	**145**
Coal	30	30	13	1	0	0
Lignite	19	8	5	1	0	0
Gas	75	94	103	104	59	18
Oil	28	27	12	4	0	0
Biomass	10	25	46	63	81	88
Geothermal	0	1	2	8	22	35
Hydrogen	0	0	0	0	0	4
CHP by producer						
Main activity producers	107	122	123	123	109	98
Autoproducers	54	63	57	58	53	47
Total generation	**808**	**944**	**1,069**	**1,223**	**1,379**	**1,550**
Fossil	453	449	376	258	132	28
Coal	121	118	73	7	3	0
Lignite	76	67	41	10	0	0
Gas	181	205	226	228	127	27
Oil	67	51	32	10	0	0
Diesel	8	7	5	3	1	0
Nuclear	132	106	59	17	3	0
Hydrogen	0	0	0	0	0	4
Renewables	**223**	**389**	**634**	**949**	**1,244**	**1,518**
Hydro	140	153	155	157	159	163
Wind	57	147	251	376	443	497
PV	5	45	144	241	381	498
Biomass	20	38	59	77	93	100
Geothermal	1	2	7	34	58	96
Solar thermal	0	2	15	43	73	99
Ocean energy	0	0	3	21	37	66
Fluctuating RES (PV, Wind, Ocean)	62	193	398	637	861	1,061
Share of fluctuating RES	7.7%	20.5%	37.2%	52.1%	62.4%	68.4%
RES share	**27.6%**	**41.2%**	**59.3%**	**77.5%**	**90.2%**	**98.0%**

table 6.17: eu 27: primary energy demand

PJ/A	2007	2015	2020	2030	2040	2050
Total	**73,876**	**69,396**	**64,473**	**57,388**	**49,703**	**46,031**
Fossil	**57,286**	**51,182**	**45,682**	**33,880**	**19,024**	**6,768**
Hard coal	9,995	7,673	5,276	1,627	763	273
Lignite	3,826	2,679	1,574	429	16	0
Natural gas	18,054	17,766	18,174	16,951	9,731	2,452
Crude oil	25,410	23,063	20,657	14,873	8,515	4,043
Nuclear	**10,205**	**8,236**	**4,636**	**1,287**	**240**	**0**
Renewables	**6,385**	**9,978**	**14,155**	**22,221**	**30,439**	**39,262**
Hydro	1,114	1,242	1,278	1,314	1,357	1,408
Wind	375	1,152	2,030	3,380	4,306	5,011
Solar	53	493	1,402	4,016	6,929	10,028
Biomass	4,594	6,383	7,858	8,438	8,932	8,856
Geothermal	247	703	1,551	4,845	8,520	13,246
Ocean Energy	2	4	36	227	396	713
RES share	**8.7%**	**14.4%**	**22.1%**	**39.2%**	**62.1%**	**85.9%**
'Efficiency' savings (compared to Ref.)	**0**	**2,696**	**7,916**	**16,573**	**24,281**	**27,184**

table 6.18: eu 27: final energy demand

PJ/a	2007	2015	2020	2030	2040	2050
Total (incl. non-energy use)	**52,228**	**50,788**	**49,582**	**46,122**	**42,187**	**39,680**
Total (energy use)	**47,418**	**46,434**	**45,354**	**42,103**	**38,377**	**36,079**
Transport	**14,010**	**13,996**	**13,281**	**11,473**	**8,781**	**7,245**
Oil products	13,331	12,678	11,561	8,523	4,333	874
Natural gas	85	110	164	153	121	10
Biofuels	331	790	892	1,039	1,050	1,105
Electricity	263	411	567	1,603	2,898	4,476
RES electricity	42	113	247	1,083	2,519	4,357
Hydrogen	0	6	97	154	379	779
RES share Transport	**2.7%**	**6.5%**	**8.9%**	**19.4%**	**44.4%**	**85.9%**
Industry	**13,686**	**12,773**	**12,619**	**12,178**	**11,732**	**11,449**
Electricity	4,142	4,117	4,056	3,986	3,977	3,962
RES electricity	659	1,132	1,764	2,692	3,457	3,857
District heat	1,660	1,534	1,633	1,896	2,232	2,501
RES district heat	289	459	665	1,063	1,862	2,447
Coal	951	759	539	386	267	20
Oil products	1,869	1,365	930	419	98	11
Gas	4,234	3,912	3,816	3,327	1,912	632
Solar	0	102	255	563	993	1,308
Biomass and waste	830	889	1,134	1,133	1,088	1,055
Geothermal	0	96	255	468	1,067	1,373
Hydrogen	0	0	0	0	99	586
RES share Industry	**13.0%**	**21.0%**	**32.3%**	**48.6%**	**72.9%**	**92.7%**
Other Sectors	**19,722**	**19,665**	**19,454**	**18,452**	**17,864**	**17,385**
Electricity	5,820	6,125	6,043	5,947	5,870	5,938
RES electricity	926	1,685	2,627	4,018	5,102	5,780
District heat	1,761	2,127	2,525	2,652	3,180	3,584
RES district heat	306	636	1,028	1,487	2,653	3,507
Coal	462	360	251	134	0	0
Oil products	3,187	3,017	2,755	1,304	532	49
Gas	6,952	6,002	5,531	4,737	3,476	830
Solar	39	134	304	1,510	2,158	3,076
Biomass and waste	1,467	1,699	1,764	1,679	1,641	1,615
Geothermal	35	201	281	489	1,008	2,293
RES share Other Sectors	**14.1%**	**22.1%**	**30.9%**	**49.8%**	**70.3%**	**93.6%**
Total RES	**4,924**	**7,937**	**11,259**	**17,327**	**25,012**	**33,103**
RES share	**10.4%**	**17.1%**	**24.8%**	**41.2%**	**65.2%**	**91.7%**
Non energy use	**4,810**	**4,354**	**4,229**	**4,019**	**3,810**	**3,601**
Oil	4,127	3,736	3,628	3,449	3,269	3,089
Gas	628	569	552	525	498	470
Coal	55	49	48	46	43	41

eu 27: total new investment by technology

table 6.19: eu 27: total investment

MILLION €	2007-2010	2011-2020	2021-2030	2007-2050	2007-2050 AVERAGE PER YEAR
Reference scenario					
Conventional (fossil & nuclear)	**96,970**	**154,432**	**168,475**	**604,171**	**14,050**
Renewables	**130,590**	**378,685**	**270,924**	**1,364,158**	**31,725**
Biomass	26,268	51,402	45,191	196,598	4,572
Hydro	36,617	102,107	80,196	377,453	8,778
Wind	38,932	134,189	79,066	468,785	10,902
PV	25,024	68,949	48,162	234,773	5,460
Geothermal	2,407	9,157	7,709	32,557	757
Solar thermal power plants	987	11,034	6,267	38,883	904
Ocean energy	355	1,847	4,334	15,109	351
Energy [R]evolution					
Conventional (fossil & nuclear)	**94,351**	**99,928**	**57,240**	**326,112**	**7,584**
Renewables	**130,590**	**719,257**	**420,130**	**2,390,561**	**55,594**
Biomass	26,268	145,217	71,501	461,913	10,742
Hydro	36,617	75,118	62,376	285,465	6,639
Wind	38,932	200,250	105,417	624,586	14,525
PV	25,024	221,540	89,387	563,645	13,108
Geothermal	2,407	36,684	54,464	256,610	5,968
Solar thermal power plants	987	37,617	30,354	163,766	3,809
Ocean energy	355	2,831	6,631	34,577	804
Advanced Energy [R]evolution					
Conventional (fossil & nuclear)	**94,351**	**100,809**	**50,052**	**335,479**	**7,802**
Renewables	**130,590**	**802,831**	**705,512**	**3,481,499**	**80,965**
Biomass	26,268	145,217	70,246	438,614	10,200
Hydro	36,617	74,955	62,376	303,052	7,048
Wind	38,932	200,250	144,448	749,141	17,422
PV	25,024	253,858	119,665	733,479	17,058
Geothermal	2,407	54,491	164,427	659,405	15,335
Solar thermal power plants	987	65,330	108,392	469,622	10,921
Ocean energy	355	8,730	35,958	128,187	2,981

notes

2005 – 2010: 5 years of energy [r]evolution scenarios – 5 years of development

Since Greenpeace published the first Energy [R]evolution scenario in May 2005 (covering the EU-25 countries) during a seven month long ship tour from Poland all the way down to Egypt, the project has developed significantly. That very first scenario was launched on board the ship with the support of former EREC Policy Director Oliver Schäfer. This was the beginning of a long lasting and fruitful collaboration between Greenpeace International and the European Renewable Energy Council. The German Space Agency's Institute for Technical Thermodynamics, under Dr. Wolfram Krewitt´s leadership, was the scientific research institute behind all the analysis which supports the scenario. Between 2005 and 2009 these three very different stakeholders have managed to put together over 30 scenarios for countries from all continents of the world and published two editions of the Global Energy [R]evolution. It has since become a well respected blueprint for progress towards an alternative energy future. The work has been translated into over 15 different languages, including Chinese, Japanese, Arabic, Hebrew, Spanish, Thai and Russian.

The concept of the Energy [R]evolution scenario has been under constant development from the beginning. Now, for example, we are able to calculate the employment effects in parallel with the scenario development. The program MESAP/PlaNet has also been developed by software company seven2one, providing many features to make the project more sophisticated. For the 2010 edition we have developed a specific standard report tool which provides us with a "ready to print" executive summary for each region or country. This allows our calculations to interact between all the world regions, resulting in the global scenario opening up like a cascade. All these new developments have enabled us to provide ever improving quality, faster development times and more user friendly outputs. Over the past few years an experienced team of 20 scientists from all regions of the world has been formed in order to review the regional and/or country specific scenarios and to make sure that they are appropriate to the specific geographical area.

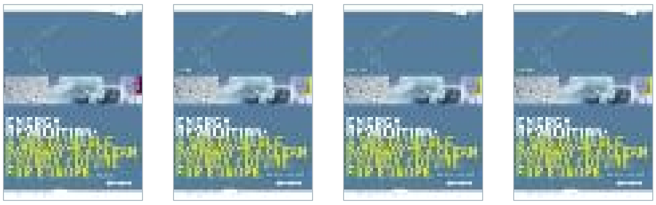
In some cases the Energy [R]evolution Scenarios have been the first ever long term energy scenario produced for a particular country, for example the Turkish scenario published in 2009. Since the first Global Energy [R]evolution scenario published in January 2007, we have organised side events at every single UNFCCC climate conference, countless energy conferences and panel debates. Over 200 presentations in more than 30 languages always had one message in common: "The Energy Revolution is possible; it is needed and will pay for itself in benefits for future generations!" Many high level meetings have taken place, for example on 15th July 2009, when the Chilean President Michelle Bachelet attended our launch event for the Energy [R]evolution in Chile.

The Energy [R]evolution work is a cornerstone of the Greenpeace climate and energy work worldwide and we would like to thank all the stakeholders who have been involved. Unfortunately, in October 2009, Dr Wolfram Krewitt from DLR passed away far too early and left a huge gap for everybody. His energy and dedication helped to make the project a true success story. Arthouros Zervos and Christine Lins from EREC have been involved in this work from the very beginning and Sven Teske from Greenpeace International has led the project since its first beginnings in late 2004. The well received layout of all the Energy [R]evolution series has been produced – also from the very beginning – by Tania Dunster and Jens Christiansen from "onehemisphere" in Sweden, and with enormous passion, especially in the final phase as the reports have gone to print. Finally, all the Global Energy [R]evolution Scenarios have been reported in a number of scientific and peer review journals such as Energy Policy.

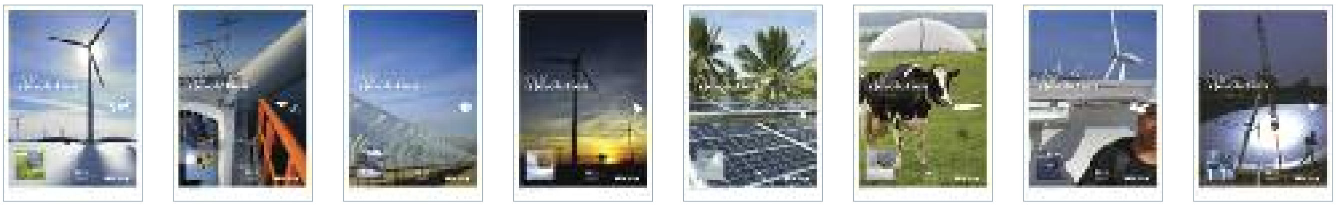
Listed here is a selection of milestones from the progress of the Energy [R]evolution story between 2005 and June 2010.

June 2005: First Energy [R]evolution Scenario for EU 25 presented in Luxembourg for members of the EU´s Environmental Council.
July – August 2005: National Energy [R]evolution scenarios for France, Poland and Hungary launched during an "Energy [R]evolution" ship tour with a sailing vessel across Europe.
January 2007: First Global Energy [R]evolution Scenario published parallel in Brussels and Berlin.
April 2007: Launch of the Turkish translation from the Global Scenario.
July 2007: Launch of Futu[r]e Investment – an analysis of the needed global investment pathway for the Energy [R]evolution scenarios.
November 2007: Launch of the Energy [R]evolution for Indonesia in Jakarta/Indonesia.
January 2008: Launch of the Energy [R]evolution for New Zealand in Wellington/NZ.
March 2008: Launch of the Energy [R]evolution for Brazil in Rio de Janeiro/Brazil.
March 2008: launch of the Energy [R]evolution for China in Beijing/China.
June 2008: Launch of the Energy [R]evolution for Japan in Aoi Mori & Tokyo/Japan.
June 2008: Launch of the Energy [R]evolution for Australia in Canberra/Australia .
August 2008: Launch of the Energy [R]evolution for the Philippines in Manila/Philippines.
August 2008: Launch of the Energy [R]evolution for the Mexico in Mexico City/Mexico.
October 2008: Launch of the second edition of the Global Energy [R]evolution Report.
December 2008: Launch of the Energy [R]evolution for the EU 27 in Brussels/Belgium.
December 2008: Launch of a concept for specific feed in-tariff mechanism to implement the Global Energy [R]evolution Report in developing countries at a COP13 side event in Poznan/Poland.
March 2009: Launch of the Energy [R]evolution for the USA in Washington/USA.
March 2009: Launch of the Energy [R]evolution for India in Delhi/India.
April 2009: Launch of the Energy [R]evolution for Russia in Mosko/Russia.
May 2009: Launch of the Energy [R]evolution for Canada in Ottawa/Canada.
June 2009: Launch of the Energy [R]evolution for Greece in Athens/Greece.
June 2009: Launch of the Energy [R]evolution for Italy in Rome/Italy.
July 2009: Launch of the Energy [R]evolution for Chile in Santiago/Chile.
July 2009: Launch of the Energy [R]evolution for Argentina in Buenos Aires/Argentina.
September 2009: Launch of the first detailed Job Analysis "Working for the Climate" – based on the global Energy [R]evolution report in Sydney/Australia.
October 2009: Launch of the Energy [R]evolution for South Africa in Johannesburg/SA.
November 2009: Launch of the Energy [R]evolution for Turkey in Istanbul/Turkey.
November 2009: Launch of "Renewable 24/7" a detailed analysis for the needed grid infrastructure in order to implement the Energy [R]evolution for Europe with 90% renewable power in Berlin/Germany.

2005



2007



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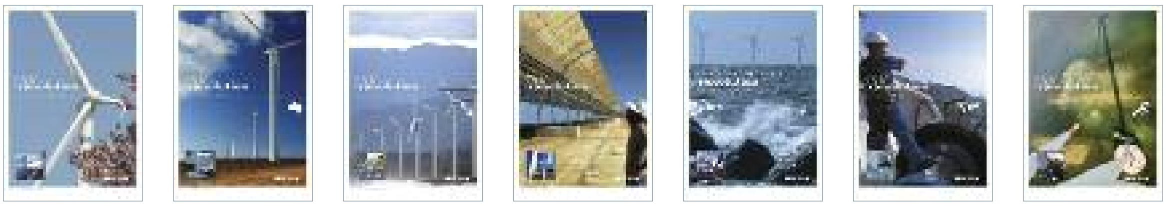

2009

2009

energy
[r]evolution

GREENPEACE

Greenpeace is a global organisation that uses non-violent direct action to tackle the most crucial threats to our planet's biodiversity and environment. Greenpeace is a non-profit organisation, present in 40 countries across Europe, the Americas, Africa, Asia and the Pacific. It speaks for 2.8 million supporters worldwide, and inspires many millions more to take action every day. To maintain its independence, Greenpeace does not accept donations from governments or corporations but relies on contributions from individual supporters and foundation grants.

Greenpeace has been campaigning against environmental degradation since 1971 when a small boat of volunteers and journalists sailed into Amchitka, an area west of Alaska, where the US Government was conducting underground nuclear tests. This tradition of 'bearing witness' in a non-violent manner continues today, and ships are an important part of all its campaign work.

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EREC

european renewable energy council - [EREC]
Created in April 2000, the European Renewable Energy Council (EREC) is the umbrella organisation of the European renewable energy industry, trade and research associations active in the sectors of bioenergy, geothermal, ocean, small hydro power, solar electricity, solar thermal and wind energy. EREC thus represents the European renewable energy industry with an annual turnover of €70 billion and employing 550,000 people.

EREC is composed of the following non-profit associations and federations: AEBIOM (European Biomass Association); EGEC (European Geothermal Energy Council); EPIA (European Photovoltaic Industry Association); ESHA (European Small Hydro power Association); ESTIF (European Solar Thermal Industry Federation); EUBIA (European Biomass Industry Association); EWEA (European Wind Energy Association); EUREC Agency (European Association of Renewable Energy Research Centers); EREF (European Renewable Energies Federation); EU-OEA (European Ocean Energy Association); ESTELA (European Solar Thermal Electricity Association).

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image ICE MELTING ON A BERG ON THE GREENLANDIC COAST. GREENPEACE AND AN INDEPENDENT NASA-FUNDED SCIENTIST COMPLETED MEASUREMENTS OF MELT LAKES ON THE GREENLAND ICE SHEET THAT SHOW ITS VULNERABILITY TO WARMING TEMPERATURES. **front cover images** INSTALLATION AND TESTING OF A WINDPOWER STATION IN RYSUMER NACKEN NEAR EMDEN WHICH IS MADE FOR OFFSHORE USAGE ONSHORE. © PAUL LANGROCK / ZENIT / GREENPEACE. INSTALLING PV PANELS © GP/FLAVIO CANNALONGA. THE POWER OF THE SEA © MCDONNELL/ISTOCK