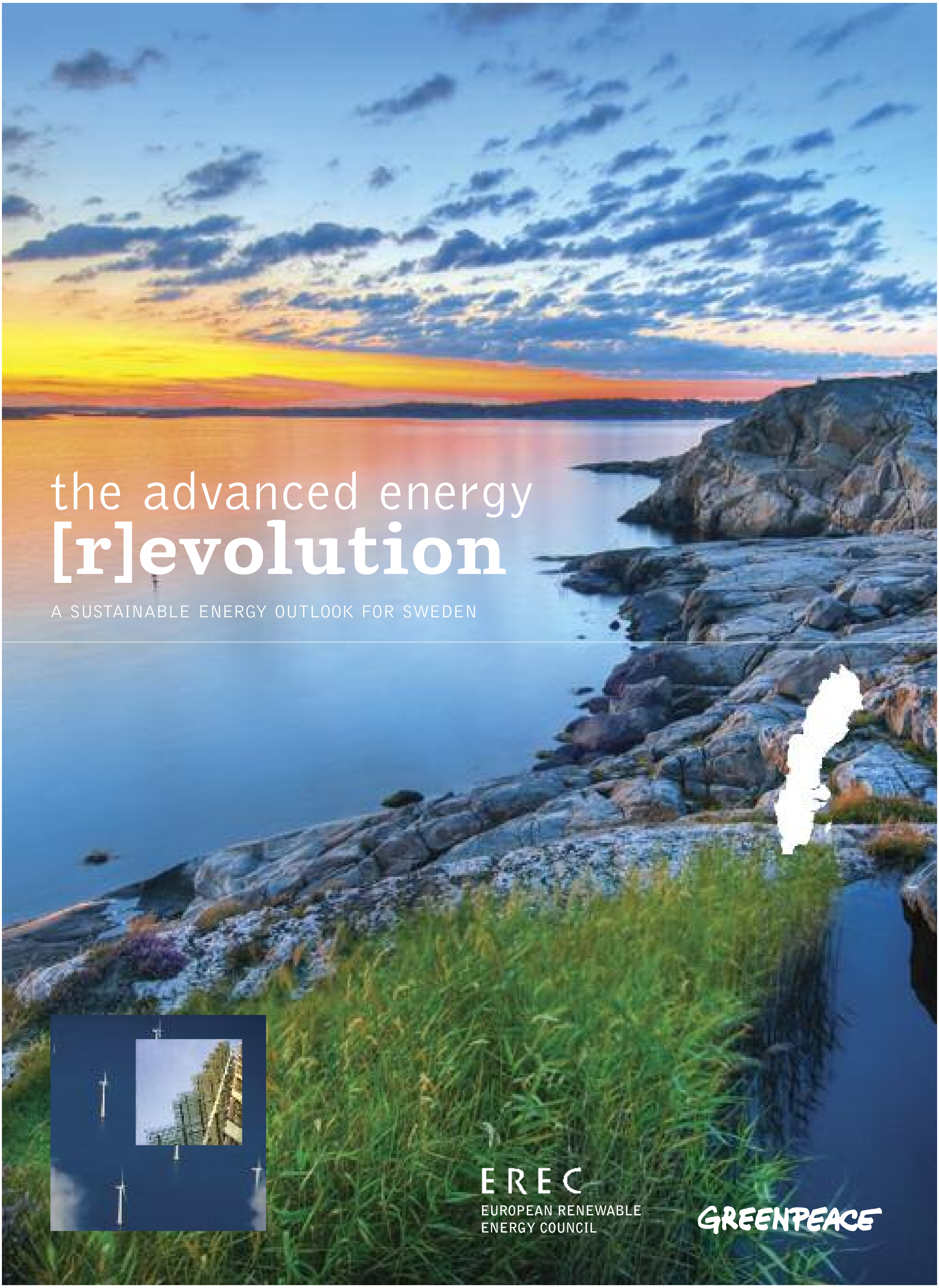

the advanced energy [r]evolution

A SUSTAINABLE ENERGY OUTLOOK FOR SWEDEN

EREC
EUROPEAN RENEWABLE ENERGY COUNCIL

GREENPEACE

report 2011 sweden energy scenario

Greenpeace International, European Renewable Energy Council (EREC)

date October 2011

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partners

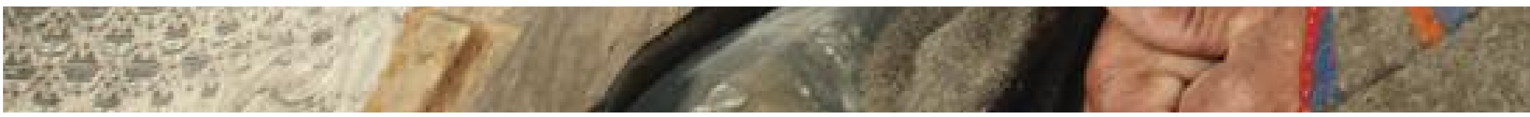
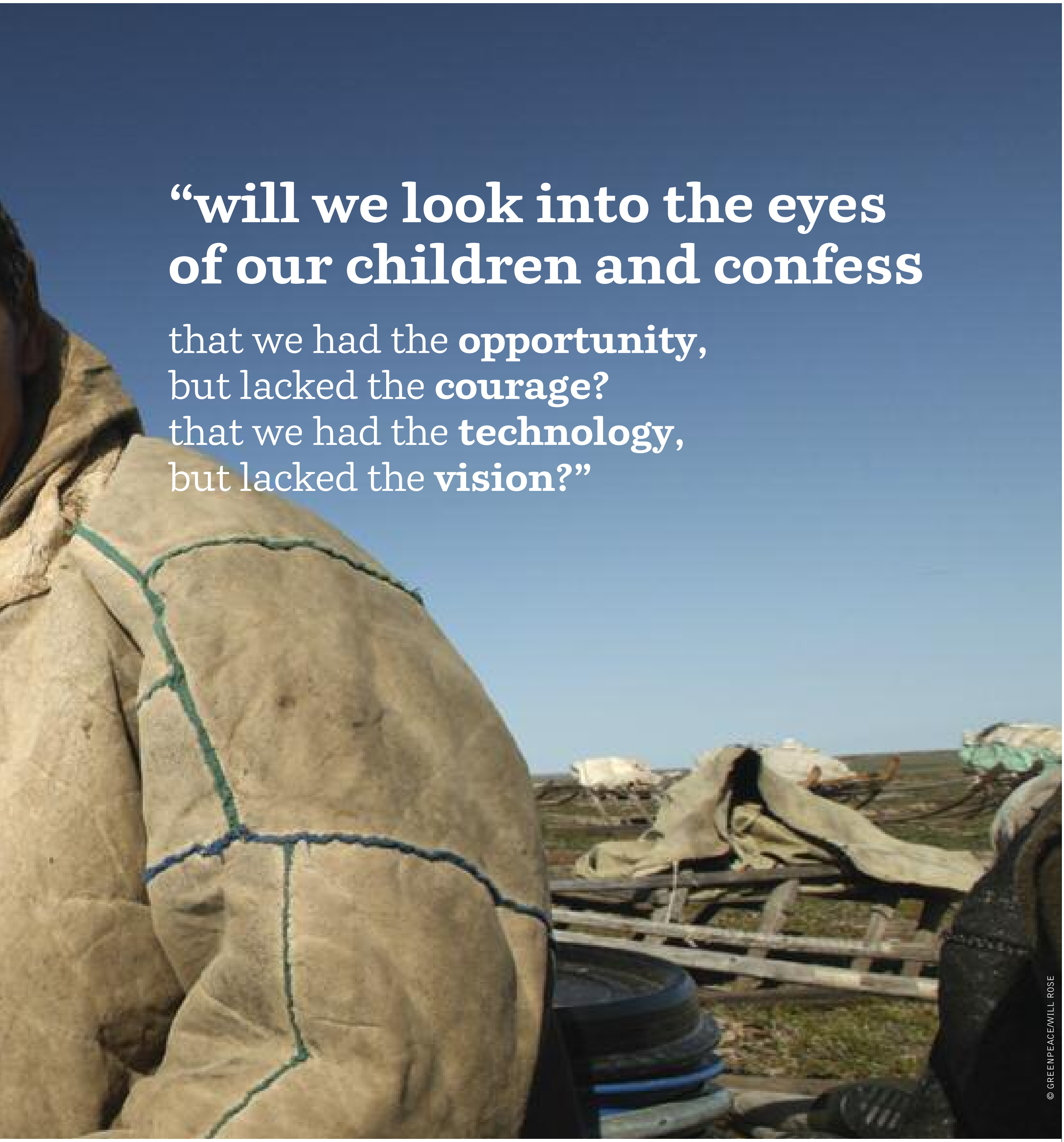


image THE INDIGENOUS NENETS PEOPLE IN RUSSIA MOVE EVERY 3 OR 4 DAYS SO THAT THEIR REINDEER DO NOT OVER GRAZE THE GROUND AND THEY DO NOT OVER FISH THE LAKES. THE YAMAL PENINSULA IS UNDER HEAVY THREAT FROM GLOBAL WARMING AS TEMPERATURES INCREASE AND RUSSIA'S ANCIENT PERMAFROST MELTS.

“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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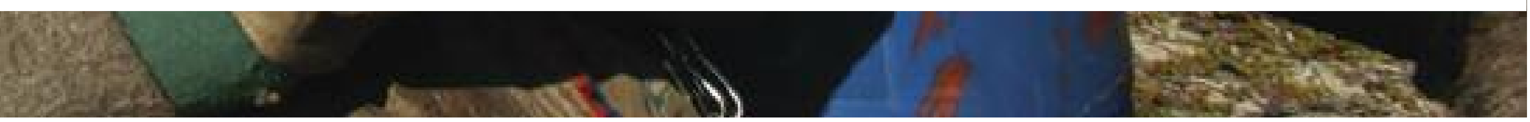

for further information about the global, regional and national scenarios please visit the Energy [R]evolution website: **www.energyblueprint.info/**

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foreword

Renewable energy visions presented decades ago by Environmental Citizens Groups are now becoming reality through investments by the private sector in the old industrial countries and even faster in some Asian countries.

However, some countries will economically suffer from governments, caught by established power companies, protecting the old technologies against competition from the new.

According to the European Commission, publishing when preparing the strategic energy technology plan, the EU spend ⅔ of its' energy research funding on nuclear technologies, the corporations only ¼.

Some countries maintain direct subsidies to oil consumption and coal mining. Others are providing decisive economic benefits to nuclear-, oil- and gas-installations by legislation socialising costs of accidents as well as decommissioning.

While such subsidies and supporting legislation is actively hidden or even denied, a lot of attention is given to support provided for the introduction of new, renewable energy. The subsidies to new technologies sometimes presented as an argument against them.

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.

Removing subsidies, all together, while introducing environmental taxes on pollution causing health effects or climate change would result in competitive renewable energy use.

But more important: Removing subsidies and imposing environmental taxes would increase the cost and price of old energy supplies, making energy efficiency even more profitable. This in turn would facilitate over all efficiency in the development of a sustainable society capable of continued economic progress on a global scale.

Swedish policies have been successful regarding fossil fuels in some sectors of society. Nuclear policy, however, is still tied by old commitments to protects the nuclear power-plant owners from costs of nuclear waste and accidents. This attitude is obsolete and economically indefensible. After Chernobyl and Fukushima it is shown that the economic magnitude of an accident may threaten the survival of the nation, a risk no sensible government should place on its unwilling citizens.

Luckily, there is a generation shift going on in the political and energy sectors. Young people have discovered that renewable energy is not only environmentally superior but often economically competitive. They see, further, that industrial experience has reduced costs and improved competitiveness. They also understand that this development is likely to continue making renewable energy generally economically superior to fossil fuels and nuclear.

Insight into the industrial potential of renewables is already governing the redirection of major international vendors, such as ABB, GE and Siemens. Even Areva, mostly known for heroically trying to complete the costly and delayed nuclear reactor project in Finland, has developed a renewable energy business segment growing faster than older segments.

This Energy (R)evolution report is useful, providing inspiration and guidance towards rational sustainable energy future.
May it be read, debated and outperformed by real developments!

Tomas Kåberger,

SEPTEMBER 2011

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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.

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introduction

"WITH POLITICAL WILL AND SWEDEN'S ABUNDANCE OF RENEWABLE ENERGY RESOURCES AND TOP CLASS TECHNOLOGY, THE COUNTRY COULD EASILY BECOME A RENEWABLE ENERGY LEADER."

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).

On 11 March 2011 an enormous earthquake and tsunami hit Japan. It is a day that will be remembered in history, not only for the unimaginable human tragedy, but for the resulting nuclear disaster, the scale of which, after Chernobyl, we were told could never happen again. The nuclear accident at Japan's Fukushima Daiichi Nuclear Power Plant will also be seen as a turning point in world energy policy. It triggered intensive discussions on the safety of nuclear power, and as a result, Germany, Switzerland, and Italy chose to end their nuclear programmes and to phase out existing reactors. Sweden had only the year before undone its ambitions to phase out nuclear and instead allowed for construction of new nuclear reactors, but the accident in Japan has even led to discussions about the future of nuclear in Sweden.

As the biggest challenge of our age, climate change is having a huge impact on our fragile environment. Droughts and flooding in many parts of the world and the increasing loss of the Arctic ice-cap are warning signs that we cannot ignore. And it is the world's poorest and most vulnerable people who are on the frontline of the devastating effects of climate change.

The solution is the Energy [R]evolution. Only a dynamic shift in how we generate and use energy will make it possible to achieve both the phase out of nuclear and minimize the risk of climate change. Sweden has vast renewable energy sources, from wind to solar photovoltaic and is already using bioenergy and geothermal resources. Harnessing these resources would not only make a huge contribution to averting runaway climate change, but would also create new economic opportunities including jobs. We can and must create a much more sustainable society, using existing clean technologies.

This is a turning point for Sweden's sustainable energy future. With political will and Sweden's abundance of renewable energy resources and top class technology, the country could easily become a renewable energy leader. It is also well placed to become much more energy efficient and reduce the costs of energy as well as emissions. But the political decisions need to be taken now, so that nuclear energy will not, as in the past, block the development of renewable energy sources.

image WIND TURBINES AT THE NAN WIND FARM IN NAN'AO. GUANGDONG PROVINCE HAS ONE OF THE BEST WIND RESOURCES IN CHINA AND IS ALREADY HOME TO SEVERAL INDUSTRIAL SCALE WIND FARMS.

The Energy [R]evolution scenario is one of potential pathways which Sweden can take.

The Advanced Energy [R]evolution—A sustainable Energy Outlook for Sweden, has been created to show the paths we can follow for a clean energy future. The 'reference scenario' is based on the Swedish Energy Agency's longterm prognosis from 2008. The Energy [R]evolution scenario was calculated by the German Space Agency (DLR) with support from the Institute for Sustainable Energy Policies (ISEP).

The scenario indicates that if we decide and take the `Energy [R]evolution' pathway in Sweden it is possible to achieve a renewable energy future by:

- Phasing out nuclear power generation by 2030
- Generating 84% of electricity from renewable energy by 2020
- Reducing 95% of CO_2 emissions by 2050 (in comparison of 1990)

Renewable energy is mature and can be deployed on a large scale. Decades of technological progress have seen renewable energy technologies move steadily into the mainstream and its rapid development has seen costs cut dramatically. Renewable energy will play a vital role in providing secure, reliable and zero-emission energy in the future.

The global market for renewable energy is booming internationally. Between 2005 and 2010, installed capacity of wind power grew by 333% globally, while solar photovoltaic grew by over 700%. As renewable energy is scaled up, we can start phasing out nuclear and fossil fuels. There is no need to keep relying on uncontrollable nuclear and dirty coal/oil-fired power. Enhanced efficiency and renewable energy supply can not only meet Sweden's energy demand, but also help us minimize the effects of climate change and create green jobs and a sustainable clean future. Sweden has abundant renewable energy resources like biomass, wind, solar and geothermal and crucially, it has economic power and world top class engineering technology to make these viable. All that's needed now is the political will to make it happen.

the forgotten solution: energy efficiency

The Sweden Energy [R]evolution scenario takes advantage of the enormous potential for the country to become much more energy efficient. Energy efficiency offers some of the simplest, easiest and quickest measures for reducing energy demands, greenhouse gas emissions and cost to end-users.

on the front foot

The Advanced Energy [R]evolution scenario demonstrates that making the necessary transformation in how we use energy is achievable, and provides new opportunities and creates green and sustainable jobs. We call on Sweden's political leaders to turn the Energy [R]evolution scenario into a reality and to begin the inevitable transition from nuclear/fossil-fuels to renewable energy now, delivering a safe, nuclear-free environment, reduced threat from climate change and a sustainable, prosperous future.

Arthouros Zervos
PRESIDENT
EUROPEAN RENEWABLE
ENERGY COUNCIL (EREC)

Sven Teske
CLIMATE & ENERGY UNIT
GREENPEACE INTERNATIONAL

AUGUST 2011

Mads Flarup Christensen
GENERALSEKRETÆR / EXECUTIVE DIRECTOR
GREENPEACE NORDIC

> **"we want sweden to be the first country in the world to have an energy system based wholly on renewable energy."**

ENVIRONMENT MINISTER CARLGREN
IN DEBATE ARTICLE SUMMER 2011

executive summary

"AT THE CORE OF THE ENERGY [R]EVOLUTION WILL BE A CHANGE IN THE WAY THAT ENERGY IS PRODUCED, DISTRIBUTED AND CONSUMED."

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.

The threat of climate change, caused by rising global temperatures, is the most significant environmental challenge facing the world at the beginning of the 21st century. It has major implications for the world's social and economic stability, its natural resources and in particular, the way we produce our energy.

The Copenhagen Accord, agreed at the international climate change summit in December 2009, has the stated aim of keeping the increase in global temperatures to below 2°C, and then considering a 1.5°C limit by 2015. However, the national emissions reduction pledges submitted by various countries to the United Nations coordinating body, the UNFCCC, in the first half of 2010 are likely to lead to a world with global emissions of between 47.9 and 53.6 gigatonnes of carbon dioxide equivalent per year by 2020. This is about 10–20% higher than today's levels. In the worst case, the Copenhagen Accord pledges could even permit emission allowances to exceed a 'business as usual' projection[1].

In order to avoid the most catastrophic impacts of climate change, the global temperature increase must be kept as far below 2°C as possible. This is still possible, but time is running out. To stay within this limit, global greenhouse gas emissions will need to peak by 2015 and decline rapidly after that, reaching as close to zero as possible by the middle of the 21st century.

a safe level of warming?

Keeping the global temperature increase to 2°C is often referred to as a 'safe level' of warming, but this does not reflect the reality of the latest science. This shows that a warming of 2°C above pre-industrial levels would pose unacceptable risks to many of the world's key natural and human systems[2]. Even with a 1.5°C warming, increases in droughts, heatwaves and floods, along with other adverse impacts such as increased water stress for up to 1.7 billion people, and wildfire frequency, are projected in many regions. Neither does staying below 2°C rule out large scale disasters such as melting ice sheets. Partial de-glaciation of the Greenland ice sheet, and possibly the West Antarctic ice sheet, could even occur from additional warming within a range of 0.8 – 3.8°C above current levels[3]. If rising temperatures are

references

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2 W. L. HARE. A SAFE LANDING FOR THE CLIMATE. STATE OF THE WORLD. WORLDWATCH INSTITUTE. 2009.
3 JOEL B. SMITH, STEPHEN H. SCHNEIDER, MICHAEL OPPENHEIMER, GARY W. YOHE, WILLIAM HARE, MICHAEL D. MASTRANDREA, ANAND PATWARDHAN, IAN BURTON, JAN CORFEE-MORLOT, CHRIS H. D. MAGADZA, HANS-MARTIN FÜSSEL, A. BARRIE PITTOCK, ATIQ RAHMAN, AVELINO SUAREZ, AND JEAN-PASCAL VAN YPERSELE: ASSESSING DANGEROUS CLIMATE CHANGE THROUGH AN UPDATE OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC) "REASONS FOR CONCERN". PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES. PUBLISHED ONLINE BEFORE PRINT FEBRUARY 26, 2009, DOI: 10.1073/PNAS.0812355106. THE ARTICLE IS FREELY AVAILABLE AT: HTTP://WWW.PNAS.ORG/CONTENT/EARLY/2009/02/25/0812355106.FULL.PDF A COPY OF THE GRAPH CAN BE FOUND ON APPENDIX 1.

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

to be kept within acceptable limits then we need to significantly reduce our greenhouse gas emissions. This makes both environmental and economic sense. The main greenhouse gas is carbon dioxide (CO_2) produced by using fossil fuels for energy and transport.

climate change and security of supply

Spurred by recent rapidly fluctuating oil prices, the issue of security of supply – both in terms of access to supplies and financial stability – is now at the top of the energy policy agenda. One reason for these price fluctuations is the fact that supplies of all proven resources of fossil fuels – oil, gas and coal – are becoming scarcer and more expensive to produce. So-called 'non-conventional' resources such as shale oil have even in some cases become more prevalent, with devastating consequences for the local environment. What is certain is that the days of 'cheap oil and gas' are coming to an end. Uranium, the fuel for nuclear power, is also a finite resource. By contrast, the reserves of renewable energy that are technically accessible globally are large enough to provide about six times more power than the world currently consumes - forever.

Renewable energy technologies vary widely in their technical and economic maturity, but there are a range of sources which offer increasingly attractive options. These include wind, biomass, photovoltaics, solar thermal, geothermal, ocean and hydroelectric power. Their common feature is that they produce little or no greenhouse gases, and rely on virtually inexhaustible natural elements for their 'fuel'. Some of these technologies are already competitive. The wind power industry, for example, continued its explosive growth in the face of a global recession and a financial crisis and is a testament to the inherent attractiveness of renewable technology.

At the same time there is enormous potential for reducing our consumption of energy, and still continuing to provide the same level of energy services. This study details a series of energy efficiency measures which together can substantially reduce demand across industry, homes, business and services.

the energy [r]evolution

The climate change imperative demands nothing short of an Energy [R]evolution, a transformation that has already started as renewable energy markets continue to grow. In the first global edition of the Energy [R]evolution, published in January 2007, we projected a global installed renewable capacity of 156 GW by 2010. At the end of 2009, 158 GW has been installed. More needs to be done, however. At the core of this revolution will be a change in the way that energy is produced, distributed and consumed.

the five key principles behind this shift will be to:

- Implement renewable solutions, especially through decentralised energy systems
- Respect the natural limits of the environment
- Phase out dirty, unsustainable energy sources
- Create greater equity in the use of resources
- Decouple economic growth from the consumption of fossil fuels

Decentralised energy systems, where power and heat are produced close to the point of final use, will avoid the current waste of energy during conversion and distribution. Investments in 'climate infrastructure' such as smart interactive grids, as well as super grids to transport large quantities of offshore wind and concentrating solar power, are essential. Building up clusters of renewable micro grids, especially for people living in remote areas, will be a central tool in providing sustainable electricity to the almost two billion people around the world for whom access to electricity is presently denied.

The Advanced Energy [R]evolution scenario follows the first series of Energy [R]evolution scenarios published between 2007-2009, increasing the emission reductions as needed according to latest climate science. While the Basic Energy [R]evolution scenario is based on a global CO_2 reduction target of minus 50% by 2050 (base year 1990) and a global per capita emission of around 1 tonne CO_2 per year, the advanced aims for a 80% reduction target and a per capita of around 0.5 tonne CO_2 per capita and year

towards a renewable future

Today, renewable energy sources account for 30% of Sweden's primary energy demand. Biomass, which is mostly used in the heat sector, and large hydro power stations for power generation are the main sources. The share of renewable energies for electricity generation is 53%, while their contribution to heat supply is around 66%, to a large extent accounted for by biomass. About 35% of the primary energy supply today still comes from fossil fuels. Both Energy [R]evolution Scenarios describe development pathways which turn the present situation into a sustainable energy supply, with the Advanced version achieving the urgently needed CO_2 reduction target more than a decade earlier than the Basic scenario.

The following summary shows the results of the Advanced Energy [R]evolution scenario, which will be achieved through the following measures:

1. Exploitation of existing large energy efficiency potentials will ensure that primary energy demand decreases from the current 2,248 PJ/a (2007) to 1,315 PJ/a in 2050, compared to 2,374 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. More electric drives are used in the transport sector and hydrogen produced by electrolysis from excess renewable electricity plays a much bigger role in the Advanced than in the Basic scenario. After 2020, the final energy share of electric vehicles on the road increases to 5 % and by 2050 to 60 %. More public transport systems also use electricity, as well as there being a greater shift in transporting freight from road to rail.

"The long term scenario has been developed further towards a complete phasing out of fossil fuels in the second half of this century."

3. The increased use of combined heat and power generation (CHP) also improves the supply system's energy conversion efficiency, increasingly using natural gas and biomass. In the long term, the decreasing demand for heat and the large potential for producing heat directly from renewable energy sources limit the further expansion of CHP.

4. The electricity sector will be the pioneer of renewable energy utilisation. By 2050, Sweden's entire electricity demand will be produced from renewable sources. A capacity of 56,800 MW will produce 169 TWh/a renewable electricity in 2050. A significant share of the fluctuating power generation from wind and solar photovoltaic will be used to supply electricity to 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 99 % by 2050. Fossil fuels will be increasingly replaced by more efficient modern technologies, in particular biomass, solar collectors and geothermal. Geothermal heat pumps and, in the world's sunbelt regions, concentrating solar power, will play a growing part in industrial heat production.

6. In the transport sector the existing large efficiency potentials will be exploited by a modal shift from road to rail and by using much lighter and smaller vehicles. As biomass is mainly committed to stationary applications, the production of biofuels is limited by the availability of sustainable raw materials. Electric vehicles, powered by renewable energy sources, will play an increasingly important role from 2020 onwards.

7. By 2050, 92% of primary energy demand will be covered by renewable energy sources.

To achieve an economically attractive growth of renewable energy 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.

It is also important to highlight that in the Advanced Energy Revolution scenario the majority of remaining coal power plants – which will be replaced 20 years before the end of their technical lifetime – are in China and India. This means that in practice all coal power plants built between 2005 and 2020 will be replaced by renewable energy sources. To support the building of capacity in developing countries significant new public financing, especially from industrialised countries, will be needed. It is vital that specific funding mechanisms are developed under the international climate negotiations that can assist the transfer of financial support to climate change mitigation, including technology transfer.

future costs

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 6.5). This difference will be about 0.3 euro cent/kWh. In 2050, the specific costs for one kWh add up to 6.2 euro cent in the Advanced scenario, 6.3 euro cent in the Basic Energy [R]evolution scenario and 7.2 euro cent in the Reference scenario. Under the Reference scenario, the growth in demand, the increase in fossil fuel prices and the cost of CO_2 emissions result in total electricity supply costs rising from today's €7 billion per year to €10 billion in 2050. Figure 6.5 shows that the Energy [R]evolution scenarios not only comply with Sweden's CO_2 reduction targets but also help to stabilise energy costs in the long term. Increasing energy efficiency and shifting energy supply to renewables result in long term costs for electricity supply that are even lower in the Advanced and in the Energy [R]evolution scenario than in the Reference case. This is possible because of decreasing specific investment costs for renewable technologies as a result of increasing global production volumes and corresponding learning curves. In spite of the increased electricity demand especially in the transport and industry sector the overall total supply costs in the Advanced case are €0.4 billion in 2030 lower than in the Energy [R]evolution scenario and nearly equal in 2050.

future investment

It would require €154 billion in investment for the Advanced Energy [R]evolution scenario to become reality - approximately € 600 million annual more than in the Reference scenario (€2.95 billion). Under the Reference version, the levels of investment in fossil and nuclear power plants add up to almost 68% while approx 32% would be invested in renewable energy and cogeneration until 2050. Under the Advanced scenario, however, Sweden would shift the entire investment towards renewables and cogeneration. The average annual investment in the power sector under the Advanced Energy [R]evolution scenario between today and 2050 would be approximately €3.6 billion.

Because renewable energy has no fuel costs, however, the fuel cost savings in the Basic Energy [R]evolution scenario reach a total €31.2 billion, or €700 million per year. The Advanced Energy [R]evolution has even higher fuel cost savings of €41.3 billion, or €1 billion per year.

Under the advance Energy [R]evolution scenario, the average annual additional fuel cost savings are equal to the additional annual investment of €1 billion. Therefore fuel cost savings compensate for the entire investment in renewable and cogeneration capacity required to implement the Advanced scenario. These renewable energy sources would then go on to produce electricity without any further fuel costs beyond 2050, while the costs for coal and gas will continue to be a burden on national economies.

image THOUSANDS OF FISH DIE AT THE DRY RIVER BED OF MANAQUIRI LAKE, 150 KILOMETERS FROM AMAZONAS STATE CAPITOL MANAUS, BRAZIL.

development of CO_2 emissions

While CO_2 emissions in Sweden will increase by 2% in the Reference scenario by 2050, under the Advanced Energy [R]evolution scenario they will decrease from 52 million tons in 2007 to 3 million t in 2050 (equal to a 95% emissions reduction compared to the 1990 level). Annual per capita emissions will drop from 5,6 t to 0,3 t. In spite of the phasing out of nuclear energy, 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.

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 2,8 t per capita by 2030 and 1 t by 2050. By 2050, Sweden's CO_2 emissions are 81% under 1990 levels.

table 0.1: sweden: CO_2 emissions under the advanced energy [r]evolution scenario

MILL t/a	2007	2015	2020	2030	2040	2050
Condensation power plants	**0**	**0**	**0**	**0**	**0**	**0**
Coal	0	0	0	0	0	0
Lignite	0	0	0	0	0	0
Gas	0	0	0	0	0	0
Oil	0	0	0	0	0	0
Diesel	0	0	0	0	0	0
Combined heat & power production	**5**	**4**	**3**	**2**	**1**	**0**
Coal	1	0	0	0	0	0
Lignite	1	1	0	0	0	0
Gas	1	1	1	1	1	0
Oil	2	2	1	1	0	0
CO_2 emissions power generation (incl. CHP public)	**5**	**4**	**3**	**2**	**1**	**0**
Coal	1	0	0	0	0	0
Lignite	1	1	0	0	0	0
Gas	1	1	1	1	1	0
Oil & diesel	3	2	1	1	0	0
CO_2 emissions by sector	**52**	**47**	**40**	**26**	**10**	**3**
% of 1990 emissions	92%	83%	71%	45%	17%	5%
Industry	11	9	7	4	1.3	0.3
Other sectors	3	2	2	1	0.5	0.2
Transport	23	23	21	14	5	2
Power generation (incl. CHP public)	3	2	2	1	0.3	0
Other conversion	13	11	9	6	2	1.0
Population (Mill.)	9.3	9	10	10	10	11
CO_2 emissions per capita (t/capita)	**5.6**	**5.0**	**4.1**	**2.5**	**0.9**	**0.3**

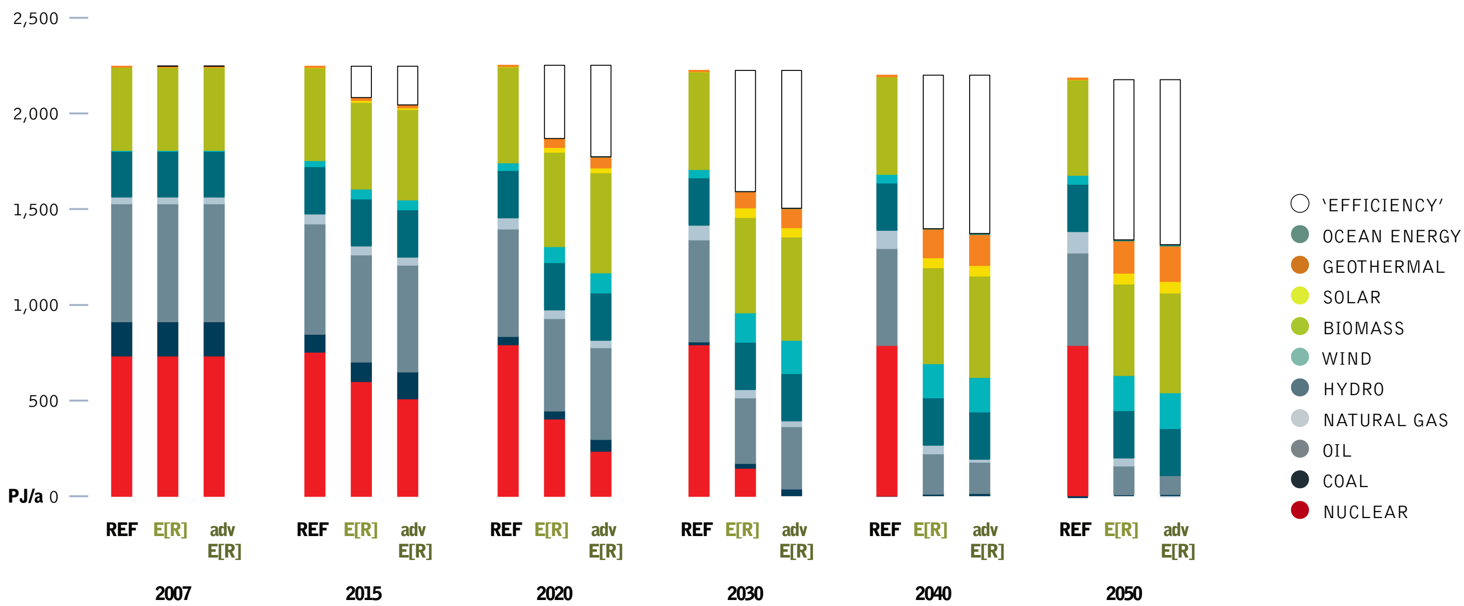
policy changes

To make the Energy [R]evolution real and to avoid dangerous climate change, Greenpeace and EREC demand that the following policies and actions are implemented in the energy sector:

1. Phase out all subsidies for fossil fuels and nuclear energy.
2. Internalise the external (social and environmental) costs of energy production through 'cap and trade' emissions trading.
3. Mandate strict efficiency standards for all energy consuming appliances, buildings and vehicles.
4. Establish legally binding targets for renewable energy and combined heat and power generation.
5. Reform the electricity markets by guaranteeing priority access to the grid for renewable power generators.
6. Provide defined and stable returns for investors, for example by effective feed-in tariff programmes.
7. Implement better labelling and disclosure mechanisms to provide more environmental product information.
8. Increase research and development budgets for renewable energy and energy efficiency.

figure 0.1: development of primary energy consumption under the advanced energy [r]evolution scenario

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



climate protection and energy policy

GLOBAL

THE KYOTO PROTOCOL
INTERNATIONAL ENERGY POLICY
RENEWABLE ENERGY TARGETS
POLICY CHANGES IN THE ENERGY SECTOR

1

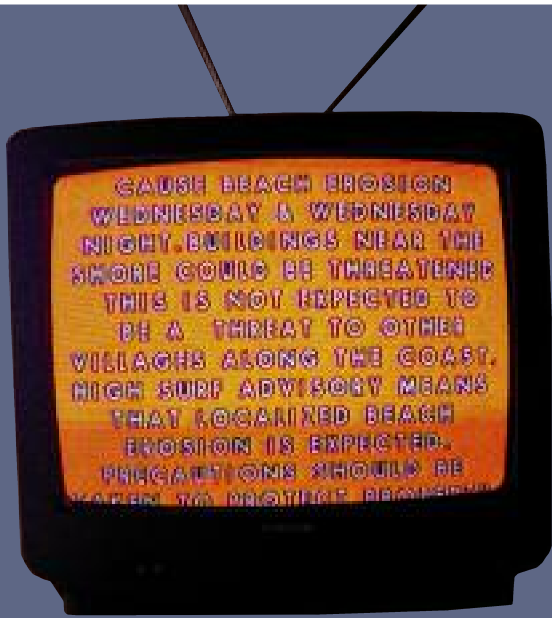


image THE LOCAL ALASKAN TELEVISION STATION BROADCASTS A WARNING FOR HIGH TIDES AND EROSION ALONG THE SEASIDE DURING A 2006 OCTOBER STORM WHICH IMPACTS ON THE VILLAGE OF SHISHMAREF. © GP/ROBERT KNOTH

never before has humanity been forced to grapple with such an immense environmental crisis.

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

The greenhouse effect is the process by which the atmosphere traps some of the sun's energy, warming the earth and moderating our climate. A human-driven increase in 'greenhouse gases' has enhanced this effect, artificially raising global temperatures and disrupting our climate. These greenhouse gases include carbon dioxide (produced by burning fossil fuels and through deforestation), methane (released from agriculture, animals and landfill sites), and nitrous oxide (resulting from agricultural production plus a variety of industrial chemicals).

Every day we damage our climate by using fossil fuels (oil, coal and gas) for energy and transport. The resulting impacts are likely to destroy the livelihoods of millions of people, especially in the developing world, as well as ecosystems and species, over the coming decades. We therefore need to significantly reduce our greenhouse gas emissions. This makes both environmental and economic sense.

According to the Intergovernmental Panel on Climate Change, the United Nations forum for established scientific opinion, the world's temperature is expected to increase over the next hundred years by up to 6.4° Celsius if no action is taken to reduce greenhouse gas emissions. This is much faster than anything experienced so far in human history. The goal of climate policy should be to keep the global mean temperature rise to less than 2°C above pre-industrial levels. If there is more than a 2°C rise, damage to ecosystems and disruption to the climate system increases dramatically. We have very little time within which we can change our energy system to meet these targets. This means that global emissions will have to peak and start to decline by the end of the next decade at the latest.

The reality of climate change can already be seen in disintegrating polar ice, thawing permafrost, rising sea levels and fatal heat waves. It is not only scientists that are witnessing these changes. From the Inuit in the far north to islanders near the equator, people are already struggling with impacts consistent with climate change. An average global warming of more than 2°C threatens millions of people with an increased risk of hunger, disease, flooding and water shortages. Never before has humanity been forced to grapple with such an immense environmental crisis. If we do not take urgent and immediate action to protect the climate, the damage could become irreversible. This can only happen through a rapid reduction in the emission of greenhouse gases into the atmosphere.

Below is a summary of some likely effects if we allow current trends to continue.

Likely effects of small to moderate warming:

- Sea level rise due to melting glaciers and the thermal expansion of the oceans as global temperature increases. Massive releases of greenhouse gases from melting permafrost and dying forests.
- A greater risk of more extreme weather events such as heat waves, droughts and floods. Already the global incidence of drought has doubled over the past 30 years.
- Severe regional impacts such as an increase in river flooding in Europe as well as coastal flooding, erosion and wetland loss. Low-lying areas in developing countries such as Bangladesh and South China are likely to be severely affected by flooding.
- Severe threats to natural systems, including glaciers, coral reefs, mangroves, alpine ecosystems, boreal forests, tropical forests, prairie wetlands and native grasslands.
- Increased risk of species extinction and biodiversity loss.

The greatest impacts will be on poorer countries in sub-Saharan Africa, South Asia, Southeast Asia and Andean South America as well as small islands least able to protect themselves from increasing droughts, rising sea levels, the spread of disease and a decline in agricultural production.

longer term catastrophic effects Warming from rising emissions may trigger the irreversible meltdown of the Greenland ice sheet, adding up to seven metres of global sea level rise over several centuries. New evidence shows that the rate of ice discharge from parts of the Antarctic means it is also at risk of meltdown. Slowing, shifting or shutting down of the Atlantic Gulf Stream current would have dramatic effects in Europe, and disrupt the global ocean circulation system. Large releases of methane from melting permafrost and from the oceans would lead to rapid increases of the gas in the atmosphere and consequent warming.

1.1 the kyoto protocol

Recognising these threats, the signatories to the 1992 UN Framework Convention on Climate Change (UNFCCC) agreed the Kyoto Protocol in 1997. The Protocol finally entered into force in early 2005 and its 165 member countries meet twice annually to negotiate further refinement and development of the agreement. Only one major industrialised nation, the United States, has not ratified Kyoto.

The Kyoto Protocol commits its signatories to reduce their greenhouse gas emissions by 5.2% from their 1990 level by the target period of 2008-2012. This has in turn resulted in the adoption of a series of regional and national reduction targets. In the European Union, for instance, the commitment is to an overall reduction of 8%. In order to help reach this target, the EU also agreed a target to increase its proportion of renewable energy from 6% to 12% by 2010.

At present, the 193 members of the UNFCCC are negotiating a new climate change agreement that should enable all countries to continue contributing to ambitious and fair emission reductions. Unfortunately the ambition to reach such an agreement in Copenhagen at the end of 2009 failed, and governments will continue negotiating in 2010 and possibly beyond to reach a new legally binding deal. Such an agreement will need to ensure that industrialised countries reduce their emissions on average by at least 40% by 2020, compared to their 1990 level. They will further need to provide funding of at least $140 billion a year to developing countries to enable them to adapt to climate change, protect their forests and achieve their part of the energy revolution. Developing countries need to reduce their greenhouse gas emissions by 15 to 30% compared to their projected growth by 2020.

This new 'fair and binding' (FAB) deal will need to incorporate the Kyoto Protocol's architecture. This relies fundamentally on legally binding emissions reduction obligations. To achieve these targets, carbon is turned into a commodity which can be traded. The aim is to encourage the most economically efficient emissions reductions, in turn leveraging the necessary investment in clean technology from the private sector to drive a revolution in energy supply.

After Copenhagen, governments need to increase their ambition to reduce emissions and invest even more in making the energy revolution happen. Greenpeace believes that it is feasible to reach a FAB deal in Cancun at the end of this year, if there is sufficient political will to conclude such an agreement. That political will seems to be lacking at the moment. But even if a FAB deal cannot be finalised in Cancun, due to lack of ambition and commitment by some countries, major parts could still be in place, specifically those related to long term financing commitments, forest protection and an overall target for emission reductions. The result would be that by the time of the Environment and Development Summit in Brazil in 2012 we would be celebrating an agreement that definitely keeps the world's temperature well below 2 degrees warming.

1.2 international energy policy

At present, renewable energy generators have to compete with old nuclear and fossil fuel power stations which produce electricity at marginal cost because consumers and taxpayers have already paid the interest and depreciation on the original investment. Political action is needed to overcome these distortions and create a level playing field for renewable energy technologies to compete.

At a time when governments around the world are in the process of liberalising their electricity markets, the increasing competitiveness of renewable energy should lead to higher demand. Without political support, however, renewable energy remains at a disadvantage, marginalised by distortions in the world's electricity markets created by decades of massive financial, political and structural support to conventional technologies. Developing renewables will therefore require strong political and economic efforts, especially through laws that guarantee stable tariffs over a period of up to 20 years. Renewable energy will also contribute to sustainable economic growth, high quality jobs, technology development, global competitiveness and industrial and research leadership.

1.3 renewable energy targets

In recent years, in order to reduce greenhouse emissions as well as increase energy security, a growing number of countries have established targets for renewable energy. These are either expressed in terms of installed capacity or as a percentage of energy consumption. These targets have served as important catalysts for increasing the share of renewable energy throughout the world.

A time period of just a few years is not long enough in the electricity sector, however, where the investment horizon can be up to 40 years. Renewable energy targets therefore need to have short, medium and long term steps and must be legally binding in order to be effective. They should also be supported by incentive mechanisms such as feed-in tariffs for renewable electricity generation. In order for the proportion of renewable energy to increase significantly, targets must be set in accordance with the local potential for each technology (wind, solar, biomass etc) and be complemented by policies that develop the skills and manufacturing bases to deliver the agreed quantity.

In recent years the wind and solar power industries have shown that it is possible to maintain a growth rate of 30 to 35% in the renewables sector. In conjunction with the European Photovoltaic Industry Association[4], the European Solar Thermal Power Industry Association[5] and the Global Wind Energy Council[6], the European Renewable Energy Council and Greenpeace have documented the development of those industries from 1990 onwards and outlined a prognosis for growth up to 2020 and 2040.

1.4 policy changes in the energy sector

Greenpeace and the renewables industry have a clear agenda for the policy changes which need to be made to encourage a shift to renewable sources. The main demands are:

1. Phase out all subsidies for fossil fuels and nuclear energy.
2. Internalise the external (social and environmental) costs of energy production through 'cap and trade' emissions trading.
3. Mandate strict efficiency standards for all energy consuming appliances, buildings and vehicles.
4. Establish legally binding targets for renewable energy and combined heat and power generation.
5. Reform the electricity markets by guaranteeing priority access to the grid for renewable power generators.
6. Provide defined and stable returns for investors, for example by effective feed-in tariff programmes.
7. Implement better labelling and disclosure mechanisms to provide more environmental product information.
8. Increase research and development budgets for renewable energy and energy efficiency.

Conventional energy sources receive an estimated $250-300 billion[7] in subsidies per year worldwide, resulting in heavily distorted markets. Subsidies artificially reduce the price of power, keep renewable energy out of the market place and prop up non-competitive technologies and fuels. Eliminating direct and indirect subsidies to fossil fuels and nuclear power would help move us towards a level playing field across the energy sector. Renewable energy would not need special provisions if markets factored in the cost of climate damage from greenhouse gas pollution. Subsidies to polluting technologies are perverse in that they are economically as well as environmentally detrimental. Removing subsidies from conventional electricity supply would not only save taxpayers' money. It would also dramatically reduce the need for renewable energy support.

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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.

table 1.1: energy [r]evolution: summary for policy makers

POLICY	WHO
Climate (targets)	
• Peak global temperature rise well below 2°C	UNFCCC
• Reduce ghg emissions by 40% by 2020 (as compared to 1990) in developed countries	UNFCCC
• Reduce ghg emissions by 15 to 30% of projected growth by 2020 in developing countries	UNFCCC
• Achieve zero deforestation globally by 2020	UNFCCC
• Agree a legally binding global climate deal as soon as possible	UNFCCC
Energy (targets)	
• USA: binding target of at least 20% renewable energy in primary energy consumption by 2020	USA
• G8: min 20% renewable energy by 2020	G8
• No new construction permits for new coal power plants in Annex 1 countries by 2012	G8
• Priority access to the grid for renewables	G8
• Establish efficiency targets and strict standards for electric applications	National Governments
• Strict efficiency target for vehicles: 80g CO_2/km by 2020	National Governments
• Build regulations with mandatory renewable energy shares (e.g. solar collectors)	National Governments
• Co-generation law for industry and district heating support program	National Governments
Finance (mechanisms)	
• Phase-out subsidies for fossil and nuclear fuels	G20
• Put in place a Climate Fund under the auspices of the UNFCCC	UNFCCC
• Provide at least 140 billion USD/year to the Climate Fund by 2020	UNFCCC
• Ensure priority access to the fund for vulnerable countries and communities	UNFCCC
• Establish feed-in law for renewable power generation in Annex 1 countries	National Governments
• Establish feed-in law with funding from Annex 1 countries for dev. countries	G8 + G77
ENERGY [R]EVOLUTION RESULTS	
Renewables & Supply	
Global Renewable Power Generation (power)	
• Shares (max = adv. ER - Min = ER): 30% / 50% / 75% / over 90%	Utilities & RE Industry
• Implementation of Smart Grids (Policy/Planning/Construction)	National Governments
• Smart Grids interconnection to Super Grids (Policy/Planning/Construction)	Gov & Grid Operator
• Renewables cost competitive (max = worst case - min = best case)	RE - Industry
• Phase out of coal power plants in OECD countries	Utilities
• Phase out of nuclear power plants in OECD countries	Utilities
Global Renewable Heat supply shares (heating)	
• Shares (max = adv. ER - Min = ER): 30% / 50% / 75% / over 90%	RE Industry
• Implementation of district heating (Policy/Planning/Construction)	National Governments
• Renewables cost competive (max = worst case - min = best case)	RE Industry
Global Renewable Final Energy shares (final energy)	
• Shares (max = adv. ER - Min = ER): 30% / 50% / 75% / over 90%	
• Consumer and business (Other Sectors)	
• Industry	
• Transport	
• Total Final Energy	
Efficiency & Demand	
Global Statonary Energy Use (consumer)	
• Efficiency standards reduce OECD household demand to 550 kWh/a per person	Cusumer Product Dev.
• Power demand for IT equipment stablized and start to decrease	IT Industry
• National energy intensity drops to 3 MJ/$GDP (Japan's level today)	Industry + Gov.
Global Transport Development (transport)	
• Shift fright from road to rail and where possible from aviation to ships	Gov. + Logistic Industry
• Shift towards more public transport	Regional Governments
• Efficient cars become mainstream	Car-Industry
Energy Related CO_2 Emissions (emissions)	
• Global CO_2 reductions (min = adv. ER - Max = ER): **Emission peak** / -30% / -50% / -80%	
• Annex 1 CO_2 reductions (min = adv. ER - Max = ER): **Emission peak** / -30% / -50% / -80%	
• Non Annex 1 CO_2 reductions (min = adv. ER - Max = ER): **Emission peak** / -30% / -50% / -80%	

2

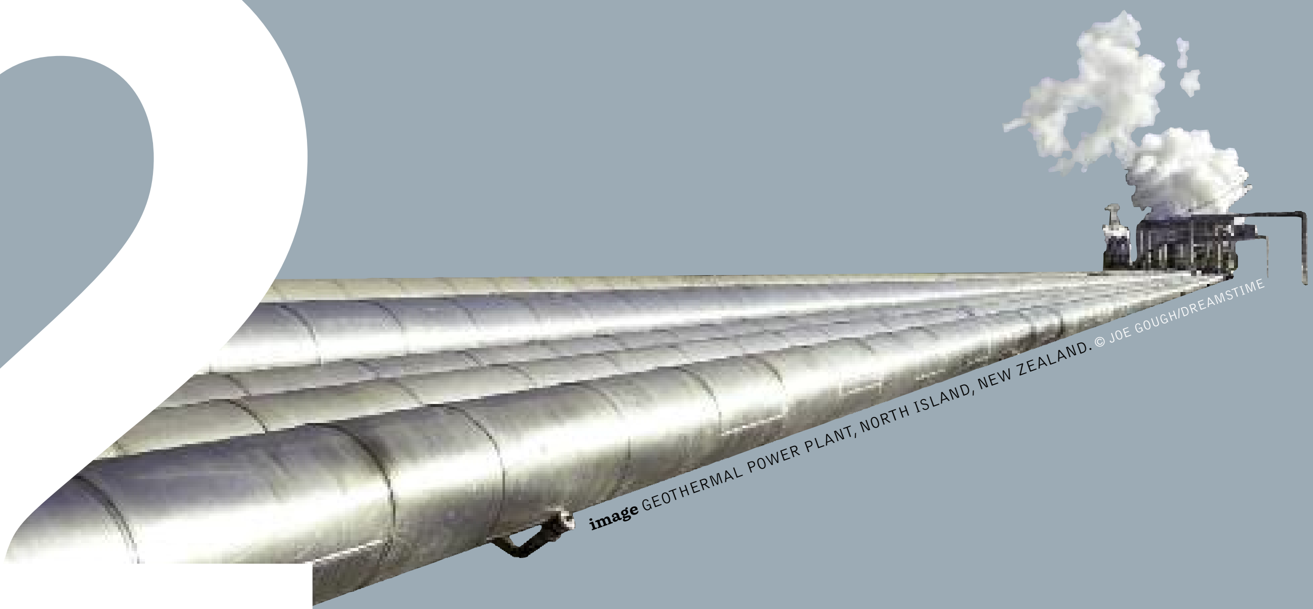


image GEOTHERMAL POWER PLANT, NORTH ISLAND, NEW ZEALAND. © JOE GOUGH/DREAMSTIME

bridging the gap.

image A WORKER ASSEMBLES WIND TURBINE ROTORS AT GANSU JINFENG WIND POWER EQUIPMENT CO. LTD. IN JIUQUAN, GANSU PROVINCE, CHINA.

© GP/MARKEL REDONDO

2.1 sweden's energy policy

This section examines the energy sector in Sweden. It provides a short background to the development of the energy sector and reviews the energy mix in the country. In addition, the section pays particular attention to electricity supply. Finally, some emphasis is given to the range of government policies on energy that have been developed, which have influenced the developments in the energy sector in Sweden.

2.1.1 background

The energy production that has dominated Sweden's power production

Steam Power The first steam machine began operation in 1728 and during the nineteenth century was the dominant source of power in Sweden. In 1804, the first steam machine was used in a Swedish factory; 1818 welcomed the first steam boat; 1849 the first steam saw and in 1856, the first hauled train. In 1884, the first electricity company opened and the power production was generated by steam power.

Hydro power Hydro turbines started to be used during the 1870s. In 1882, the first hydro power plant opened in Sweden which meant a breakthrough for the use of electricity within the Swedish industry. At the start of the twentieth century, the state started to build hydro power plants and in 1909 Trollhätte kanalbolag was transformed into The Royal Hydro Power Chair that later became Vattenfall. Today Vattenfall owns 92 hydro power plants in Sweden. In 1910, the parliament decided to expand and build out the hydro power in the Swedish rivers. In the 1970s protest movements against the hydro power exploration led to the cancellation of several projects. In 1975, the parliament adopted a goal for the hydro power's exploitation of 65 TWh/a until the year 1985. Today hydro power delivers between 50-75 TWh/a depending on water downfall during the year.

District heating In 1948, the first district heating power plant was taken into operation. During the 1960s,several more power plants were taken into operation and the production increased to 10 TWh/a. After the oil crisis and at the same time as the 'large housing areas' under the so-called million programme were constructed in the suburbs around the country, district heating got its real breakthrough. Today, 270 out of the country's 290 municipalities have power plants that produce almost 50 TWh/a of district heating. District heating makes up almost half of the heating of houses. In the rest of Europe that numbers just 10 percent. Many of the power plants are combined heat and power plants and there are also district cooling power plants. Thus there's already been a silent energy revolution in the heating sector in Sweden. The question is what will happen to the district heating if the market will be deregulated? It's clear that the competition between district heating and other sources of renewable energy will have an impact.

Nuclear power In 1954, the first nuclear research reactor was taken into operation at the technical university in the middle of Stockholm city. The reactor was closed in 1970. In 1964, the first nuclear power plant was opened and it delivered electricity to customers until 1974 when it was decommissioned because of safety concerns. The first commercial nuclear power plant in Oskarshamn was taken into operation in 1972 and during the nineteenth seventies three more (Barsebäck, Ringhals och Forsmark) nuclear power plants were opened. The last reactor started in 1985 and when there were 12 reactors in operation. The original plan was to build 24 reactors in Sweden and the industry warned that unless that happened, there would be a national shortage of energy. In 1980, after the accident at Three Mile Island in USA, a referendum resulted in a decision that the all the nuclear power should be decommissioned when all the reactors under construction had been built, and all the reactors had reached the end of their life length (which was considered to be 25 years).. The final end date for all the reactors in Sweden was given as 2010. In 1986, the accident in Chernobyl took place and parts of Sweden suffered from the fallout of radioactive cesium (meat and berries from these areas are still contaminated). In 1999, the end date for the decommissioning of the nuclear power was taken away, but one reactor in Barsebäck was closed. In 2005, the second and last reactor in Barsebäck was closed. Today there are still 10 reactors in operation owned and operated by Vattenfall, Fortum and E.ON.

Uranium mining According to the OECD/IAEA, Sweden has 4000 tons of ensured uranium assets. During the 1950s and 1960s, the possibilities to mine uranium in Sweden was examined and between 1965 and 1969, uranium was enriched in facilities in Ranstad. In 2005, the search for uranium was reinitiated and today there's over 200 approved permissions for investigations. The issue about whether uranium mining should be allowed in Sweden has not yet been up for political decision. The municipalities still have the right to veto the mining according to the current law.

Bioenergy In 1976, the Swedish farming university which had a strong emphasis on the cultivation of energy crops was opened. In the 1970s, the production of peat and biofuels were subsidized and got loan guarantees due to the effects of the two oil crises. Peat received financial support from the green certificates as well, even though it is not a renewable energy source but counts as fossil fuel. Today bioenergy is the biggest energy source in the Swedish energy system and by 2010, 129 TWh were produced. Bioenergy has passed oil (imported for the transport sector) and is bigger than hydro power and nuclear power together. Bioenergy makes up one third of the entire Swedish energy system: 90 percent of the bioenergy comes from the forest industry. In the beginning of the nineteenth century, a restoration of the Swedish forests was initiated and this was the first time the industry started to plant new forests. From the restoration and up until today there are statistical measures for how much biomass is available in the forests. That amount is today estimated to 3,000 cubic meters.

There is also ethanol and rape seed production in Sweden, although their contribution is small compared to the forest industry. Biogas production from farming, waste water or algae is now increasing fast and the biogas will play an important role for the renewable transition in the transport sector.

Wind power During the 1970s, the interest for wind power started to grow and investments gave Sweden a position far up front during the 1980s. But then things slowed down. Since no large scale wind farms were installed because the energy market was satisfied with the energy provided by the nuclear power plants, a brain-drain occurred and the frontier researchers went to countries like Denmark, Germany or China. In 1990, Sydkraft opened the world's first off-shore wind farm in Sweden. But the lack of political visions continued to put a lid on the development. Sweden has enormous theoretical wind power potential of 510 TWh/a at land and 46 TWh/a at sea. It is a spacious country and the population density is low. On top of that, the existing hydro power can be used to regulate the fluctuating production. Despite the fact that Sweden is one of the countries with the absolute best preconditions for wind power, the production only made up 2.4 percent of the electricity production in 2010.

Geothermal Geothermal energy has gradually entered the Swedish energy system and is another example of the silent energy revolution that is underway. Geothermal energy provides 12 TWh/a of heating and cooling to Swedish households and premises.

2.1.2 key players

There are three big actors on the energy market in Sweden: Vattenfall, Fortum and E.ON. They own and operate the nuclear power plants, the vast majority of the hydro power and most of the other big power production. Therefore the energy market can be considered to be an oligopoly. These companies are also involved in the new big renewable investments, demonstration projects for smart grids and the development of sustainable cities projects.

The state owned energy company Vattenfall Vattenfall is 100 percent owned by the Swedish state. Since the year 2000, the company has been transformed from a national company with hydro power as the major energy source in its portfolio and zero tons of carbon dioxide emissions per year, to one of the major energy companies in Europe with over 90 million tones of carbon dioxide emissions per year. The emissions derive from coal and gas power that Vattenfall has built and bought all over Europe. The emissions will further increase to over 100 million tones per year, when two coal power plants that are still under construction in Germany will open. Vattenfall also has plans for five new lignite mines in Germany, despite the fact that they already have enough lignite to supply the current power plants until 2030.

According to the owner directive from the state, Vattenfall should not only be a profitable company but also be one of the pioneer companies in the transition towards a sustainable energy system in Europe. Today Vattenfall is far from close to fulfilling that. After massive critique of the company and the Governments way of running the company a new strategic direction was presented in the Autumn 2010. According to the new directions, Vattenfall is planning to decrease carbon dioxide emissions to 65 millions tones of carbon dioxide in 2020. Selling, decomissioning and co-firing coal power plants with biomass is part of the strategy.

Vattenfall owns and operates seven out of the ten nuclear reactors in Sweden. It also owns two nuclear reactors in Germany that have not been in operation since 2007, and will now remain closed after the German energy agreement. The company has stated that they are interested in investing in new nuclear power in Sweden but also other countries. Vattenfall had a cooperation deal with the Swedish company Industry Power with the aim to examine possibilities for building new nuclear reactors in Sweden. But the deal expired in the early summer of 2010 and Vattenfall chose not to prolong it, with the argument that there were no good economical incentives for such projects at the moment.

Besides all the hydro power that Vattenfall owns and operates, the company also invests in other renewable energy sources. In 2010, Vattenfall opened the world's biggest off-shore wind farm in the North sea. In Sweden, the investments in wind power have been slow and one of the arguments from the company is that they build where the market conditions are better, but now a number of big wind projects are expected to be installed during the coming years. Vattenfall is also currently looking into investing in French hydro power.

Vattenfall is an important actor when it comes to the development of smart grids in Sweden and is currently working on a pilot project which aims to apply a system with smart grids for the entire island of Gotland. Vattenfall has other projects such as sustainable cities or "the one tone family" but the total investments in renewable energy are still dwarfed by investments in fossil power, CCS and nuclear power.

2.1.3 the national policies

- In 1981 an energy proposition with the aim to "save energy, decrease the oil consumption and replace the oil with nuclear power" was presented. 2010 was proposed as an end date for nuclear power.
- In 1991 it was decided that subsidies of 950 million should go to biofuel fired power heating. Investments in wind power were made and a carbon dioxide tax was applied to the market.
- In 1996 the Swedish electricity market was deregulated and both the production and selling became part of the international market.
- In 1997 a program for an "ecological and economically sustainable energy system for the long term" was launched.
- In 2001 the climate proposition suggesting that Sweden should start to work more actively to limit climate impacts and develop common instruments was presented in the parliament.
- In 2002 a new energy deal that proposed a green certificate system would be implemented in 2003 was presented. Sweden ratified the Kyoto protocol, but in the discussions in the EU regarding the burden share of the emission reductions, Sweden negotiated a deal that instead allowed for a four percent increase of emissions to 2012 compared to the base year 1990. The argument used, was that the date coincided with the decommissioning of nuclear power.
- In 2003 Sweden started the green certificate system that comprises 25 TWh of renewable energy.
- In 2006 the Swedish government accepted the first wind power proposition.

image A MAINTENANCE WORKER MARKS A BLADE OF A WINDMILL AT GUAZHOU WIND FARM NEAR YUMEN IN GANSU PROVINCE, CHINA.

- In 2009 the current climate and energy deal was first presented (see below).
- In 2009 the government asked concerned authorities to develop a biogas strategy which then resulted in a decision that biogas production will receive support between 2009-2013.
- In 2010 the parliament decided to take away the ban of nuclear new builds and the decommissioning law from the referendum in 1980. It's now up to the industry to decide whether they want to build or not.
- In 2011 Sweden signed an agreement with Norway on a joint green certificate market of 26 TWh between 2012 and 2020. This is in effect a halving of the previous announced national ambition of Sweden.

2.1.4 the current governing national policies

In February 2009, the Swedish government made an agreement on the climate and energy policy area that rules the current climate and energy politics. The governing idea is that Sweden will be out of fossil dependence and that Sweden has no net emissions of greenhouse gases to the atmosphere by the year 2050.

The deal also aims to increase investments in renewable energy and a more efficient use of energy.

targets for 2020

50 percent renewable energy in the energy system
10 percent renewable energy in the transport sector
20 percent more efficient energy use
40 percent decrease of greenhouse gas emissions for the non trading sector (transports, house stocks, waste plants, farming- and forestry industry, water use and parts of the industry). This can be translated to 20 million tones of carbon dioxide compared to 1990 levels. Two thirds will take place in Sweden and one third will use the flexible mechanisms under the UN climate system.

targets for 2050

Sweden should have zero net emissions of greenhouse gases to the atmosphere and the energy supply should be sustainable and resource effective.

course control in 2015

The climate impact in comparison to the targets, the energy balance, costs and the level of knowledge will be evaluated.

2.1.5 the different areas affected by the climate and energy policy

Heat

No fossil fuels should be used for heating in 2020. District heating and combined heat and power will play a central role and the industry and households should perform substantial energy efficiency measures.

Transport

- The transport fleet should be fossil fuel independent by 2030. That doesn't guarantee that the entire transport sector will be emission free in 2030, but that all new vehicles will be hybrids, electric or driven on biofuels or biogas.
- 10 percent of the transport fleet should be fossil fuel independent in 2020
- A guiding target state that 5.75 percent of the total use of gas or diesel should be accounted for by biofuels and renewable fuels from 2010.

Electricity

According to current government vision, nuclear power will remain as an important part of the electricity production but more renewable electricity production should be installed to decrease the vulnerability and the dependence on nuclear power in electricity production. Heat and power production, wind power and other renewable electricity production will take a dominant position in the electricity system. The harmonization of the Nordic electricity market is seen as an opportunity for increased collaboration between the Nordic countries.

Fossil energy

- According to current government strategy, natural gas can play a role in the energy system under a transition period and this installation will aim to support the introduction of biogas.
- The government hopes that Swedish industry is connected to the planned pilot project for CCS in Europe.

Renewable energy

- Sweden should allow for other countries to make financial investments in renewable electricity production in Sweden.
- The target for wind power of 30 TWh/a to 2020, 20 TWh/a at land and 10 TWh/a off-shore.
- The target for wind power is 10 TWh/a to 2015.
- Approval from concerned municipalities is acquired for projects that need an application process according to the environmental code of conduct (bigger wind farms).
- The preconditions for installation of off-shore wind power should be studied.
- No expansion of the hydro power plants will take place in the national rivers or in other rivers mentioned in the law

Nuclear power

- Industry can replace the ten existing nuclear reactors with ten new at the existing sites. Approval for such projects will be given if the industry decides that they want to build.
- Applications for upgrades of existing reactors must be approved by the government. Earlier applications have been approved.

- The nuclear phase out law was abolished in 2010 and the ban to build new reactors in the Act on Nuclear Activities was also taken away.
- No state subsidies for construction of new nuclear reactors will be handed out. The definition of state subsidies for nuclear power is under preparation.
- The law on nuclear responsibility in case of an accident follows the Paris convention and its amending protocol.

Energy efficiency measures

- The target to 2020 is 20 percent more efficient energy use. The energy intensity will be decreased by 20 percent between 2008 and 2020. Sweden follows the European parliaments and the Councils directive 2006/32/EG and has a guiding target of 9 percent energy savings to 2016 compared to the average final use of energy during the period 2001-2005. The guiding target for 2010 was 6,5 percent savings. In physical terms, the targets represent 24 TWh/a to 2010 and 33,2 TWh/a to 2016.
- The Energy Authority leads a voluntary program for the energy intensive industry.

Markets

- The Swedish government believes that Sweden should put effort into creating a functioning Nordic market for the final customers and closer collaboration in Northern Europe around grid investments.
- Bottle necks in the electricity grid should be built away and better connection of the power grids in the Baltic region are seen to create better conditions for off-shore wind farms.
- The Swedish government's view is that well functioning competition between different forms of heating is important for the heat market.
- Societal economical effective investments in new electricity production should be made possible by investments in the grids.
- The energy policy should be international, market based, apply solidarity and aim for a continuous integration of the European market.

Instruments

- Sweden applies general economical incentives such as carbon dioxide tax, international trade of emission rights and has a certificate system for renewable energy.
- The government believes that incentives should be developed step by step, to limit the risk of carbon leakage and keep the competitive edge in the Swedish enterprise. Exceptions should be limited as much as possible.
- Actions for development of techniques will complement the general instruments.
- The government's view is that the climate issue should be dealt with through international agreements and commitments and that cost efficient common instruments and effective trade should be used.

The green certificates system

- The current Swedish certificate system contains a vision of 25 TWh of new renewable energy to 2020 compared to 2002. The turnover in the system is considered to be 4,5 billion SEK per year.
- On 1 January 2011, the government decided to merge the Swedish and Norwegian certificate markets to one common market. The ambition for that common market is 26 TWh from 2012 to 2020. The common certificates market is planned to start 2012 and the collaboration deal reaches until 2036.
- The level of ambition in the certificate system is systematically reviewed by the Energy Authority.

2.1.6 key issues

The main problems with the Swedish energy policy are the lack of ambitious enough targets for energy efficiency measures and renewable energy. Nuclear power has blocked and still blocks the market for renewable energy from gathering speed. Sweden is stuck in a discussion about whether a potential replacement of the current reactors will take place or not and is left behind while other countries have already entered the energy revolution at full speed. The duality in the messaging from the government about nuclear power at the one hand, and the renewables at the other, makes it difficult for investors to predict what the future of the Swedish energy system actually will look like.

There's also a great deal of uncertainty regarding financial support mechanisms for renewable energy for solar power and different kinds of biofuels which makes investors nervous and postpone important investment decisions. The certificate system has some problems resulting in a situation where some renewable energy techniques that are already competitive still receive support while others have no chance to get their way to the market. This problem requires that additional support mechanisms are added e.g. for off-shore wind and solar energy. It also remains to be seen what the joint certificate market with Norway will result in.

It is time for the government to clearly state that the future should be renewable and then enable a faster transition to a 100 percent renewable energy system by setting a road map for the decommissioning of the nuclear reactors. The belief that Sweden s future energy system can rest on "three legs" (hydro power, nuclear power and renewable energy) is a misconception and hinders the introduction of a balanced future energy system. The base load nuclear power has no room in a large scale renewable energy system and must be decommissioned before 2030, in order to prevent huge costs for building extra transmission capacity or putting a lid on the development of the renewable sector.

The Swedish government should use Vattenfall as a key tool in the transition towards a 100 percent renewable energy system and demand that the company immediately initiate a decommission of their fossil and nuclear power production and shift investments to renewable energy.

3

image SIGN ON A RUSTY DOOR AT CHERNOBYL ATOMIC STATION.
© DMYTRO/DREAMSTIME

safety and security risks, radioactive waste, nuclear proliferation.

Nuclear energy is a relatively minor industry with major problems. It covers just one sixteenth of the world's primary energy consumption, a share set to decline over the coming decades. The average age of operating commercial nuclear reactors is 25 years. The number of operating reactors as of May 2011 was 443, less than at the historical peak of 2002.

In terms of new power stations, the amount of nuclear capacity added annually between 2000 and 2009 was on average 2,500 MWe. This was six times less than wind power (14,500 MWe per annum between 2000 and 2009). In 2009, 37,466 MW of new wind power capacity was added globally to the grid, compared to only 1,068 MW of nuclear. This new wind capacity will generate as much electricity as 12 nuclear reactors; the last time the nuclear industry managed to add this amount of new capacity in a single year was in 1988.

Despite the rhetoric of a 'nuclear renaissance', the industry is struggling with a massive increase in costs and construction delays as well as safety and security problems linked to reactor operation, radioactive waste and nuclear proliferation. The Fukushima nuclear accident (see below) 25 years after the disastrous explosion in the Chernobyl nuclear power plant in former Soviet Union, proves nuclear energy is inherently unsafe and raises additional doubts about the nuclear industry's ability to deliver on their promises of safety and security.

3.1 a solution to climate protection?

The nuclear industry's promise of nuclear energy to contribute to both climate protection and energy security needs to be checked against reality. In the most recent Energy Technology Perspectives report published by the International Energy Agency(IEA)[8], for example, its Blue Map scenario outlines a future energy mix which would halve global carbon emissions by the middle of this century. To reach this goal the IEA assumes a massive expansion of nuclear power between now and 2050, with installed capacity increasing four-fold and electricity generation reaching 9,857 TWh/year, compared to 2,608 TWh in 2007. In order to achieve this, the report says that on average 32 large reactors (1,000 MWe each) would have to be built every year from now until 2050. This is not only unrealistic, but also expensive, hazardous and too late to protect the climate. Even if realised, according to the IEA scenario, such a massive nuclear expansion would only cut carbon emissions by less than 5%.

unrealistic: Such a rapid nuclear growth is practically impossible given the technical limitations. This scale of development was achieved in the history of nuclear power for only two years at the peak of the state-driven boom of the mid-1980s. It is unlikely to be achieved again, not to mention maintained for 40 consecutive years. While 1984 and 1985 saw 31 GW of newly added nuclear capacity, the decade average was 17 GW each year. In the past ten years, less than three large reactors have been brought on line annually, and the current production capacity of the global nuclear industry cannot deliver more than an annual six units.

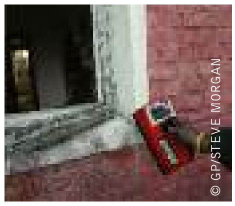
expensive: The IEA scenario assumes very optimistic investment costs of $2,100/kWe installed, in line with what the industry has been promising. The reality indicates three to four times that much. Recent estimates by US business analysts Moody's (May 2008) put the cost of nuclear investment as high as $7,500/kWe. Price quotes for projects under preparation in the US cover a range from $5,200 to 8,000/kWe[9]. The latest cost estimate for the first French EPR pressurised water reactor being built in Finland is $5,000/kWe, a figure likely to increase for later reactors as prices escalate. Building 1,400 large reactors of 1,000 MWe, even at the current cost of about $7,000/kWe, would require an investment of $9.8 trillion.

hazardous: Massive expansion of nuclear energy would necessarily lead to a large increase in related hazards. These include the risk of serious reactor accidents like in Fukushima, Japan, the growing stockpiles of deadly high level nuclear waste which will need to be safeguarded for thousands of years, and potential proliferation of both nuclear technologies and materials through diversion to military or terrorist use. The 1,400 large operating reactors in 2050 would generate an annual 35,000 tonnes of dangerous spent nuclear fuel (for light water reactors, the most common design for most new projects). This also means the production of 350,000 kilograms of plutonium each year, enough to build 35,000 crude nuclear weapons.

slow: Climate science says that we need to reach a peak of global greenhouse gas emissions in 2015 and reduce them by 20% by 2020. Even in developed countries with established nuclear infrastructure it takes at least a decade from the decision to build a reactor to the delivery of its first electricity, and often much longer. This means that even if the world's governments decided to implement strong nuclear expansion now, only a few reactors would start generating electricity before 2020. The contribution from nuclear power towards reducing emissions would come too late to help save the climate.

references
8 'ENERGY TECHNOLOGY PERSPECTIVES 2008 - SCENARIOS & STRATEGIES TO 2050', IEA.
9 PLATTS, 2008; *ENERGY BIZ*, MAY/JUNE 2008

image MEASURING RADIATION LEVELS OF A HOUSE IN THE TOWN OF PRIPYAT THAT WAS LEFT ABANDONED AFTER THE CHERNOBYL NUCLEAR DISASTER, UKRAINE.



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3.2 nuclear power blocks solutions

Even if the ambitious nuclear scenario is implemented, regardless of costs and hazards, the IEA concludes that the contribution of nuclear power to reductions in greenhouse gas emissions from the energy sector would only be 4.6% - less than 3% of the global overall reduction required.

There are other technologies that can deliver much larger emission reductions, and much faster. Their investment costs are lower and they do not create global security risks. Even the IEA finds that the combined potential of efficiency savings and renewable energy to cut emissions by 2050 is more than ten times larger than that of nuclear.

The world has limited time, finance and industrial capacity to change our energy sector and achieve a large reduction in greenhouse emissions. Choosing the pathway of spending $10 trillion on nuclear development would be a fatally wrong decision. Nuclear energy would not save the climate but it would necessarily take resources away from solutions described in this report and at the same time create serious global security hazards. Therefore new nuclear reactors are a clearly dangerous obstacle to the protection of the climate.

3.3 nuclear power in the energy [r]evolution scenario

For the reasons explained above, the Advanced Energy [R]evolution scenario envisages a nuclear phase-out. Existing reactors would be closed at the end of their average operational lifetime of 35 years. We assume that no new construction is started and only two thirds of the reactors currently under construction worldwide will be finally put into operation.

3.4 the dangers of nuclear power

Although the generation of electricity through nuclear power produces much less carbon dioxide than fossil fuels, there are multiple threats to people and the environment from its operations.

The main risks are:

- Safety Risks
- Nuclear Waste
- Nuclear Proliferation

This is the background to why nuclear power has been discounted as a future technology in the Advanced Energy [R]evolution scenario.

3.4.1 safety risks

Windscale (1957), Three Mile Island (1979), Chernobyl (1986), Tokaimura (1999) and Fukushima (2011) are only a few of the hundreds of nuclear accidents which have occurred to date. The Fukushima nuclear disaster in March 2011 has been a stark wake-up call causing governments all over the world to rethink their nuclear plans. Despite the nuclear industry's assurances that a nuclear accident on the scale of Chernobyl could never happen again, the earthquake and subsequent tsunami in Japan caused leaks and explosions in 4 reactors of the Fukushima nuclear power plant. Large areas around the nuclear power plant have been seriously contaminated by radioactive releases from the plant. An area of 30 km around the facility has been evacuated, and food and water restrictions apply at distances more than 100 km. The impacts on the lives of hundreds of thousands of people as well as the Japanese economy will be felt for decades to come.

Nuclear energy is inherently unsafe because:

- An accident like in Fukushima can happen in many of the existing nuclear reactors, as they all need continuous power to cool the reactors and spent nuclear fuel, even after the reactor has shut down. A simple power failure at a Swedish nuclear plant in 2006 highlighted this problem. Emergency power systems at the Forsmark plant failed for 20 minutes during a power cut and four of Sweden's ten nuclear power stations had to be shut down. If power had not been restored there could have been a major incident within hours.
- A nuclear chain reaction must be kept under control, and harmful radiation must, as far as possible, be contained within the reactor, with radioactive products isolated from humans and carefully managed. Nuclear reactions generate high temperatures, and fluids used for cooling are often kept under pressure. Together with the intense radioactivity, these high temperatures and pressures make operating a reactor a difficult and complex task.
- The risks from operating reactors are increasing and the likelihood of an accident is now higher than ever. Most of the world's reactors are more than 25 years old and therefore more prone to age related failures. Many utilities are attempting to extend their lifespan from the 30 years or so, they were originally designed for, to up to 60 years, posing new risks.
- De-regulation has meanwhile pushed nuclear utilities to decrease safety-related investments and limit staff whilst increasing reactor pressure and operational temperature and the burn-up of the fuel. This accelerates ageing and decreases safety margins.

3.4.2 nuclear waste

Despite 50 years of producing radioactive waste, there is no solution for the long term storage and safeguarding of these dangerous materials. Disposal sites of low level radioactive waste have already started leaking after decades, while the highly radioactive waste will need to be safely stored for hundreds of thousands of years. The nuclear industry claims it can 'dispose' of its nuclear waste by burying it deep underground, but this will not isolate the radioactive material from the environment forever. A deep dump only slows down the release of radioactivity into the environment. The industry tries to predict how fast a dump will leak so that it can claim that radiation doses to the public living nearby in the future will be "acceptably low". But scientific understanding is not sufficiently advanced to make such predictions with any certainty.

As part of its campaign to build new nuclear stations around the world, the industry claims that problems associated with burying nuclear waste are to do with public acceptability rather than technical issues. It points to nuclear dumping proposals in Finland, Sweden or the United States to underline its argument, but there is no scientific backing of its claims of safe disposal.

The most hazardous waste is the highly radioactive waste (or spent) fuel removed from nuclear reactors, which stays radioactive for hundreds of thousands of years. In some countries the situation is exacerbated by 'reprocessing' this spent fuel, which involves dissolving it in nitric acid to separate out weapons-usable plutonium. This process leaves behind a highly radioactive liquid waste. There are about 270,000 tonnes of spent nuclear waste fuel in storage, much of it at reactor sites. Spent fuel is accumulating at around 12,000 tonnes per year, with around a quarter of that going for reprocessing[10].

The least damaging currently available option for waste is to store it above ground, in dry storage at the site of origin. However, this option also presents major challenges and threats, as was seen in the Fukushima accident where the cooling of the spent nuclear fuel pools posed major problems. The only real solution is to stop producing the waste.

3.4.3 nuclear proliferation

Manufacturing a nuclear bomb requires fissile material - either uranium-235 or plutonium-239. Most nuclear reactors use uranium as a fuel and produce plutonium during their operation. It is impossible to adequately prevent the diversion of plutonium to nuclear weapons. A small-scale plutonium separation plant can be built in four to six months, so any country with an ordinary reactor can produce nuclear weapons relatively quickly.

The result is that nuclear power and nuclear weapons have grown up like Siamese twins. Since international controls on nuclear proliferation began, Israel, India, Pakistan and North Korea have all obtained nuclear weapons, demonstrating the link between civil and military nuclear power. Both the International Atomic Energy Agency (IAEA) and the Nuclear Non-proliferation Treaty (NPT) embody an inherent contradiction - seeking to promote the development of 'peaceful' nuclear power whilst at the same time trying to stop the spread of nuclear weapons.

Israel, India and Pakistan all used their civil nuclear operations to develop weapons capability, operating outside international safeguards. North Korea developed a nuclear weapon even as a signatory of the NPT. A major challenge to nuclear proliferation controls has been the spread of uranium enrichment technology to Iran, Libya and North Korea. The former Director General of the International Atomic Energy Agency, Mohamed ElBaradei, has said that "should a state with a fully developed fuel-cycle capability decide, for whatever reason, to break away from its non-proliferation commitments, most experts believe it could produce a nuclear weapon within a matter of months"[11].

The United Nations Intergovernmental Panel on Climate Change has also warned that the security threat of trying to tackle climate change with a global fast reactor programme (using plutonium fuel) "would be colossal"[12]. All of the reactor designs currently being promoted around the world could be fuelled by MOX (mixed oxide fuel), from which plutonium can be easily separated.

Restricting the production of fissile material to a few 'trusted' countries will not work. It will engender resentment and create a colossal security threat. A new UN agency is needed to tackle the twin threats of climate change and nuclear proliferation by phasing out nuclear power and promoting sustainable energy, in the process promoting world peace rather than threatening it.

"despite the rhetoric of a 'nuclear-renaissance', the industry is struggling with a massive increase in costs and construction delays as well as safety and security problems."

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10 'WASTE MANAGEMENT IN THE NUCLEAR FUEL CYCLE', WORLD NUCLEAR ASSOCIATION, INFORMATION AND ISSUE BRIEF, FEBRUARY 2006 (WWW.WORLD-NUCLEAR.ORG/INFO/INF04.HTM)
11 MOHAMED ELBARADEI, 'TOWARDS A SAFER WORLD', ECONOMIST, 18 OCTOBER 2003.
12 IPCC WORKING GROUP II, 'IMPACTS, ADAPTATIONS AND MITIGATION OF CLIMATE CHANGE: SCIENTIFIC-TECHNICAL ANALYSES', 1995.

image NUCLEAR REACTOR IN LIANYUNGANG, CHINA.

figure 3.1: the nuclear fuel chain

U#92

1. uranium mining

Uranium, used in nuclear power plants, is extracted from mines in a handful of countries. Over 90% of supply comes from just seven countries: Canada, Kazakhstan, Australia, Namibia, Russia, Niger and Uzbekistan. Mine workers breathe in radioactive gas from which they are in danger of contracting lung cancer. Uranium mining produces huge quantities of mining debris, including radioactive particles that can contaminate surface water and food.

2. uranium enrichment

Natural uranium and concentrated 'yellow cake' contain just 0.7% of the fissionable uranium isotope 235. To be suitable for use in most nuclear reactors, its share must go up to 3 or 5% via enrichment. This process can be carried out in 16 facilities around the world. 80% of the total volume is rejected as 'tails', a waste product. Enrichment generates massive amounts of 'depleted uranium' that ends up as long-lived radioactive waste or is used in weapons or as tank shielding.

3. fuel rod – production

Enriched material is converted into uranium dioxide and compressed to pellets in fuel rod production facilities. These pellets fill 4 metre long tubes called fuel rods. There are 29 fuel rod production facilities globally. The worst accident in this type of facility happened in September 1999 in Tokaimura, Japan, when two workers died. Several hundred workers and villagers were also exposed to radiation.

4. power plant operation

Uranium nuclei are split in a nuclear reactor, releasing energy which heats up water. The compressed steam is converted in a turbine generator into electricity. This process creates a radioactive 'cocktail' which involves more than 100 products. One of these is the highly toxic and long-lasting plutonium. Radioactive material can enter the environment through accidents at nuclear power plants. The worst accidents to date happened at Chernobyl in 1986 and Fukushima in 2011. A typical nuclear reactor generates enough plutonium every year for the production of 40 nuclear weapons.

5. reprocessing

Reprocessing involves the chemical extraction of contaminated uranium and plutonium from used reactor fuel rods. There are now over 230,000 kilograms of plutonium stockpiled around the world from reprocessing – five kilograms is sufficient for one nuclear bomb. Reprocessing is not the same as recycling: the volume of waste increases many tens of times and millions of litres of radioactive waste are discharged into the sea and air each day. The process also demands the transport of radioactive material and nuclear waste by ship, rail, air and road around the world. An accident or terrorist attack could release vast quantities of nuclear material into the environment. There is no way to guarantee the safety of nuclear transport.

6. waste storage

There is not a single final storage facility for highly radioactive nuclear waste available anywhere in the world. Safe secure storage of high level waste over thousands of years remains unproven, leaving a deadly legacy for future generations. Despite this the nuclear industry continues to generate more and more waste each day.

the energy [r]evolution

GLOBAL

KEY PRINCIPLES

FROM PRINCIPLES TO PRACTICE

A SUSTAINABLE DEVELOPMENT PATHWAY

NEW BUSINESS MODEL

THE NEW ELECTRICITY GRID

HYBRID SYSTEMS

SMART GRIDS

4

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

half the solution to climate change is the smart use of power.

image GREENPEACE AND AN INDEPENDENT NASA-FUNDED SCIENTIST COMPLETED MEASUREMENTS OF MELT LAKES ON THE GREENLAND ICE SHEET THAT SHOW ITS VULNERABILITY TO WARMING TEMPERATURES.

The climate change imperative demands nothing short of an Energy [R]evolution. 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, while at the same time maintaining economic growth. Nothing short of such a revolution will enable us to limit global warming to less than a rise in temperature of 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.

4.1 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** We must learn to respect natural limits. There is only so much carbon that the atmosphere can absorb. Each year humans emit 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.

   The global Energy [R]evolution scenario has a target to reduce energy related CO_2 emissions to a maximum of 10 Gigatonnes (Gt) by 2050 and phase out fossil fuels by 2085.

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 core 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 Advanced Energy [R]evolution scenario has 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.

4.2 from principles to practice

In 2008, renewable energy sources accounted for 13% of the world's primary energy demand[13]. Biomass, which is mostly used for heating, was the main renewable energy source. The share of renewable energy in electricity generation was 19%. 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[14].

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,

references
13 WORLD ENERGY OUTLOOK 2010, IEA 2010.
14 'ENERGY BALANCE OF NON-OECD COUNTRIES' AND 'ENERGY BALANCE OF OECD COUNTRIES', IEA, 2009.

such as China, India and Brazil, are looking to satisfy the growing energy demand created by their expanding economies.

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 Advanced 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.

4.3 a sustainable 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 Advanced 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 Reference scenario – 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 Advanced Energy [R]evolution scenario makes extensive use of Decentralised Energy (DE).

figure 4.1: energy loss, by centralised generation systems

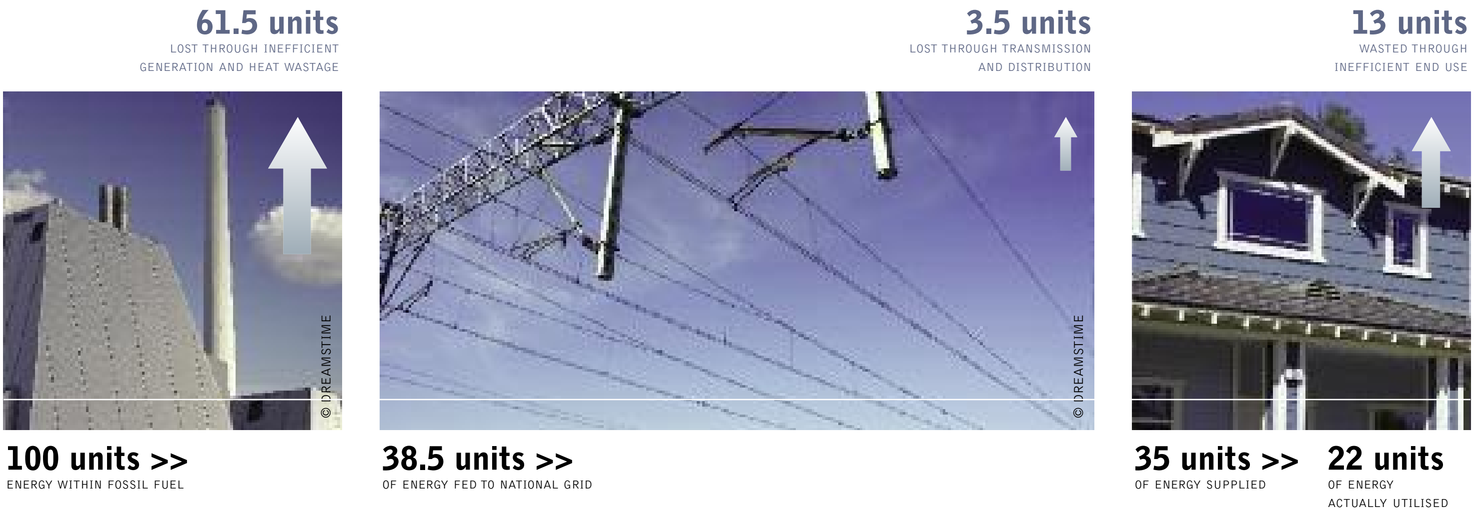


image GREENPEACE OPENS A SOLAR ENERGY WORKSHOP IN BOMA, DEMOCRATIC REPUBLIC OF CONGO. A MOBILE PHONE GETS CHARGED BY A SOLAR ENERGY POWERED CHARGER.

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.

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 Advanced 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.

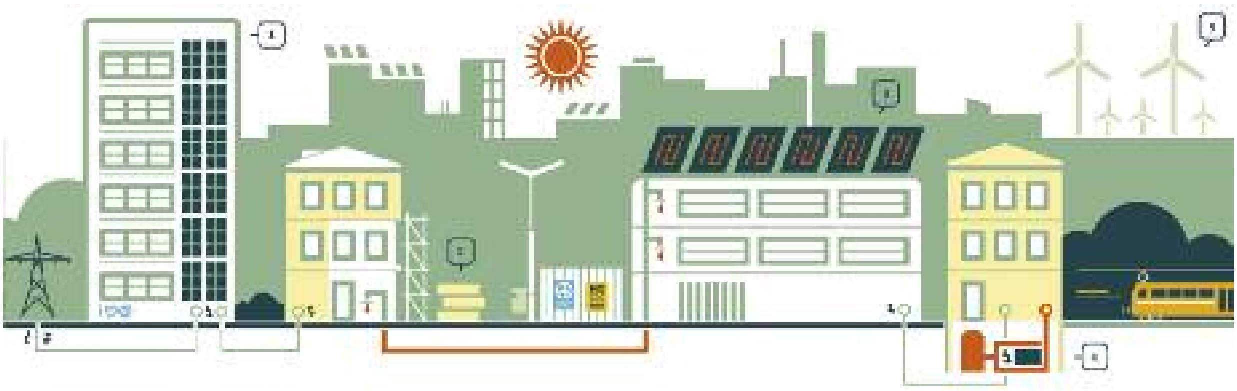
renewable heating In the heat supply sector, the contribution of renewables will increase significantly. Growth rates are expected to be similar to those of the renewable electricity sector. Fossil fuels will be increasingly replaced by more efficient modern technologies, in particular biomass, solar 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 biofuels, 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 biofuels for transport is limited by the availability of sustainably grown biomass[15]. Electric vehicles will therefore play an even more important role in improving energy efficiency in transport and substituting for fossil fuels.

figure 4.2: 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.

references
15 SEE CHAPTER 8.

Overall, to achieve an economically attractive growth of renewable energy sources, the 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.

4.4 new business model

The Advanced 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. Table 4.1 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 Advanced 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.

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 Advanced Energy [R]evolution scenario 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.

rural electrification[16] Energy is central to reducing poverty, providing major benefits in the areas of health, literacy and equity. More than a quarter of the world's population has no access to modern energy services. In sub-Saharan Africa, 80% of people have no electricity supply. For cooking and heating, they depend almost exclusively on burning biomass – wood, charcoal and dung.

table 4.1: power plant value chain

TASK & MARKET PLAYER	(LARGE SCALE) GENERATION	PROJECT DEVELOPMENT	INSTALLATION	PLANT OWNER	OPERATION & MAINTENANCE	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								
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.

Poor people spend up to a third of their income on energy, mostly to cook food. Women in particular devote a considerable amount of time to collecting, processing and using traditional fuel for cooking. In India, two to seven hours each day can be devoted to the collection of cooking fuel. This is time that could be spent on child care, education or income generation. The World Health Organisation estimates that 2.5 million women and young children in developing countries die prematurely each year from breathing the fumes from indoor biomass stoves.

The Millennium Development Goal of halving global poverty by 2015 will not be reached without adequate energy to increase production, income and education, create jobs and reduce the daily grind involved in having to just survive. Halving hunger will not come about without energy for more productive growing, harvesting, processing and marketing of food. Improving health and reducing death rates will not happen without energy for the refrigeration needed for clinics, hospitals and vaccination campaigns. The world's greatest child killer, acute respiratory infection, will not be tackled without dealing with smoke from cooking fires in the home. Children will not study at night without light in their homes. Clean water will not be pumped or treated without energy.

The UN Commission on Sustainable Development argues that "to implement the goal accepted by the international community of halving the proportion of people living on less than US $1 per day by 2015, access to affordable energy services is a prerequisite".

the role of sustainable, clean renewable energy To achieve the dramatic emissions cuts needed to avoid climate change – in the order of 80% in OECD countries by 2050 – will require a massive uptake of renewable energy. The targets for renewable energy must be greatly expanded in industrialised countries both to substitute for fossil fuel and nuclear generation and to create the necessary economies of scale necessary for global expansion. Within the Energy [R]evolution scenario we assume that modern renewable energy sources, such as solar collectors, solar cookers and modern forms of bio energy will replace inefficient, traditional biomass use.

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 Advanced 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 Advanced 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 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'[17].

4.5 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.

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 4.3).

references

16 'SUSTAINABLE ENERGY FOR POVERTY REDUCTION: AN ACTION PLAN', IT POWER/GREENPEACE INTERNATIONAL, 2002.

17 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.

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.

4.6 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 "Renewables 24/7" report - 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.

4.7 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.

elements in the new power system architecture

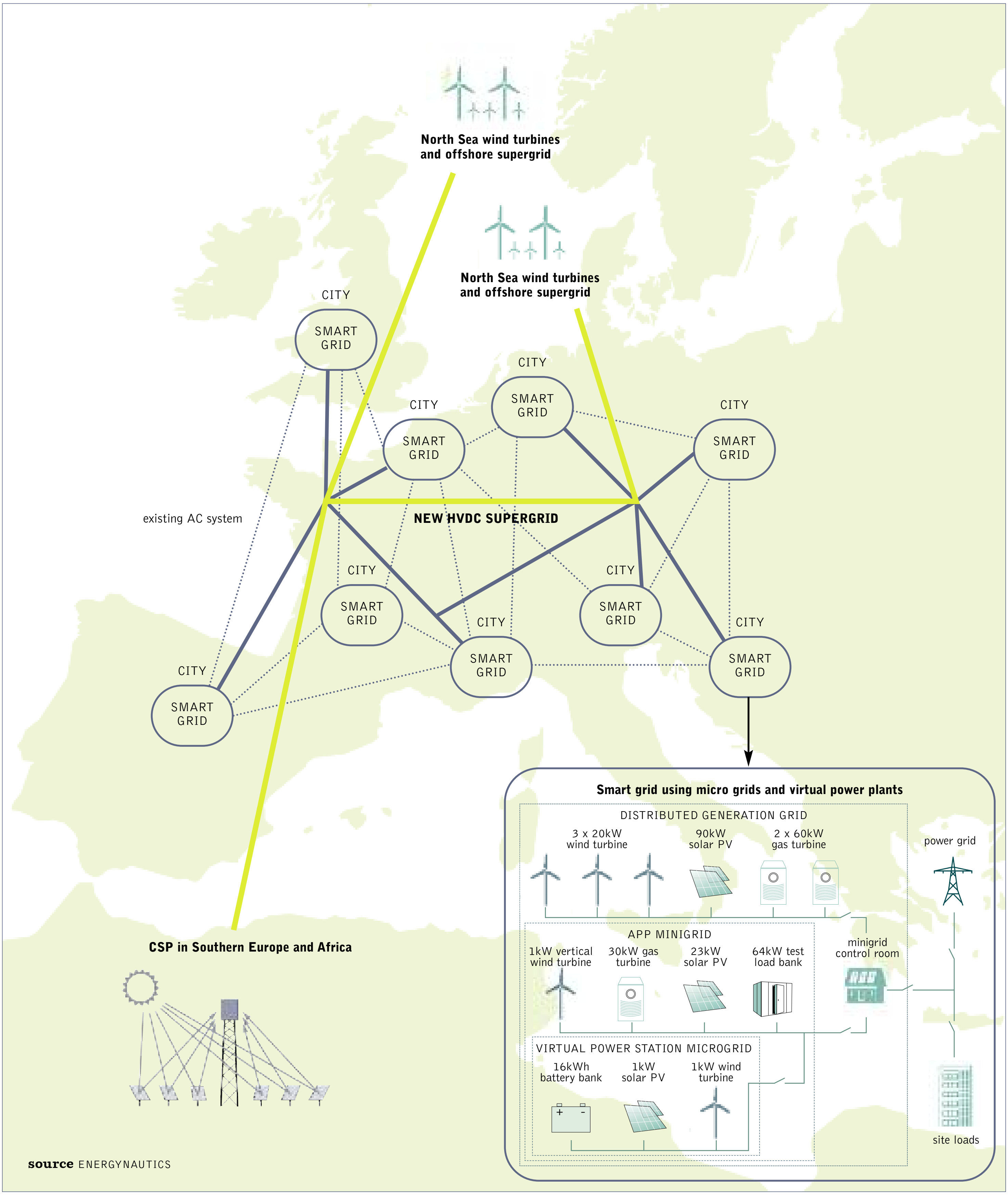
A **hybrid system** based on more than one generating source, for example solar and wind power, is a method of providing a secure supply in remote rural areas or islands, especially where there is no grid-connected electricity. This is particularly appropriate in developing countries. In the future, 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.

figure 4.3: overview of the future power system with high penetration of renewables



source ENERGYNAUTICS

Integrating renewable energy by using a smart grid means moving away from the issue of baseload power and 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[18]. Figure 4.4 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.

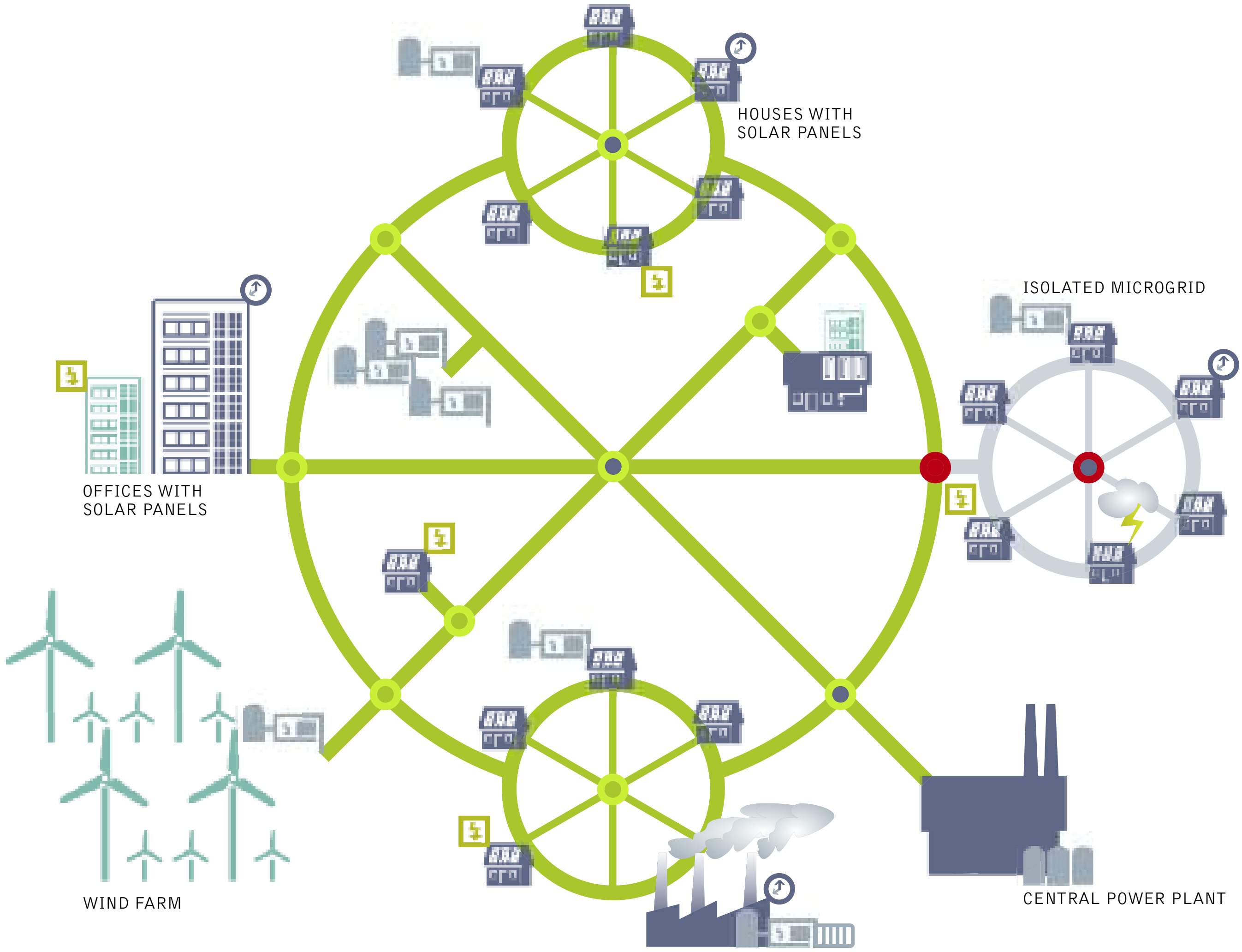
A **Virtual Power Plant** (VPP) interconnects a range of real power plants (for example solar, wind and hydro) as well as storage options distributed in the power system using information technology. A real life example of a VPP is the Combined Renewable Energy Power Plant developed by three German companies[19]. 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[20]. Together the combination ensures sufficient electricity supply to cover demand.

references
18 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
19 SEE ALSO HTTP://WWW.KOMBIKRAFTWERK.DE/INDEX.PHP?ID=27
20 SEE ALSO HTTP://WWW.SOLARSERVER.DE/SOLARMAGAZIN/ANLAGEJANUAR2008_E.HTML

image CHECKING THE SOLAR PANELS ON TOP OF THE GREENPEACE POSITIVE ENERGY TRUCK IN BRAZIL.

figure 4.4: 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

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.

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 Advanced 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.

4.8 the super grid

A Greenpeace simulation study has shown that extreme situations with low solar radiation and little wind in many parts of Europe are not frequent, but they can occur (see box "A European Super Grid"). The power system, even with massive amounts of renewable energy, must be adequately designed to cope with such an event. A key element in achieving this is through the construction of new onshore and offshore super grids.

In the Energy Revolution scenario it is assumed that about 70% of all generation is distributed and located close to load centres. The remaining 30% will be large scale renewable generation such as large offshore wind farms or large arrays of concentrating solar power plants. A North Sea offshore super grid, for example, would enable the efficient integration of renewable energy into the power system across the whole North Sea region, linking the UK, France, Germany, Belgium, the Netherlands, Denmark and Norway. By aggregating power generation from wind farms spread across the whole area, periods of very low or very high power flows would be reduced to a negligible amount. A dip in wind power generation in one area would be balanced by higher production in another area, even hundreds of kilometres away. Over a year, an installed offshore wind power capacity of 68.4 GW in the North Sea would be able to generate an estimated 247 TWh of electricity.

The cost of developing the grid is expected to be between €15 and 20 billion. This investment would not only allow the broad integration of renewable energy but also unlock unprecedented power trading opportunities and cost efficiency. In a recent example, a new 600 kilometre-long power line between Norway and the Netherlands cost €600 million to build, but is already generating a daily cross-border trade valued at €800,000[21].

reference
21 GREENPEACE REPORT, 'NORTH SEA ELECTRICITY GRID [R]EVOLUTION', SEPTEMBER 2008.

image A WOMAN STUDIES SOLAR POWER SYSTEMS AT THE BAREFOOT COLLEGE. THE COLLEGE SPECIALISES IN SUSTAINABLE DEVELOPMENT AND PROVIDES A SPACE WHERE STUDENTS FROM ALL OVER THE WORLD CAN LEARN TO UTILISE RENEWABLE ENERGY. THE STUDENTS TAKE THEIR NEW SKILLS HOME AND GIVE THEIR VILLAGES CLEAN ENERGY.

[r]enewables 24/7 – towards 100% renewables

The Greenpeace report "[R]enewables 24/7" examined weather patterns across Europe in order to work out what kind of grid technology would be needed to achieve a secure power supply based on the Energy Revolution energy mix, which relies extensively on variable sources such as wind and solar power. Although we know that there are technically enough resources to power the whole continent with renewables – solar in the south, wind in the north plus geothermal, biomass and cogeneration – a new network of interactive smart grids will be needed, in turn interconnected with a 'super grid' providing transmission capacity for large scale renewables such as offshore wind and concentrated solar power. This new grid design also needs to take into account rare events when weather-based renewable energy in certain areas drops below the supply level needed. To evaluate the frequency of extreme events, the study analysed Europe-wide wind data for the last 30 years. The resulting simulations showed that problems could occur particularly in winter, when electricity demand is high and solar production low. Over the last 30 years, however, the potential power production from wind during the winter months in the Energy [R]evolution scenario would have dropped below 50 GW for only 0.4% of the time, equivalent to once a year if the average duration of the event was 12 hours. In terms of the balance between wind and solar production, the study selected key 'extreme events' and created a model of power supply based on the Energy [R]evolution supply mix. The results were:

- In an extreme summer event of high demand and extremely low wind (as in August 2003), the available power from locally distributed solar PV would be enough to compensate for the lack of wind. Therefore no change to the existing grid would be needed.
- In an extreme winter event of high demand and low solar power production in most parts of Europe, combined with low wind power production in Central and Northern Europe (as in January 1997), electricity would have to be transmitted from Northern Europe (mainly hydro power) and from Southern Europe (mainly solar power) into Central Europe. For this to be achieved by renewable energy, a new super grid would be needed.
- In an extreme autumn event (as in November 1987), with very low solar radiation and low wind production, reinforcement of the existing high voltage grid, as well as installation of the proposed super grid, would be sufficient.

To be able to provide a reliable, secure power supply to Europe, taking into account extreme weather and high demand scenarios, the study looked into grid expansion and optimization possibilities for the needed infrastructure. Part 1 has been published in February 2010 and part 2 in February 2011.

1. In 2030, gas plants provide most of the non-renewable electricity and serve as a flexible backup for wind and solar power. Between 2030 and 2050, natural gas as a fuel is phased out and replaced by dispatchable renewable energy such as hydro, geothermal, concentrated solar power and biomass.

2. Because coal and nuclear plants are too inflexible and cannot sufficiently respond to variations in wind or solar generation, 90% of the existing coal and nuclear plants have to be phased out by 2030, and by 2050 they are completely phased out.

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

4. Between 2030 and 2050, two different scenario's have been analysed in this report. In a 'High Grid' scenario, the European grid could be connected to North Africa to take advantage of the intense solar radiation. This would lower the cost to produce electricity, but increases investments in transmission to €466 billion between 2030 and 2050. In the 'Low Grid' scenario, more renewable energy is produced closer to regions with a high demand (large cities and heavy industry). This lowers the investment in transmission to only €23 billion for 2030-50, but increases the costs to produce electricity because more solar panels will be installed in less sunny regions. In between those two very distinct High and Low Grid scenarios, many intermediate combinations are possible.

5. At the moment, wind turbines are often regularly switched off during periods of high electricity supply, to give priority to nuclear or coal fired power, which is a bad decision for the planet. To win the battle of the grids, priority dispatching for renewable energy on the European grids will be needed, including priority on the interconnections between countries, because their surplus production can be exported to other regions with a net demand.

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

- Even if technical adaptations would enable coal and nuclear plants to become more flexible and 'fit in' the renewable mix, they would be needed for only 46% of the year by 2030 and further decreasing afterwards, making investments in a nuclear reactor of some €6 billion highly uneconomic. Building a new nuclear reactor is a very high risk for investors.
- In a 'Dirty Scenario', of the future with a share of inflexible coal and nuclear plants in 2030 close to what is installed today, the renewable sources will have to be switched off more often and the cost of this lost renewable production will raise to €15 billion/year.
- Flexible gas plants are less capital intensive than nuclear plants and could thus still economically produce at a load factor of 46% by 2030, functioning as a backup for variable renewable power. After 2030, gas plants can be converted progressively to use biogas, avoiding stranded investments in both production plants and gas grids.

scenarios for a future energy supply

GLOBAL

PRICE PROJECTIONS FOR FOSSIL FUELS AND BIOMASS

COST OF CO_2 EMISSIONS

COST PROJECTIONS FOR EFFICIENT FOSSIL FUEL GENERATION

COST PROJECTIONS FOR RENEWABLE ENERGY TECHNOLOGIES

5

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

towards a sustainable global energy supply system.

image THE MARANCHON WIND TURBINE FARM IN GUADALAJARA, SPAIN IS THE LARGEST IN EUROPE WITH 104 GENERATORS, WHICH COLLECTIVELY PRODUCE 208 MEGAWATTS OF ELECTRICITY, ENOUGH POWER FOR 590,000 PEOPLE, ANUALLY.

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. Two different kinds of scenario 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 the Energy [R]evolution Scenarios, which are designed to achieve a set of dedicated environmental policy targets.

The Reference Scenario is based on the Swedish energy agency's long term prognosis until 2030. The energy agency in its series of long term analysis, looks at the energy system development under current policies and an analysis of market developments and energy consumption and production in the longer term. The last such long term analysis was published in 2009 with a time horizon to 2030.

5.1 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.

5.2 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 $10/t$CO_2$ in 2010, rising to $50/t$CO_2$ by 2050. Additional CO_2 costs are applied in Kyoto Protocol Non-Annex B (developing) countries only after 2020.

table 5.1: 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.

table 5.2: assumptions on CO_2 emissions cost development

($/t$CO_2$)

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

5.3 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[22].

There is much speculation about the potential for 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 tonne of captured CO_2[23], while a recent US Department of Energy report found installing carbon capture systems to most modern plants resulted in a near doubling of costs[24]. These costs are estimated to increase the price of electricity in a range from 21-91%[25].

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[26]. 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[27].

The Intergovernmental Panel on Climate Change estimates a cost range for pipelines of €1-7/tonne of CO_2 transported[28]. Storage and subsequent monitoring and verification costs are estimated by the IPCC 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[29].

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

Table 5.3 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 5.3: 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

22 'GREENPEACE INTERNATIONAL BRIEFING: CARBON CAPTURE AND STORAGE', GOERNE, 2007.
23 ABANADES, J C ET AL., 2005, PG 10.
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25 RUBIN ET AL., 2005A, PG 40.
26 RAGDEN, P ET AL., 2006, PG 18.
27 HEDDLE, G ET AL., 2003, PG 17.
28 PARFOMAK, P & FOLGER, P, 2008, PG 5 AND 12.
29 RUBIN ET AL., 2005B, PG 4444.

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.

5.4 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 Advanced Energy [R]evolution scenario are derived from a review of learning curve studies, for example by Lena Neij and others[30], from the analysis of recent technology foresight and road mapping studies, including the European Commission funded NEEDS project (New Energy Externalities Developments for Sustainability)[31] 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.

5.4.1 photovoltaics (pv)

The worldwide PV market has been growing at over 40% 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 5.4: 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**

30 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.
31 WWW.NEEDS-PROJECT.ORG

5.4.2 concentrating solar power (CSP)

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.

5.4.3 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 5.5: 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 5.6: 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**

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

5.4.4 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.

5.4.5 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 5.7: 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 5.8: 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**

- for conventional geothermal power, from 5.8 €cents/kWh to about 1.6 €cents/kWh;
- for EGS, despite the presently high figures (about 17 €cents/kWh), electricity production costs - depending on the payments for heat supply - are expected to come down to around 4 €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.

5.4.6 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[38].

5.4.7 hydro power

Hydro power 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-off river projects with little or no reservoir impoundment) and for repowering of existing sites. The significance of hydro power 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 hydro power which makes an effort to integrate plants with river ecosystems while reconciling ecology with economically attractive power generation.

table 5.9: ocean energy cost assumptions

	2007	2015	2020	2030	2040	**2050**
Energy [R]evolution						
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 5.10: hydro power cost assumptions

	2007	2015	2020	2030	2040	**2050**
Energy [R]evolution						
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**

38 WWW.NEEDS-PROJECT.ORG

image A COW IN FRONT 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.

5.4.8 summary of renewable energy cost development

Figure 5.1 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 5.2. Generation costs today are around 8 to 25 €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.

figure 5.1: future development of renewable energy investment costs (NORMALISED TO CURRENT COST LEVELS) FOR RENEWABLE ENERGY TECHNOLOGIES

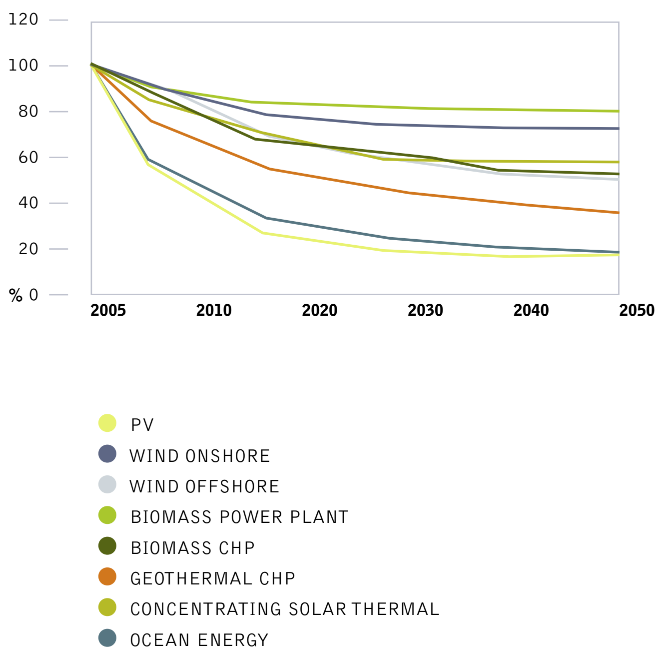
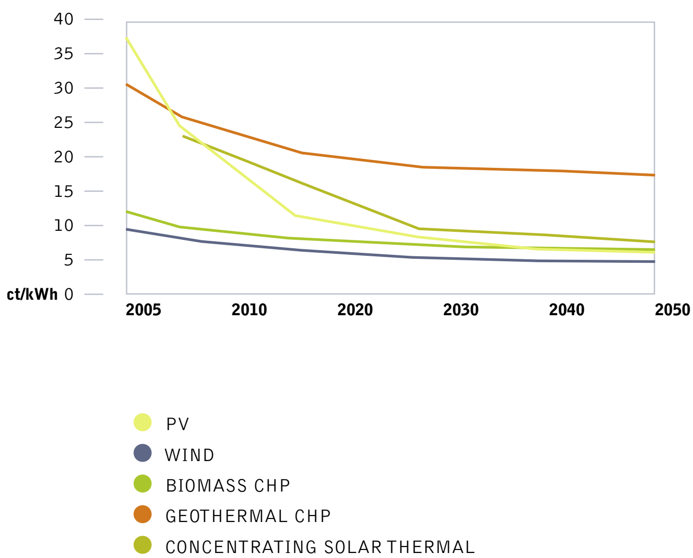
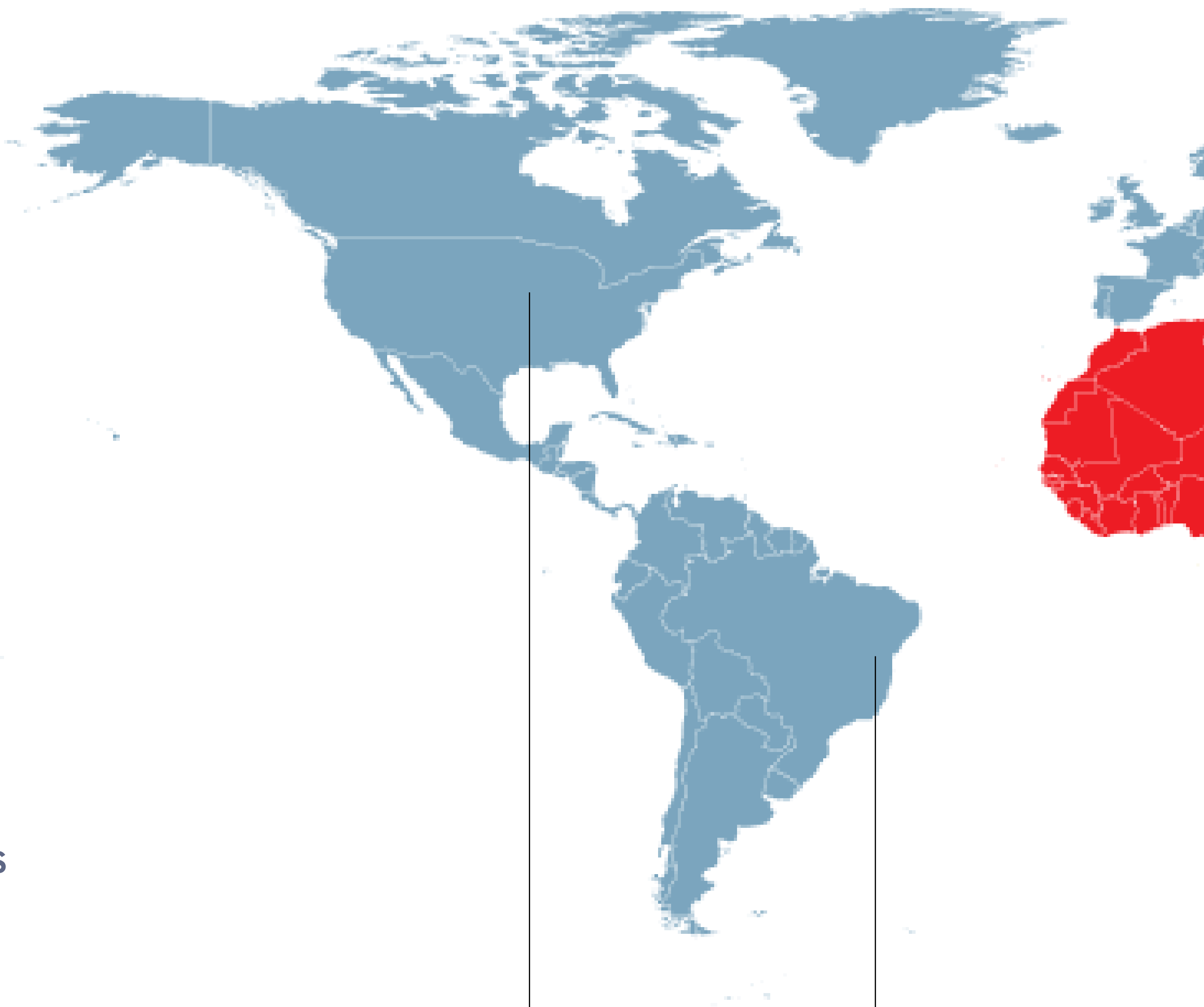


figure 5.2: expected development of electricity generation costs



map 5.1: 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

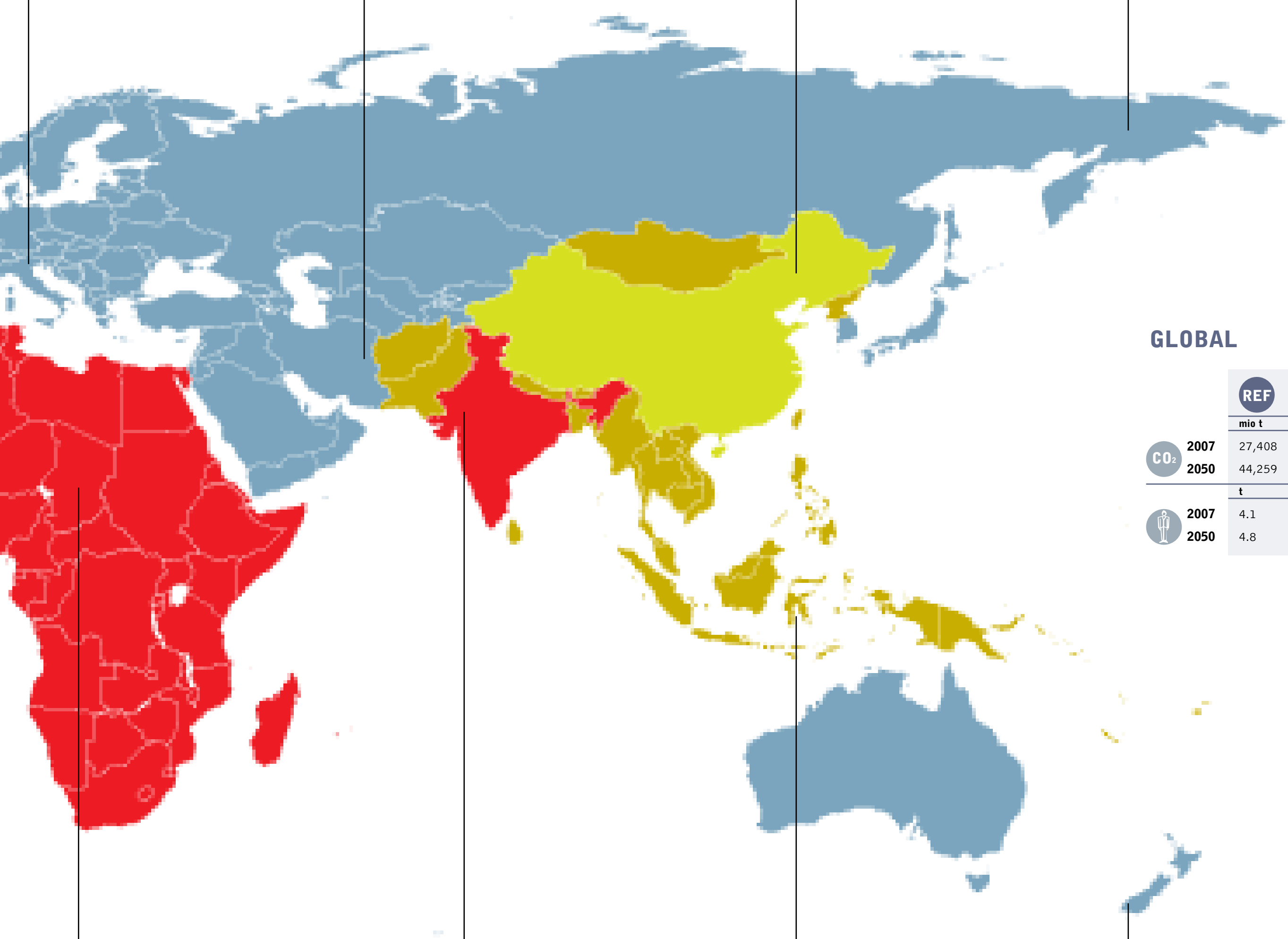
		REF		E[R]	
		mio t	%	mio t	%
CO_2	2007	1,374	234	1,374	234
	2050	3,208	546	122	21
		t		t	
	2007	6.79M		6.79	
	2050	9.08		0.35	

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

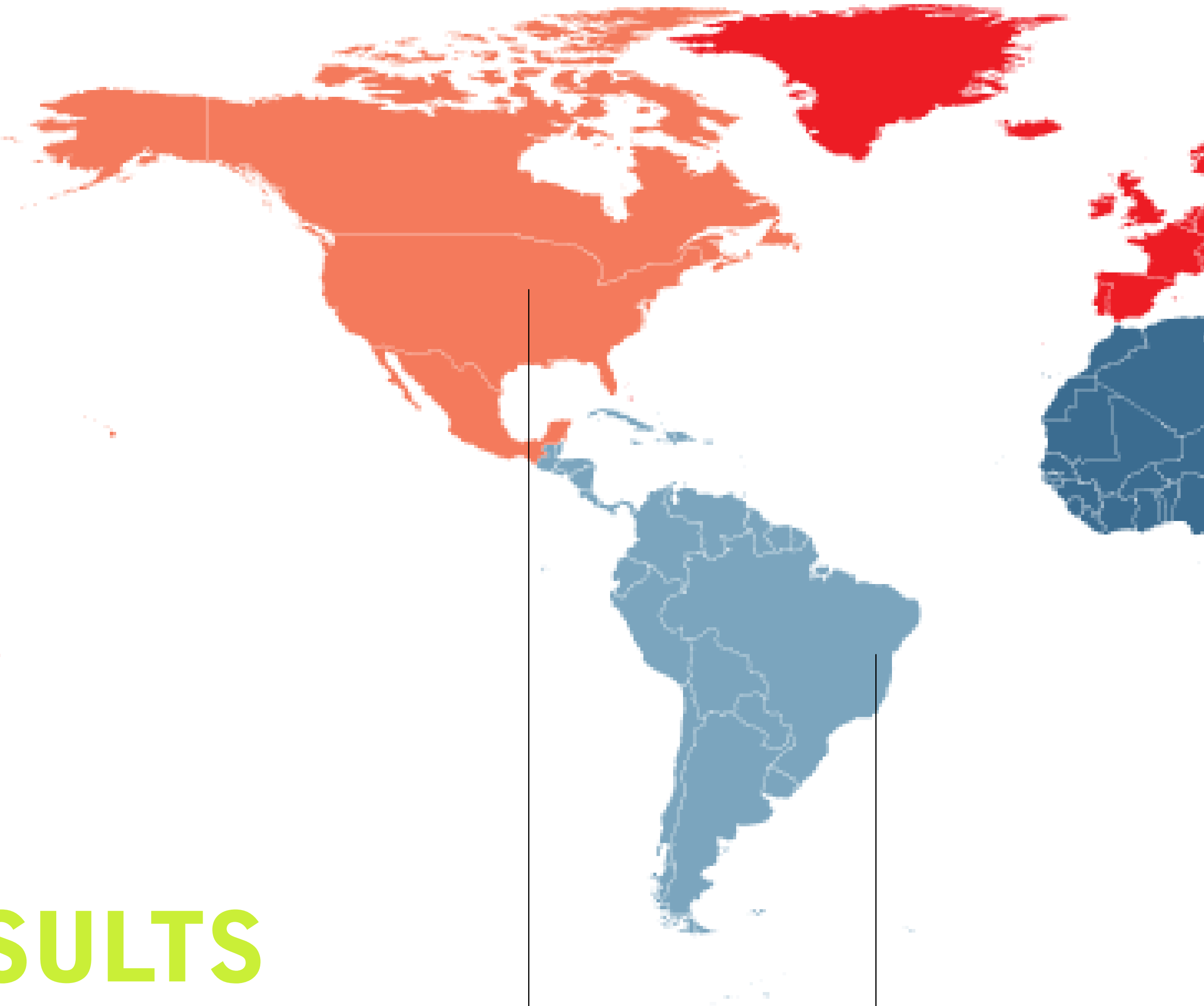
		REF		E[R]	
		mio t	%	mio t	%
CO_2	2007	1,488	216	1,488	216
	2050	3,846M	557	428	62
		t		t	
	2007	1.47		1.47	
	2050	2.54		0.28	

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

WORLDWIDE SCENARIO



SCENARIO
RESULTS

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		

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

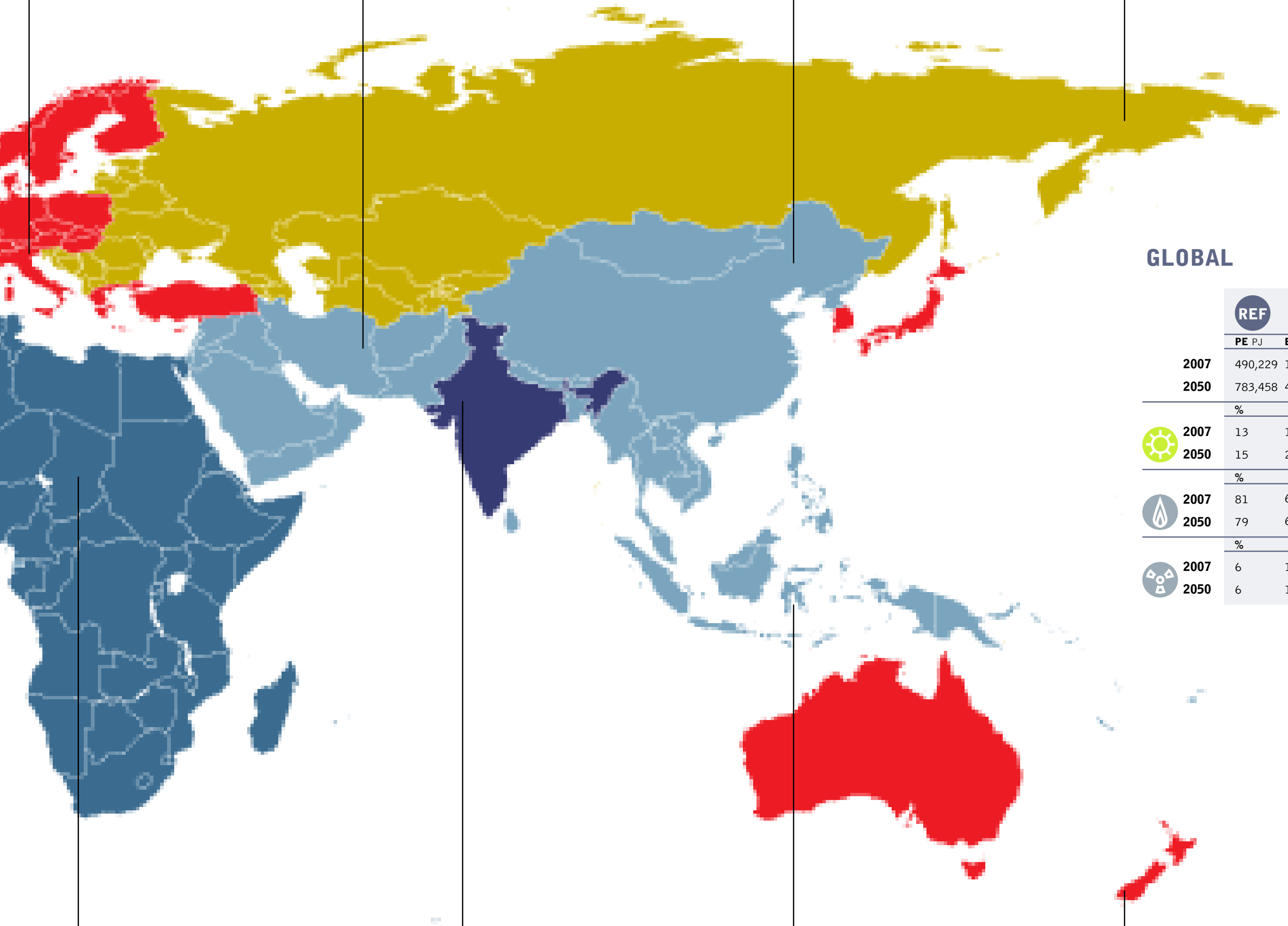
	REF PE PJ	REF EL TWh	E[R] PE PJ	E[R] EL TWh
2007	21,372	715	21,372	715
2050	51,281	2,404	27,475	2,786L
	%		%	
2007	1L	3	1L	3L
2050	2L	7	76	99H
	%		%	
2007	99H	97	99H	97H
2050	97H	92	23	1L
	%		%	
2007	0L	0	NO NUCLEAR ENERGY DEVELOPMENT	
2050	0L	0		

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 sweden energy [r]evolution scenario

SWEDEN

6

image SOLAR PANEL. © BERND JUERGENS/DREAMSTIME

"we want sweden to be the first country in the world to have an energy system based wholly on renewable energy."

ENVIRONMENT MINISTER CARLGREN
IN DEBATE ARTICLE SUMMER 2011

image WIND TURBINES IN THE SOUTH OF SWEDEN.

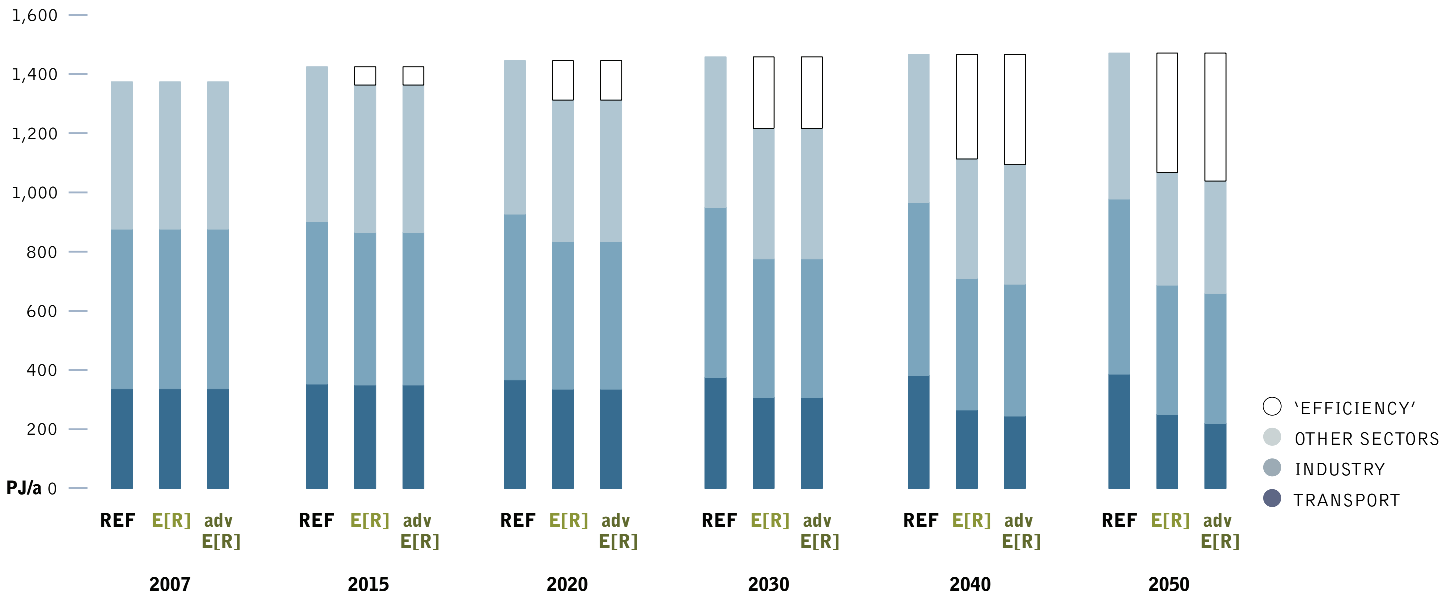
image BIOMASS ENERGY PLANT NEAR VARNAMO, SMÅLAND, SWEDEN.

6.1 development of energy demand to 2050

The future development pathways for Sweden's energy demand are shown in Figure 6.1. Under the Reference scenario, total primary energy demand in Sweden increases by 8% from the current 2,200 PJ/a to 2,370 PJ/a in 2050. The energy demand in 2050 under the Basic Energy [R]evolution scenario decreases by 37% and 39% in the Advanced case, compared to current consumption. By 2050 it is expected to reach 1,390 PJ/a and 1,340 PJ/a respectively. Under the Advanced Energy [R]evolution scenario, electricity demand in the industrial, residential and service sectors is expected to decrease after 2015 (see Figure 6.2). Efficiency measures in industry and other sectors avoid the generation of about 25 TWh/a (30 TWh/a in the Energy [R]evolution scenario) compared to the Reference scenario.

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 36 TWh/a in the Advanced scenario in 2050 (33 TWh/a in the Basic Energy [R]evolution scenario), compared to 5 TWh/a in the Reference scenario. In the transport sector, it is assumed under the Energy [R]evolution scenario that energy demand will decrease to 220 PJ/a by 2050, saving 43% 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.

figure 6.1: projection of total final energy demand by sector under three scenarios



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 6.3). Compared to the Reference scenario, heat consumption equivalent to 150 PJ/a, or 25%, in the Advanced case 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 houses' for new buildings, enjoyment of 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 electricity demand rising to 170TWh in the Advanced Energy [R]evolution by 2050.

figure 6.2: development of electricity demand by sector under both energy [r]evolution scenarios

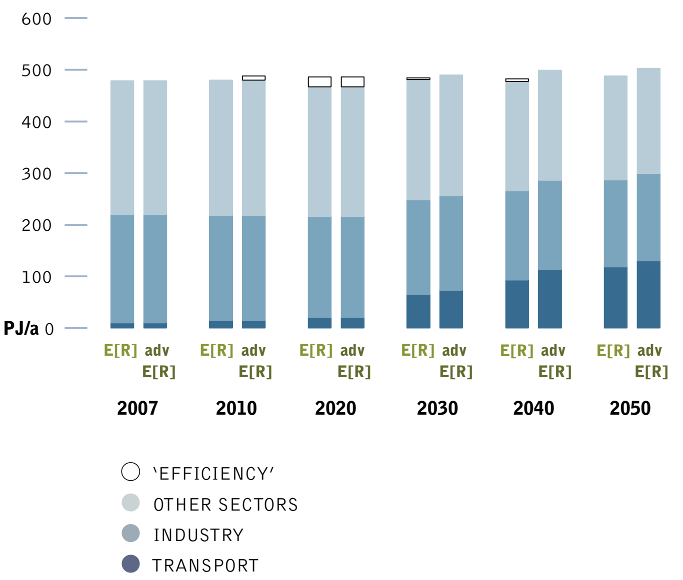


figure 6.3: development of heat demand by sector under both energy [r]evolution scenarios

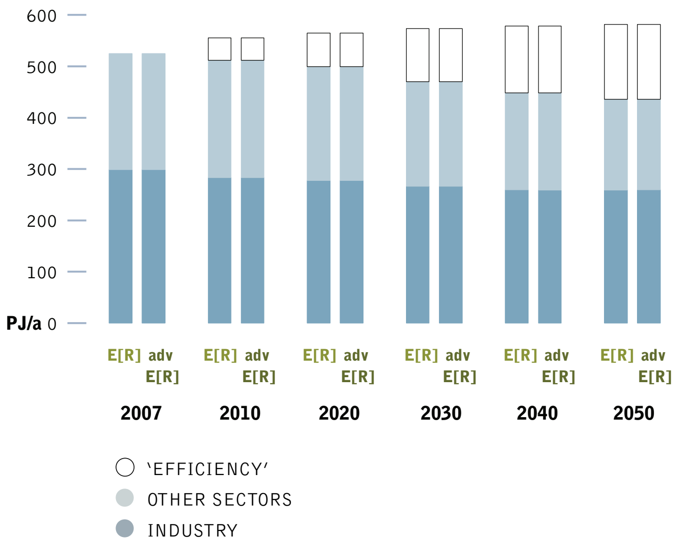
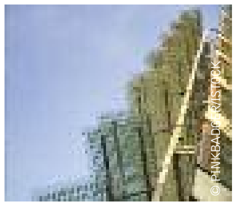


image A DOMESTIC SOLAR HEATING INSTALLATION, SWEDEN.

image SOLAR PANELS ON AN OFFICE BUILDING IN KISTA, SWEDEN.



6.2 electricity generation

The future development pathways for Sweden's energy demand are showThe 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, all the electricity produced in Sweden will come from renewable energy sources (100%).

Figure 6.4 shows the evolution of the electricity mix in Sweden under 3 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 and geothermal. The Advanced Energy [R]evolution scenario will lead to a higher share of variable power generation sources (photovoltaic, wind and ocean) of 35% by 2030 and of 36% by 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 19 GW to 57 GW in 2050, increasing renewable capacity by a factor of 3 (see Table 6.1) in the Advanced Energy [R]evolution scenario. Wind power and photovoltaics will cover around 57% of the total installed renewable capacity. The remaining capacity is mainly provided by hydro power and biomass.

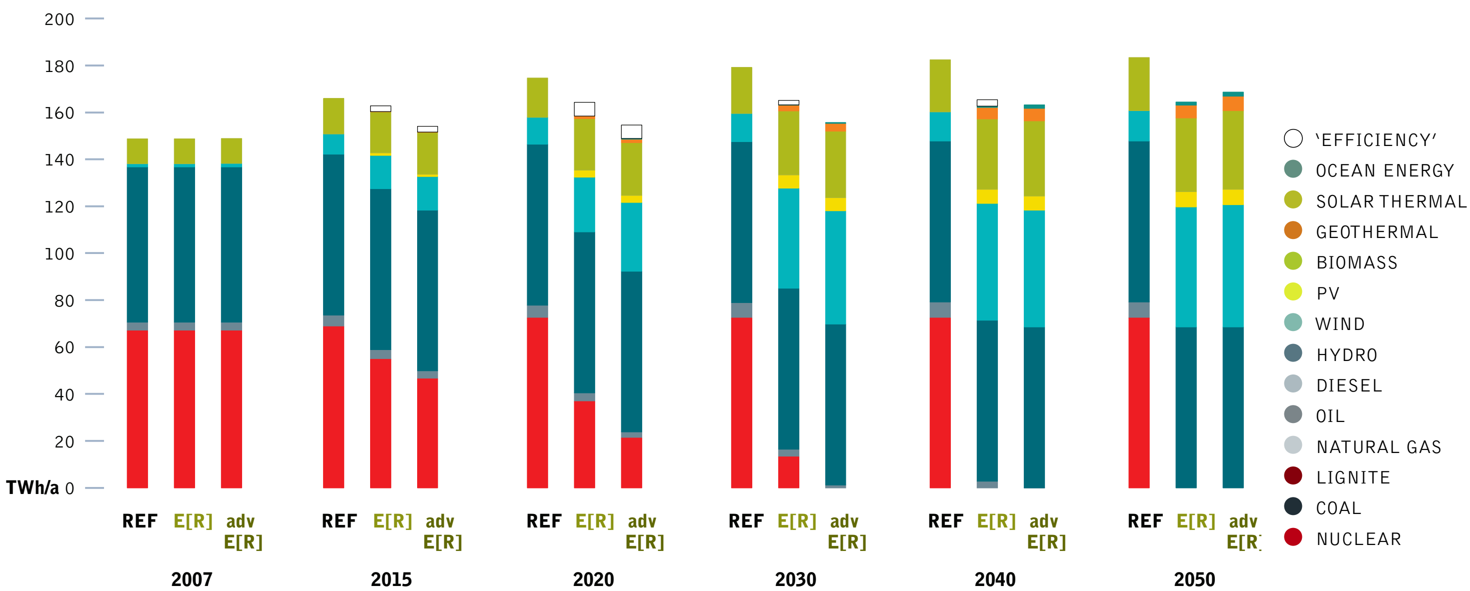
table 6.1: projection of renewable electricity generation capacity under both energy [r]evolution scenarios

IN GW

		2007	2020	2030	2040	2050
Hydro	E[R]	16	16	16	16	16
	Advanced E[R]	16	16	16	16	16
Biomass	E[R]	2	4	5	6	6
	Advanced E[R]	2	4	5	6	6
Wind	E[R]	1	11	21	24	24
	Advanced E[R]	1	14	24	24	25
Geothermal	E[R]	0	0	0	1	1
	Advanced E[R]	0	0	1	1	1
PV	E[R]	0	4	6	7	7
	Advanced E[R]	0	4	6	7	7
CSP	E[R]	0	0	0	0	0
	Advanced E[R]	0	0	0	0	0
Ocean energy	E[R]	0	0	0	0	0
	Advanced E[R]	0	0	0	1	1
Total	**E[R]**	**19**	**36**	**49**	**54**	**56**
	Advanced E[R]	**19**	**39**	**52**	**54**	**57**

figure 6.4: development of electricity generation structure under three scenarios

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



6.3 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 6.5). This difference will be about 0.3 euro cent/kWh. In 2050, the specific costs for one kWh add up to 6.2 euro cent in the Advanced scenario, 6.3 euro cent in the Basic Energy [R]evolution scenario and 7.2 euro cent in the Reference scenario. Under the Reference scenario, the growth in demand, the increase in fossil fuel prices and the cost of CO_2 emissions result in total electricity supply costs rising from today's €7 billion per year to €10 billion in 2050. Figure 6.5 shows that the Energy [R]evolution scenarios not only comply with Sweden's CO_2 reduction targets but also help to stabilise energy costs in the long term. Increasing energy efficiency and shifting energy supply to renewables result in long term costs for electricity supply that are even lower in the Advanced and in the Energy [R]evolution scenario than in the Reference case. This is possible because of decreasing specific investment costs for renewable technologies as a result of increasing global production volumes and corresponding learning curves. In spite of the increased electricity demand especially in the transport and industry sector the overall total supply costs in the Advanced case are €0.4 billion in 2030 lower than in the Energy [R]evolution scenario and nearly equal in 2050.

figure 6.5: development of total electricity supply costs & development of specific electricity generation costs under three scenarios

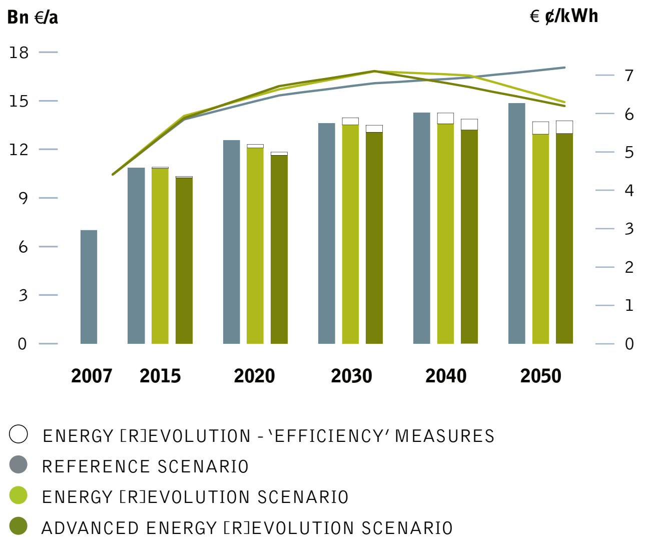
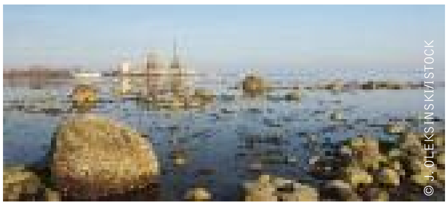


image THE DECOMISSIONED BARSEBÄCK NUCLEAR POWER STATION, SWEDEN.

image HAMMARBY THERMAL POWER PLANT, SWEDEN.



6.4 future investment

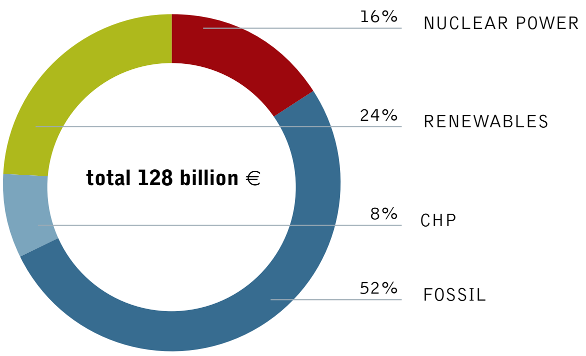
It would require €154 billion in investment for the Advanced Energy [R]evolution scenario to become reality – approximately €600 million annual more than in the Reference scenario (€2.95 billion). Under the Reference version, the levels of investment in fossil and nuclear power plants add up to almost 68% while approx 32% would be invested in renewable energy and cogeneration until 2050. Under the Advanced scenario, however, Sweden would shift the entire investment towards renewables and cogeneration. The average annual investment in the power sector under the Advanced Energy [R]evolution scenario between today and 2050 would be approximately €3.6 billion.

Because renewable energy has no fuel costs, however, the fuel cost savings in the Basic Energy [R]evolution scenario reach a total €31.2 billion, or €700 million per year. The Advanced Energy [R]evolution has even higher fuel cost savings of €41.3 billion, or €1 billion per year.

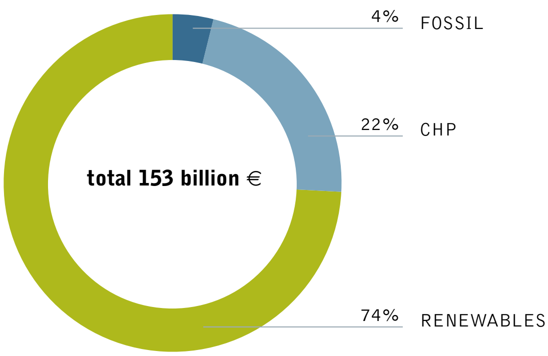
Under the advance Energy [R]evolution scenario, the average annual additional fuel cost savings are equal to the additional annual investment of €1 billion. Therefore fuel cost savings compensate for the entire investment in renewable and cogeneration capacity required to implement the Advanced scenario. These renewable energy sources would then go on to produce electricity without any further fuel costs beyond 2050, while the costs for coal and gas will continue to be a burden on national economies.

figure 6.6: investment shares - reference versus energy [r]evolution scenarios

reference scenario 2007 - 2050



energy [r]evolution scenario 2007 - 2050



advanced energy [r]evolution scenario 2007 - 2050

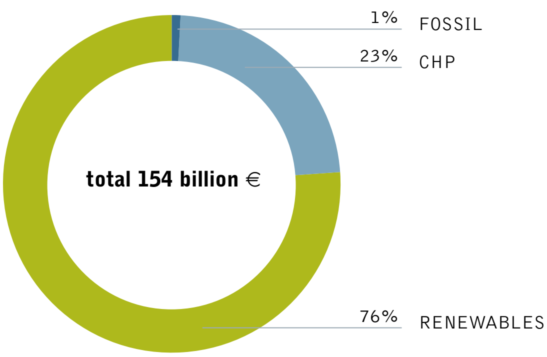


figure 6.7: change in cumulative power plant investment in both energy [r]evolution scenarios

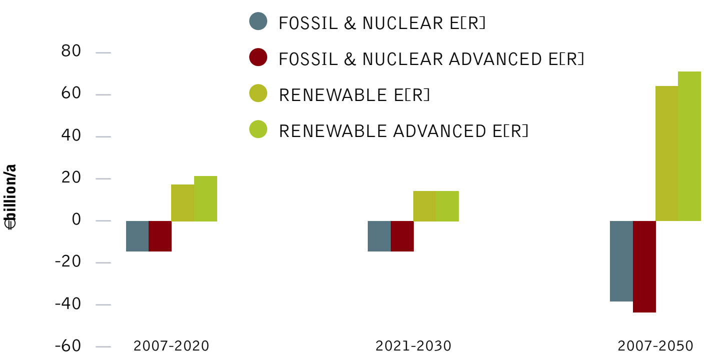


figure 6.8: renewable energy investment costs

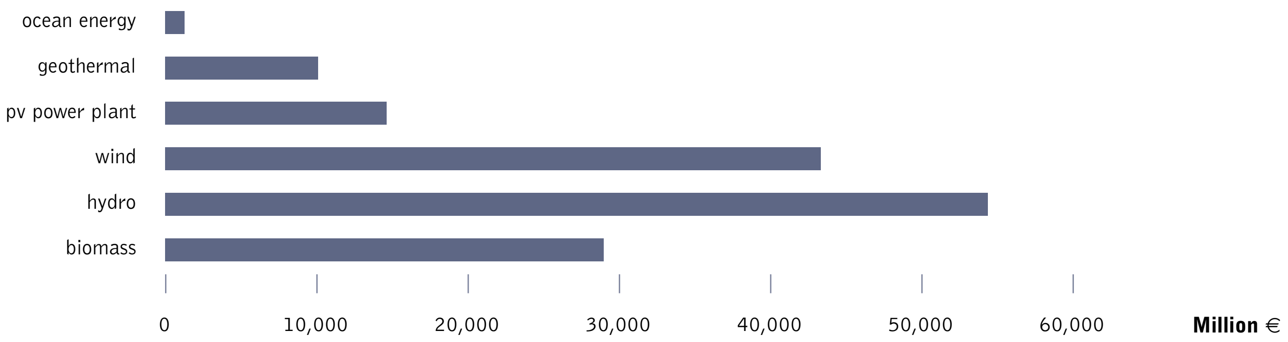


table 6.2: fuel cost savings and investment costs under three scenarios

INVESTMENT COST	EURO	2007-2020	2021-2030	2007-2050	2007-2050 AVERAGE PER YEAR
SWEDEN (2011) DIFFERENCE E[R] VERSUS REF					
Conventional (fossil & nuclear)	billion €	-15	-15	-38	-1
Renewables (incl. CHP)	billion €	18	14	62	1
Total	billion €	**3**	**0**	**24**	**1**
SWEDEN (2011) DIFFERENCE ADV E[R] VERSUS REF					
Conventional (fossil & nuclear)	billion €	-15	-14	-44	-1
Renewables (incl. CHP)	billion €	21	14	69	2
Total	billion €	**7**	**1**	**25**	**1**
CUMULATED FUEL COST SAVINGS					
SAVINGS E[R] CUMULATED IN €					
Fuel oil	billion €/a	0.4	1.4	4.9	0.1
Gas	billion €/a	0.2	1.0	6.2	0.3
Hard coal	billion €/a	0.2	0.4	1.5	0.0
Total	billion €/a	**2.0**	**6.6**	**31.2**	**0.7**
SAVINGS ADV E[R] CUMULATED IN €					
Fuel oil	billion €/a	0.5	1.4	5.0	0.1
Gas	billion €/a	0.7	2.1	13.9	0.3
Hard coal	billion €/a	0.2	0.4	1.6	0.0
Total		**3.1**	**8.9**	**41.3**	**1.0**

image SWEDISH TRAIN IN DALARNA, SWEDEN.

image A HYDROELECTRIC POWER STATION IN SWEDEN.

6.5 heating and cooling supply

Renewables currently provide 65% of Sweden primary energy demand for heat supply, mostly through biomass. The high investment costs are currently a severe barrier to the large scale utilisation of geothermal energy for district heating. In the Advanced Energy [R]evolution scenario, renewables provide 99% of Sweden total heating and cooling demand by 2050. This value is 7 percentage points higher than in the Energy [R]evolution scenario. The high renewable share is due to two main effects:

- Strict energy efficiency measures through tight building standards and renewable heating systems, among other things, are introduced in both Energy [R]evolution scenarios. They can decrease the current demand for heat supply by 150 PJ/a or 25%, compared to the Reference scenario by 2050.
- 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 (99%).

6.6 transport

For the transport sector, the Advanced Energy [R]evolution scenario assumes that energy demand will decrease by 35% of current level to 220 PJ/a by 2050 (250 PJ/a in the Energy [R]evolution scenario), saving 43% 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 see the car stock grow more slowly than in the Reference scenario. A shift towards biogas, electrified road vehicles, triggered by economic incentives, will also contribute, as will a reduction of annual vehicle kilometres travelled. New investments in the Swedish railway will also be necessary to meet the shift in the transport sector.

In 2030, electricity will provide 24% of the transport sector's total energy demand in the Advanced Energy [R]evolution scenario (21% in the Basic Energy [R]evolution scenario) and increase to 59% (48% respectively) by 2050. Hydrogen is introduced in the energy system as one option for the chemical storage of excess renewable power. It could be used as additional renewable fuel in the transport sector depending on market developments in combustion engines or fuel cell vehicles but also, converted to renewable methane, in CNG vehicles.

figure 6.9: development of heat supply structure under three scenarios

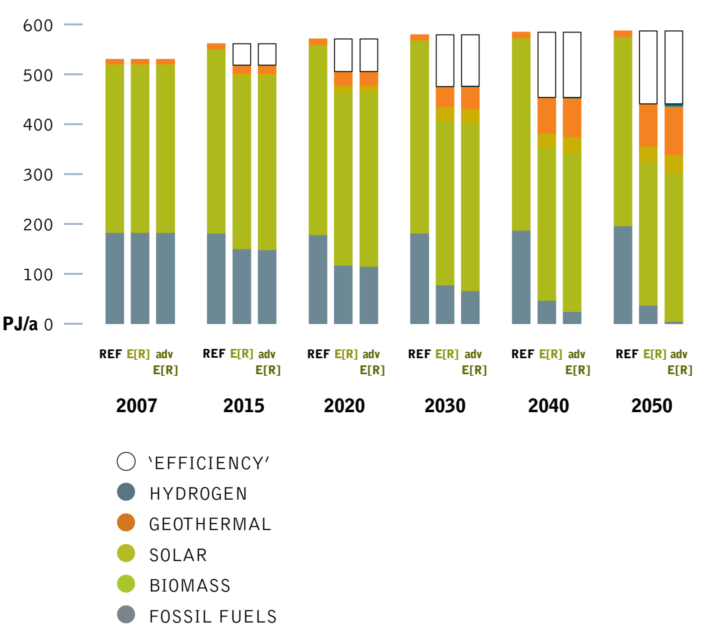
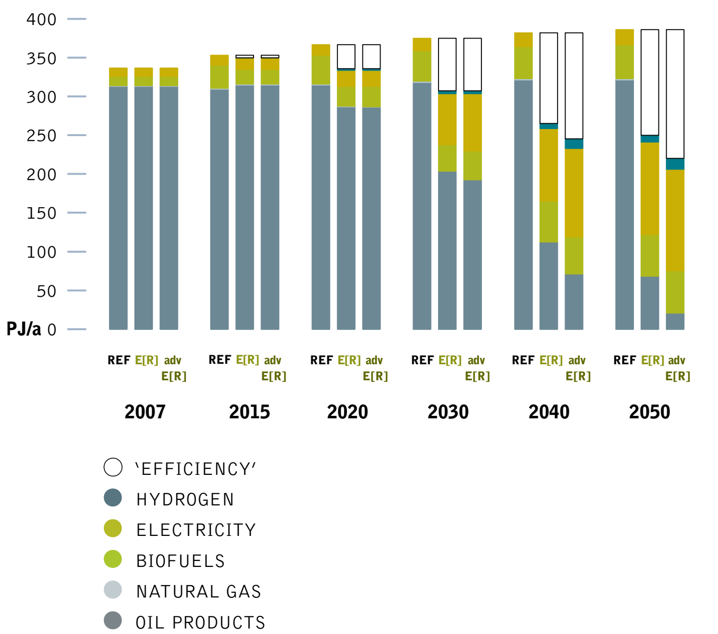


figure 6.10: transport under three scenarios



6.7 development of CO_2 emissions

While CO_2 emissions in Sweden will increase by 2% in the Reference scenario by 2050, under the Advanced Energy [R]evolution scenario, they will decrease from 52 million tonnes in 2007 to 3 million t in 2050 (equal to a 95% emissions reduction compared to the 1990 level). Annual per capita emissions will drop from 5.6 t to 0.3 t. In spite of the phasing out of nuclear energy, 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.

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 2.8 t per capita by 2030 and 1 t by 2050. By 2050, Sweden's CO_2 emissions are 81% under 1990 levels.

6.8 primary energy consumption

Taking into account the assumptions discussed above, the resulting primary energy consumption under the Energy [R]evolution scenario is shown in Figure 6.12. Compared to the Reference scenario, overall energy demand will be reduced to 56% in 2050. Around 92% of the remaining demand will be covered by renewable energy sources. Compared to the Basic Energy [R]evolution scenario, the absolute primary energy savings are similar, whereas the renewable energy share reaches only 85%.

figure 6.11: development of CO_2 emissions by sector under both energy [r]evolution scenarios

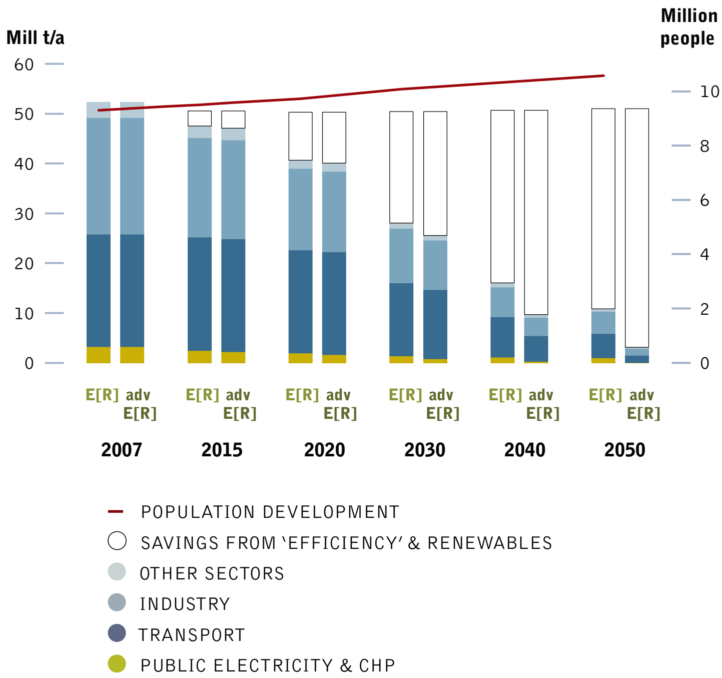
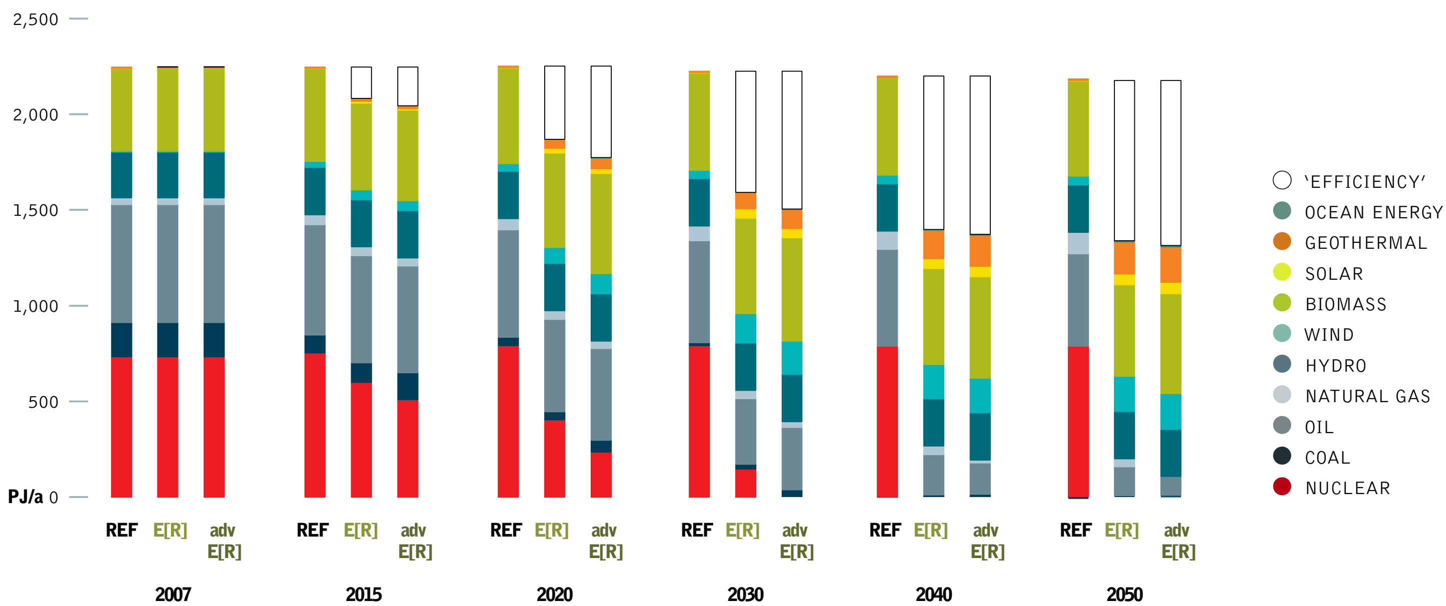


figure 6.12: development of primary energy consumption under three scenarios



7

the bright future for renewable energy is already underway.

The bright future for renewable energy is already underway. This analysis of the global power plant market shows that since the late 1990s, wind and solar installations grew faster than any other power plant technology across the world – about 430,000 MW total installed capacity between 2000 and 2010. However it is too early to claim the end of the fossil fuel based power generation, as at the same time more than 475,000 MW new coal power plants, with embedded cumulative emissions of over 55 billion tonnes CO_2 over their technical lifetime.

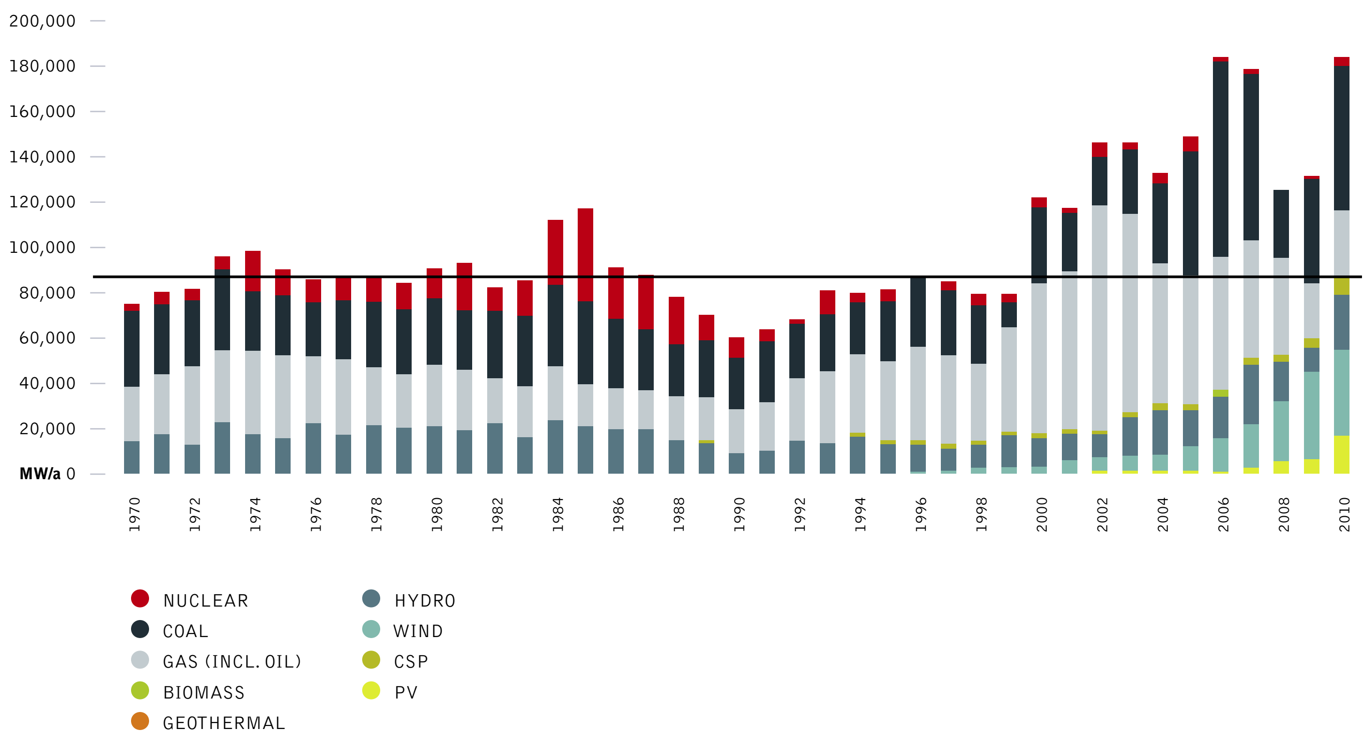
The global market volume of renewable energies in 2010 was on average, as much as the total global energy market volume each year between 1970 and 2000. The window of opportunity for renewables to both dominates new installations replacing old plants in OECD countries, as well as ongoing electrification in developing countries, closes within the next years. Good renewable energy policies and legally binding CO_2 reduction targets are urgently needed.

This briefing provides an overview of the global annual power plant market of the past 40 years and a vision of its potential growth over the next 40 years, powered by renewable energy. Between 1970 and 1990, OECD countries that electrified their economies mainly with coal, gas and hydro power plants dominated the global power plant market. The power sector, at this time, was in the hands of state-owned utilities with regional or nationwide supply monopolies. The nuclear industry had a relatively short period of steady growth between 1970 and the mid 1980s - with a peak in 1985, one year before the Chernobyl accident - while the following years were in decline, with no sign of a 'nuclear renaissance', despite the rhetoric.

Between 1990 and 2000, the global power plant industry went through a series of changes. While OECD countries began to liberalise their electricity markets, electricity demand did not match previous growth, so fewer new power plants were built. Capital-intensive projects with long payback times, such as coal and nuclear power plants, were unable to get sufficient financial support. The decade of gas power plants started.

Economies of developing countries, especially in Asia, started growing during the 1990s, and a new wave of power plant projects began. Similarly to the US and Europe, most of the new markets in the 'tiger states' of Southeast Asia partly deregulated their power sectors. A large number of new power plants in this region were built from Independent Power Producers (IPPs), who sell the electricity mainly to state-owned utilities. The dominating new built power plant technology in liberalised power markets are gas power plants. However, over the last decade, China focused on the development of new coal power plants. Excluding China, the global power plant market has seen a phase-out of coal since the late 1990s; the growth is in gas power plants and renewables, particularly wind.

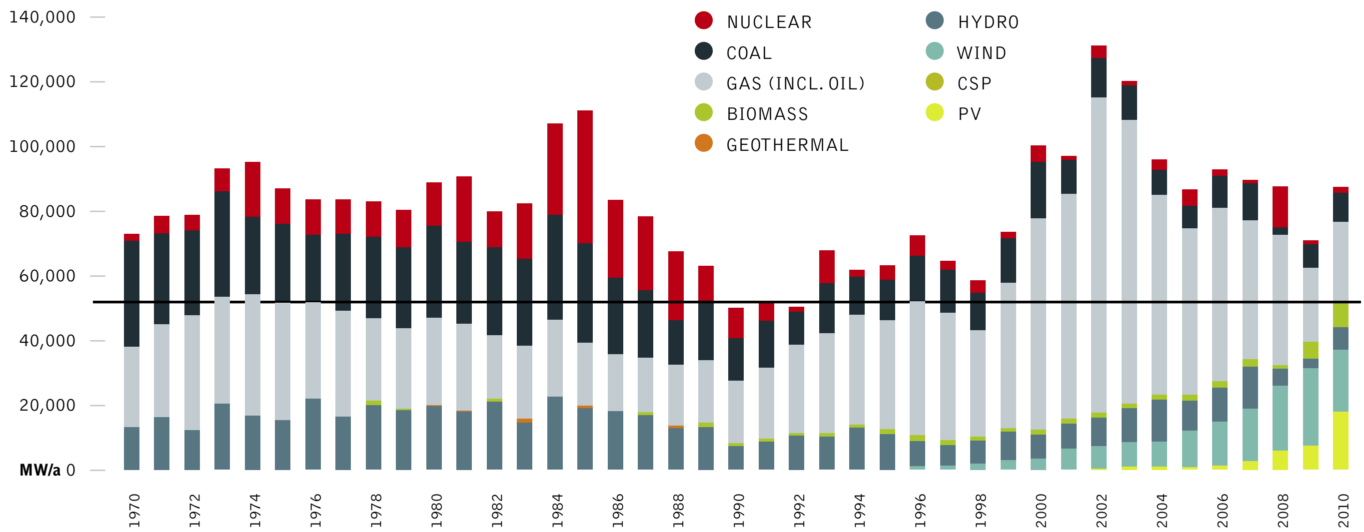
figure 7.1: global power plant market 1970-2010



source PLATTS, IEA, BREYER, TESKE.

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

figure 7.2: global power plant market 1970-2010, excluding china



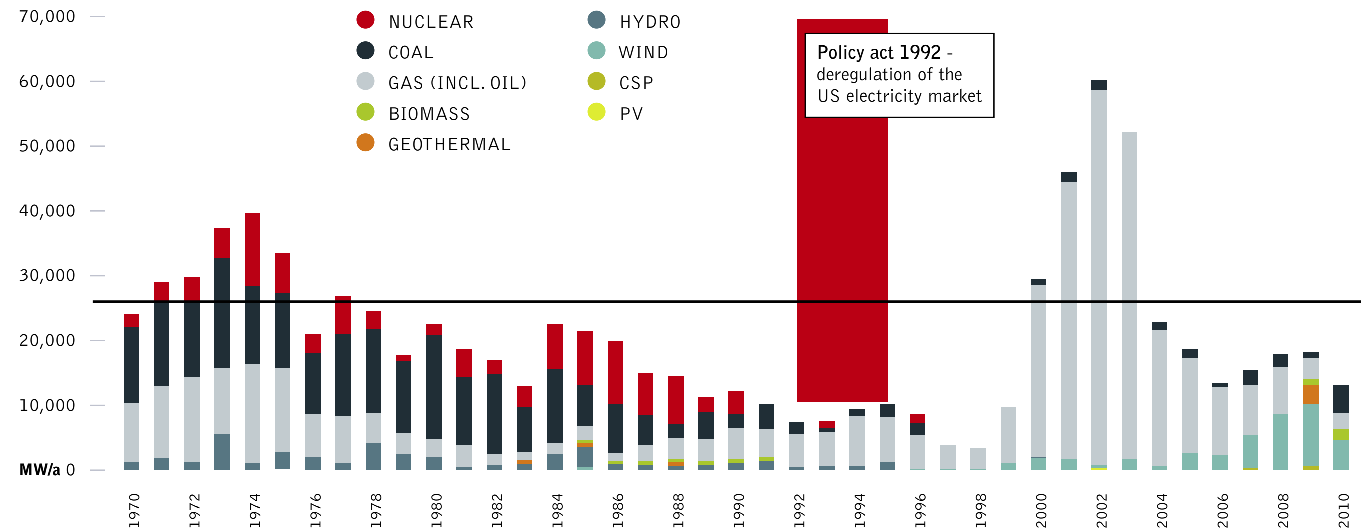
source PLATTS, IEA, BREYER, TESKE.

7.1 power plant markets in the us, europe and china

Electricity market liberalisation has a great influence on the chosen power plant technology. While the power sector in the US and Europe moved towards deregulated markets, which favour mainly gas power plants, China added a large amount of coal until 2009, with the first signs for a change in favour of renewables in 2009 and 2010.

USA: The liberalisation of the power sector in the US started with the Energy Policy Act 1992, and became a game changer for the entire power sector. While the US in 2010 is still far away from a fully liberalised electricity market, the effect on the chosen power plant technology has changed from coal and nuclear towards gas and wind. Since 2005, a growing number of wind power plants make up an increasing share of the new installed capacities as a result of mainly state based RE support programmes. Over the past year, solar photovoltaic plays a growing role with a project pipeline of 22,000 MW (Photon 4-2011, page 12).

figure 7.3: usa: annual power plant market 1970-2010



source PLATTS, IEA, BREYER, TESKE.

Europe: About five years after the US began deregulating the power sector, the European Community started a similar process. Once again, the effect on the power plant market was the same. Investors backed fewer new power plants and extended the lifetime of the existing ones. New coal and nuclear power plants have seen a market share of well below 10% since than. The growing share of renewables, especially wind and solar photovoltaic, are due to a legally-binding target for renewables and the associated renewable energy feed-in laws which are in force in several member states of the EU 27 since the late 1990s. Overall, new installed power plant capacity jumped to a record high, due to the repowering needs of the aged power plant fleet in Europe.

figure 7.4: europe: annual power plant market 1970-2010

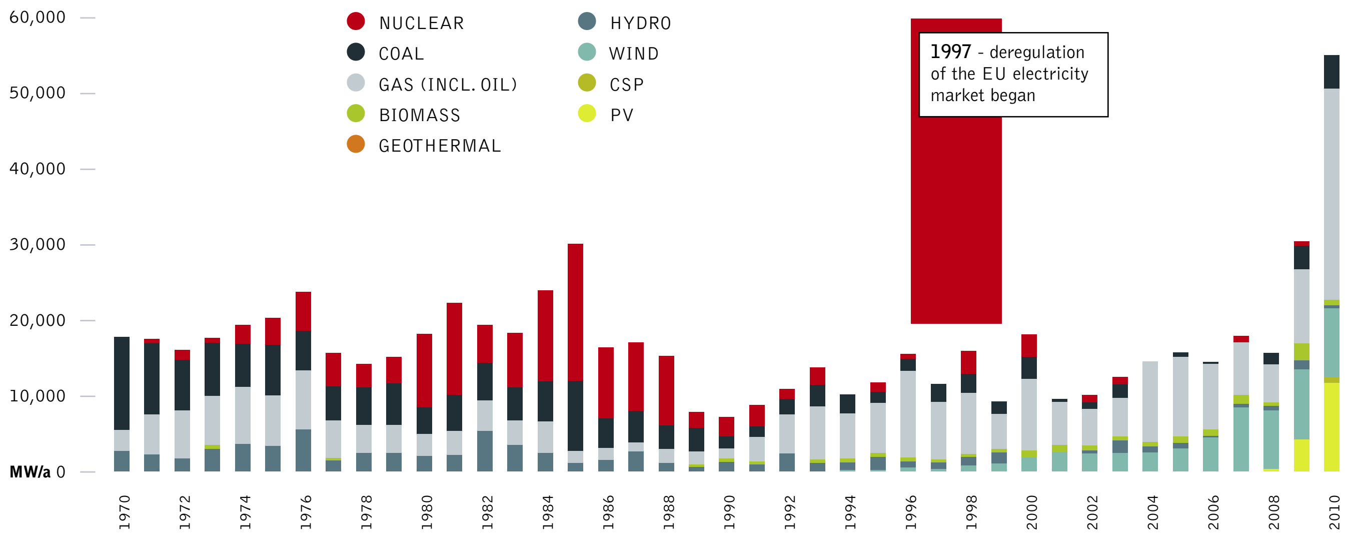
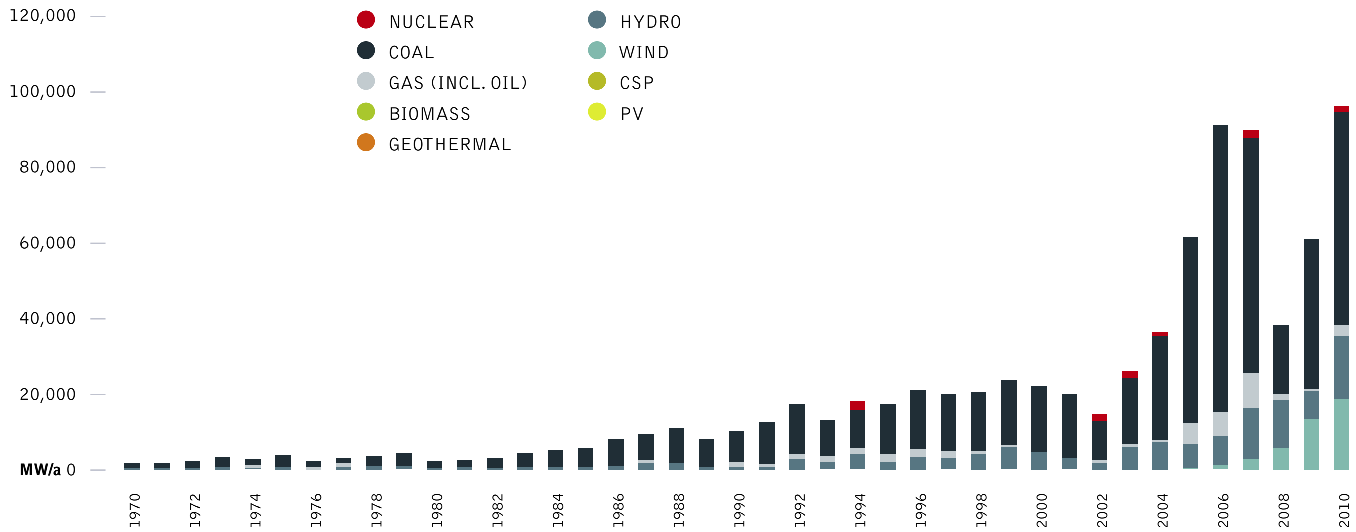


figure 7.5: china: annual power plant market 1970-2010



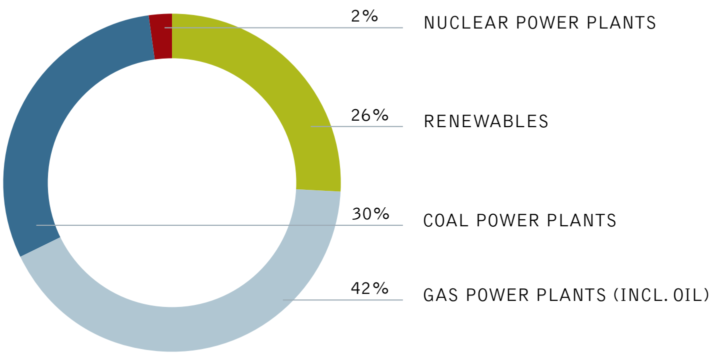
source PLATTS, IEA, BREYER, TESKE.

image GREENPEACE AND AN INDEPENDENT NASA-FUNDED SCIENTIST COMPLETED MEASUREMENTS OF MELT LAKES ON THE GREENLAND ICE SHEET THAT SHOW ITS VULNERABILITY TO WARMING TEMPERATURES.

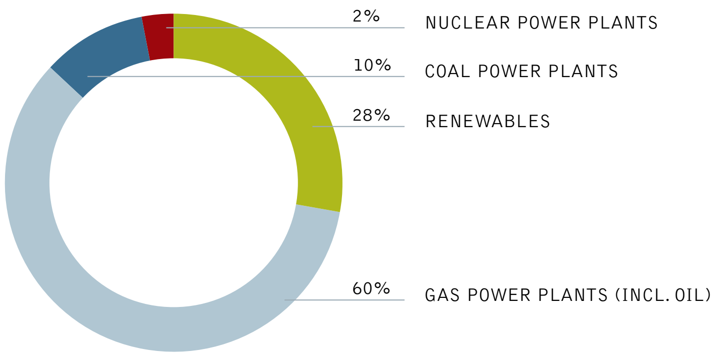
China: The steady economic growth in China since the late 1990s, and the growing power demand, led to an explosion of the coal power plant market, especially after 2002. In 2006 the market hit the peak year for new coal power plants: 88% of the newly installed coal power plants worldwide were built in China. At the same time, China is trying to take its dirtiest plants offline, within 2006~2010, total 76.825MW of small coal power plants were phased out under the "11th Five Year" programme. While coal still dominates the new added capacity, wind power is rapidly growing as well. Since 2003 the wind market doubled each year and was over 18,000 MW[33] by 2010, 49% of the global wind market. However, coal still dominates the power plant market with over 55 GW of new installed capacities in 2010 alone. The Chinese government aims to increase investments into renewable energy capacity, and during 2009, about US$25.1 billion (RMB 162.7 billion) went to wind and hydro power plants which represents 44% of the overall investment in new power plants, for the first time larger than that of coal (RMB 149.2 billion), and in 2010 the figure was US$26 billion (RMB 168 billion) – 4.8% more in the total investment mix compared with the previous year 2009.

figure 7.6: power plant market shares

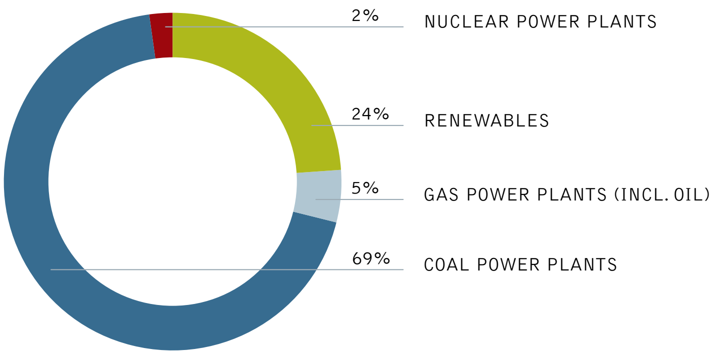
global power plant market shares 2000-2010



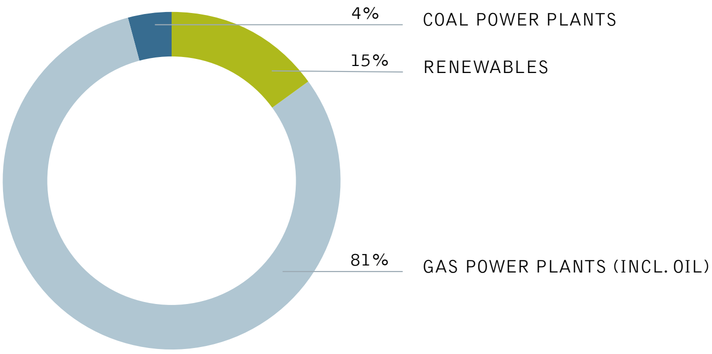
global power plant market shares 2000-2010 - excluding china



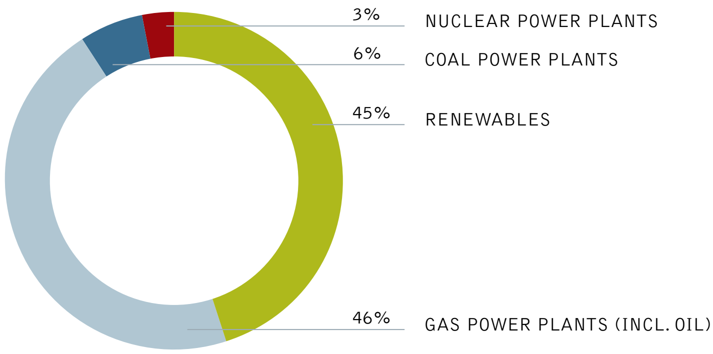
china: power plant market shares 2000-2010



usa: power plant market shares 2000-2010



EU27: power plant market shares 2000-2010 - excluding china



source PLATTS, IEA, BREYER, TESKE, GWAC, EPIA.

reference
33 WHILE THE OFFICIAL STATISTIC OF THE GLOBAL AND CHINESE WIND INDUSTRY ASSOCIATIONS (GWEC/CREIA) ADDS UP TO 18.900 MW FOR 2010, THE NATIONAL ENERGY BUREAU SPEAKS ABOUT 13,999 MW. DIFFERENCES BETWEEN SOURCES AS DUE TO THE TIME OF GRID CONNECTION, AS SOME TURBINES HAVE BEEN INSTALLED IN THE LAST MONTHS OF 2010, BUT HAVE BEEN CONNECTED TO THE GRID IN 2011.

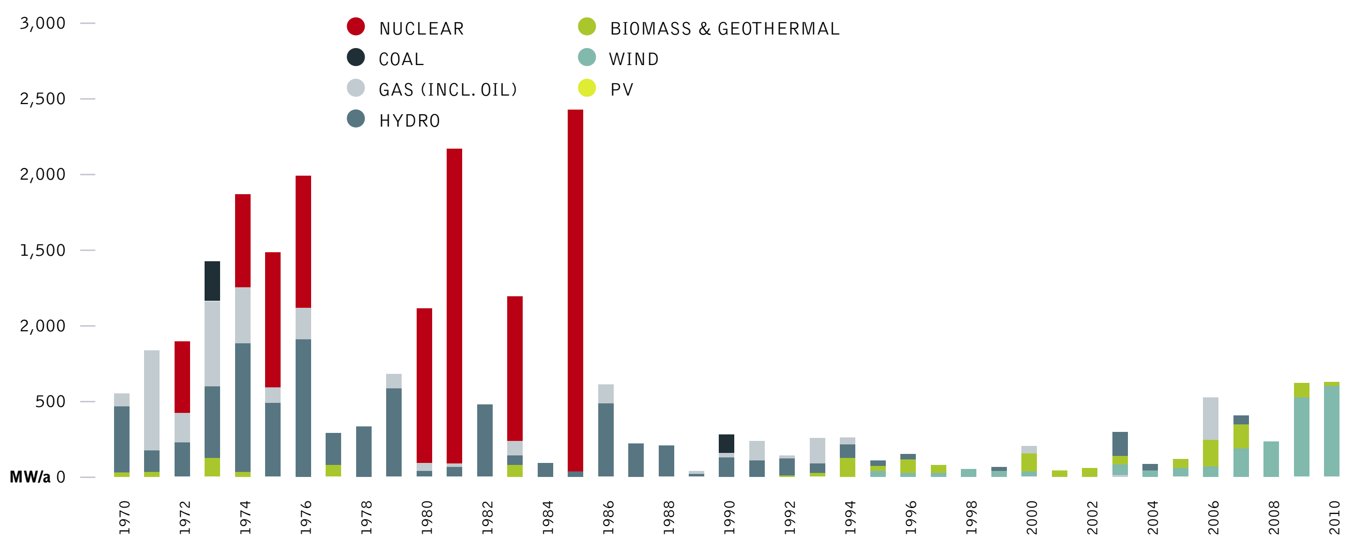
The energy revolution towards renewables and gas, away from coal and nuclear, has started on a global level already. This picture is even clearer, when we look into the global market shares excluding China, the only country with a massive expansion of coal. About 28% of all new power plants have been renewables and 60% have been gas power plants (88% in total). Coal gained a market share of only 10% globally, excluding China. Between 2000 and 2010, China has added over 350,000 MW of new coal capacity: twice as much as the entire coal capacity of the EU. However China has recently kick-started its wind market, and solar photovoltaics is expected to follow in the years to come.

7.2 country analysis: sweden

Sweden's power plant market is currently dominated by investments in wind and bioenergy. Since the start of the green certificates in 2003 investments in especially wind has increased significantly and the exponential trend will continue if policy targets are met. Although comparison with countries that instead chose a system with feed in tariffs display that the growth of the renewable sector could have been even faster. Sweden has among the world s best potentials for renewable energy but the installed capacity of wind and PV is still small compared to many other countries. It's time for the government to strengthen the financial support system for renewable energy and get up to speed with installing renewable capacity. This is also the obvious choice in the light of the discussion about the possible replacement of the ten aging nuclear reactors.

Through the state owned company Vattenfall Sweden has made extensive investments in coal and gas power plants all over Europe during the last decade. Vattenfall has transformed from being a national company with Sweden as a core market with zero emissions per year and turned in to one of the biggest electricity companies in Europe emitting more than 90 million tonne carbon dioxide per year (expected to raise to over 100 million tonne carbon dioxide per year when the two coal power plants under construction in Germany are taken in to operation). That's twice the amount of Sweden's entire carbon dioxide emissions per year and something the government urgently needs to put an end to.

figure 7.7: sweden: annual power plant market 1970-2010



source PLATTS, IEA, BREYER, TESKE.

methodology THE ANALYSIS IS BASED ON DATABASES FROM UDI WEPP PLATTS, THE IEA, GLOBAL WIND ENERGY COUNCIL, EUROPEAN PHOTOVOLTAIC INDUSTRY ASSOCIATION, AND RESEARCH PAPER FROM DR. CHRISTIAN BREYER AND MARZELLA AMATA GÖRIG. PLEASE NOTE THAT THE DIFFERENT STATISTICAL DATABASE USE DIFFERENT FUEL CATEGORIES AND SOME POWER PLANTS RUN ON MORE THAN ONE FUEL. IN ORDER TO AVOID DOUBLE COUNTING, DIFFERENT FUEL GROUPS HAVE BEEN ESTABLISHED. NATIONAL DATA MIGHT DIFFER FROM THE INTERNATIONAL DATA BASIS.

image PETROCHEMICAL REFINERY, ARGENTINA.

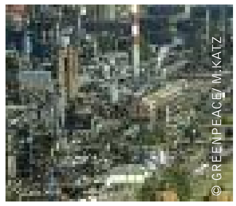
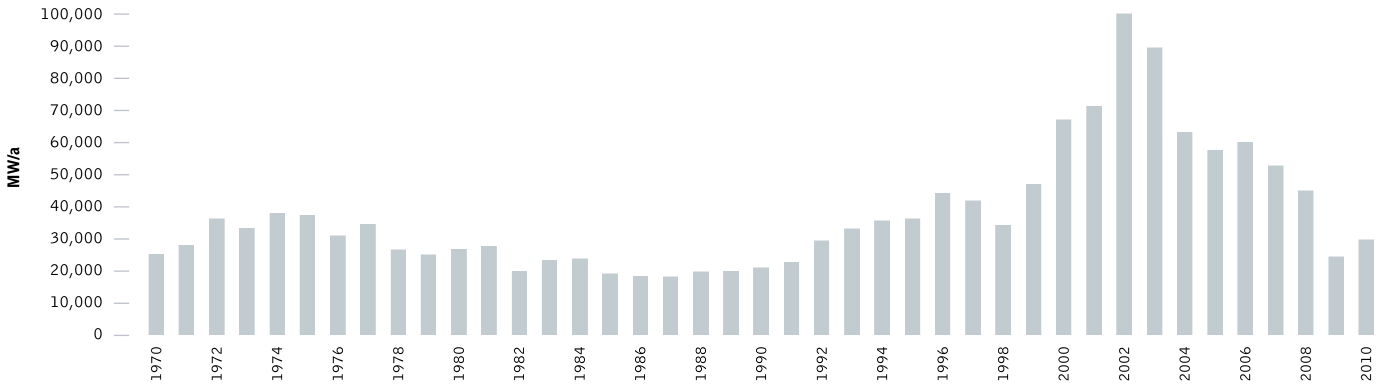
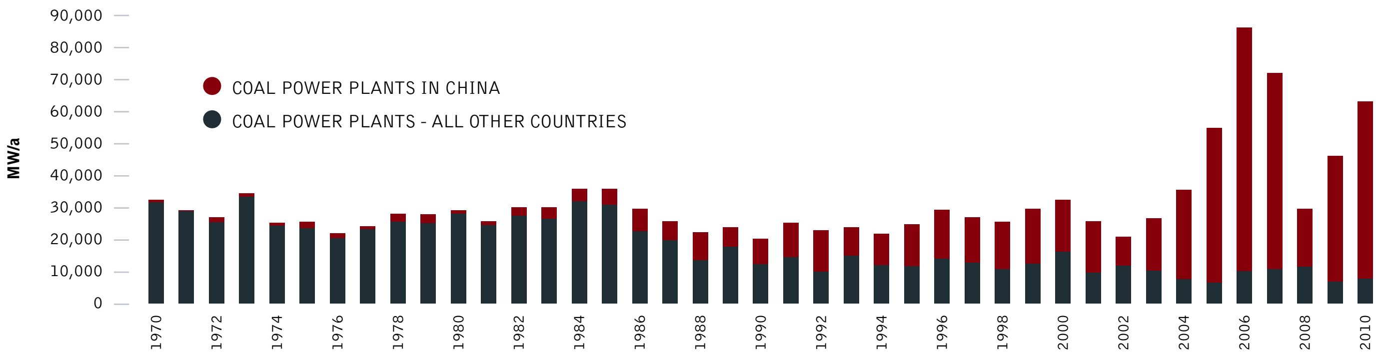


figure 7.8: historic developments of the global power plant market by technology

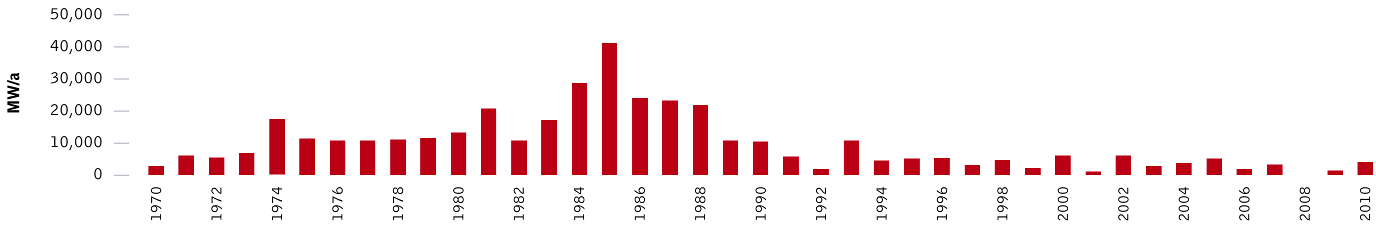
global annual gas power plant market (incl. oil) 1970-2010



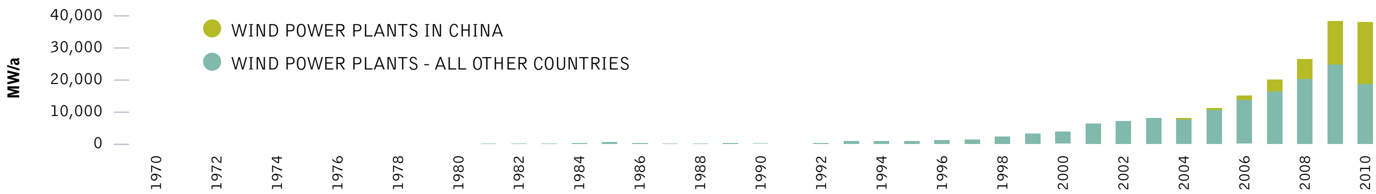
global annual coal power plant market 1970-2010



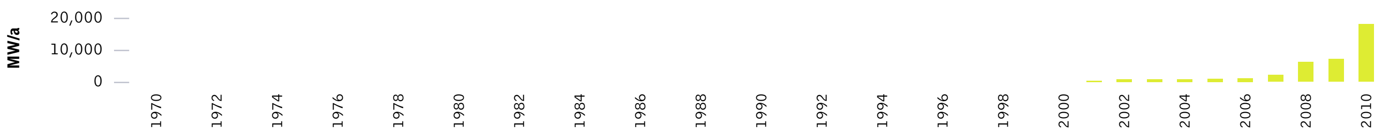
global annual nuclear power plant market 1970-2010



global annual wind power market 1970-2010



global annual solar photovoltaic market 1970-2010



7.3 the global renewable energy market

The renewable energy sector has been growing substantially over the last four years. In 2008, the increases in the installation level of both wind and solar power were particularly impressive. The total amount of renewable energy installed worldwide is reliably tracked by the Renewable Energy Policy Network for the 21st Century (REN21). Its latest global status report (2011) shows how the technologies have grown.

table 7.1: annual growth rates of global renewable energy

wind	29% increase in 2008	255% increase since 2005
solar photovoltaics (PV)	130% increase in 2010	1.063% increase since 2005

The global installed capacity of new renewable energy at the end of 2010 (excluding large hydro) was 310 GW, with wind power making up around two thirds (197 GW) and solar photovoltaic 12% (39 GW). The new capacity commissioned in 2010 alone amounted to roughly 65 GW (excluding large hydro power), with the highest growth in wind power and solar photovoltaic.

figure 7.9: average annual growth rates of renewable energy capacity and biofuel production, 2005-2010

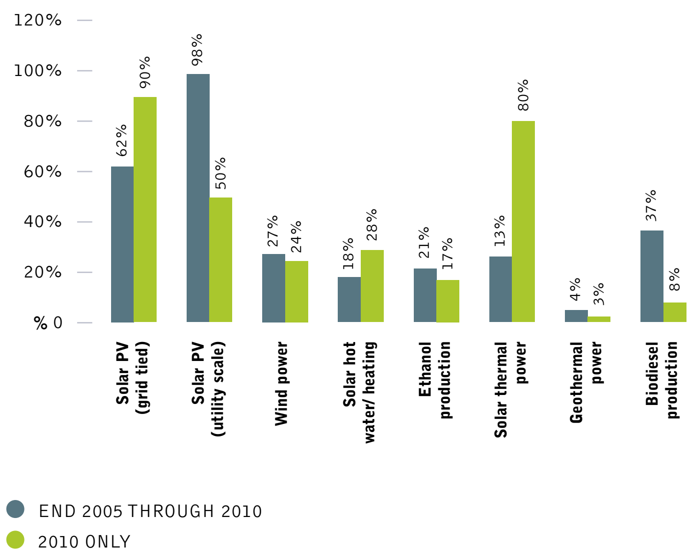


table 7.2: top five countries

	#1	#2	#3	#4	#5
Annual amounts for 2010					
New capacity investment	China	Germany	Italy	United States	Czech Rep.
Wind power added	China	United States	Spain	India	Germany
Solar PV added (grid-connected)	Germany	Italy	Czech Rep.	Japan	United States
Solar hot water/heat added	China	Germany	Turkey	India	Australia
Ethanol production	United States	Brazil	China	Canada	France
Bioediesel production	Germany	Brazil	Argentina	France	United States
Existing capacity as of end-2010					
Renewables power capacity (not including hydro)	United States	China	Germany	Spain	India
Renewable power capacity (including hydro)	China	United States	Canada	Brazil	Germany
Wind power	China	United States	Germany	Spain	India
Biomass power	United States	Brazil	Germany	China	Sweden
Geothermal power	United States	Philippines	Indonesia	Mexico	Italy
Solar PV (grid-connected)	Germany	Spain	Japan	Italy	United States
Solar hot water/heat	China	Turkey	Germany	Japan	Greece

image WIND TURBINES, ARGENTINA.

The top five countries for new renewable energy in 2010 were China, Italy, Germany, the United States of America and Czech Republic. China doubled its wind power capacity for the seventh year in a row. The growth of grid-connected solar PV in Germany was six times the level in 2007 (2007: 1.2 GW – 2010: 7.4 GW)

7.4 employment in global renewable energy

Based on those countries for which statistics are available, the current global employment in renewable energy is as high as 3,5 million people.

Although so far it has been mostly the advanced economies that have shown leadership in encouraging viable renewable energy, developing countries are beginning to play a growing role. China and Brazil, for example, account for a large share of the global total, with a strong commitment to both solar thermal and biomass development. Many of the jobs created are in installation, operation and maintenance, as well as in manufaction of wind and solar equipment. The outlook for the future is that more developing countries are expected to generate substantial numbers of jobs.

To make sure that the renewables sector can provide large scale green employment, strong energy policies are essential. Some countries have already shown that renewable energy can form an important part of national economic strategies. Germany, for instance, views its investment in wind and solar PV as making a crucial contribution to its export markets. The government's intention is to gain a major slice of the world market in the coming decades, with most German jobs in these industries depending on sales abroad of wind turbines and solar panels. Although only a few countries currently have the requisite scientific and manufacturing know-how to develop such a strategy, the markets for wind and solar equipment in particular are experiencing rapid growth.

figure 7.10: renewable power capacities, developing countries, eu and top six countries, 2010 (not including hydropower)

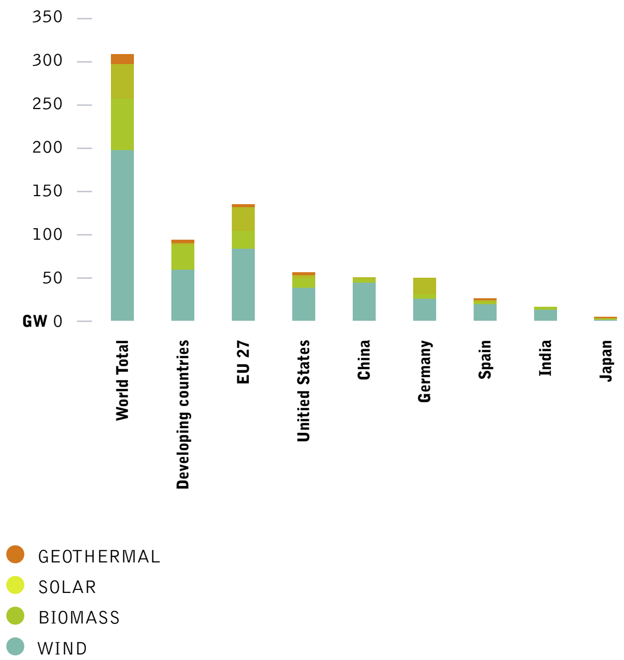


table 7.3: employment in renewable electricity – selected countries and world estimates

INDUSTRY	ESTIMATED JOBS WORLDWIDE	SELECTED NATIONAL ESTIMATES
Biofuels	> 1,500,000	Brazil 730,000 for sugarcane and ethanol production
Wind power	~630,000	China 150,000; Germany 100,000; United States 85,000; Spain 40,000; Italy 28,000; Denmark 24,000; Brazil 14,000; India 10,000
Solar hot water	~300,000	China 250,000; Spain 7,000
Solar PV	~350,000	China 120,000; Germany 120,000; Japan 26,000; Spain 20,000; United States 17,000; Spain 14,000
Biomass power	---	Germany 120,000; United States 66,000; Spain 5,000
Hydropower	---	Europe 20,000; United States 8,000; Spain 7,000
Geothermal	---	Germany 13,000; United States 9,000
Biogas	---	Germany 20,000
Solar thermal power	~15,000	Spain 1,000; United States 1,000
Total estimated	**~3,500,000**	

notes/sources FIGURES ARE ROUNDED TO NEAREST 1,000 OR 10,000 AS ALL NUMBERS ARE ROUGH ESTIMATES AND NOT EXACT. GWEC/GREENPEACE 2010, GWEC 2010, WWEA 2009, EPIA 2010, BSW 2010, SOLAR PACES 2010, BMU 2010, CREIA 2010, MARTINOT AND LI 2007; NAVIGANT 2009; NIETO 2007; REN 21 2005 AND 2008; SUZION 2007; UNEP 2008; US GEOTHERMAL INDUSTRY ASSOCIATION 2009; US SOLAR ENERGY INDUSTRY ASSOCIATION 2009. DATA ADJUSTED BASED ON SUBMISSIONS FROM REPORT CONTRIBUTORS AND OTHER SOURCES, ALONG WITH ESTIMATES FOR BIOFUELS AND SOLAR HOT WATER BY ERIC MARTINOT. EARLIER ESTIMATES WERE MADE BY UNEP IN 2008 (1.7 MILLION GLOBAL TOTAL) AND BY SVEN TESKE AND GREENPEACE INTERNATIONAL IN 2009 (1.9 MILLION GLOBAL TOTAL) NOT INCLUDING BIOFUELS AND SOLAR HOT WATER. BRAZIL ETHANOL ESTIMATE FROM LABOR MARKET RESEARCH AND EXTENSTION GROUP (GEMT, ESALQ/USP). SOLAR HOT WATER EMPLOYMENT ESTIMATE USES THE FIGURE OF 150,000 FOR CHINA IN 2007 CITED IN MARTINOT AND LI 2007, ADJUSTED FOR GROWTH IN 2008-2009, AND ASSUMING EMPLOYMEN IN OTHER COUNTRIES IS IN PROPORTINO TO CHINA'S GLOBAL MARKET SHARE.

energy resources & security of supply

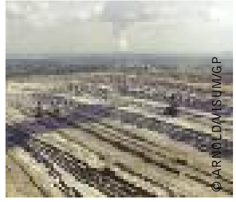
GLOBAL | OIL | GAS | COAL | NUCLEAR | RENEWABLE ENERGY

8

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

the issue of security of supply is now at the top of the energy policy agenda.

image BROWN COAL SURFACE MINING IN HAMBACH, GERMANY. GIANT COAL EXCAVATOR AND SPOIL PILE.



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'[34], as well as information from the International Energy Agency's World Energy Outlook 2008 and 2009 reports.

8.1 oil

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.

8.1.1 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.

8.1.2 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[35] 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.

8.2 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.

34 '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.
35 *THE INDEPENDENT*, 10 DECEMBER 2007

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 reserves have been almost constant since 1980 because discoveries have roughly matched production.

8.2.1 shale gas[36]

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.

table 8.1: 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.

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

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.

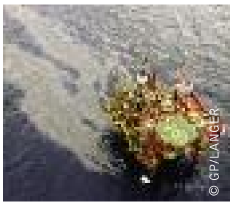


table 8.2: assumptions on fossil fuel use in the three scenarios

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 = 10E9m^3]	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 = 10E9m^3]		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 = 10E9m^3]		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

8.3 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 coal. 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.

8.4 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.

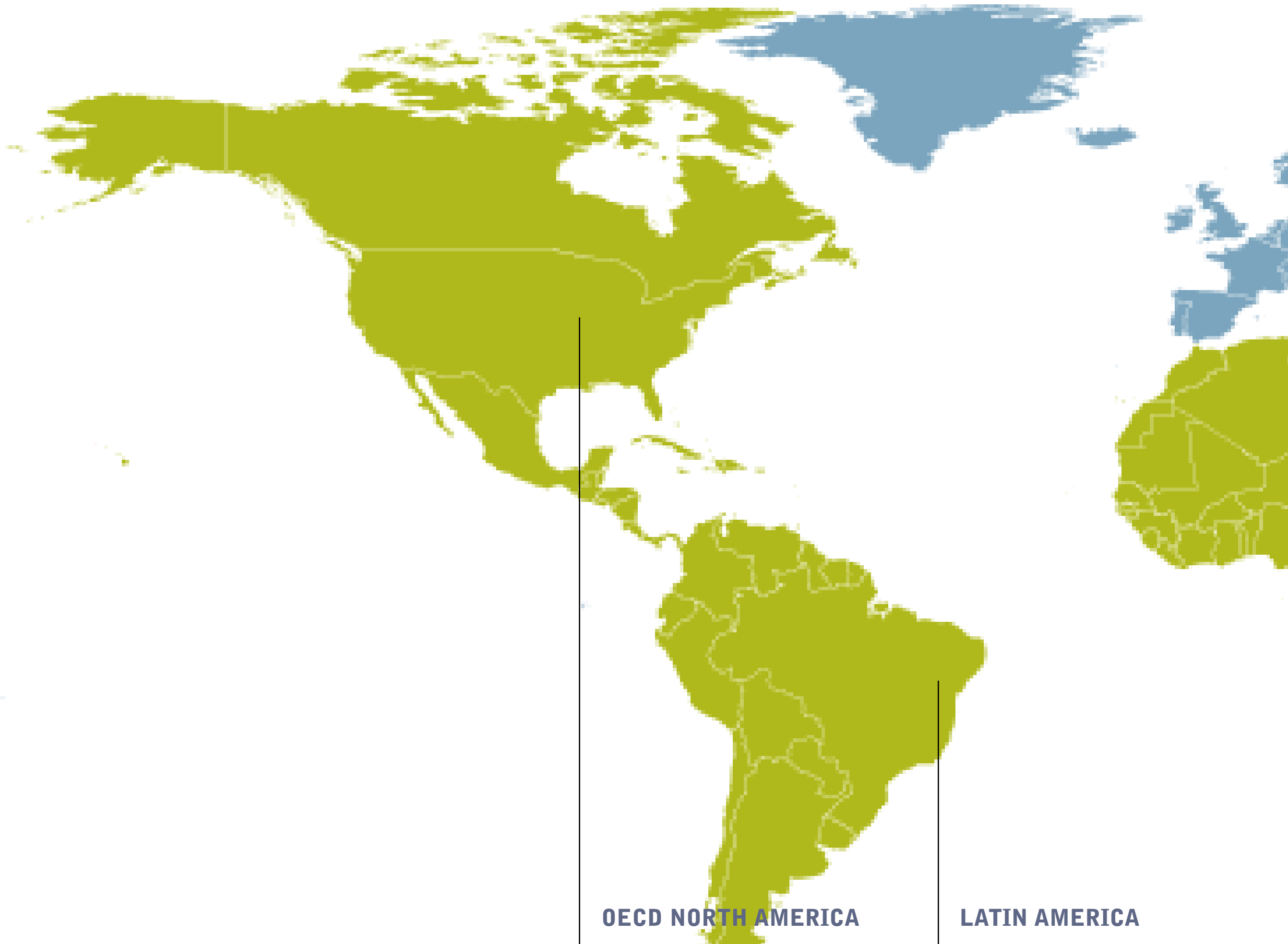
Secondary sources, such as old deposits, currently make up nearly half of worldwide uranium reserves. These will soon be used up, however. Mining capacities will have to be nearly doubled in the next few years to meet current needs.

A joint report by the OECD Nuclear Energy Agency and the International Atomic Energy Agency[37] 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.

37 'URANIUM 2003: RESOURCES, PRODUCTION AND DEMAND'

map 8.1: oil reference scenario and the advanced energy [r]evolution scenario

WORLDWIDE SCENARIO



OECD NORTH AMERICA

		REF		E[R]	
		TMB	%	TMB	%
Reserves total	2007	69.3	5.6%	69.3	5.6%
		MB	PJ	MB	PJ
Consumption per region	2007	7,429H	45,466H	7,429H	45,466H
	2050	6,594H	40,352H	1,225	7,494
		L		L	
Consumption per person	2007	2,707H		2,707H	
	2050	1,816H		337	

LATIN AMERICA

		REF		E[R]	
		TMB	%	TMB	%
Reserves total	2007	111.2	9.0%	111.2	9.0%
		MB	PJ	MB	PJ
Consumption per region	2007	1,691	10,349	1,691	10,349
	2050	2,597	15,895	292	1,788
		L		L	
Consumption per person	2007	598		598	
	2050	653		73	

NON RENEWABLE RESOURCE

OIL

LEGEND

>60 | 50-60 | 40-50 | 30-40 | 20-30 | 10-20 | 5-10 | 0-5 % RESOURCES GLOBALLY

REF REFERENCE SCENARIO

E[R] ADVANCED ENERGY [R]EVOLUTION SCENARIO

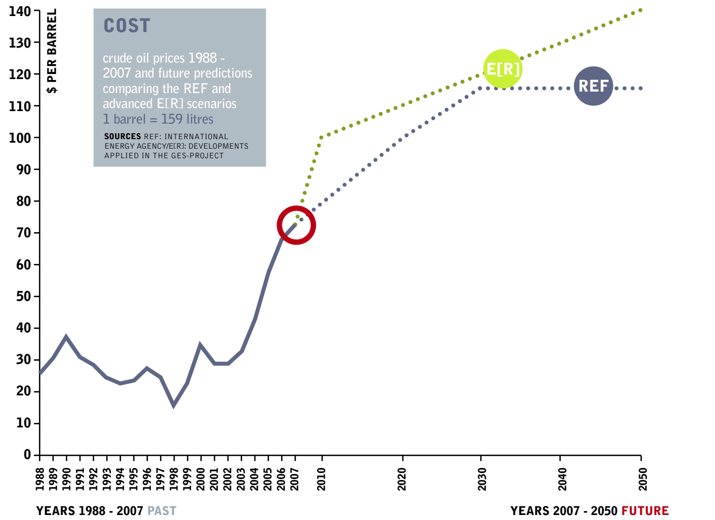
0 1000 KM

RESERVES TOTAL THOUSAND MILLION BARRELS [TMB] | SHARE IN % OF GLOBAL TOTAL [END OF 2007]

CONSUMPTION PER REGION MILLION BARRELS [MB] | PETA JOULE [PJ]

CONSUMPTION PER PERSON LITERS [L]

H HIGHEST | **M** MIDDLE | **L** LOWEST



OECD EUROPE

	REF		E[R]	
	TMB	%	TMB	%
2007	16.9	1.4%M	16.9	1.4%M
	MB	PJ	MB	PJ
2007	4,337	26,541	4,337	4,418
2050	3,590M	21,970M	722M	9,361M
	L		L	
2007	1,285		1,285	
2050	1,013M		204	

MIDDLE EAST

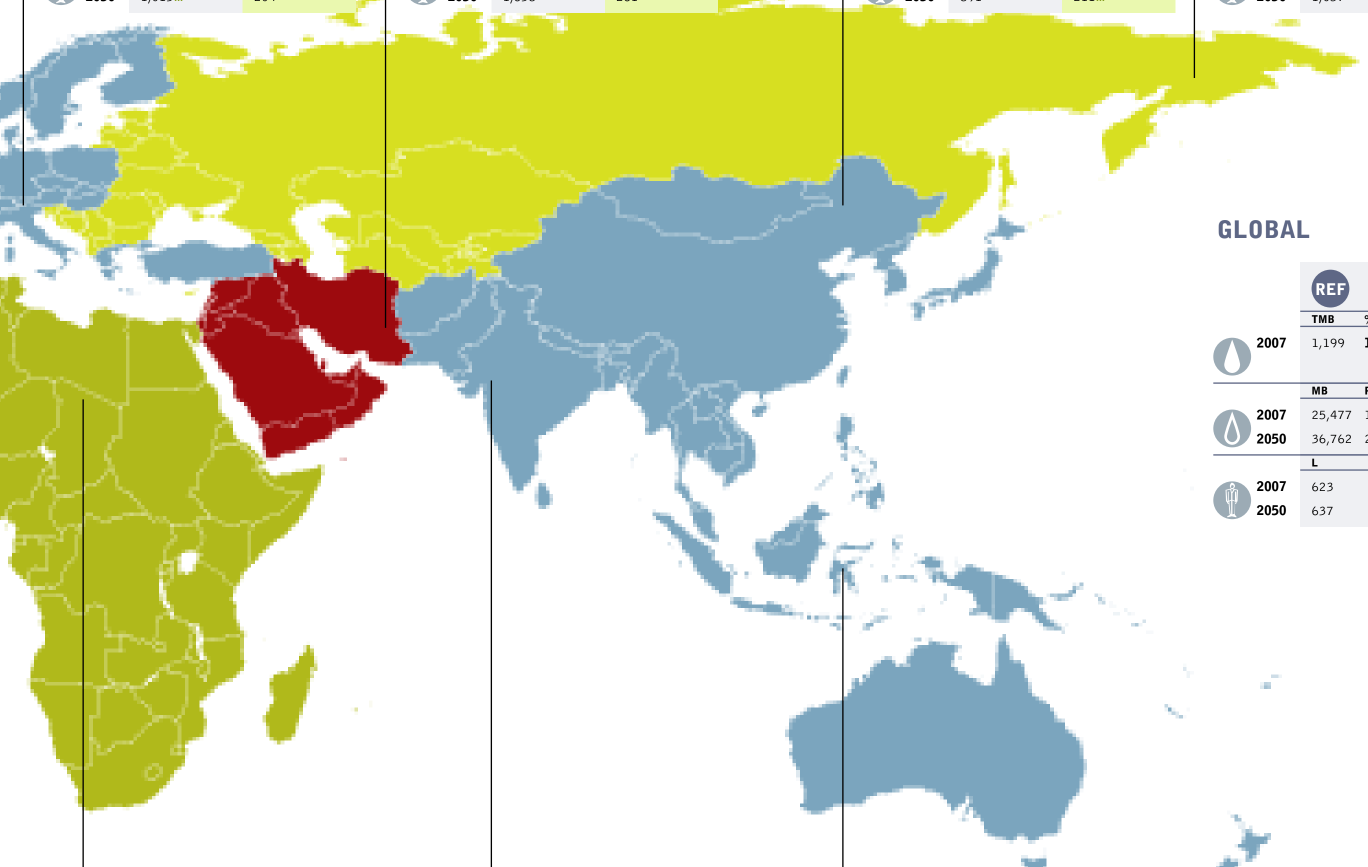
	REF		E[R]	
	TMB	%	TMB	%
2007	755.3H	61.0%H	755.3H	61.0%H
	MB	PJ	MB	PJ
2007	1,913	11,709	1,913	11,709
2050	3,574	21,871	569	3,482
	L		L	
2007	1,617		1,617	
2050	1,638		261	

CHINA

	REF		E[R]	
	TMB	%	TMB	%
2007	15.5	1.3%	15.5	1.3%
	MB	PJ	MB	PJ
2007	2,445	14,966	2,445	14,966
2050	7,946	48,629	1,881H	11,513H
	L		L	
2007	294		294	
2050	891		211M	

TRANSITION ECONOMIES

	REF		E[R]	
	TMB	%	TMB	%
2007	87.6	10.1%L	87.6	10.1%L
	MB	PJ	MB	PJ
2007	1,605	9,826	1,605	9,826
2050	1,953L	11,955L	441L	2,701L
	L		L	
2007	748M		748M	
2050	1,057		239	



GLOBAL

	REF		E[R]	
	TMB	%	TMB	%
2007	1,199	100%	1,199	100%
	MB	PJ	MB	PJ
2007	25,477	155,919	25,477	155,919
2050	36,762	224,981	8,459	51,770
	L		L	
2007	623		623	
2050	637		147	

AFRICA

	REF		E[R]	
	TMB	%	TMB	%
2007	117.5M	9.5%	117.5M	9.5%
	MB	PJ	MB	PJ
2007	924	5,654	924	5,654
2050	1,667	10,202	689	4,214
	L		L	
2007	159		159	
2050	133L		55L	

INDIA

	REF		E[R]	
	TMB	%	TMB	%
2007	5.5	0.5%	5.5	0.5%
	MB	PJ	MB	PJ
2007	1,011L	6,187L	1,011	6,187
2050	3,669	22,455	1,169	7,152
	L		L	
2007	142L		142L	
2050	352		112	

DEVELOPING ASIA

	REF		E[R]	
	TMB	%	TMB	%
2007	14.8	1.2%	14.8	1.2%
	MB	PJ	MB	PJ
2007	1,656	10,136	1,656	10,136
2050	3,448	21,099	1,014	6,204
	L		L	
2007	270		270	
2050	365		107	

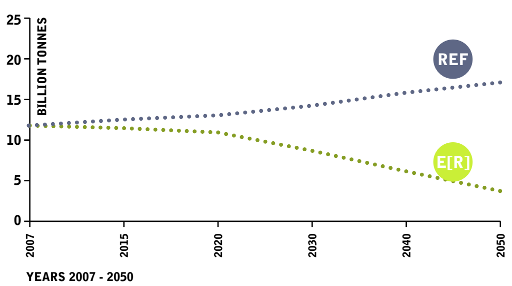
OECD PACIFIC

	REF		E[R]	
	TMB	%	TMB	%
2007	5.1L	0.4%	5.1L	0.4%
	MB	PJ	MB	PJ
2007	2,465M	15,089M	2,465	15,086
2050	1,724	10,552	458	2,805
	L		L	
2007	1,958		1,958	
2050	1,539		409H	

CO_2 EMISSIONS FROM OIL

comparison between the REF and advanced E[R] scenarios 2007 - 2050 billion tonnes

SOURCE GPI/EREC



RESERVES AND CONSUMPTION

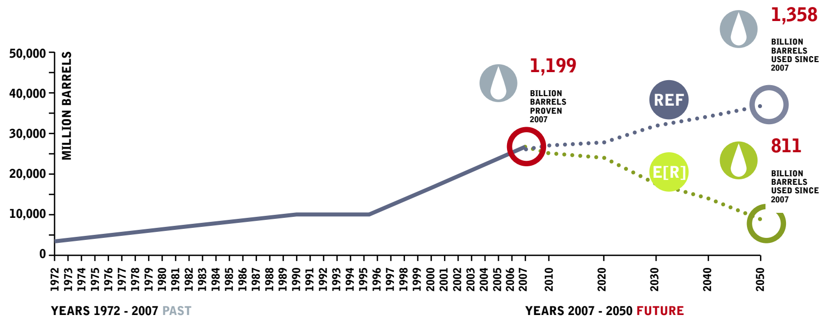
oil reserves versus global demand, production and consumption. global consumption comparison between the REF and advanced E[R] scenarios.

million barrels. 1 barrel = 159 litres

SOURCE BP 2008

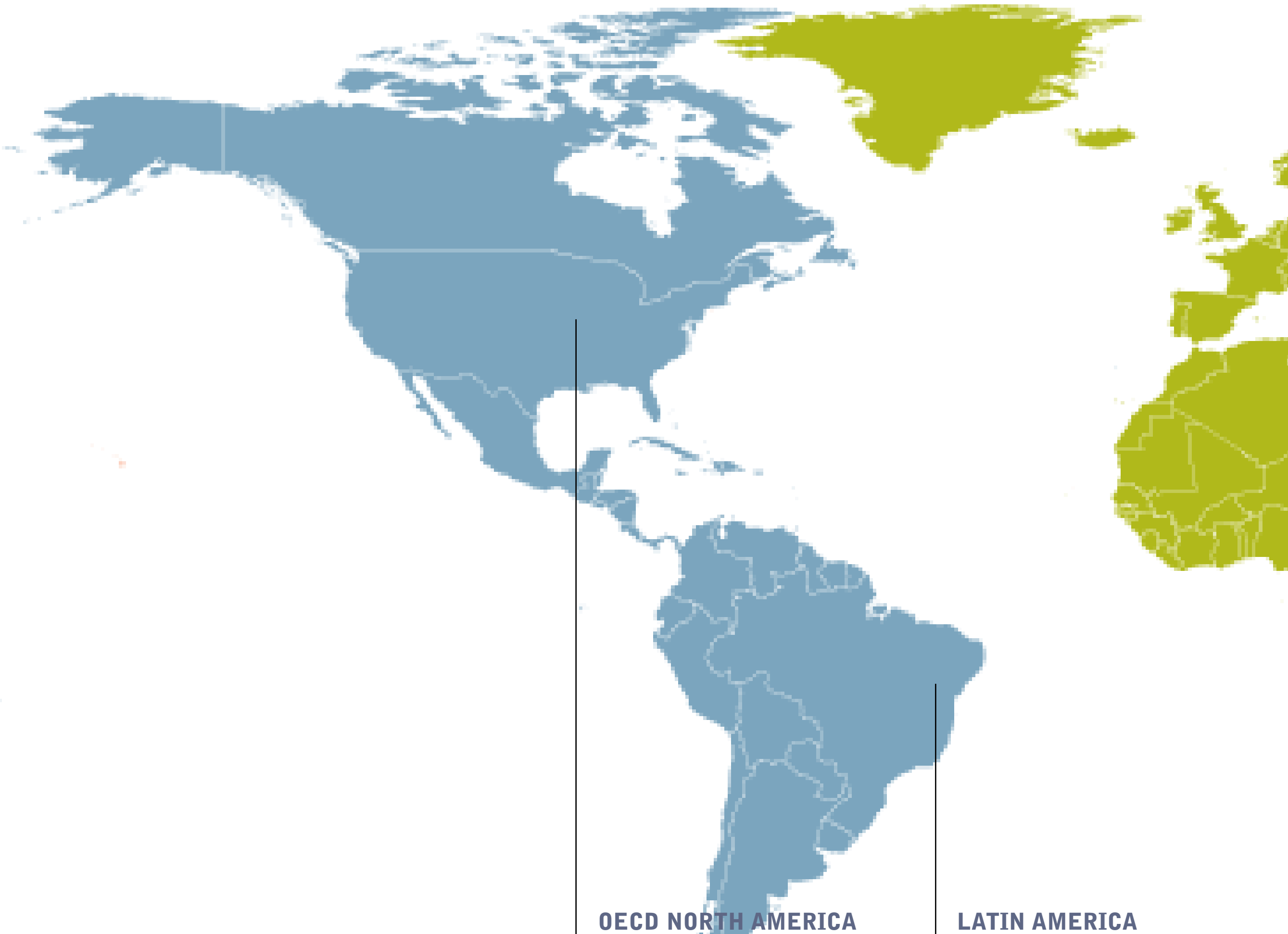
REF global consumption

ADV E[R] global consumption



map 8.2: gas reference scenario and the advanced energy [r]evolution scenario

WORLDWIDE SCENARIO



OECD NORTH AMERICA

	REF		E[R]	
	tn m³	%	tn m³	%
2007	8.0	4.4%	8.0	4.4%
	bn m³	PJ	bn m³	PJ
2007	722H	27,435H	722H	27,435H
2050	767H	29,144H	71H	2,688H
	m³		m³	
2007	1,608		1,608	
2050	1,328		123	

LATIN AMERICA

	REF		E[R]	
	tn m³	%	tn m³	%
2007	7.7	4.3%	7.7	4.3%
	bn m³	PJ	bn m³	PJ
2007	117	4,465	117	4,465
2050	246M	9,358M	34	1,303
	m³		m³	
2007	254		254	
2050	410		57	

NON RENEWABLE RESOURCE

GAS

LEGEND

>50 | 40-50 | 30-40 | 20-30 | 10-20 | 5-10 | 0-5 % RESOURCES GLOBALLY

REF REFERENCE SCENARIO

E[R] ADVANCED ENERGY [R]EVOLUTION SCENARIO

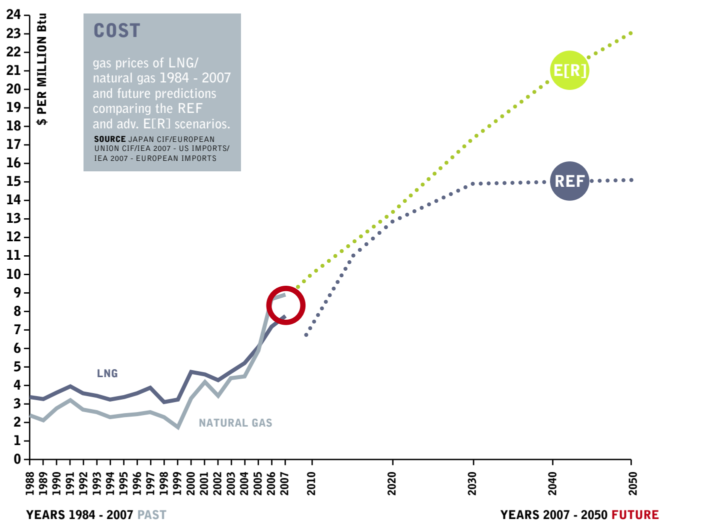
0 1000 KM

RESERVES TOTAL TRILLION CUBIC METRES [tn m³] | SHARE IN % OF GLOBAL TOTAL [END OF 2007]

CONSUMPTION PER REGION BILLION CUBIC METRES [bn m³] | PETA JOULE [PJ]

CONSUMPTION PER PERSON CUBIC METRES [m³]

H HIGHEST | **M** MIDDLE | **L** LOWEST



COST

gas prices of LNG/ natural gas 1984 - 2007 and future predictions comparing the REF and adv. E[R] scenarios.

SOURCE JAPAN CIF/EUROPEAN UNION CIF/IEA 2007 - US IMPORTS/ IEA 2007 - EUROPEAN IMPORTS

OECD EUROPE

	REF		E[R]	
	tn m^3	%	tn m^3	%
2007	9.8	5.4%	9.8	5.4%
	bn m^3	PJ	bn m^3	PJ
2007	504	19,170	504	19,170
2050	644	24,469	69	2,613
	m^3		m^3	
2007	934		934	
2050	1,120M		120	

MIDDLE EAST

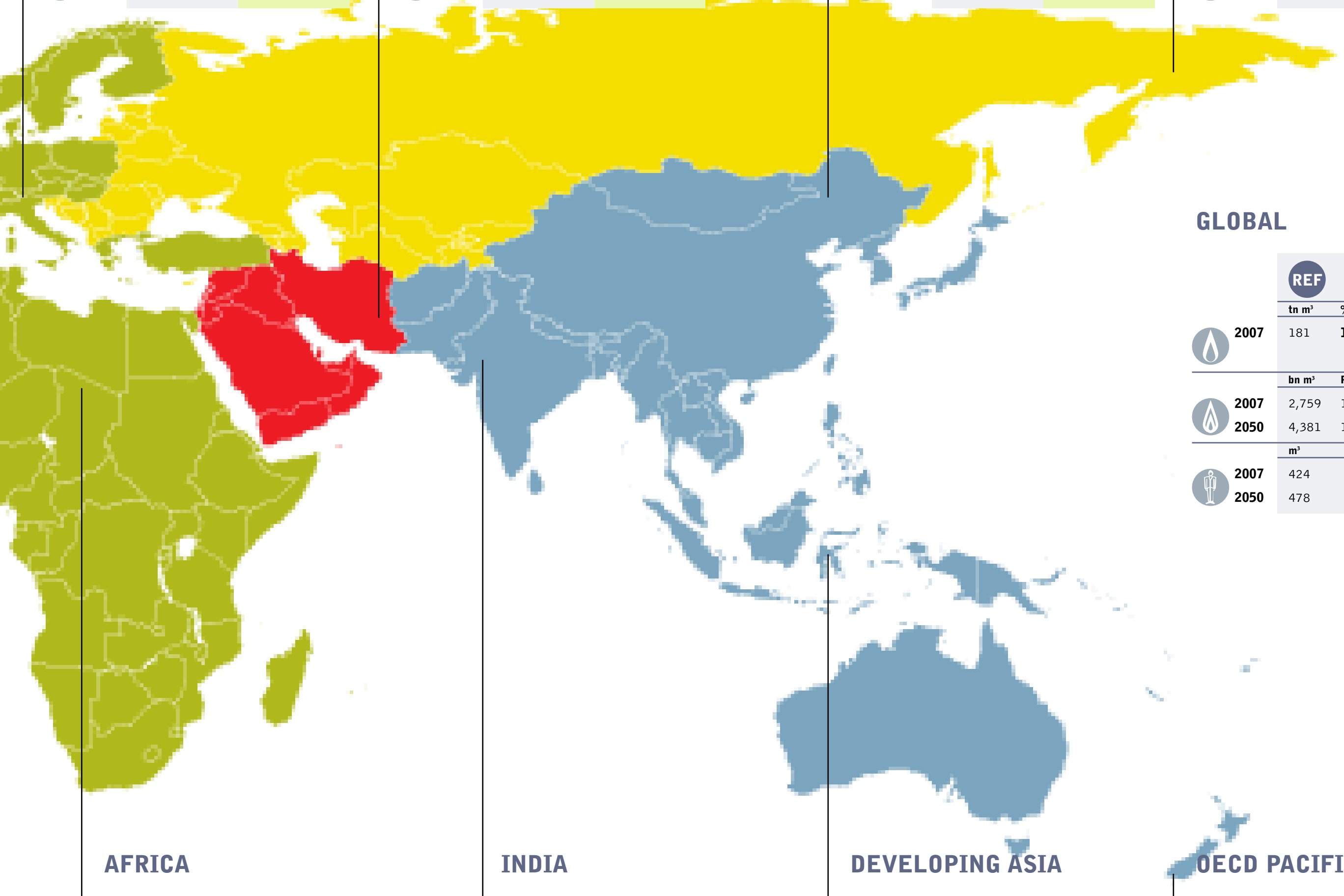
	REF		E[R]	
	tn m^3	%	tn m^3	%
2007	73.2H	40.4%H	73.2H	40.4%H
	bn m^3	PJ	bn m^3	PJ
2007	238M	9,056M	239	9,056
2050	685	26,034	74	2,805
	m^3		m^3	
2007	1,178		1,178	
2050	1,939		209M	

CHINA

	REF		E[R]	
	tn m^3	%	tn m^3	%
2007	1.9	1.0%	1.9	1.0%
	bn m^3	PJ	bn m^3	PJ
2007	71	2,716	71	2,716
2050	341	12,953	212	8,061
	m^3		m^3	
2007	54		54	
2050	239		149	

TRANSITION ECONOMIES

	REF		E[R]	
	tn m^3	%	tn m^3	%
2007	53.3	29.4%	53.3	29.4%
	bn m^3	PJ	bn m^3	PJ
2007	638	24,225	638	24,225
2050	776	29,478	138	5,248
	m^3		m^3	
2007	1,874H		1,874H	
2050	2,496H		444H	



GLOBAL

	REF		E[R]	
	tn m^3	%	tn m^3	%
2007	181	100%	181	100%
	bn m^3	PJ	bn m^3	PJ
2007	2,759	104,846	2,759	104,846
2050	4,381	166,489	902	34,285
	m^3		m^3	
2007	424		424	
2050	478		99	

AFRICA

	REF		E[R]	
	tn m^3	%	tn m^3	%
2007	14.6M	8.0%M	14.6M	8.0%M
	bn m^3	PJ	bn m^3	PJ
2007	91	3,472	91	3,472
2050	167	6,338	65	2,456
	m^3		m^3	
2007	95		95	
2050	83		32L	

INDIA

	REF		E[R]	
	tn m^3	%	tn m^3	%
2007	1.1L	0.6%L	1.1L	0.6%L
	bn m^3	PJ	bn m^3	PJ
2007	37L	1,397L	37L	1,397L
2050	164L	6,227L	107M	4,075M
	m^3		m^3	
2007	32L		32L	
2050	102L		66	

DEVELOPING ASIA

	REF		E[R]	
	tn m^3	%	tn m^3	%
2007	8.6	4.8%	8.6	4.8%
	bn m^3	PJ	bn m^3	PJ
2007	184	6,998	184	6,998
2050	422	16,020	115	4,368
	m^3		m^3	
2007	182		182	
2050	278		76	

OECD PACIFIC

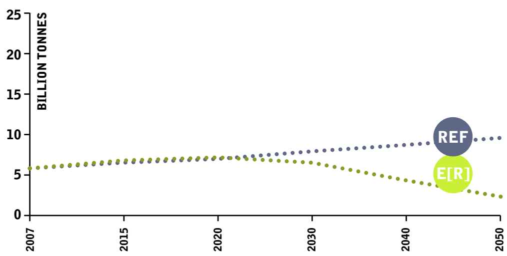
	REF		E[R]	
	tn m^3	%	tn m^3	%
2007	2.9	1.6%	2.9	1.6%
	bn m^3	PJ	bn m^3	PJ
2007	156	5,912	156	5,912
2050	170	6,467	18L	667L
	m^3		m^3	
2007	776M		776M	
2050	946		98	

CO_2 EMISSIONS FROM GAS

comparison between the REF and adv. E[R] scenarios 2007 - 2050

billion tonnes

SOURCE GPI/EREC

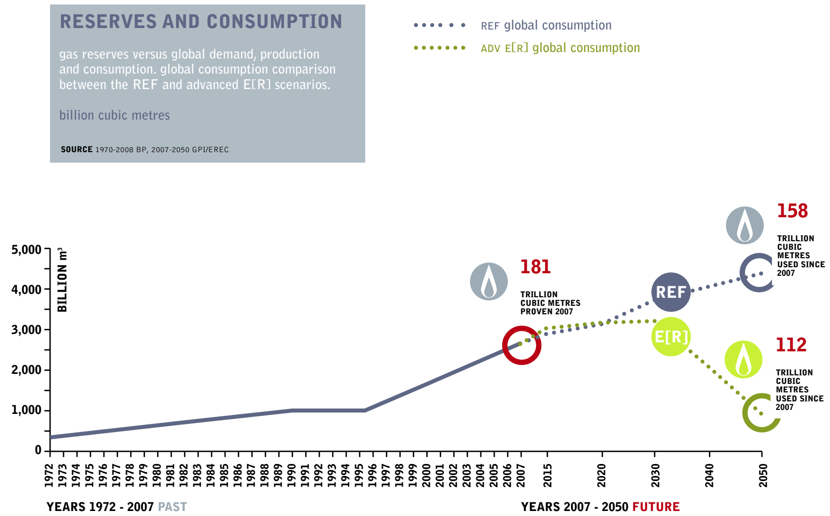


RESERVES AND CONSUMPTION

gas reserves versus global demand, production and consumption. global consumption comparison between the REF and advanced E[R] scenarios.

billion cubic metres

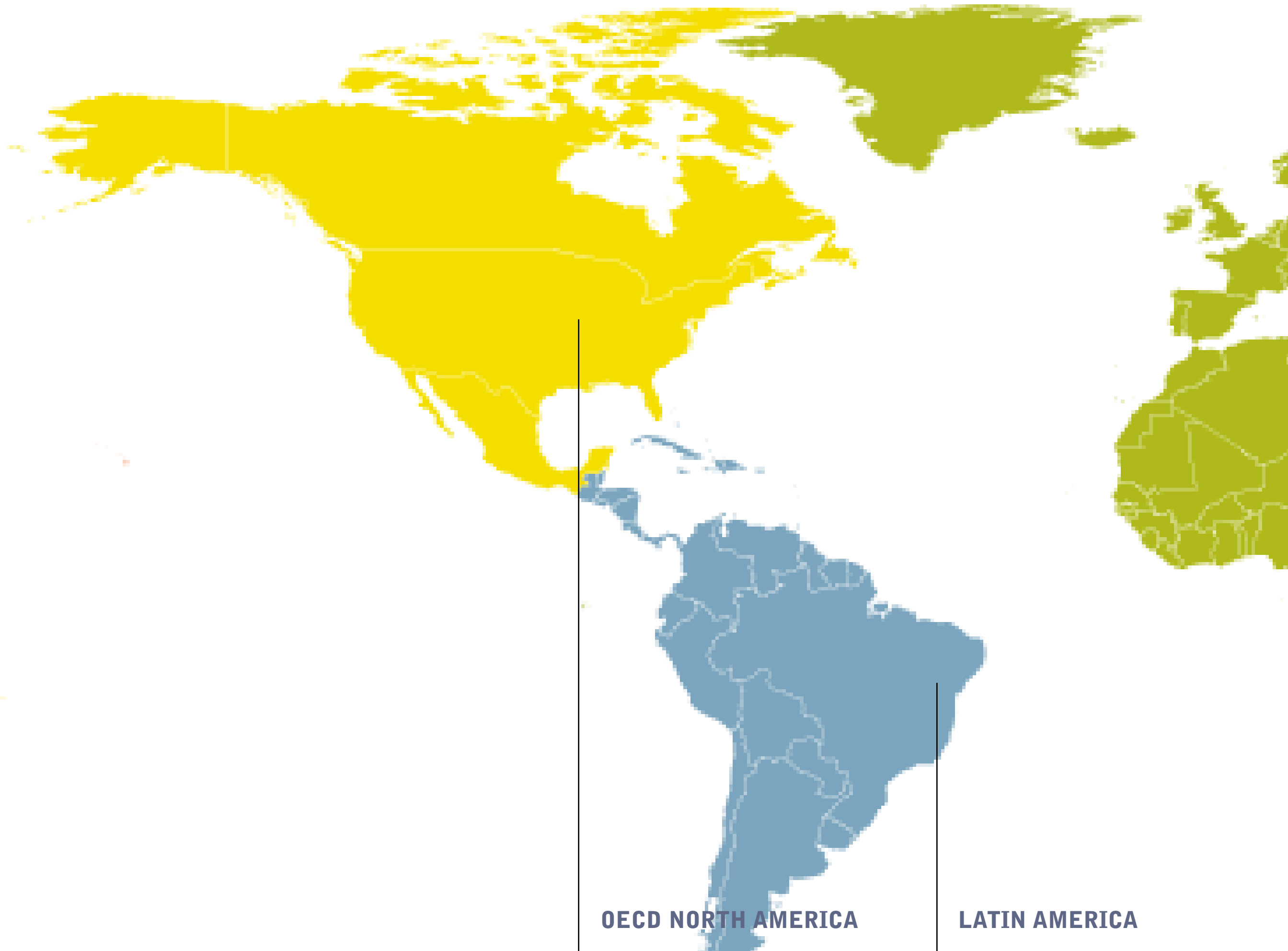
SOURCE 1970-2008 BP, 2007-2050 GPI/EREC



GREENPEACE
DESIGN WWW.ONEHEMISPHERE.SE **CONCEPT** SVEN TESKE/GREENPEACE INTERNATIONAL.

map 8.3: coal reference scenario and the advanced energy [r]evolution scenario

WORLDWIDE SCENARIO



OECD NORTH AMERICA

		REF mn t	REF %	E[R] mn t	E[R] %
Reserves total	2007	250,510	**29.6%**	250,510	**29.6%**
		mn t	**PJ**	**mn t**	**PJ**
Consumption per region	2007	1,882	24,923	1,882	24,923
	2050	1,351	27,255	6	134
		t		**t**	
Consumption per person	2007	2.4		2.4	
	2050	2.0		0.0	

LATIN AMERICA

		REF mn t	REF %	E[R] mn t	E[R] %
Reserves total	2007	16,276	**1.9%**	16,276	**1.9%**
		mn t	**PJ**	**mn t**	**PJ**
Consumption per region	2007	45	891	45	891
	2050	165	3,122	11	247
		t		**t**	
Consumption per person	2007	0.1		0.1	
	2050	0.2		0.0	

NON RENEWABLE RESOURCE

COAL

LEGEND

>60 | 50-60 | 40-50 | 30-40 | 20-30 | 10-20 | 5-10 | 0-5 — % RESOURCES GLOBALLY

REF REFERENCE SCENARIO

E[R] ADVANCED ENERGY [R]EVOLUTION SCENARIO

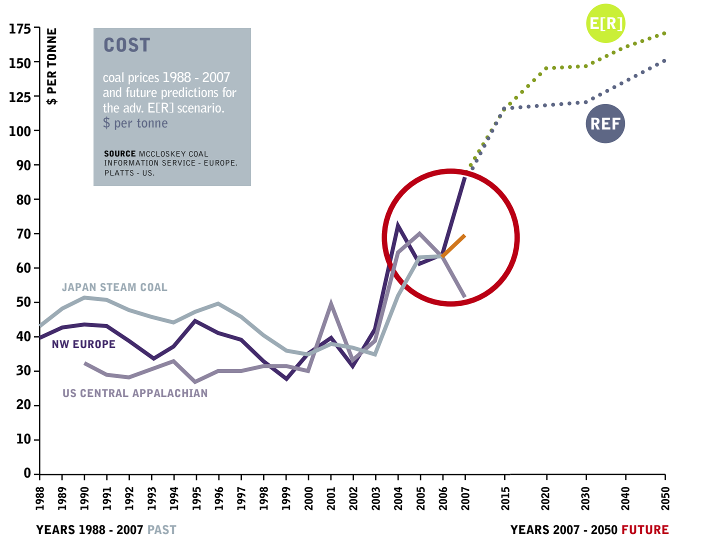
0 1000 KM

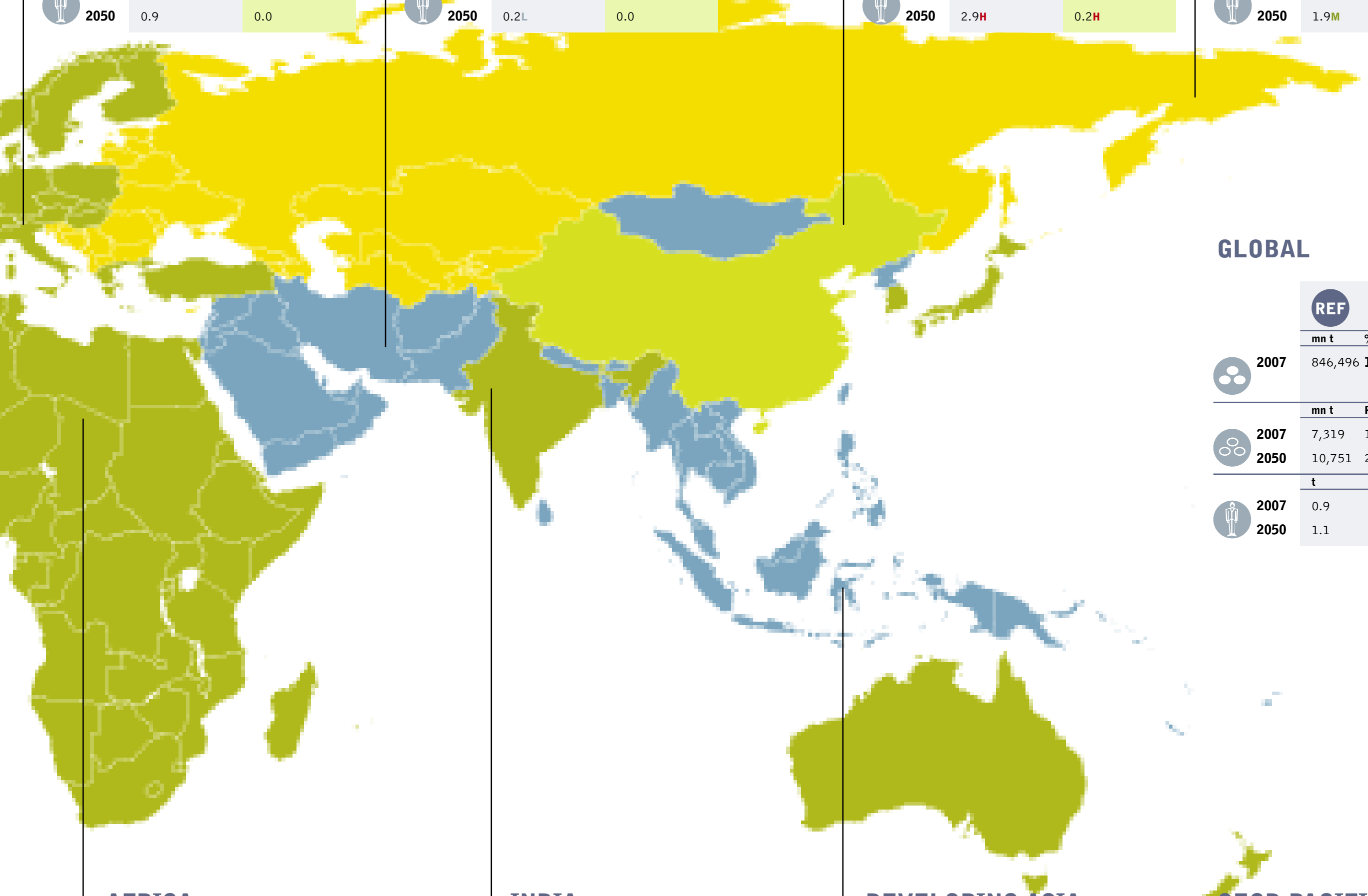
RESERVES TOTAL MILLION TONNES [mn t] | SHARE IN % OF GLOBAL TOTAL [END OF 2007]

CONSUMPTION PER REGION MILLION TONNES [mn t] | PETA JOULE [PJ]

CONSUMPTION PER PERSON TONNES [t]

H HIGHEST | M MIDDLE | L LOWEST





OECD EUROPE

		REF mn t	REF %	E[R] mn t	E[R] %
Reserves	2007	50,063	5.9%	50,063	5.9%
		mn t	**PJ**	**mn t**	**PJ**
Production	2007	897	14,371	897	14,371
	2050	710	11,899	10	231
		t		**t**	
Per capita	2007	1.2		1.2	
	2050	0.9		0.0	

MIDDLE EAST

		REF mn t	REF %	E[R] mn t	E[R] %
Reserves	2007	1,386	0.2%L	1,386	0.2%L
		mn t	**PJ**	**mn t**	**PJ**
Production	2007	19L	437L	19	437
	2050	91L	2,092L	1L	13
		t		**t**	
Per capita	2007	0.0L		0.0	
	2050	0.2L		0.0	

CHINA

		REF mn t	REF %	E[R] mn t	E[R] %
Reserves	2007	114,500	13.5%	114,500	13.5%
		mn t	**PJ**	**mn t**	**PJ**
Production	2007	2,403H	55,333H	2,403	55,333
	2050	4,148H	95,527H	218H	5,027H
		t		**t**	
Per capita	2007	1.8		1.8	
	2050	2.9H		0.2H	

TRANSITION ECONOMIES

		REF mn t	REF %	E[R] mn t	E[R] %
Reserves	2007	222,183	26%	222,183	26%
		mn t	**PJ**	**mn t**	**PJ**
Production	2007	532	9,003	532	9,003
	2050	904	13,665	14	327
		t		**t**	
Per capita	2007	1.1		1.1	
	2050	1.9M		0.0	

GLOBAL

		REF mn t	REF %	E[R] mn t	E[R] %
Reserves	2007	846,496	100%	846,496	100%
		mn t	**PJ**	**mn t**	**PJ**
Production	2007	7,319	135,890	7,319	135,890
	2050	10,751	225,244	326	7,501
		t		**t**	
Per capita	2007	0.9		0.9	
	2050	1.1		0.0	

AFRICA

		REF mn t	REF %	E[R] mn t	E[R] %
Reserves	2007	49,605	5.9%	49,605	5.9%
		mn t	**PJ**	**mn t**	**PJ**
Production	2007	188	4,330	188	4,330
	2050	303	6,977	19	427
		t		**t**	
Per capita	2007	0.2		0.2	
	2050	0.2		0.0	

INDIA

		REF mn t	REF %	E[R] mn t	E[R] %
Reserves	2007	56,498	6.7%M	56,498	6.7%M
		mn t	**PJ**	**mn t**	**PJ**
Production	2007	459	10,126	459	10,126
	2050	1,692	36,709	37	851
		t		**t**	
Per capita	2007	0.4		0.4	
	2050	1.0		0.0	

DEVELOPING ASIA

		REF mn t	REF %	E[R] mn t	E[R] %
Reserves	2007	7,814	0.9%	7,814	0.9%
		mn t	**PJ**	**mn t**	**PJ**
Production	2007	330	5,824	330	5,824
	2050	868M	17,902	9	217
		t		**t**	
Per capita	2007	0.3		0.3	
	2050	0.5		0.0	

OECD PACIFIC

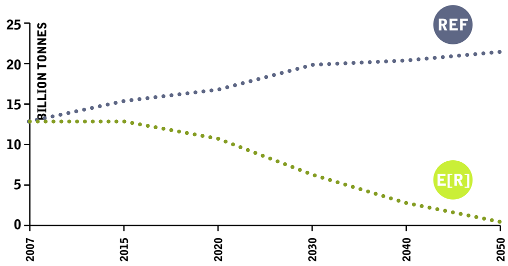
		REF mn t	REF %	E[R] mn t	E[R] %
Reserves	2007	77,661	9%	77,661	9%
		mn t	**PJ**	**mn t**	**PJ**
Production	2007	565	10,652	565	10,652
	2050	518	10,097	1L	27
		t		**t**	
Per capita	2007	2.3		2.3	
	2050	2.4		0.0	

CO2 EMISSIONS FROM COAL

comparison between the REF and adv. E[R] scenarios 2007 - 2050

billion tonnes

SOURCE GPI/EREC

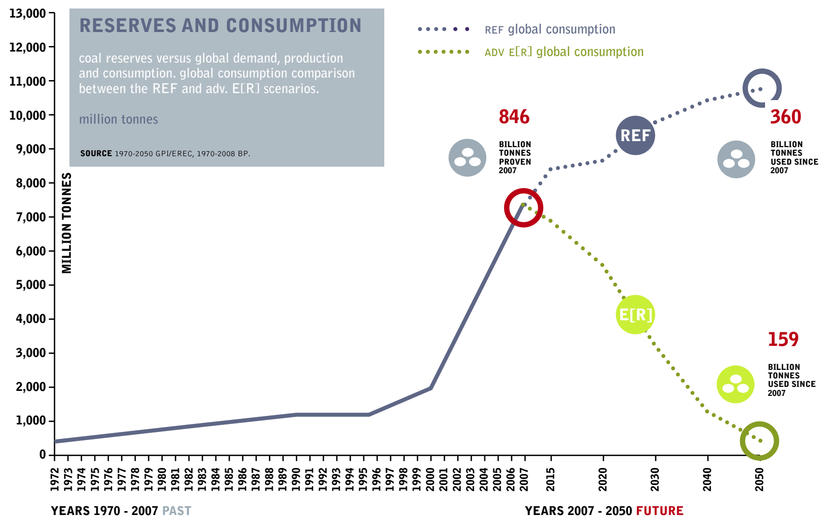


RESERVES AND CONSUMPTION

coal reserves versus global demand, production and consumption. global consumption comparison between the REF and adv. E[R] scenarios.

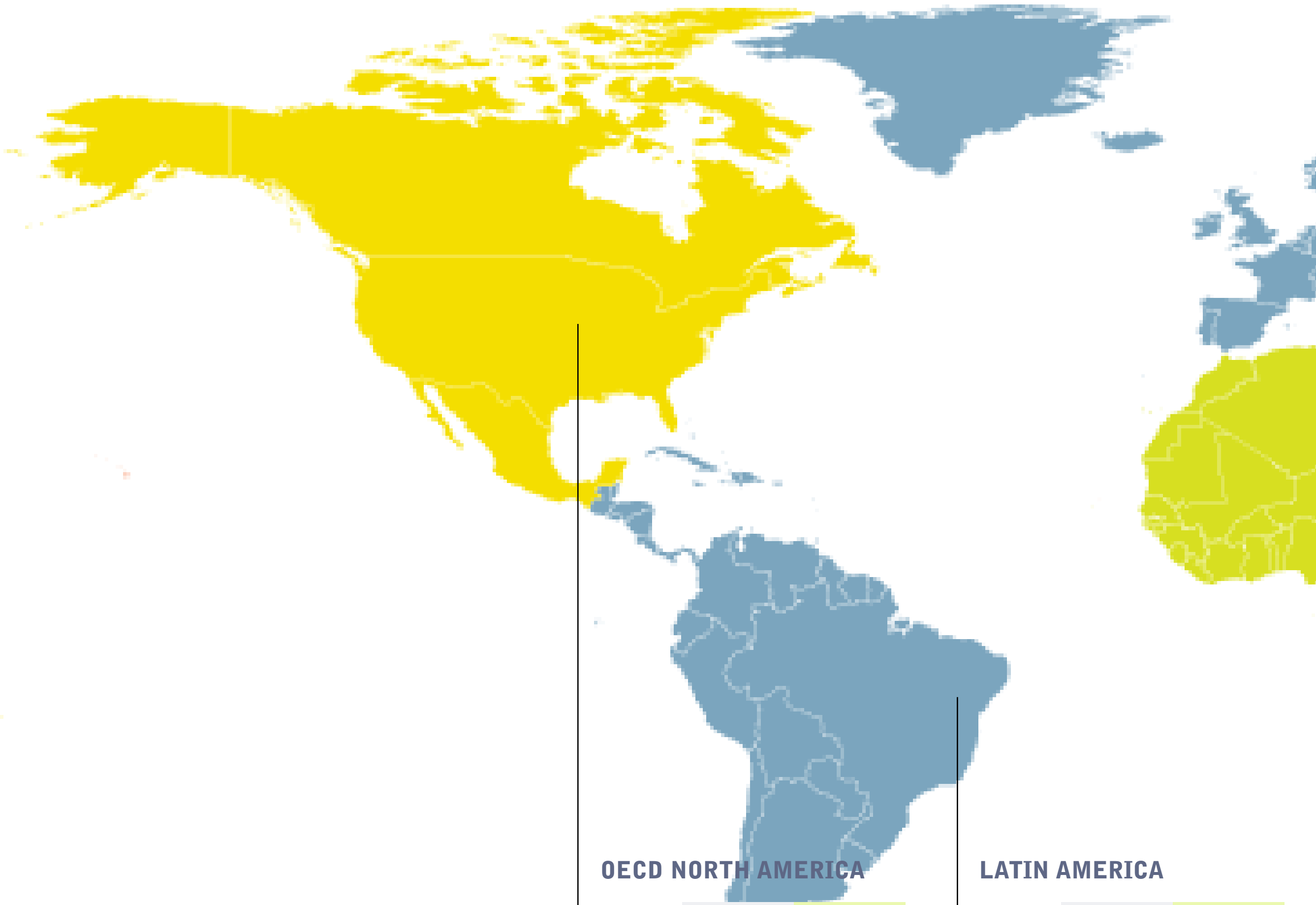
million tonnes

SOURCE 1970-2050 GPI/EREC, 1970-2008 BP.



map 8.4: nuclear reference scenario and the advanced energy [r]evolution scenario

WORLDWIDE SCENARIO



OECD NORTH AMERICA

		REF		E[R]	
		t	%	t	%
Reserves	2007	680,109	21.5%	680,109	21.5%
		TWh		TWh	
Generation	2007	941H		NUCLEAR POWER PHASED OUT BY 2040	
	2050	1,259H			
		PJ		PJ	
Consumption	2007	10,260H		10,260H	
	2050	13,735H		0	
		kWh		kWh	
Per person	2007	2,094H		2,094H	
	2050	2,181		0	

LATIN AMERICA

		REF		E[R]	
		t	%	t	%
Reserves	2007	95,045	3%	95,045	3%
		TWh		TWh	
Generation	2007	20		PHASED OUT BY 2030	
	2050	60			
		PJ		PJ	
Consumption	2007	214		214	
	2050	655		0	
		kWh		kWh	
Per person	2007	42		42	
	2050	100		0	

NON RENEWABLE RESOURCE

NUCLEAR

LEGEND

>30 | 20-30 | 10-20 | 5-10 | 0-5 % RESOURCES GLOBALLY

REF REFERENCE SCENARIO

E[R] ADVANCED ENERGY [R]EVOLUTION SCENARIO

0 1000 KM

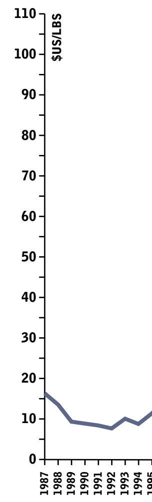
RESERVES TOTAL TONNES | SHARE IN % OF GLOBAL TOTAL [END OF 2007]

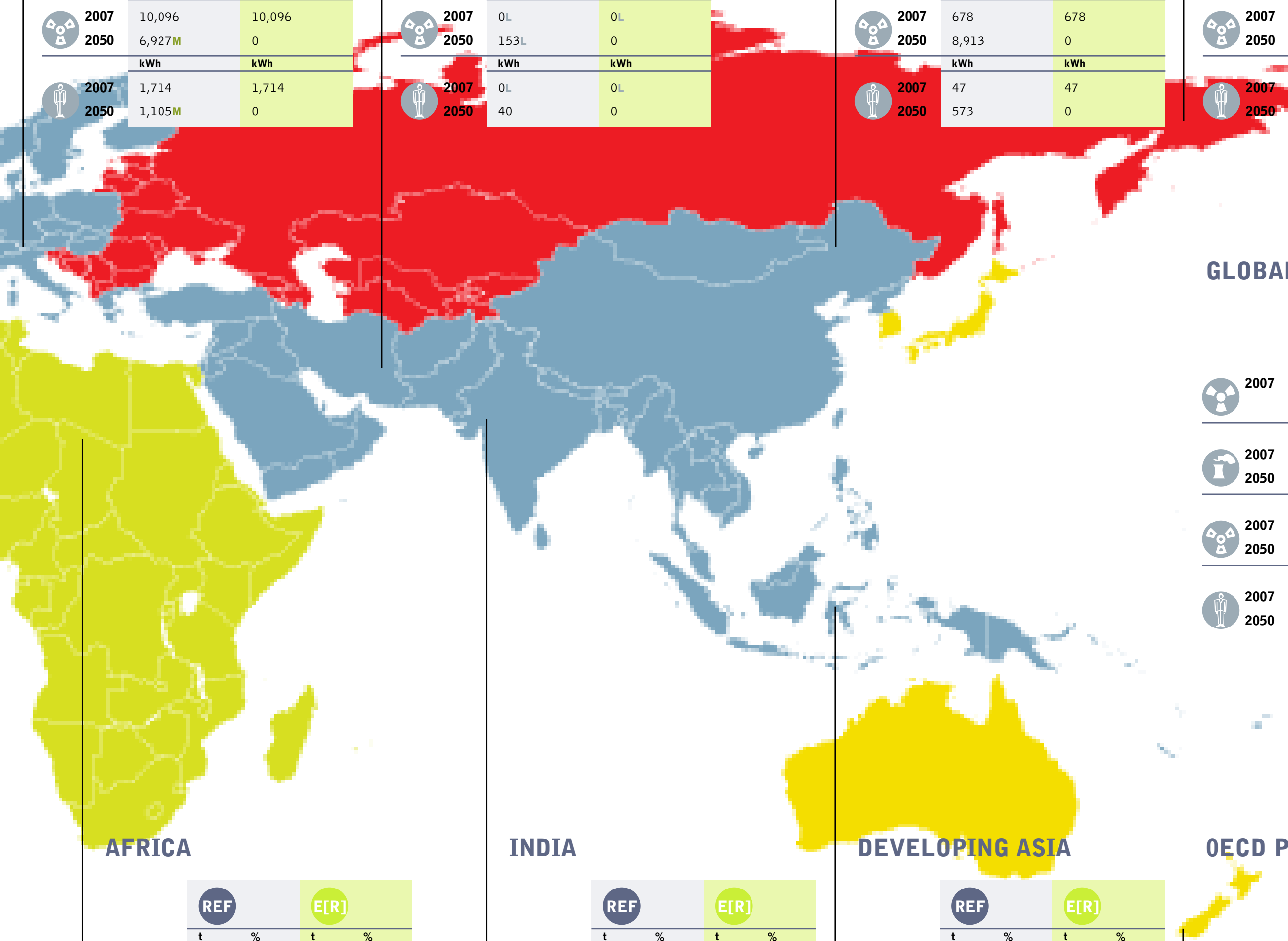
GENERATION PER REGION TERAWATT HOURS [TWh]

CONSUMPTION PER REGION PETA JOULE [PJ]

CONSUMPTION PER PERSON KILOWATT HOURS [kWh]

H HIGHEST | M MIDDLE | L LOWEST





OECD EUROPE

	Year	REF	E[R]
t / %	2007	56,445 1.8%	56,445 1.8%
TWh	2007	925	PHASED OUT BY 2030
	2050	635M	
PJ	2007	10,096	10,096
	2050	6,927M	0
kWh	2007	1,714	1,714
	2050	1,105M	0

MIDDLE EAST

	Year	REF	E[R]
t / %	2007	370L 0%L	370L 0%L
TWh	2007	0L	NO NUCLEAR ENERGY DEVELOPMENT
	2050	14L	
PJ	2007	0L	0L
	2050	153L	0
kWh	2007	0L	0L
	2050	40	0

CHINA

	Year	REF	E[R]
t / %	2007	35,060 1.1%	35,060 1.1%
TWh	2007	62	NUCLEAR POWER PHASED OUT BY 2045
	2050	817	
PJ	2007	678	678
	2050	8,913	0
kWh	2007	47	47
	2050	573	0

TRANSITION ECONOMIES

	Year	REF	E[R]
t / %	2007	1,043,687H 32.9%H	1,043,687H 32.9%H
TWh	2007	293M	NUCLEAR POWER PHASED OUT BY 2045
	2050	463	
PJ	2007	3,197M	3,197M
	2050	5,051	0
kWh	2007	861M	861M
	2050	1,490	0

GLOBAL

	Year	REF	E[R]
t / %	2007	3,169,238 100%	3,169,238 100%
TWh	2007	2,719	NUCLEAR POWER PHASED OUT BY 2045
	2050	4,413	
PJ	2007	29,664	29,664
	2050	48,142	0
kWh	2007	418	418
	2050	481	0

AFRICA

	Year	REF	E[R]
t / %	2007	470,312M 14.8%M	470,312M 14.8%M
TWh	2007	11	NUCLEAR POWER PHASED OUT BY 2025
	2050	45	
PJ	2007	123	123
	2050	491	0
kWh	2007	12	12
	2050	23L	0

INDIA

	Year	REF	E[R]
t / %	2007	40,980 1.3%	40,980 1.3%
TWh	2007	17	NUCLEAR POWER PHASED OUT BY 2045
	2050	172	
PJ	2007	183	183
	2050	1,876	0
kWh	2007	17	17
	2050	172	0

DEVELOPING ASIA

	Year	REF	E[R]
t / %	2007	5,630 0.2%	5,630 0.2%
TWh	2007	44	NUCLEAR POWER PHASED OUT BY 2045
	2050	80	
PJ	2007	476	476
	2050	873	0
kWh	2007	43	43
	2050	53	0

OECD PACIFIC

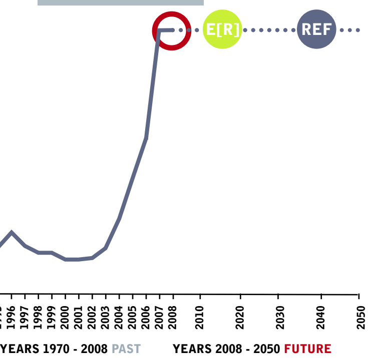
	Year	REF	E[R]
t / %	2007	741,600 23.4%	741,600 23.4%
TWh	2007	407	NUCLEAR POWER PHASED OUT BY 2045
	2050	868	
PJ	2007	4,437	4,437
	2050	9,469	0
kWh	2007	2,030	2,030
	2050	4,827H	0

COST

yellow cake prices 1987 - 2008 and future predictions comparing the REF and adv. E[R] scenarios

tonnes

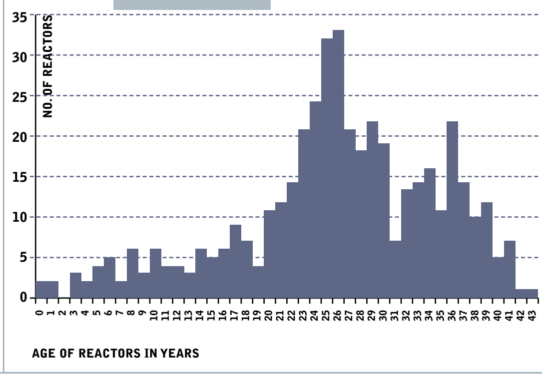
SOURCES REF: INTERNATIONAL ENERGY AGENCY/E[R]: DEVELOPMENTS APPLIED IN THE GES-PROJECT



REACTORS

age and number of reactors worldwide

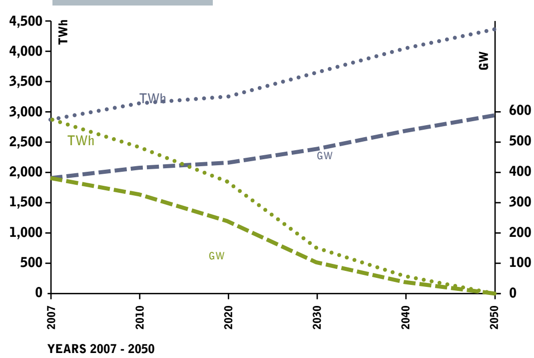
SOURCES IAEA



PRODUCTION

nuclear generation versus installed capacity. comparison between the REF and adv. E[R] scenrios. TWh and GW

SOURCES GREENPEACE INTERNATIONAL



8.5 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 role 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 Agency), 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[39]. 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 8.3).

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[38]

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.

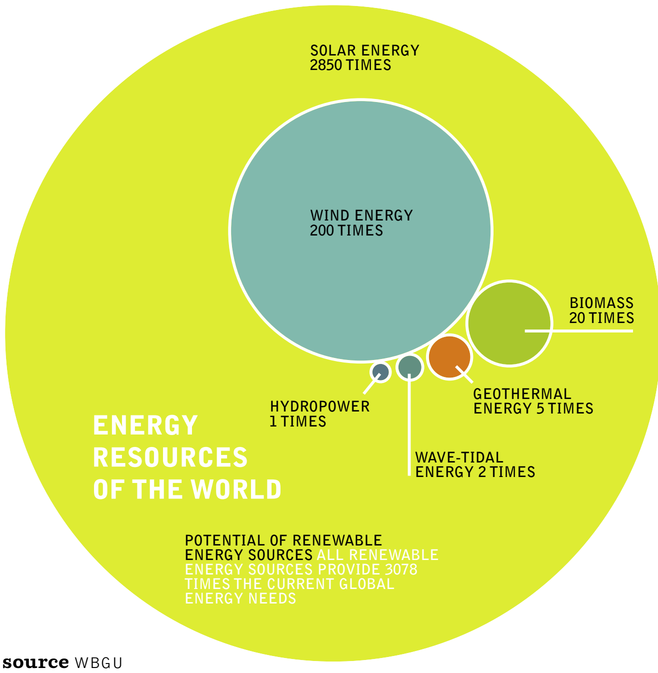
conversion potential This is derived from the annual efficiency of the respective conversion technology. It is therefore not a strictly defined value, since the efficiency of a particular technology depends on technological progress.

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 8.1: energy resources of the world



source WBGU

38 WBGU (GERMAN ADVISORY COUNCIL ON GLOBAL CHANGE).
39 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;

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.

table 8.3: 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.

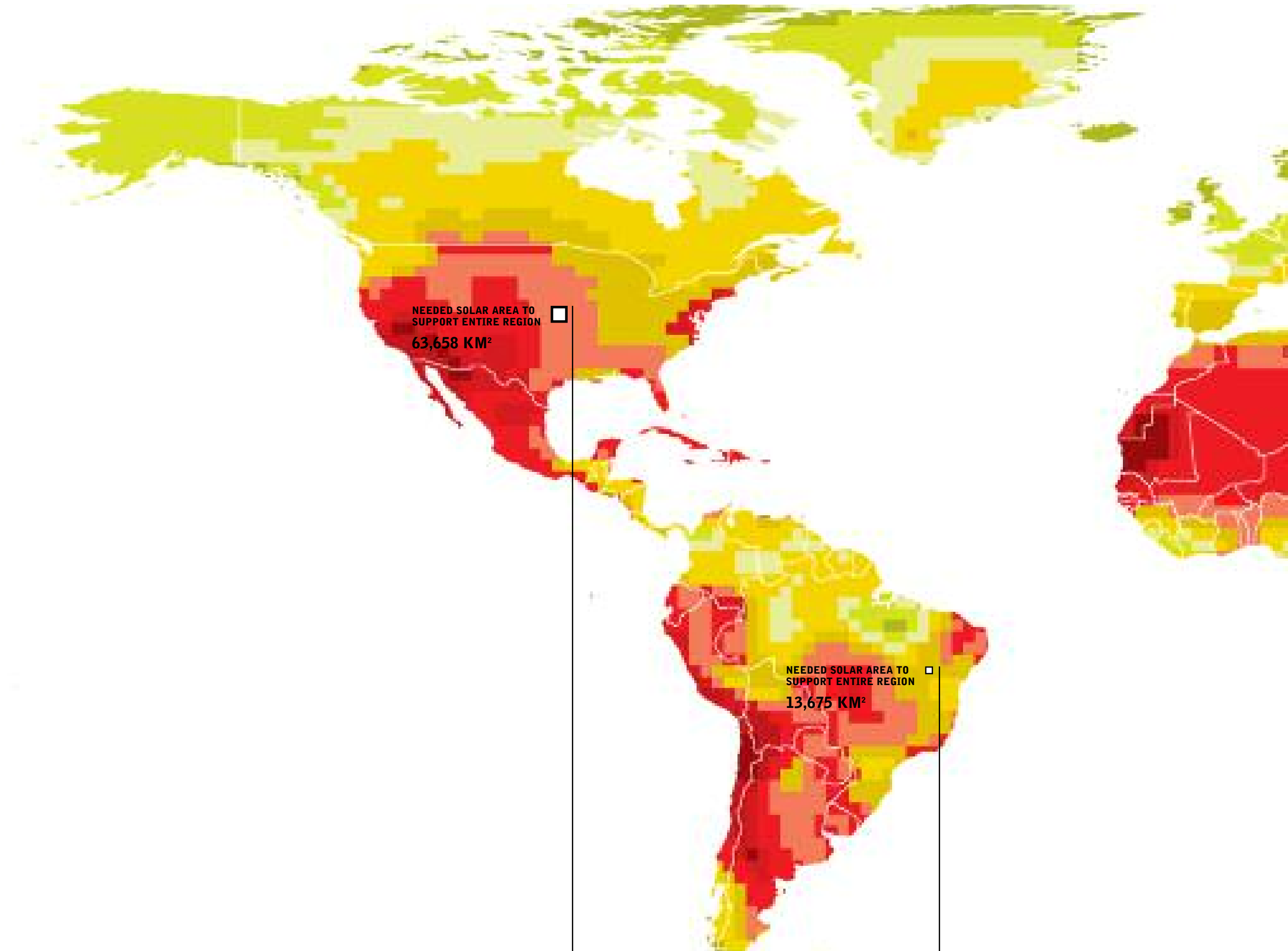
Given the large unexploited resources which exist, even without having reached the full development limits of the various technologies, it can be concluded that the technical potential is not a limiting factor to expansion of renewable energy generation.

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 operations 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.

map 8.5: solar reference scenario and the advanced energy [r]evolution scenario

WORLDWIDE SCENARIO



OECD NORTH AMERICA

		REF %	REF PJ	E[R] %	E[R] PJ
Production per region	2007	0.06M	64H		
	2050	1.04M	1,343	25M	17,683
			kWh		kWh
Production per person	2007		40		
	2050		646		8,508

LATIN AMERICA

		REF %	REF PJ	E[R] %	E[R] PJ
Production per region	2007	0.03	6		
	2050	0.52	214	14L	3,799L
			kWh		kWh
Production per person	2007		4		
	2050		99		1,758

RENEWABLE RESOURCE

SOLAR

LEGEND

2600-2800 | 2400-2600 | 2200-2400 | 2000-2200 | 1800-2000 | 1600-1800 | 1400-1600 | 1200-1400 | 1000-1200 | 800-1000 | 600-800 | 400-600 | 200-400 | 0-200

RADIATION IN kW/h PER SQUARE METER
SOURCE DLR

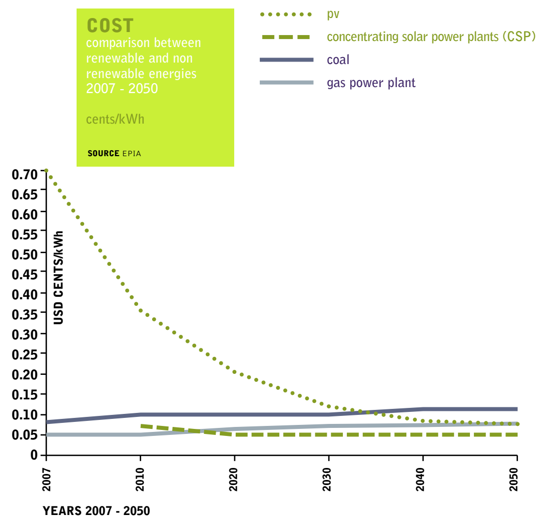
REF REFERENCE SCENARIO
E[R] ADVANCED ENERGY [R]EVOLUTION SCENARIO

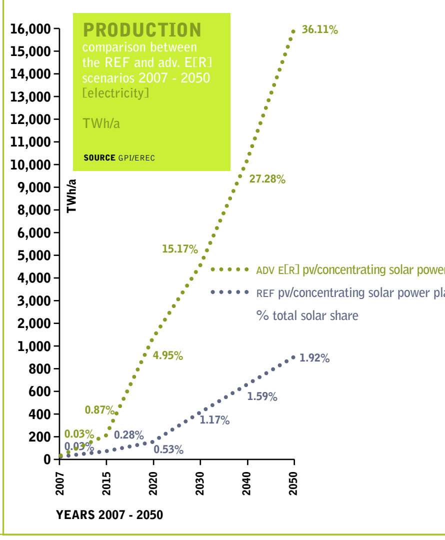
0 1000 KM

PRODUCTION PER REGION % OF GLOBAL SHARE | PETA JOULE [PJ]

PRODUCTION PER PERSON KILOWATT HOUR [kWh]

H HIGHEST | M MIDDLE | L LOWEST





OECD EUROPE

	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.09M	70		
2050	1.42H	1,173	23	10,680
		kWh		kWh
2007		36M		
2050		567		5,160M

MIDDLE EAST

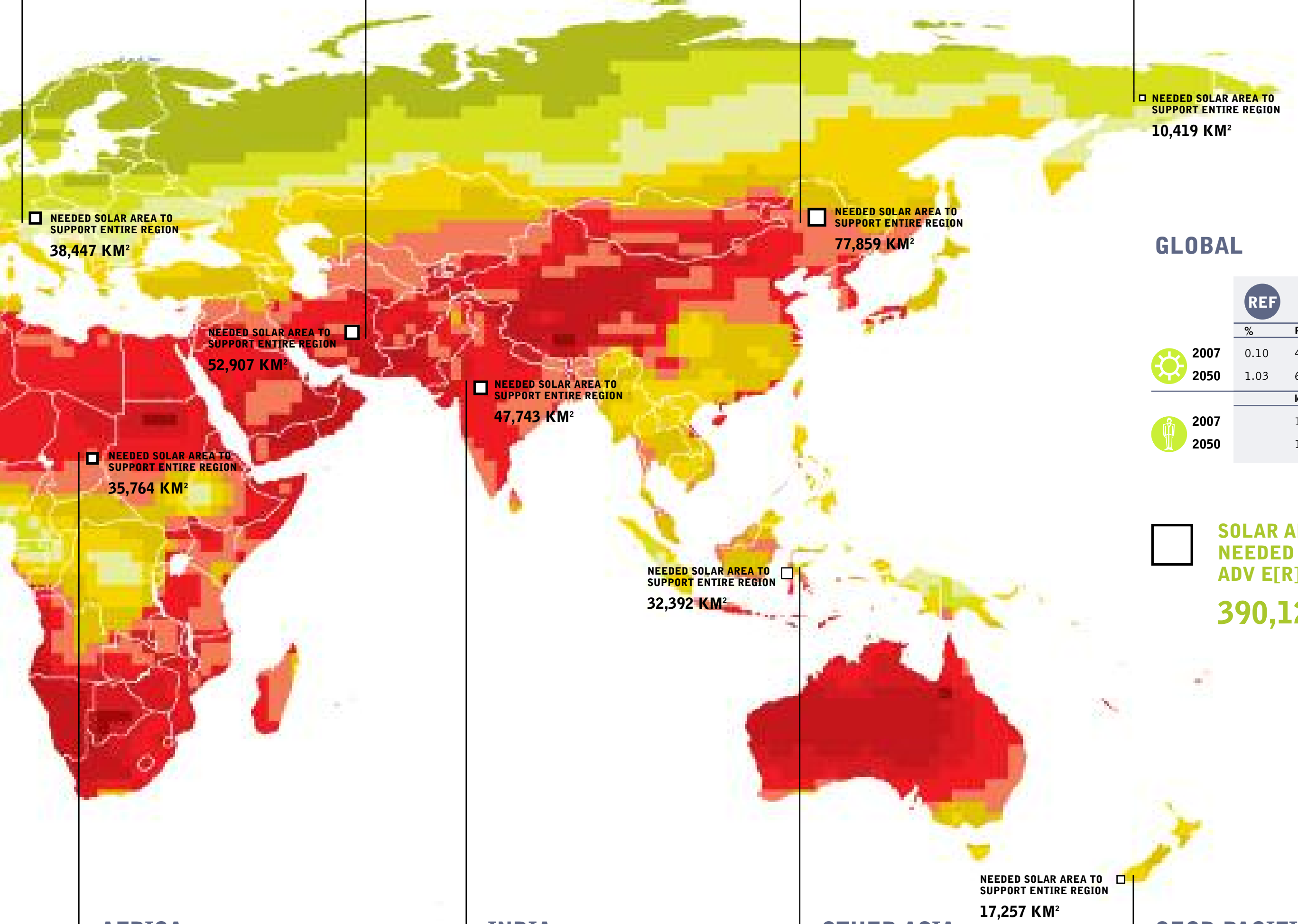
	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.17H	36		
2050	0.62	319	53H	14,696
		kWh		kWh
2007		50H		
2050		251		11,552H

CHINA

	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.22L	182L		
2050	0.95	1,754H	20	21,628H
		kWh		kWh
2007		38		
2050		342M		4,213

TRANSITION ECONOMIES

	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.01L	2		
2050	0.10L	63L	8,34	2,894
		kWh		kWh
2007		2		
2050		56		2,586



GLOBAL

	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.10	402		
2050	1.03	6,322	23.26	108,367
		kWh		kWh
2007		17		
2050		192		2,468

SOLAR AREA NEEDED TO SUPPORT ADV E[R] 2050 SCENARIO

390,122 KM²

AFRICA

	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.00	1		
2050	0.94	405	28	9,934
		kWh		kWh
2007		0.2		
2050		56L		1,380

INDIA

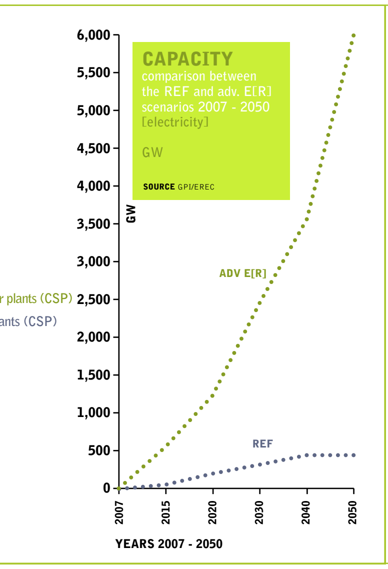
	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.02L	6L		
2050	0.23	182	24	13,262M
		kWh		kWh
2007		1		
2050		31		2,282

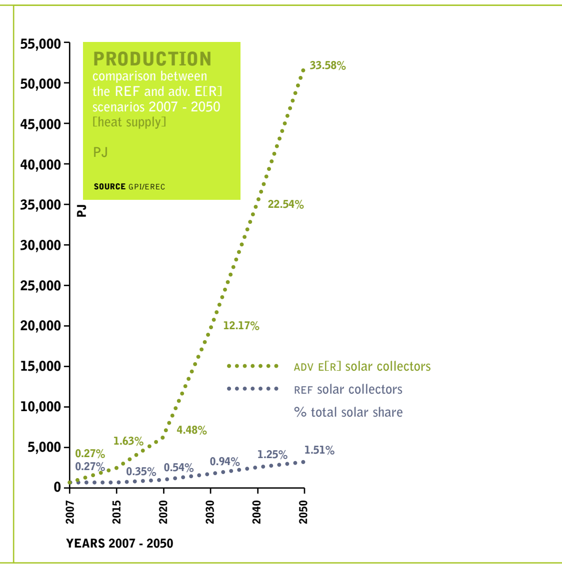
OTHER ASIA

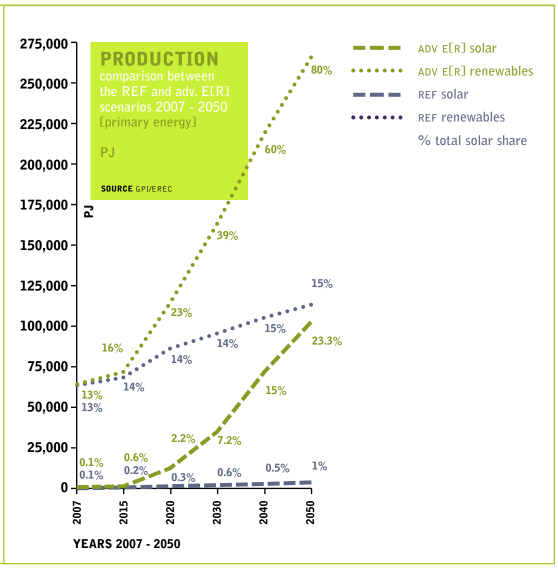
	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.01L	4L		
2050	0.58	405	22	8,998
		kWh		kWh
2007		1L		
2050		74		1,649L

OECD PACIFIC

	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.08	30M		
2050	1.14	466M	23	4,794
		kWh		kWh
2007		42		
2050		719H		7,405



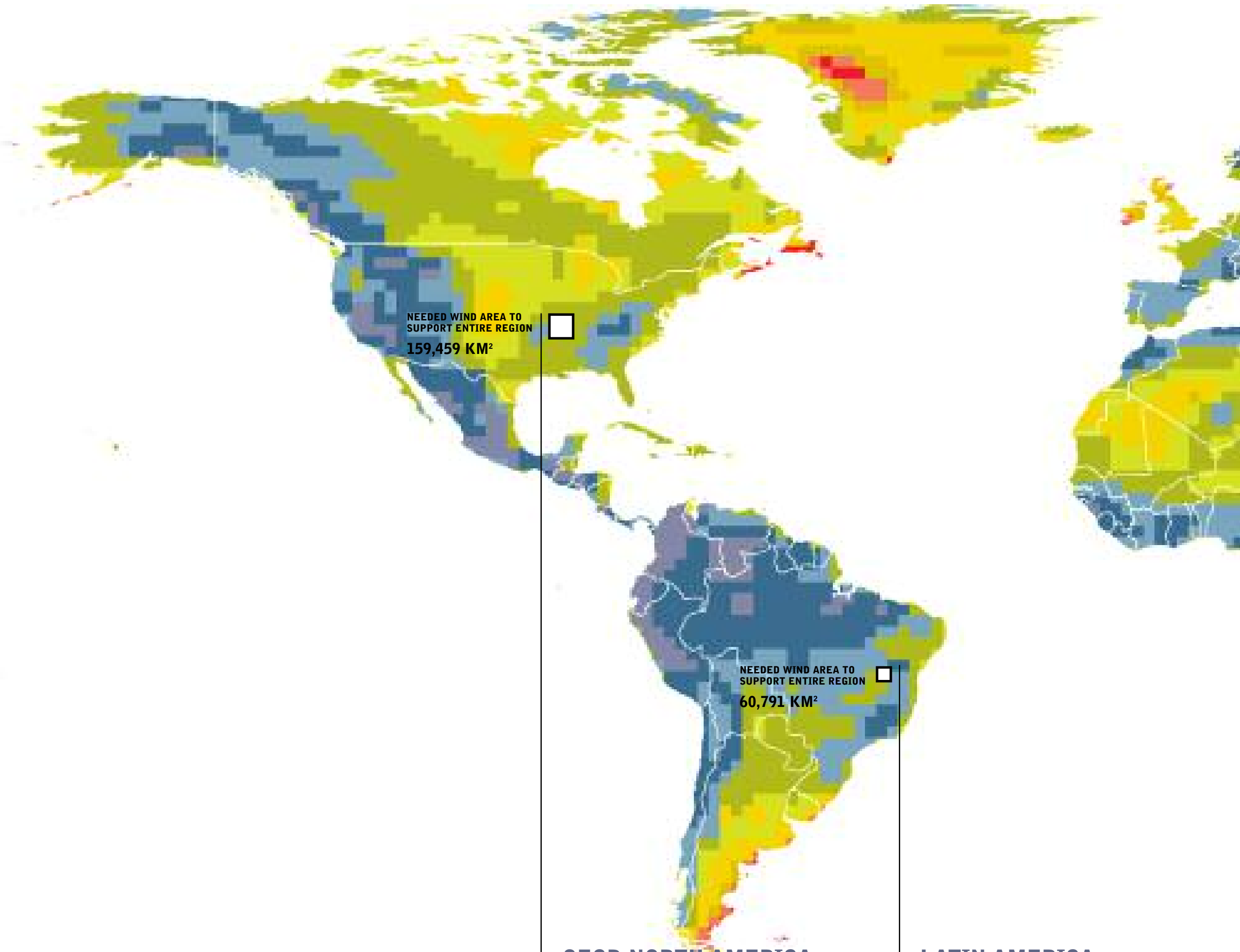




GREENPEACE
DESIGN WWW.ONEHEMISPHERE.SE CONCEPT SVEN TESKE/GREENPEACE INTERNATIONAL.

map 8.6: wind reference scenario and the advanced energy [r]evolution scenario

WORLDWIDE SCENARIO



RENEWABLE RESOURCE

WIND

OECD NORTH AMERICA

	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.12M	136		
2050	1.71	2,210	11.11	7,805H
		kWh		kWh
2007		84		
2050		1,064		3,755

LATIN AMERICA

	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.02	3		
2050	0.65	266	10.54	2,878
		kWh		kWh
2007		2		
2050		123		1,332

LEGEND

>11 | 10-11 | 9-10 | 8-9 | 7-8 | 6-7 | 5-6 | 4-5 | 3-4 | 1-2 | 0-1

AVERAGE WIND SPEED IN METRES PER SECOND
SOURCE DLR

REF REFERENCE SCENARIO

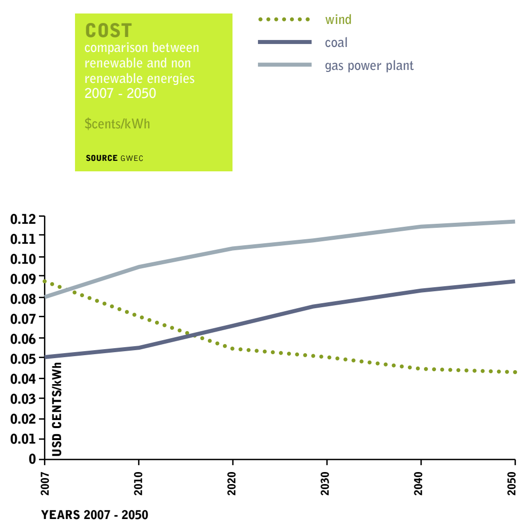
E[R] ADVANCED ENERGY [R]EVOLUTION SCENARIO

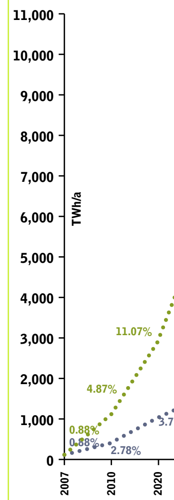
0 1000 KM

PRODUCTION PER REGION % OF GLOBAL SHARE | PETA JOULE [PJ]

PRODUCTION PER PERSON KILOWATT HOUR [kWh]

H HIGHEST | M MIDDLE | L LOWEST





8 energy resources & security of supply | WIND

OECD EUROPE

	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.49H	379H		
2050	4.14H	3,420H	10.41	4,867
		kWh		kWh
2007		195H		
2050		1,652H		2,352M

MIDDLE EAST

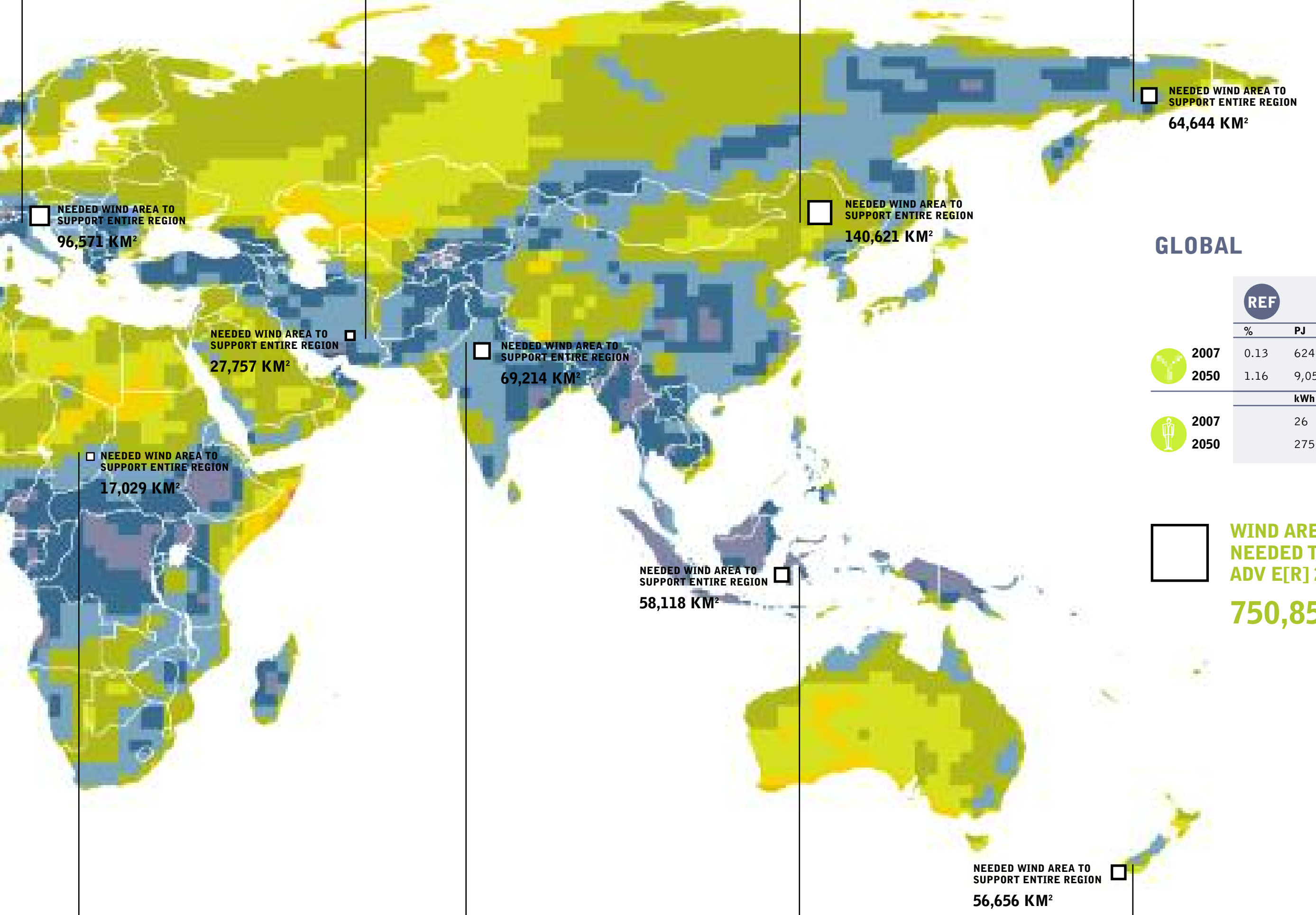
	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.00L	1L		
2050	0.26L	133L	4.78	1,314
		kWh		kWh
2007		1		
2050		105		1,033

CHINA

	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.04	32		
2050	0.66	1,220M	6.85M	7,340
		kWh		kWh
2007		7		
2050		238		1,430

TRANSITION ECONOMIES

	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.00	1		
2050	0.56	360	9.83	3,413
		kWh		kWh
2007		1		
2050		322M		3,050



GLOBAL

	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.13	624		
2050	1.16	9,058	8.38	39,029
		kWh		kWh
2007		26		
2050		275		1,182

WIND AREA NEEDED TO SUPPORT ADV E[R] 2050 SCENARIO

750,859 KM²

AFRICA

	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.02	4		
2050	0.47	202	3.00L	1,073L
		kWh		kWh
2007		1		
2050		28L		149L

INDIA

	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.17	42M		
2050	0.48	374	6.38	3,488
		kWh		kWh
2007		10		
2050		64		600

ASIA

	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.01	2L		
2050	0.69	475	8.75	3,557
		kWh		kWh
2007		0L		
2050		87		652

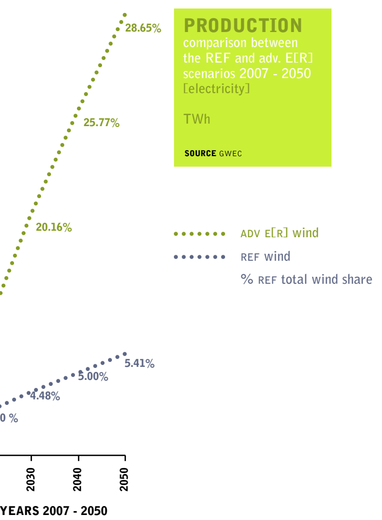
OECD PACIFIC

	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.06	24		
2050	0.97M	396	15.47H	3,294M
		kWh		kWh
2007		33M		
2050		611		5,089H

PRODUCTION comparison between the REF and adv. E[R] scenarios 2007 - 2050 [electricity]

TWh

SOURCE GWEC



CAPACITY comparison between the REF and adv. E[R] scenarios 2007 - 2050 [electricity]

GW

SOURCE GPI/GWEC

PRODUCTION comparison between the REF and adv. E[R] scenarios 2007 - 2050 [primary energy]

PJ

SOURCE GPI/GWEC

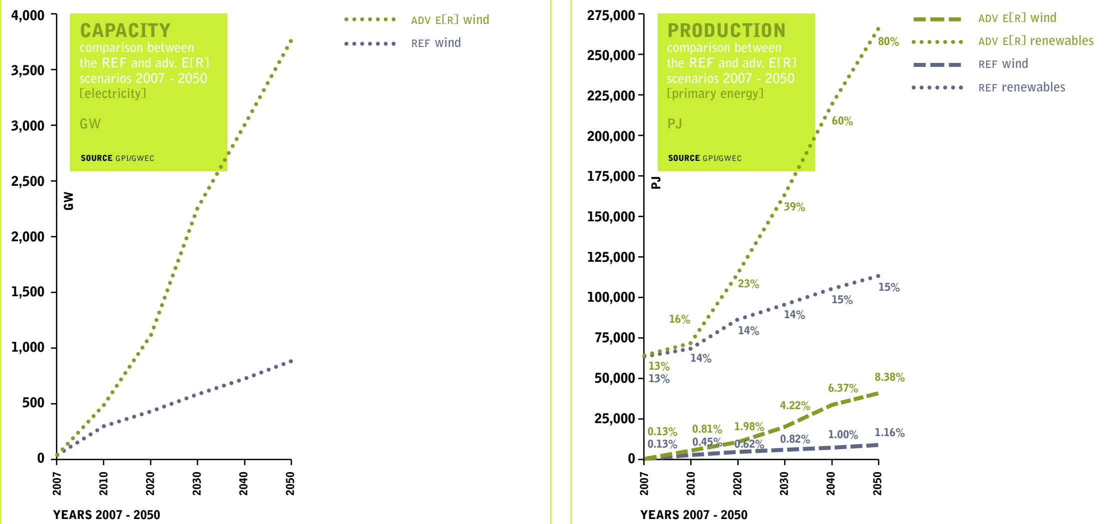
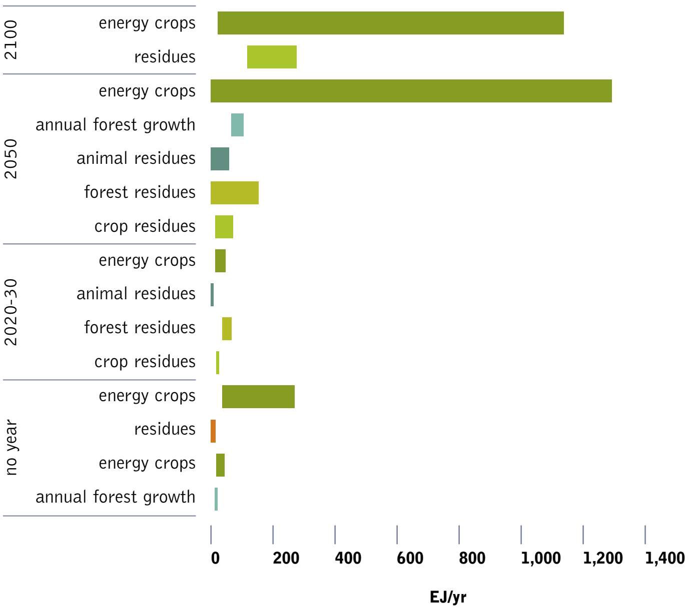


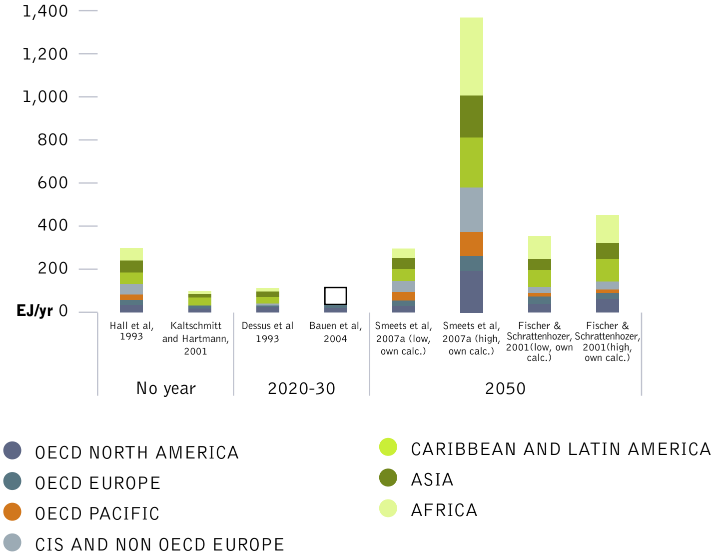
figure 8.2: ranges of potential for different biomass types



source GERMAN BIOMASS RESEARCH CENTRE (DBFZ)

figure 8.3: bio energy potential analysis from different authors

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



source GERMAN BIOMASS RESEARCH CENTRE (DBFZ)

8.5.1 the global potential for sustainable biomass

As part of background research for the Advanced Energy [R]evolution Scenario, 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[40].

8.5.2 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 8.2 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.

8.5.3 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. 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

40 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 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.

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 (SRC) (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.

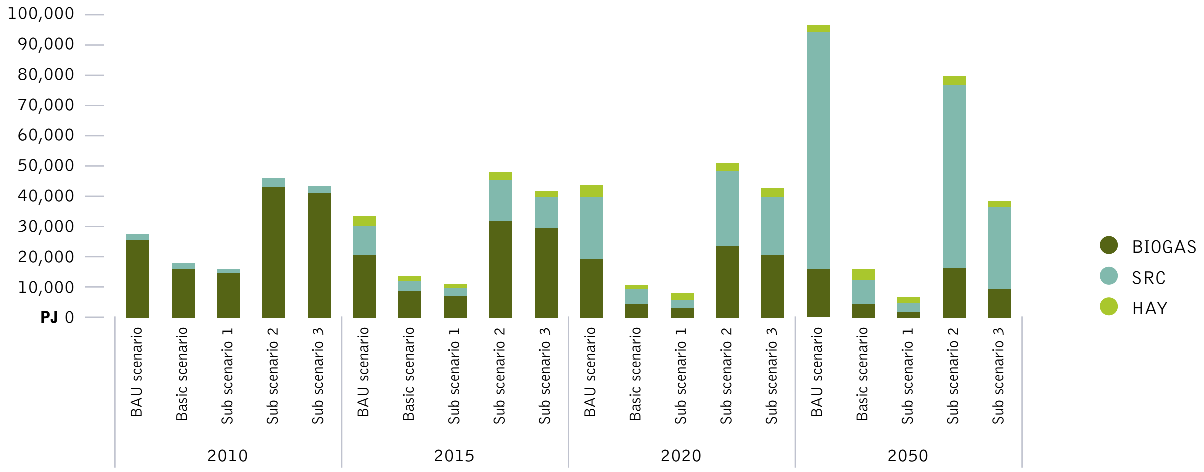
The result is that the global biomass potential from energy crops in 2050 falls within a range from 6 EJ in Sub-scenario 1 up to 97 EJ in the BAU scenario.

The best example of a country that 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 8.4: 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 biofuels 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.

renewable energy technologies

GLOBAL RENEWABLE ENERGY TECHNOLOGIES

9

"the technology is here, all we need is political will."

ANNA
SUPORTER, SWEDEN

image BIOGAS FACILITY "SCHRADEN BIOGAS" IN GROEDEN NEAR DRESDEN, GERMANY.

image WIND TURBINES AT THE NAN WIND FARM IN NAN'AO. GUANGDONG PROVINCE HAS ONE OF THE BEST WIND RESOURCES IN CHINA AND IS ALREADY HOME TO SEVERAL INDUSTRIAL SCALE WIND FARMS.

9.1 renewable energy technologies

Renewable energy covers a range of natural sources which are constantly renewed and therefore, unlike fossil fuels and uranium, will never be exhausted. Most of them derive from the effect of the sun and moon on the earth's weather patterns. They also produce none of the harmful emissions and pollution associated with 'conventional' fuels. Although hydroelectric power has been used on an industrial scale since the middle of the last century, the serious exploitation of other renewable sources has a more recent history.

9.1.1 solar power (photovoltaics)

There is more than enough solar radiation available all over the world to satisfy a vastly increased demand for solar power systems. The sunlight which reaches the earth's surface is enough to provide 2,850 times as much energy as we can currently use. On a global average, each square metre of land is exposed to enough sunlight to produce 1,700 kWh of power every year. The average irradiation in Europe is about 1,000 kWh per square metre, however, compared with 1,800 kWh in the Middle East.

Photovoltaic (PV) technology involves the generation of electricity from light. The essence of this process is the use of a semiconductor material which can be adapted to release electrons, the negatively charged particles that form the basis of electricity. The most common semiconductor material used in photovoltaic cells is silicon, an element most commonly found in sand. All PV cells have at least two layers of such semiconductors, one positively charged and one negatively charged. When light shines on the semiconductor, the electric field across the junction between these two layers causes electricity to flow. The greater the intensity of the light, the greater the flow of electricity. A photovoltaic system does not therefore need bright sunlight in order to operate, and can generate electricity even on cloudy days. Solar PV is different from a solar thermal collecting system (see below) where the sun's rays are used to generate heat, usually for hot water in a house, swimming pool etc.

The most important parts of a PV system are the cells which form the basic building blocks, the modules which bring together large numbers of cells into a unit, and, in some situations, the inverters used to convert the electricity generated into a form suitable for everyday use. When a PV installation is described as having a capacity of 3 kWp (peak), this refers to the output of the system under standard testing conditions, allowing comparison between different modules. In central Europe a 3 kWp rated solar electricity system, with a surface area of approximately 27 square metres, would produce enough power to meet the electricity demand of an energy conscious household.

There are several different PV technologies and types of installed system.

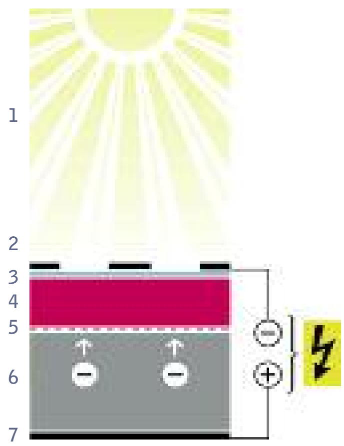
technologies

- **crystalline silicon technology** Crystalline silicon cells are made from thin slices cut from a single crystal of silicon (mono crystalline) or from a block of silicon crystals (polycrystalline or multi crystalline). This is the most common technology, representing about 80% of the market today. In addition, this technology also exists in the form of ribbon sheets.
- **thin film technology** Thin film modules are constructed by depositing extremely thin layers of photosensitive materials onto a substrate such as glass, stainless steel or flexible plastic. The latter opens up a range of applications, especially for building integration (roof tiles) and end-consumer purposes. Four types of thin film modules are commercially available at the moment: Amorphous Silicon, Cadmium Telluride, Copper Indium/Gallium Diselenide/Disulphide and multi-junction cells.
- **other emerging cell technologies** (at the development or early commercial stage): These include Concentrated Photovoltaic, consisting of cells built into concentrating collectors that use a lens to focus the concentrated sunlight onto the cells, and Organic Solar Cells, whereby the active material consists at least partially of organic dye, small, volatile organic molecules or polymer.

systems

- **grid connected** The most popular type of solar PV system for homes and businesses in the developed world. Connection to the local electricity network allows any excess power produced to be sold to the utility. Electricity is then imported from the network outside daylight hours. An inverter is used to convert the DC power produced by the system to AC power for running normal electrical equipment.
- **grid support** A system can be connected to the local electricity network as well as a back-up battery. Any excess solar electricity produced after the battery has been charged is then sold to the network. This system is ideal for use in areas of unreliable power supply.
- **off-grid** Completely independent of the grid, the system is connected to a battery via a charge controller, which stores the electricity generated and acts as the main power supply. An inverter can be used to provide AC power, enabling the use of normal appliances. Typical off-grid applications are repeater stations for mobile phones or rural electrification. Rural electrification means either small solar home systems covering basic electricity needs or solar mini grids, which are larger solar electricity systems providing electricity for several households.
- **hybrid system** A solar system can be combined with another source of power - a biomass generator, a wind turbine or diesel generator - to ensure a consistent supply of electricity. A hybrid system can be grid connected, stand alone or grid support.

figure 9.1: photovoltaics technology



1. LIGHT (PHOTONS)
2. FRONT CONTACT GRID
3. ANTI-REFLECTION COATING
4. N-TYPE SEMICONDUCTOR
5. BOARDER LAYOUT
6. P-TYPE SEMICONDUCTOR
7. BACKCONTACT

9.1.2 concentrating solar power (CSP)

Concentrating solar power (CSP) plants, also called solar thermal power plants, produce electricity in much the same way as conventional power stations. They obtain their energy input by concentrating solar radiation and converting it to high temperature steam or gas to drive a turbine or motor engine. Large mirrors concentrate sunlight into a single line or point. The heat created there is used to generate steam. This hot, highly pressurised steam is used to power turbines which generate electricity. In sun-drenched regions, CSP plants can guarantee a large proportion of electricity production.

Four main elements are required: a concentrator, a receiver, some form of transfer medium or storage, and power conversion. Many different types of system are possible, including combinations with other renewable and non-renewable technologies, but there are four main groups of solar thermal technologies:

- **parabolic trough** Parabolic trough plants use rows of parabolic trough collectors, each of which reflect the solar radiation into an absorber tube. Synthetic oil circulates through the tubes, heating up to approximately 400°C. This heat is then used to generate electricity. Some of the plants under construction have been designed to produce power not only during sunny hours but also to store energy, allowing the plant to produce an additional 7.5 hours of nominal power after sunset, which dramatically improves their integration into the grid. Molten salts are normally used as storage fluid in a hot-and-cold two-tank concept. Plants in operation in Europe: Andasol 1 and 2 (50 MW +7.5 hour storage each); Puertollano (50 MW); Alvarado (50 MW) and Extresol 1 (50 MW + 7.5 hour storage).
- **central receiver or solar tower** A circular array of heliostats (large individually tracking mirrors) is used to concentrate sunlight on to a central receiver mounted at the top of a tower. A heat-transfer medium absorbs the highly concentrated radiation reflected by the heliostats and converts it into thermal energy to be used for the subsequent generation of superheated steam for turbine operation. To date, the heat transfer media demonstrated include water/steam, molten salts, liquid sodium and air. If pressurised gas or air is used at very high temperatures of about 1,000°C or more as the heat transfer medium, it can even be used to directly replace natural gas in a gas turbine, thus making use of the excellent efficiency (60%+) of modern gas and steam combined cycles.

  After an intermediate scaling up to 30 MW capacity, solar tower developers now feel confident that grid-connected tower power plants can be built up to a capacity of 200 MWe solar-only units. Use of heat storage will increase their flexibility. Although solar tower plants are considered to be further from commercialisation than parabolic trough systems, they have good longer-term prospects for high conversion efficiencies. Projects are being developed in Spain, South Africa and Australia.
- **parabolic dish** A dish-shaped reflector is used to concentrate sunlight on to a receiver located at its focal point. The concentrated beam radiation is absorbed into the receiver to heat a fluid or gas to approximately 750°C. This is then used to generate electricity in a small piston, Stirling engine or micro turbine attached to the receiver. The potential of parabolic dishes lies primarily for decentralised power supply and remote, stand-alone power systems. Projects are currently planned in the United States, Australia and Europe.
- **linear fresnel systems** Collectors resemble parabolic troughs, with a similar power generation technology, using a field of horizontally mounted flat mirror strips, collectively or individually tracking the sun. There is one plant currently in operation in Europe: Puerto Errado (2 MW).

figures 9.2: csp technologies: parabolic trough, central receiver/solar tower and parabolic dish

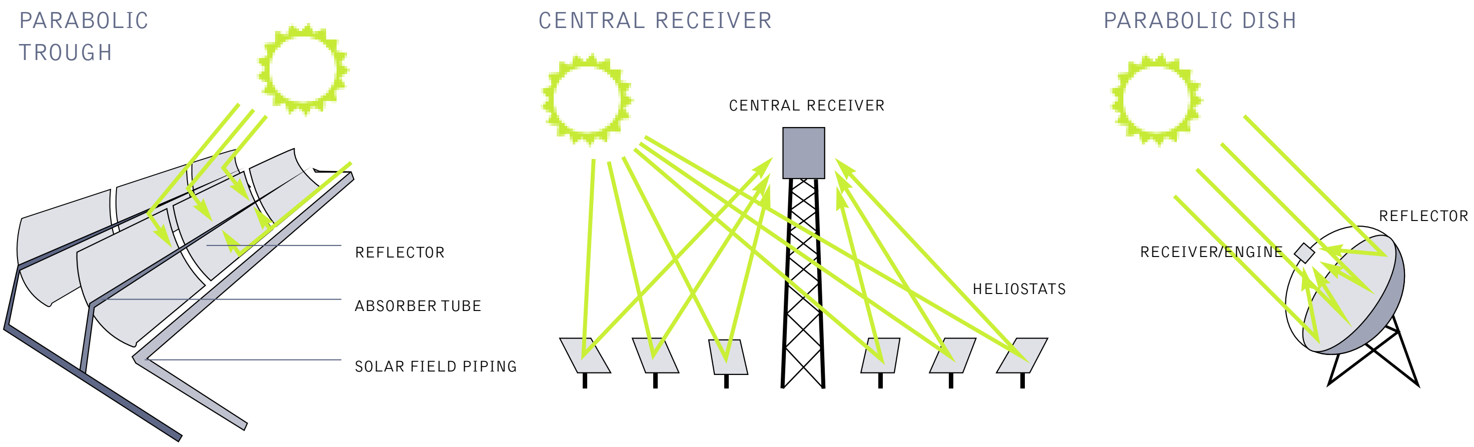


image SOLAR PROJECT IN PHITSANULOK, THAILAND. SOLAR FACILITY OF THE INTERNATIONAL INSTITUTE AND SCHOOL FOR RENEWABLE ENERGY.

image SOLAR PANELS ON CONISTON STATION, NORTH WEST OF ALICE SPRINGS, NORTHERN TERRITORY.

9.1.3 solar thermal collectors

Solar thermal collecting systems are based on a centuries-old principle: the sun heats up water contained in a dark vessel. Solar thermal technologies on the market now are efficient and highly reliable, providing energy for a wide range of applications - from domestic hot water and space heating in residential and commercial buildings to swimming pool heating, solar-assisted cooling, industrial process heat and the desalination of drinking water.

Although mature products exist to provide domestic hot water and space heating using solar energy, in most countries they are not yet the norm. Integrating solar thermal technologies into buildings at the design stage or when the heating (and cooling) system is being replaced is crucial, thus lowering the installation cost. Moreover, the untapped potential in the non-residential sector will be opened up as newly developed technology becomes commercially viable.

solar domestic hot water and space heating Domestic hot water production is the most common application. Depending on the conditions and the system's configuration, most of a building's hot water requirements can be provided by solar energy. Larger systems can additionally cover a substantial part of the energy needed for space heating. There are two main types of technology:

- **vacuum tubes** The absorber inside the vacuum tube absorbs radiation from the sun and heats up the fluid inside. Additional radiation is picked up from the reflector behind the tubes. Whatever the angle of the sun, the round shape of the vacuum tube allows it to reach the absorber. Even on a cloudy day, when the light is coming from many angles at once, the vacuum tube collector can still be effective.
- **flat panel** This is basically a box with a glass cover which sits on the roof like a skylight. Inside is a series of copper tubes with copper fins attached. The entire structure is coated in a black substance designed to capture the sun's rays. These rays heat up a water and antifreeze mixture which circulates from the collector down to the building's boiler.

solar assisted cooling Solar chillers use thermal energy to produce cooling and/or dehumidify the air in a similar way to a refrigerator or conventional air-conditioning. This application is well-suited to solar thermal energy, as the demand for cooling is often greatest when there is most sunshine. Solar cooling has been successfully demonstrated and large-scale use can be expected in the future.

figure 9.3: flat panel solar technology

9.1.4 wind power

Over the last 20 years, wind energy has become the world's fastest growing energy source. Today's wind turbines are produced by a sophisticated mass production industry employing a technology that is efficient, cost effective and quick to install. Turbine sizes range from a few kW to over 5,000 kW, with the largest turbines reaching more than 100m in height. One large wind turbine can produce enough electricity for about 5,000 households. State-of-the-art wind farms today can be as small as a few turbines and as large as several hundred MW.

The global wind resource is enormous, capable of generating more electricity than the world's total power demand, and well distributed across the five continents. Wind turbines can be operated not just in the windiest coastal areas but in countries which have no coastlines, including regions such as central Eastern Europe, central North and South America, and central Asia. The wind resource out at sea is even more productive than on land, encouraging the installation of offshore wind parks with foundations embedded in the ocean floor. In Denmark, a wind park built in 2002 uses 80 turbines to produce enough electricity for a city with a population of 150,000.

Smaller wind turbines can produce power efficiently in areas that otherwise have no access to electricity. This power can be used directly or stored in batteries. New technologies for using the wind's power are also being developed for exposed buildings in densely populated cities.

wind turbine design Significant consolidation of wind turbine design has taken place since the 1980s. The majority of commercial turbines now operate on a horizontal axis with three evenly spaced blades. These are attached to a rotor from which power is transferred through a gearbox to a generator. The gearbox and generator are contained within a housing called a nacelle. Some turbine designs avoid a gearbox by using direct drive. The electricity output is then channelled down the tower to a transformer and eventually into the local grid network.

Wind turbines can operate from a wind speed of 3-4 metres per second up to about 25 m/s. Limiting their power at high wind speeds is achieved either by 'stall' regulation – reducing the power output – or 'pitch' control – changing the angle of the blades so that they no longer offer any resistance to the wind. Pitch control has become the most common method. The blades can also turn at a constant or variable speed, with the latter enabling the turbine to follow more closely the changing wind speed.

The main design drivers for current wind technology are:

- high productivity at both low and high wind sites
- grid compatibility
- acoustic performance
- aerodynamic performance
- visual impact
- offshore expansion

Although the existing offshore market represents only just over 1% of the world's land-based installed wind capacity, the latest developments in wind technology are primarily driven by this emerging potential. This means that the focus is on the most effective ways to make very large turbines.

Modern wind technology is available for a range of sites - low and high wind speeds, desert and arctic climates. European wind farms operate with high availability, are generally well integrated into the environment and accepted by the public. In spite of repeated predictions of a levelling off at an optimum mid-range size, and the fact that wind turbines cannot get larger indefinitely, turbine size has increased year on year - from units of 20-60 kW in California in the 1980s up to the latest multi-MW machines with rotor diameters over 100 m. The average size of turbine installed around the world during 2009 was 1,599 kW, whilst the largest machine in operation is the Enercon E126, with a rotor diameter of 126 metres and a power capacity of 6 MW.

This growth in turbine size has been matched by the expansion of both markets and manufacturers. More than 150,000 wind turbines now operate in over 50 countries around the world. The US market is currently the largest, but there has also been impressive growth in Germany, Spain, Denmark, India and China.

9.1.5 biomass energy

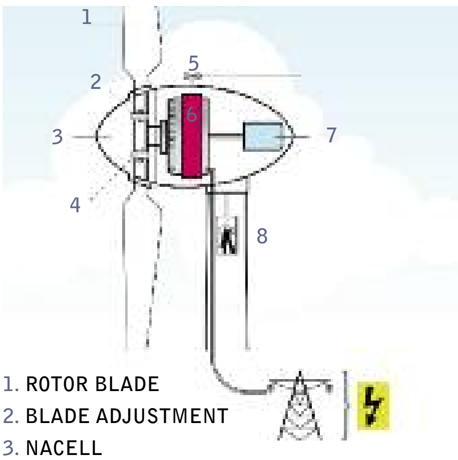
Biomass is a broad term used to describe material of recent biological origin that can be used as a source of energy. This includes wood, crops, algae and other plants as well as agricultural and forest residues. Biomass can be used for a variety of end uses: heating, electricity generation or as fuel for transportation. The term 'bio energy' is used for biomass energy systems that produce heat and/or electricity and 'bio fuels' for liquid fuels used in transport. Biodiesel manufactured from various crops has become increasingly used as vehicle fuel, especially as the cost of oil has risen.

Biological power sources are renewable, easily stored, and, if sustainably harvested, CO_2 neutral. This is because the gas emitted during their transfer into useful energy is balanced by the carbon dioxide absorbed when they were growing plants.

Electricity generating biomass power plants work just like natural gas or coal power stations, except that the fuel must be processed before it can be burned. These power plants are generally not as large as coal power stations because their fuel supply needs to grow as near as possible to the plant. Heat generation from biomass power plants can result either from utilising a Combined Heat and Power (CHP) system, piping the heat to nearby homes or industry, or through dedicated heating systems. Small heating systems using specially produced pellets made from waste wood, for example, can be used to heat single family homes instead of natural gas or oil.

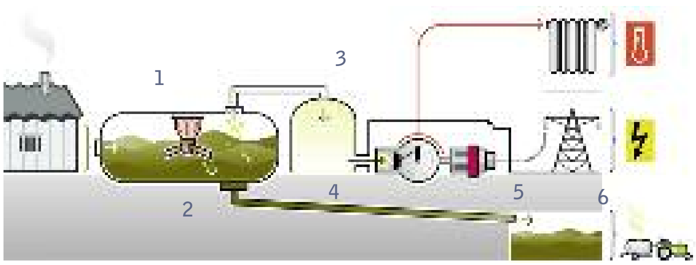
biomass technology A number of processes can be used to convert energy from biomass. These divide into thermal systems, which involve direct combustion of solids, liquids or a gas via pyrolysis or gasification, and biological systems, which involve decomposition of solid biomass to liquid or gaseous fuels by processes such as anaerobic digestion and fermentation.

figure 9.4: wind turbine technology



1. ROTOR BLADE
2. BLADE ADJUSTMENT
3. NACELL
4. ROTOR SHAFT
5. WIND MEASUREMENT
6. GENERATOR
7. SYSTEM CONTROL
8. LIFT

figure 9.5: biomass technology



1. HEATED MIXER
2. CONTAINMENT FOR FERMENTATION
3. BIOGAS STORAGE
4. COMBUSTION ENGINE
5. GENERATOR
6. WASTE CONTAINMENT

image SOLAR PANELS FEATURED IN A RENEWABLE ENERGY EXHIBIT ON BORACAY ISLAND, ONE OF THE PHILIPPINES' PREMIER TOURIST DESTINATIONS.

image VESTAS VM 80 WIND TURBINES AT AN OFFSHORE WIND PARK IN THE WESTERN PART OF DENMARK.

- **thermal systems** *Direct combustion* is the most common way of converting biomass into energy, for heat as well as electricity. Worldwide it accounts for over 90% of biomass generation. Technologies can be distinguished as either fixed bed, fluidised bed or entrained flow combustion. In **fixed bed combustion**, such as a grate furnace, primary air passes through a fixed bed, in which drying, gasification and charcoal combustion takes place. The combustible gases produced are burned after the addition of secondary air, usually in a zone separated from the fuel bed. In **fluidised bed combustion**, the primary combustion air is injected from the bottom of the furnace with such high velocity that the material inside the furnace becomes a seething mass of particles and bubbles. **Entrained flow combustion** is suitable for fuels available as small particles, such as sawdust or fine shavings, which are pneumatically injected into the furnace.

  Gasification Biomass fuels are increasingly being used with advanced conversion technologies, such as gasification systems, which offer superior efficiencies compared with conventional power generation. Gasification is a thermochemical process in which biomass is heated with little or no oxygen present to produce a low energy gas. The gas can then be used to fuel a gas turbine or combustion engine to generate electricity. Gasification can also decrease emission levels compared to power production with direct combustion and a steam cycle.

  Pyrolysis is a process whereby biomass is exposed to high temperatures in the absence of air, causing the biomass to decompose. The products of pyrolysis always include gas ('biogas'), liquid ('bio-oil') and solid ('char'), with the relative proportions of each depending on the fuel characteristics, the method of pyrolysis and the reaction parameters, such as temperature and pressure. Lower temperatures produce more solid and liquid products and higher temperatures more biogas.

- **biological systems** These processes are suitable for very wet biomass materials such as food or agricultural wastes, including farm animal slurry.

  Anaerobic digestion Anaerobic digestion means the breakdown of organic waste by bacteria in an oxygen-free environment. This produces a biogas typically made up of 65% methane and 35% carbon dioxide. Purified biogas can then be used both for heating and electricity generation.

  Fermentation Fermentation is the process by which growing plants with a high sugar and starch content are broken down with the help of micro-organisms to produce ethanol and methanol. The end product is a combustible fuel that can be used in vehicles.

  Biomass power station capacities typically range up to 15 MW, but larger plants are possible of up to 400 MW capacity, with part of the fuel input potentially being fossil fuel, for example pulverised coal. The world's largest biomass fuelled power plant is located at Pietarsaari in Finland. Built in 2001, this is an industrial CHP plant producing steam (100 MWth) and electricity (240 MWe) for the local forest industry and district heat for the nearby town. The boiler is a circulating fluidised bed boiler designed to generate steam from bark, sawdust, wood residues, commercial bio fuel and peat.

  A 2005 study commissioned by Greenpeace Netherlands concluded that it was technically possible to build and operate a 1,000 MWe biomass fired power plant using fluidised bed combustion technology and fed with wood residue pellets[41].

9.1.6 biofuels

Converting crops into ethanol and bio diesel made from rapeseed methyl ester (RME) currently takes place mainly in Brazil, the USA and Europe. Processes for obtaining synthetic fuels from 'biogenic synthesis' gases will also play a larger role in the future. Theoretically biofuels can be produced from any biological carbon source, although the most common are photosynthetic plants. Various plants and plant-derived materials are used for biofuel production.

Globally biofuels are most commonly used to power vehicles, but can also be used for other purposes. The production and use of biofuels must result in a net reduction in carbon emissions compared to the use of traditional fossil fuels to have a positive effect in climate change mitigation. Sustainable biofuels can reduce the dependency on petroleum and thereby enhance energy security.

- **bioethanol** is a fuel manufactured through the fermentation of sugars. This is done by accessing sugars directly (sugar cane or beet) or by breaking down starch in grains such as wheat, rye, barley or maize. In the European Union bio ethanol is mainly produced from grains, with wheat as the dominant feedstock. In Brazil the preferred feedstock is sugar cane, whereas in the USA it is corn (maize). Bio ethanol produced from cereals has a by-product, a protein-rich animal feed called Dried Distillers Grains with Solubles (DDGS). For every tonne of cereals used for ethanol production, on average one third will enter the animal feed stream as DDGS. Because of its high protein level this is currently used as a replacement for soy cake. Bio ethanol can either be blended into gasoline (petrol) directly or be used in the form of ETBE (Ethyl Tertiary Butyl Ether).

- **biodiesel** is a fuel produced from vegetable oil sourced from rapeseed, sunflower seeds or soybeans as well as used cooking oils or animal fats. If used vegetable oils are recycled as feedstock for bio diesel production this can reduce pollution from discarded oil and provides a new way of transforming a waste product into transport energy. Blends of bio diesel and conventional hydrocarbon-based diesel are the most common products distributed in the retail transport fuel market.

  Most countries use a labelling system to explain the proportion of bio diesel in any fuel mix. Fuel containing 20% biodiesel is labelled B20, while pure bio diesel is referred to as B100. Blends of 20% bio diesel with 80% petroleum diesel (B20) can generally be used in unmodified diesel engines. Used in its pure form (B100) an engine may require certain modifications. Bio diesel can also be used as a heating fuel in domestic and commercial boilers. Older furnaces may contain rubber parts that would be affected by bio diesel's solvent properties, but can otherwise burn it without any conversion.

41 'OPPORTUNITIES FOR 1,000 MWE BIOMASS-FIRED POWER PLANT IN THE NETHERLANDS', GREENPEACE NETHERLANDS, 2005

9.1.7 geothermal energy

Geothermal energy is heat derived from deep underneath the earth's crust. In most areas, this heat reaches the surface in a very diffuse state. However, due to a variety of geological processes, some areas, including the western part of the USA, west and central Eastern Europe, Iceland, Asia and New Zealand are underlain by relatively shallow geothermal resources. These are classified as either low temperature (less than 90°C), moderate temperature (90° - 150°C) or high temperature (greater than 150°C). The uses to which these resources can be put depend on the temperature. The highest temperature is generally used only for electric power generation. Current global geothermal generation capacity totals approximately 10,700 MW, and the leading country is currently the USA, with over 3,000 MW, followed by the Philippines (1,900 MW) and Indonesia (1,200 MW). Low and moderate temperature resources can be used either directly or through ground-source heat pumps.

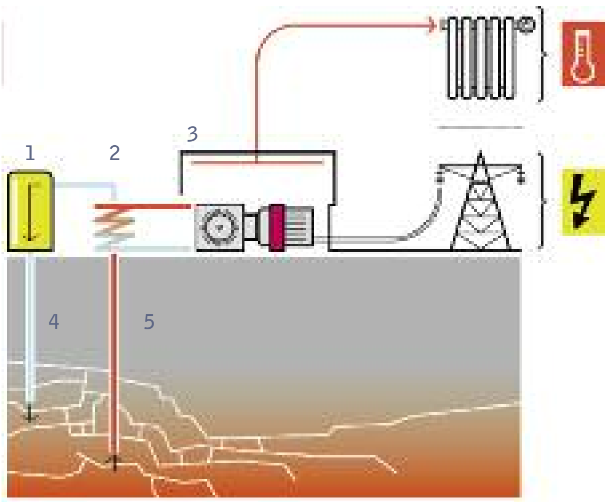
Geothermal power plants use the earth's natural heat to vaporise water or an organic medium. The steam created then powers a turbine which produces electricity. In the USA, New Zealand and Iceland this technique has been used extensively for decades. In Germany, where it is necessary to drill many kilometres down to reach the necessary temperatures, it is only in the trial stages. **Geothermal heat plants** require lower temperatures and the heated water is used directly.

9.1.8 hydro power

Water has been used to produce electricity for about a century. Today, around one fifth of the world's electricity is produced from hydro power. Large hydroelectric power plants with concrete dams and extensive collecting lakes often have very negative effects on the environment, however, requiring the flooding of habitable areas. Smaller 'run-of-the-river' power stations, which are turbines powered by one section of running water in a river, can produce electricity in an environmentally friendly way.

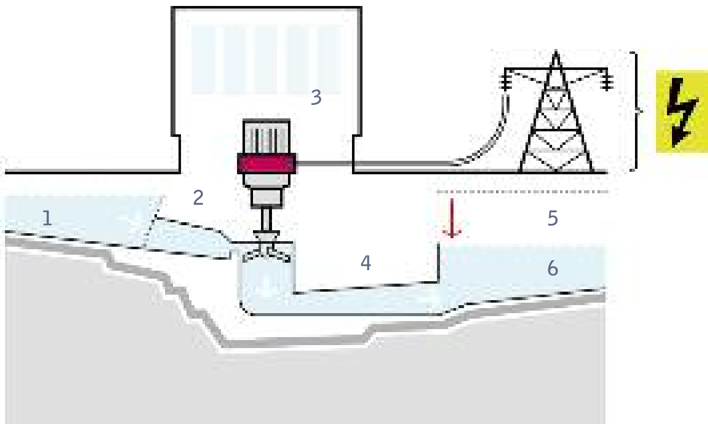
The main requirement for hydro power is to create an artificial head so that water, diverted through an intake channel or pipe into a turbine, discharges back into the river downstream. Small hydro power is mainly 'run-of-the-river' and does not collect significant amounts of stored water, requiring the construction of large dams and reservoirs. There are two broad categories of turbines. In an impulse turbine (notably the Pelton), a jet of water impinges on the runner designed to reverse the direction of the jet and thereby extracts momentum from the water. This turbine is suitable for high heads and 'small' discharges. Reaction turbines (notably Francis and Kaplan) run full of water and in effect generate hydrodynamic 'lift' forces to propel the runner blades. These turbines are suitable for medium to low heads and medium to large discharges.

figure 9.6: geothermal technology



1. PUMP
2. HEAT EXCHANGER
3. GAS TURBINE & GENERATOR
4. DRILLING HOLE FOR COLD WATER INJECTION
5. DRILLING HOLE FOR WARM WATER EXTRACTION

figure 9.7: hydro technology



1. INLET
2. SIEVE
3. GENERATOR
4. TURBINE
5. HEAD
6. OUTLET

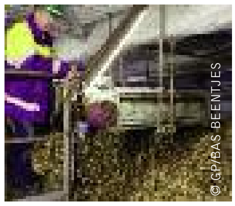


image THROUGH BURNING OF WOOD CHIPS THE POWER PLANT GENERATES ELECTRICITY, ENERGY OR HEAT. HERE WE SEE THE STOCK OF WOOD CHIPS WITH A CAPACITY OF 1000 M^3 ON WHICH THE PLANT CAN RUN, UNMANNED, FOR ABOUT 4 DAYS. LELYSTAD, THE NETHERLANDS.

9.1.9 ocean energy

tidal power Tidal power can be harnessed by constructing a dam or barrage across an estuary or bay with a tidal range of at least five metres. Gates in the barrage allow the incoming tide to build up in a basin behind it. The gates then close so that when the tide flows out the water can be channelled through turbines to generate electricity. Tidal barrages have been built across estuaries in France, Canada and China but a mixture of high cost projections coupled with environmental objections to the effect on estuarial habitats has limited the technology's further expansion.

wave and tidal stream power In **wave power** generation, a structure interacts with the incoming waves, converting this energy to electricity through a hydraulic, mechanical or pneumatic power take-off system. The structure is kept in position by a mooring system or placed directly on the seabed/seashore. Power is transmitted to the seabed by a flexible submerged electrical cable and to shore by a sub-sea cable.

In **tidal stream** generation, a machine similar to a wind turbine rotor is fitted underwater to a column fixed to the sea bed; the rotor then rotates to generate electricity from fast-moving currents. 300 kW prototypes are in operation in the UK.

Wave power converters can be made up from connected groups of smaller generator units of 100 – 500 kW, or several mechanical or hydraulically interconnected modules can supply a single larger turbine generator unit of 2 – 20 MW. The large waves needed to make the technology more cost effective are mostly found at great distances from the shore, however, requiring costly sub-sea cables to transmit the power. The converters themselves also take up large amounts of space. Wave power has the advantage of providing a more predictable supply than wind energy and can be located in the ocean without much visual intrusion.

There is no commercially leading technology on wave power conversion at present. Different systems are being developed at sea for prototype testing. The largest grid-connected system installed so far is the 2.25 MW Pelamis, with linked semi-submerged cyclindrical sections, operating off the coast of Portugal. Most development work has been carried out in the UK.

Wave energy systems can be divided into three groups, described below.

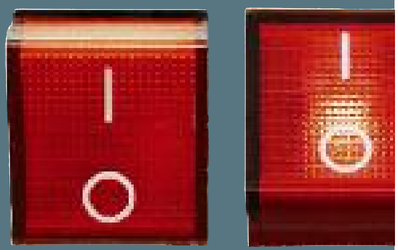
- **shoreline devices** are fixed to the coast or embedded in the shoreline, with the advantage of easier installation and maintenance. They also do not require deep-water moorings or long lengths of underwater electrical cable. The disadvantage is that they experience a much less powerful wave regime. The most advanced type of shoreline device is the oscillating water column (OWC). One example is the Pico plant, a 400 kW rated shoreline OWC equipped with a Wells turbine constructed in the 1990s. Another system that can be integrated into a breakwater is the Seawave Slot-Cone converter.
- **near shore devices** are deployed at moderate water depths (~20-25 m) at distances up to ~500 m from the shore. They have the same advantages as shoreline devices but are exposed to stronger, more productive waves. These include 'point absorber systems'.
- **offshore devices** exploit the more powerful wave regimes available in deep water (>25 m depth). More recent designs for offshore devices concentrate on small, modular devices, yielding high power output when deployed in arrays. One example is the AquaBuOY system, a freely floating heaving point absorber system that reacts against a submersed tube, filled with water. Another example is the Wave Dragon, which uses a wave reflector design to focus the wave towards a ramp and fill a higher-level reservoir.

images 1. BIOMASS CROPS. **2.** OCEAN ENERGY. **3.** CONCENTRATING SOLAR POWER (CSP).

climate and energy policy

GLOBAL

10



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.

political leadership is urgently needed.

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.

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.

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.

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 bio fuels is limited. The European Union and individual governments should ensure the effective implementation and improvement of sustainability standards for bio fuels 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 techniques, 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

GLOSSARY OF COMMONLY USED TERMS AND ABBREVIATIONS

DEFINITIONS OF SECTORS

11

the numbers don't lie –it's possible to power shift.

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


© GP/PETER CATON

image A PRAWN SEED FARM ON MAINLAND INDIA'S SUNDARBANS COAST LIES FLOODED AFTER CYCLONE AILA. INUNDATING AND DESTROYING NEARBY ROADS AND HOUSES WITH SALT WATER.

11.1 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

table 11.1: **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

table 11.2: **conversion factors - different energy units**

FROM	TO: TJ MULTIPLY BY	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

11.2 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.

sweden: reference scenario

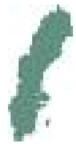


table 11.3: sweden: electricity generation

TWh/a	2007	2015	2020	2030	2040	2050
Power plants	**135**	**146**	**153**	**153**	**154**	**154**
Coal	0	0	0	0	0	0
Lignite	0	0	0	0	0	0
Gas	0	0	0	0	0	0
Oil	0.1	0.1	0.1	0.1	0.1	0.1
Diesel	0	0	0	0	0	0
Nuclear	67	69	72	72	72	72
Biomass	0	0	0	0	0	0
Hydro	66	69	69	69	69	69
Wind	1.4	8.7	12	12	13	13
PV	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0
Solar thermal power plants	0	0	0	0	0	0
Ocean energy	0	0	0	0	0	0
Combined heat & power production	**14**	**20**	**22**	**26**	**29**	**29**
Coal	0.7	0.9	0.9	1.1	1.0	0.8
Lignite	0.3	0.3	0.3	0.3	0.3	0.3
Gas	1.5	2.4	3.0	4.0	4.6	5.0
Oil	1.0	1.1	1.1	1.0	0.8	0.6
Biomass	11	15	17	20	22	23
Geothermal	0	0	0	0	0	0
Hydrogen	0	0	0	0	0	0
CHP by producer						
Main activity producers	8	13	14	18	20	20
Autoproducers	6	7	8	8	9	9
Total generation	**149**	**166**	**175**	**179**	**183**	**183**
Fossil	3.6	4.8	5.5	6.5	6.8	6.8
Coal	0.7	0.9	1.0	1.1	1.0	0.8
Lignite	0.3	0.3	0.3	0.3	0.3	0.3
Gas	1.5	2.4	3.0	4.0	4.6	5.0
Oil	1.1	1.1	1.2	1.1	0.9	0.6
Diesel	0	0	0	0	0	0
Nuclear	67	69	72	72	72	72
Hydrogen	0	0	0	0	0	0
Renewables	**78**	**92**	**97**	**100**	**103**	**104**
Hydro	66	69	69	69	69	69
Wind	1.4	8.7	12	12	13	13
PV	0	0	0	0	0	0
Biomass	11	15	17	20	22	23
Geothermal	0	0	0	0	0	0
Solar thermal	0	0	0	0	0	0
Ocean energy	0	0	0	0	0	0
Distribution losses	11	12	12	12	12	12
Own consumption electricity	6	5	5	5	5	5
Electricity for hydrogen production	0	0	0	0	0	0
Final energy consumption (electricity)	**133**	**136**	**135**	**135**	**134**	**134**
Fluctuating RES (PV, Wind, Ocean)	1	9	12	12	13	13
Share of fluctuating RES	1.0%	5.2%	6.6%	6.7%	6.8%	7.1%
RES share	**52.6%**	**55.7%**	**55.4%**	**56.0%**	**56.6%**	**56.8%**

table 11.4: sweden: heat supply

PJ/a	2007	2015	2020	2030	2040	2050
District heating plants	**82**	**95**	**96**	**89**	**87**	**86**
Fossil fuels	13	15	16	14	14	14
Biomass	69	79	80	75	73	72
Solar collectors	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0
Heat from CHP	**116**	**122**	**122**	**126**	**125**	**122**
Fossil fuels	37	33	30	29	28	26
Biomass	79	90	92	97	98	96
Geothermal	0	0	0	0	0	0
Fuel cell (hydrogen)	0	0	0	0	0	0
Direct heating[1)]	**332**	**345**	**354**	**364**	**373**	**379**
Fossil fuels	133	134	133	139	146	157
Biomass	190	199	209	214	215	210
Solar collectors	0	1	1	1	1	1
Geothermal[2)]	9	11	11	11	11	11
Total heat supply[1)]	**530**	**562**	**571**	**580**	**585**	**588**
Fossil fuels	183	182	179	182	188	197
Biomass	337	368	381	386	385	379
Solar collectors	0	1	1	1	1	1
Geothermal[2)]	9	11	11	11	11	11
Fuel cell ((hydrogen)	0	0	0	0	0	0
RES share (including RES electricity)	**65.4%**	**67.6%**	**68.7%**	**68.6%**	**67.9%**	**66.5%**

1) including cooling. 2) including heat pumps

table 11.5: sweden: CO_2 emissions

MILL t/a	2007	2015	2020	2030	2040	2050
Condensation power plants	**0**	**0**	**0**	**0**	**0**	**0**
Coal	0	0	0	0	0	0
Lignite	0	0	0	0	0	0
Gas	0	0	0	0	0	0
Oil	0	0	0	0	0	0
Diesel	0	0	0	0	0	0
Combined heat & power production	**5**	**5**	**4**	**4**	**4**	**3**
Coal	1	1	1	1	1	1
Lignite	1	0	0	0	0	0
Gas	1	1	2	2	2	2
Oil	2	2	2	1	1	0
CO_2 emissions power generation (incl. CHP public)	**5**	**5**	**5**	**4**	**4**	**4**
Coal	1	1	1	1	1	1
Lignite	1	0	0	0	0	0
Gas	1	1	2	2	2	2
Oil & diesel	3	2	2	1	1	0
CO_2 emissions by sector	**52**	**51**	**50**	**50**	**51**	**51**
% of 1990 emissions	92%	89%	89%	89%	90%	90%
Industry	11	11	10	10	10	10
Other sectors	3	3	3	2	2	2
Transport	23	22	23	23	23	23
Power generation (incl. CHP public)	3	3	3	3	3	3
Other conversion	13	12	12	12	12	12
Population (Mill.)	9.3	9.5	9.7	10.1	10.3	10.6
CO_2 emissions per capita (t/capita)	**5.6**	**5.3**	**5.2**	**5.0**	**4.9**	**4.8**

table 11.6: sweden: installed capacity

GW	2007	2015	2020	2030	2040	2050
Power plants	**27**	**30**	**32**	**32**	**32**	**32**
Coal	0	0	0	0	0	0
Lignite	0	0	0	0	0	0
Gas	0	0	0	0	0	0
Oil	0.1	0.1	0.1	0.1	0.1	0.1
Diesel	0	0	0	0	0	0
Nuclear	9.5	9.5	9.5	9.5	9.5	9.5
Biomass	0	0	0	0	0	0
Hydro	16	16	16	16	16	16
Wind	0.8	4.2	5.6	5.9	6.0	6.2
PV	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0
Solar thermal power plants	0	0	0	0	0	0
Ocean energy	0	0	0	0	0	0
Combined heat & power production	**3.2**	**4.4**	**4.8**	**5.4**	**6.0**	**6.1**
Coal	0.1	0.2	0.2	0.2	0.2	0.2
Lignite	0.1	0.1	0.1	0.1	0.1	0.1
Gas	0.4	0.6	0.7	1.0	1.1	1.2
Oil	0.6	0.7	0.7	0.6	0.5	0.3
Biomass	2.0	2.9	3.1	3.6	4.1	4.3
Geothermal	0	0	0	0	0	0
Hydrogen	0	0	0	0	0	0
CHP by producer						
Main activity producers	2	3	3	4	4	4
Autoproducers	1	2	2	2	2	2
Total generation	**30**	**35**	**36**	**37**	**38**	**38**
Fossil	1.2	1.6	1.7	1.9	1.9	1.9
Coal	0.1	0.2	0.2	0.2	0.2	0.2
Lignite	0.1	0.1	0.1	0.1	0.1	0.1
Gas	0.4	0.6	0.7	1.0	1.1	1.2
Oil	0.7	0.7	0.7	0.7	0.5	0.4
Diesel	0	0	0	0	0	0
Nuclear	9.5	9.5	9.5	9.5	9.5	9.5
Hydrogen	0	0	0	0	0	0
Renewables	**19**	**24**	**25**	**26**	**27**	**27**
Hydro	16	16	16	16	16	16
Wind	0.8	4.2	5.6	5.9	6.0	6.2
PV	0	0	0	0	0	0
Biomass	2.0	2.9	3.1	3.6	4.1	4.3
Geothermal	0	0	0	0	0	0
Solar thermal	0	0	0	0	0	0
Ocean energy	0	0	0	0	0	0
Fluctuating RES (PV, Wind, Ocean)	1	4	6	6	6	6
Share of fluctuating RES	2.6%	12.2%	15.4%	15.7%	15.7%	16.2%
RES share	**64.0%**	**68.0%**	**69.3%**	**69.5%**	**70.1%**	**70.4%**

table 11.7: sweden: primary energy demand

PJ/a	2007	2015	2020	2030	2040	2050
Total	**2,204**	**2,311**	**2,382**	**2,390**	**2,389**	**2,374**
Fossil	**774**	**747**	**736**	**724**	**713**	**704**
Hard coal	116	115	114	112	110	107
Lignite	6	3	3	2	2	2
Natural gas	35	51	59	77	95	113
Crude oil	617	577	561	533	506	481
Nuclear	**731**	**750**	**790**	**790**	**790**	**790**
Renewables	**700**	**814**	**856**	**876**	**886**	**881**
Hydro	238	247	247	247	247	247
Wind	5	31	41	43	45	47
Solar	0	1	1	1	1	1
Biomass	451	529	560	578	586	578
Geothermal	5	7	7	7	8	8
Ocean Energy	0	0	0	0	0	0
RES share	**30.4%**	**34.3%**	**35.4%**	**36.3%**	**36.8%**	**36.8%**

table 11.8: sweden: final energy demand

PJ/a	2007	2015	2020	2030	2040	2050
Total (incl. non-energy use)	**1,476**	**1,517**	**1,535**	**1,543**	**1,548**	**1,547**
Total (energy use)	**1,375**	**1,425**	**1,446**	**1,458**	**1,467**	**1,471**
Transport	**337**	**353**	**367**	**375**	**382**	**386**
Oil products	313	310	315	318	321	321
Natural gas	1	1	1	1	2	2
Biofuels	12	29	37	39	41	44
Electricity	11	13	14	16	18	20
RES electricity	6	7	8	9	10	11
Hydrogen	0	0	0	0	0	0
RES share Transport	**5.2%**	**10.4%**	**12.2%**	**12.9%**	**13.5%**	**14.2%**
Industry	**540**	**549**	**561**	**575**	**585**	**593**
Electricity	210	209	210	212	214	216
RES electricity	110	116	116	119	121	123
District heat	44	48	47	45	44	43
RES district heat	34	39	38	37	35	35
Coal	28	29	28	27	26	25
Oil products	64	57	55	53	51	49
Gas	24	30	35	46	57	68
Solar	0	0	0	0	0	0
Biomass and waste	171	176	187	192	194	191
Geothermal	0	0	0	0	0	0
Hydrogen	0	0	0	0	0	0
RES share Industry	**58.3%**	**60.2%**	**60.8%**	**60.5%**	**59.8%**	**58.7%**
Other Sectors	**498**	**524**	**518**	**508**	**500**	**493**
Electricity	259	267	263	256	251	246
RES electricity	136	149	146	143	142	140
District heat	148	162	163	164	162	159
RES district heat	113	129	131	132	129	127
Coal	1	0	0	0	0	0
Oil products	33	29	25	20	17	15
Gas	7	13	13	15	17	21
Solar	0	1	1	1	1	1
Biomass and waste	44	46	46	46	45	43
Geothermal	6	7	7	7	8	8
RES share Other Sectors	**60.0%**	**63.1%**	**63.7%**	**64.6%**	**65.0%**	**64.7%**
Total RES	**631**	**697**	**716**	**724**	**726**	**722**
RES share	**45.9%**	**48.9%**	**49.5%**	**49.7%**	**49.5%**	**49.1%**
Non energy use	**102**	**92**	**89**	**85**	**80**	**76**
Oil	101	91	89	84	80	75
Gas	0	0	0	0	0	0
Coal	1	1	1	1	1	1

sweden: energy [r]evolution scenario

table 11.9: sweden: electricity generation

TWh/a	2007	2015	2020	2030	2040	2050
Power plants	**135**	**139**	**132**	**132**	**127**	**130**
Coal	0	0	0	0	0	0
Lignite	0	0	0	0	0	0
Gas	0	0	0	0	0	0
Oil	0.1	0	0	0	0	0
Diesel	0	0	0	0	0	0
Nuclear	67	55	37	13	0	0
Biomass	0	0	0	0	0	0
Hydro	66	69	69	69	69	69
Wind	1.4	14	23	43	50	51
PV	0	1.0	3.0	5.6	6.0	7
Geothermal	0	0	0.6	1.5	2.3	2.3
Solar thermal power plants	0	0	0	0	0	0
Ocean energy	0	0	0	0.2	0.5	1.4
Combined heat & power production	**14**	**22**	**27**	**32**	**36**	**37**
Coal	0.7	0.4	0.4	0	0	0
Lignite	0.3	0.4	0.4	0.2	0	0
Gas	1.5	2.3	2.5	2.9	3.1	2.8
Oil	1.0	1.1	0.8	0.5	0.1	0
Biomass	11	18	22	27	30	31
Geothermal	0	0.1	0.4	1.0	2.6	3.2
Hydrogen	0	0	0	0	0	0
CHP by producer						
Main activity producers	8	15	18	23	25	25
Autoproducers	6	7	8	9	11	12
Total generation	**149**	**161**	**159**	**164**	**163**	**167**
Fossil	3.6	4.3	4.1	3.7	3.2	2.8
Coal	0.7	0.4	0.4	0	0	0
Lignite	0.3	0.4	0.4	0.2	0	0
Gas	1.5	2.3	2.5	2.9	3.1	2.8
Oil	1.1	1.1	0.8	0.5	0.1	0
Diesel	0	0	0	0	0	0
Nuclear	67	55	37	13	0	0
Hydrogen	0	0	0	0	0	0
Renewables	**78**	**101**	**118**	**147**	**160**	**164**
Hydro	66	69	69	69	69	69
Wind	1.4	14	23	43	50	51
PV	0	1.0	3.0	5.6	6.0	6.5
Biomass	11	18	22	27	30	31
Geothermal	0	0.1	1.0	2.5	4.9	5.5
Solar thermal	0	0	0	0	0	0
Ocean energy	0	0	0	0.2	0.5	1.4
Distribution losses	11	12	12	12	12	12
Own consumption electricity	6	4	4	4	3	3
Electricity for hydrogen production	0	0	1	2	3	3
Final energy consumption (electricity)	**133**	**133**	**130**	**134**	**133**	**136**
Fluctuating RES (PV, Wind, Ocean)	1	15	26	49	56	59
Share of fluctuating RES	1.0%	9.5%	16.6%	29.6%	34.5%	35.3%
RES share	**52.6%**	**63.2%**	**74.3%**	**89.7%**	**98.0%**	**98.3%**
'Efficiency' savings (compared to Ref.)	**0**	**3**	**7**	**15**	**23**	**26**

table 11.10: sweden: heat supply

PJ/a	2007	2015	2020	2030	2040	2050
District heating plants	**82**	**66**	**56**	**34**	**21**	**15**
Fossil fuels	13	11	9	5	3	2
Biomass	69	55	47	29	18	13
Solar collectors	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0
Heat from CHP	**116**	**138**	**152**	**165**	**170**	**173**
Fossil fuels	37	30	23	17	13	11
Biomass	79	107	125	139	133	134
Geothermal	0	1	4	9	23	29
Fuel cell (hydrogen)	0	0	0	0	0	0
Direct heating[1]	**332**	**315**	**298**	**277**	**263**	**253**
Fossil fuels	133	110	86	56	31	24
Biomass	190	184	175	161	155	140
Solar collectors	0	6	14	29	30	32
Geothermal[2]	9	15	23	31	48	55
Total heat supply[1]	**530**	**518**	**506**	**476**	**454**	**441**
Fossil fuels	183	151	118	78	47	37
Biomass	337	346	346	329	306	287
Solar collectors	0	6	14	29	30	32
Geothermal[2]	9	16	27	41	71	84
Fuel cell (hydrogen)	0	0	0	0	0	0
RES share (including RES electricity)	**65.4%**	**70.9%**	**76.6%**	**83.6%**	**89.6%**	**91.5%**
'Efficiency' savings (compared to Ref.)	**0**	**43**	**66**	**104**	**131**	**146**

1) including cooling. 2) including heat pumps

table 11.11: sweden: CO_2 emissions

MILL t/a	2007	2015	2020	2030	2040	2050
Condensation power plants	**0**	**0**	**0**	**0**	**0**	**0**
Coal	0	0	0	0	0	0
Lignite	0	0	0	0	0	0
Gas	0	0	0	0	0	0
Oil	0	0	0	0	0	0
Diesel	0	0	0	0	0	0
Combined heat & power production	**5**	**4**	**3**	**2**	**2**	**1**
Coal	1	0	0	0	0	0
Lignite	1	1	0	0	0	0
Gas	1	1	1	1	1	1
Oil	2	2	1	1	0	0
CO_2 emissions power generation (incl. CHP public)	**5**	**4**	**3**	**2**	**2**	**1**
Coal	1	0	0	0	0	0
Lignite	1	1	0	0	0	0
Gas	1	1	1	1	1	1
Oil & diesel	3	2	1	1	0	0
CO_2 emissions by sector	**52**	**48**	**41**	**28**	**16**	**11**
% of 1990 emissions	92%	84%	72%	50%	28%	19%
Industry	11	9	7	4	2	2
Other sectors	3	2	2	1	1	1
Transport	23	23	21	15	8	5
Power generation (incl. CHP public)	3	3	2	1	1	1
Other conversion	13	11	9	6	4	3
Population (Mill.)	9.3	9	10	10	10	11
CO_2 emissions per capita (t/capita)	**5.6**	**5.0**	**4.2**	**2.8**	**1.6**	**1.0**

table 11.12: sweden: installed capacity

GW	2007	2015	2020	2030	2040	2050
Power plants	**27**	**32**	**36**	**46**	**47**	**49**
Coal	0	0	0	0	0	0
Lignite	0	0	0	0	0	0
Gas	0	0	0	0	0	0
Oil	0.1	0	0	0	0	0
Diesel	0	0	0	0	0	0
Nuclear	9.5	7.5	4.8	1.7	0	0
Biomass	0	0	0	0	0	0
Hydro	16	16	16	16	16	16
Wind	0.8	7.0	11	21	24	24
PV	0	1.2	3.5	6.2	6.7	7.2
Geothermal	0	0	0.1	0.3	0.4	0.4
Solar thermal power plants	0	0	0	0	0	0
Ocean energy	0	0	0	0.1	0.2	0.5
Combined heat & power production	**3.2**	**4.8**	**5.5**	**6.3**	**6.9**	**7.2**
Coal	0.1	0.1	0.1	0	0	0
Lignite	0.1	0	0	0	0	0
Gas	0.4	0.6	0.6	0.7	0.8	0.7
Oil	0.6	0.6	0.5	0.3	0.1	0
Biomass	2.0	3.3	4.1	5.0	5.6	5.9
Geothermal	0	0	0.1	0.2	0.5	0.6
Hydrogen	0	0	0	0	0	0
CHP by producer						
Main activity producers	2	3	4	4	5	5
Autoproducers	1	2	2	2	2	2
Total generation	**30**	**37**	**42**	**52**	**54**	**56**
Fossil	1.2	1.5	1.3	1.1	0.8	0.7
Coal	0.1	0.1	0.1	0	0	0
Lignite	0.1	0	0	0	0	0
Gas	0.4	0.6	0.6	0.7	0.8	0.7
Oil	0.7	0.7	0.5	0.3	0.1	0
Diesel	0	0	0	0	0	0
Nuclear	9.5	7.5	4.8	1.7	0	0
Hydrogen	0	0	0	0	0	0
Renewables	**19**	**28**	**36**	**49**	**54**	**55**
Hydro	16	16	16	16	16	16
Wind	0.8	7.0	11	21	24	24
PV	0	1.2	3.5	6.2	6.7	7.2
Biomass	2.0	3.3	4.1	5.0	5.6	5.9
Geothermal	0	0	0.2	0.5	0.9	1.1
Solar thermal	0	0	0	0	0	0
Ocean energy	0	0	0	0.1	0.2	0.5
Fluctuating RES (PV, Wind, Ocean)	1	8	15	27	31	32
Share of fluctuating RES	2.6%	22.1%	35.7%	52.3%	56.1%	57.0%
RES share	**64.0%**	**75.6%**	**85.4%**	**94.5%**	**98.5%**	**98.8%**

table 11.13: sweden: primary energy demand

PJ/a	2007	2015	2020	2030	2040	2050
Total	**2,204**	**2,112**	**1,930**	**1,650**	**1,450**	**1,388**
Fossil	**774**	**694**	**599**	**429**	**274**	**203**
Hard coal	116	84	68	40	19	12
Lignite	6	5	4	2	0	0
Natural gas	35	46	44	44	45	41
Crude oil	617	559	483	343	210	150
Nuclear	**731**	**597**	**401**	**144**	**0**	**0**
Renewables	**700**	**821**	**931**	**1,077**	**1,176**	**1,185**
Hydro	238	247	247	247	247	247
Wind	5	51	84	154	179	184
Solar	0	10	25	49	51	56
Biomass	451	499	529	541	546	524
Geothermal	5	14	46	85	151	169
Ocean Energy	0	0	0	1	2	5
RES share	**30.4%**	**37.2%**	**47.9%**	**64.9%**	**80.9%**	**85.0%**
'Efficiency' savings (compared to Ref.)	**0**	**164**	**383**	**633**	**801**	**837**

table 11.14: sweden: final energy demand

PJ/a	2007	2015	2020	2030	2040	2050
Total (incl. non-energy use)	**1,476**	**1,456**	**1,402**	**1,302**	**1,195**	**1,144**
Total (energy use)	**1,375**	**1,364**	**1,313**	**1,217**	**1,114**	**1,068**
Transport	**337**	**350**	**336**	**308**	**265**	**250**
Oil products	313	315	287	204	113	69
Natural gas	1	1	1	0	0	0
Biofuels	12	19	26	34	53	54
Electricity	11	15	20	65	93	119
RES electricity	6	9	15	59	92	117
Hydrogen	0	0	2	4	7	9
RES share Transport	**5.2%**	**8.2%**	**12.7%**	**31.4%**	**56.9%**	**71.7%**
Industry	**540**	**516**	**499**	**469**	**445**	**438**
Electricity	210	204	196	183	173	168
RES electricity	110	129	146	164	169	165
District heat	44	47	54	59	64	71
RES district heat	34	39	46	53	59	66
Coal	28	25	21	11	0	0
Oil products	64	47	34	18	5	2
Gas	24	24	24	21	20	20
Solar	0	4	9	18	19	20
Biomass and waste	171	162	154	143	138	125
Geothermal	0	3	8	15	26	31
Hydrogen	0	0	0	0	0	0
RES share Industry	**58.3%**	**65.2%**	**72.7%**	**83.9%**	**92.2%**	**93.0%**
Other Sectors	**498**	**498**	**478**	**441**	**404**	**381**
Electricity	259	262	251	233	211	201
RES electricity	136	166	186	209	207	198
District heat	148	150	147	134	121	112
RES district heat	113	123	126	120	110	103
Coal	1	0	0	0	0	0
Oil products	33	22	15	7	5	2
Gas	7	12	10	9	9	6
Solar	0	2	6	10	11	12
Biomass and waste	44	42	40	36	34	31
Geothermal	6	7	10	12	13	15
RES share Other Sectors	**60.0%**	**68.4%**	**77.1%**	**87.7%**	**93.1%**	**94.6%**
Total RES	**631**	**706**	**774**	**877**	**937**	**947**
RES share	**45.9%**	**51.7%**	**58.9%**	**72.0%**	**84.1%**	**88.6%**
Non energy use	**102**	**92**	**89**	**85**	**80**	**76**
Oil	101	91	89	84	80	75
Gas	0	0	0	0	0	0
Coal	1	1	1	1	1	1

sweden: advanced energy [r]evolution scenario

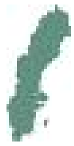


table 11.15: sweden: electricity generation

TWh/a	2007	2015	2020	2030	2040	2050
Power plants	**135**	**130**	**123**	**125**	**129**	**132**
Coal	0	0	0	0	0	0
Lignite	0	0	0	0	0	0
Gas	0	0	0	0	0	0
Oil	0.1	0	0	0	0	0
Diesel	0	0	0	0	0	0
Nuclear	67	46	21	0	0	0
Biomass	0	0	0	0	0	0
Hydro	66	69	69	69	69	69
Wind	1.4	14	29	48	50	52
PV	0	1.0	3.0	5.6	6.0	6.5
Geothermal	0	0	1.1	2.2	2.8	2.9
Solar thermal power plants	0	0	0	0	0	0
Ocean energy	0	0	0.2	0.5	1.5	1.8
Combined heat & power production	**14**	**22**	**27**	**32**	**36**	**37**
Coal	0.7	0.4	0.4	0	0	0
Lignite	0.3	0	0	0	0	0
Gas	1.5	1.9	2.0	1.9	1.1	0
Oil	1.0	1.1	0.8	0.5	0.1	0
Biomass	11	18	23	28	32	34
Geothermal	0	0.1	0.4	1.0	2.6	3.2
Hydrogen	0	0	0	0	0.1	0.6
CHP by producer						
Main activity producers	8	15	18	23	25	25
Autoproducers	6	7	8	9	11	12
Total generation	**149**	**152**	**150**	**157**	**165**	**169**
Fossil	3.6	3.5	3.4	2.5	1.2	0
Coal	0.7	0.1	0.2	0	0	0
Lignite	0.3	0	0	0	0	0
Gas	1.5	1.9	2.0	1.9	1.1	0
Oil	1.1	1.1	0.8	0.5	0.1	0
Diesel	0	0	0	0	0	0
Nuclear	67	46	21	0	0	0
Hydrogen	0	0	0	0	0.1	0.6
Renewables	**78**	**102**	**125**	**155**	**163**	**169**
Hydro	66	69	69	69	69	69
Wind	1.4	14	29	48	50	52
PV	0	1.0	3.0	5.6	6.0	6.5
Biomass	11	18	23	28	32	34
Geothermal	0	0.1	1.5	3.2	5.4	6.1
Solar thermal	0	0	0	0	0	0
Ocean energy	0	0	0.2	0.5	1.5	1.8
Distribution losses	11	12	12	12	12	12
Own consumption electricity	6	4	4	4	3	3
Electricity for hydrogen production	0	0	1	2	5	6
Final energy consumption (electricity)	**133**	**133**	**130**	**136**	**139**	**142**
Fluctuating RES (PV, Wind, Ocean)	1	15	32	54	57	60
Share of fluctuating RES	1.0%	10.1%	21.6%	34.6%	34.8%	35.7%
RES share	**52.6%**	**67.1%**	**83.5%**	**98.4%**	**99.3%**	**100.0%**
'Efficiency' savings (compared to Ref.)	**0**	**3**	**7**	**14**	**22**	**25**

table 11.16: sweden: heat supply

PJ/a	2007	2015	2020	2030	2040	2050
District heating plants	**82**	**66**	**55**	**31**	**18**	**10**
Fossil fuels	13	10	9	5	3	1
Biomass	69	55	46	26	15	9
Solar collectors	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0
Heat from CHP	**116**	**138**	**152**	**167**	**171**	**175**
Fossil fuels	37	27	20	12	5	0
Biomass	79	110	128	145	142	144
Geothermal	0	1	4	9	23	29
Fuel cell (hydrogen)	0	0	0	0	0	2
Direct heating[1]	**332**	**315**	**299**	**278**	**264**	**253**
Fossil fuels	133	110	86	50	17	4
Biomass	190	184	175	165	160	145
Solar collectors	0	6	14	29	33	37
Geothermal[2]	9	15	24	35	54	68
Hydrogen	0	0	0	0	0	3
Total heat supply[1]	**530**	**518**	**506**	**476**	**454**	**441**
Fossil fuels	183	148	115	66	25	5
Biomass	337	348	349	336	318	298
Solar collectors	0	6	14	29	33	37
Geothermal[2]	9	16	27	45	78	97
Fuel cell (hydrogen)	0	0	0	0	1	5
RES share (including RES electricity)	**65.4%**	**71.4%**	**77.2%**	**86.1%**	**94.6%**	**98.9%**
'Efficiency' savings (compared to Ref.)	**0**	**43**	**65**	**104**	**131**	**146**

1) including cooling. 2) including heat pumps

table 11.17: sweden: CO_2 emissions

MILL t/a	2007	2015	2020	2030	2040	2050
Condensation power plants	**0**	**0**	**0**	**0**	**0**	**0**
Coal	0	0	0	0	0	0
Lignite	0	0	0	0	0	0
Gas	0	0	0	0	0	0
Oil	0	0	0	0	0	0
Diesel	0	0	0	0	0	0
Combined heat & power production	**5**	**4**	**3**	**2**	**1**	**0**
Coal	1	0	0	0	0	0
Lignite	1	1	0	0	0	0
Gas	1	1	1	1	1	0
Oil	2	2	1	1	0	0
CO_2 emissions power generation (incl. CHP public)	**5**	**4**	**3**	**2**	**1**	**0**
Coal	1	0	0	0	0	0
Lignite	1	1	0	0	0	0
Gas	1	1	1	1	1	0
Oil & diesel	3	2	1	1	0	0
CO_2 emissions by sector	**52**	**47**	**40**	**26**	**10**	**3**
% of 1990 emissions	92%	83%	71%	45%	17%	5%
Industry	11	9	7	4	1.3	0.3
Other sectors	3	2	2	1	0.5	0.2
Transport	23	23	21	14	5	2
Power generation (incl. CHP public)	3	2	2	1	0.3	0
Other conversion	13	11	9	6	2	1.0
Population (Mill.)	9.3	9	10	10	10	11
CO_2 emissions per capita (t/capita)	**5.6**	**5.0**	**4.1**	**2.5**	**0.9**	**0.3**

table 11.18: sweden: installed capacity

GW	2007	2015	2020	2030	2040	2050
Power plants	**27**	**31**	**37**	**47**	**48**	**50**
Coal	0	0	0	0	0	0
Lignite	0	0	0	0	0	0
Gas	0	0	0	0	0	0
Oil	0.1	0	0	0	0	0
Diesel	0	0	0	0	0	0
Nuclear	9.5	6	3	0	0	0
Biomass	0	0	0	0	0	0
Hydro	16	16	16	16	16	16
Wind	0.8	7.0	14	24	24	25
PV	0	1.2	3.5	6.2	6.7	7.2
Geothermal	0	0	0.2	0.4	0.5	0.5
Solar thermal power plants	0	0	0	0	0	0
Ocean energy	0	0	0.1	0.2	0.5	0.6
Combined heat & power production	**3.2**	**4.7**	**5.4**	**6.2**	**6.8**	**7.1**
Coal	0.1	0.1	0.1	0	0	0
Lignite	0.1	0	0	0	0	0
Gas	0.4	0.5	0.5	0.4	0.3	0
Oil	0.6	0.6	0.5	0.3	0.1	0
Biomass	2.0	3.4	4.2	5.2	5.9	6.3
Geothermal	0	0	0.1	0.2	0.5	0.6
Hydrogen	0	0	0	0	0.02	0.1
CHP by producer						
Main activity producers	2	3	4	4	5	5
Autoproducers	1	2	2	2	2	2
Total generation	**30**	**36**	**43**	**53**	**55**	**57**
Fossil	1.2	1.3	1.1	0.7	0.3	0
Coal	0.1	0.1	0.1	0	0	0
Lignite	0.1	0	0	0	0	0
Gas	0.4	0.5	0.5	0.4	0.3	0
Oil	0.7	0.6	0.5	0.3	0.1	0
Diesel	0	0	0	0	0	0
Nuclear	9.5	6	3	0	0	0
Hydrogen	0	0	0	0	0.02	0.1
Renewables	**19**	**28**	**39**	**52**	**54**	**57**
Hydro	16	16	16	16	16	16
Wind	0.8	7.0	14	24	24	25
PV	0	1.2	3.5	6.2	6.7	7.2
Biomass	2.0	3.4	4.2	5.2	5.9	6.3
Geothermal	0	0	0.3	0.6	1.0	1.2
Solar thermal	0	0	0	0	0	0
Ocean energy	0	0	0.1	0.2	0.5	0.6
Fluctuating RES (PV, Wind, Ocean)	1	8	18	30	31	33
Share of fluctuating RES	2.6%	22.9%	41.8%	56.6%	56.5%	57.5%
RES share	**64.0%**	**78.4%**	**90.9%**	**98.7%**	**99.4%**	**100.0%**

table 11.19: sweden: primary energy demand

PJ/a	2007	2015	2020	2030	2040	2050
Total	**2,204**	**2,019**	**1,791**	**1,523**	**1,396**	**1,336**
Fossil	**774**	**689**	**591**	**398**	**198**	**109**
Hard coal	116	84	69	41	19	11
Lignite	6	5	4	1	0	0
Natural gas	35	42	39	30	15	-1
Crude oil	617	558	479	326	164	98
Nuclear	**731**	**506**	**232**	**0**	**0**	**0**
Renewables	**700**	**824**	**968**	**1,124**	**1,199**	**1,227**
Hydro	238	247	247	247	247	247
Wind	5	51	105	174	179	187
Solar	0	10	25	49	55	60
Biomass	451	502	533	553	550	541
Geothermal	5	14	57	100	162	186
Ocean Energy	0	0	1	2	5	6
RES share	**30.4%**	**38.9%**	**54.0%**	**73.8%**	**85.8%**	**91.8%**
'Efficiency' savings (compared to Ref.)	**0**	**202**	**478**	**720**	**826**	**862**

table 11.20: sweden: final energy demand

PJ/a	2007	2015	2020	2030	2040	2050
Total (incl. non-energy use)	**1,476**	**1,456**	**1,402**	**1,302**	**1,175**	**1,115**
Total (energy use)	**1,375**	**1,364**	**1,313**	**1,217**	**1,094**	**1,039**
Transport	**337**	**350**	**336**	**308**	**245**	**220**
Oil products	313	315	286	193	71	21
Natural gas	1	1	1	0	0	0
Biofuels	12	19	26	37	48	54
Electricity	11	15	21	74	114	131
RES electricity	6	10	17	72	113	131
Hydrogen	0	0	2	4	12	14
RES share Transport	**5.2%**	**8.3%**	**13.5%**	**36.9%**	**70.6%**	**90.4%**
Industry	**540**	**516**	**499**	**469**	**445**	**438**
Electricity	210	204	196	183	173	169
RES electricity	110	137	164	180	171	169
District heat	44	47	54	59	64	71
RES district heat	34	40	47	55	62	70
Coal	28	25	23	14	1	0
Oil products	64	47	31	14	3	0
Gas	24	24	24	18	11	5
Solar	0	4	9	18	21	23
Biomass and waste	171	162	154	147	145	131
Geothermal	0	3	9	15	26	34
Hydrogen	0	0	0	0	1	3
RES share Industry	**58.3%**	**66.9%**	**76.6%**	**88.7%**	**95.7%**	**98.6%**
Other Sectors	**498**	**498**	**478**	**441**	**404**	**381**
Electricity	259	262	251	233	213	203
RES electricity	136	176	209	230	212	203
District heat	148	150	147	133	119	108
RES district heat	113	125	128	123	115	108
Coal	1	0	0	0	0	0
Oil products	33	22	15	7	3	1
Gas	7	12	10	8	5	3
Solar	0	2	6	10	12	13
Biomass and waste	44	42	40	36	33	30
Geothermal	6	7	10	14	18	22
RES share Other Sectors	**60.0%**	**70.8%**	**82.4%**	**93.7%**	**96.5%**	**98.8%**
Total RES	**631**	**727**	**822**	**943**	**988**	**1,007**
RES share	**45.9%**	**53.3%**	**62.6%**	**77.5%**	**90.3%**	**96.9%**
Non energy use	**102**	**92**	**89**	**85**	**80**	**76**
Oil	101	91	89	84	80	75
Gas	0	0	0	0	0	0
Coal	1	1	1	1	1	1

sweden: total new investment by technology

table 11.21: sweden: total investment

MILLION $	2007-2010	2011-2020	2021-2030	2031-2040	2041-2050	2007-2050	2007-2050 AVERAGE PER YEAR
Reference scenario							
Conventional (fossil & nuclear)	**391**	**15,114**	**14,866**			**45,324**	**1,054**
Renewables	**10,330**	**22,461**	**20,619**			**83,459**	**1,941**
Biomass	3,767	5,263	4,835			18,592	432
Hydro	4,194	13,798	13,764			53,929	1,254
Wind	2,370	3,400	2,020			10,937	254
PV	0	0	0			0	0
Geothermal	0	0	0			0	0
Solar thermal power plants	0	0	0			0	0
Ocean energy	0	0	0			0	0
Energy [R]evolution							
Conventional (fossil & nuclear)	**391**	**495**	**343**			**7,311**	**170**
Renewables	**10,330**	**40,022**	**34,802**			**145,607**	**3,386**
Biomass	3,767	8,651	6,014			27,238	633
Hydro	4,194	13,798	13,764			53,929	1,254
Wind	2,370	9,185	9,907			40,251	936
PV	0	6,797	3,040			14,798	344
Geothermal	0	1,592	1,941			8,652	201
Solar thermal power plants	0	0	0			0	0
Ocean energy	0	0	135			740	17
Advanced Energy [R]evolution							
Conventional (fossil & nuclear)	**391**	**495**	**1,016**			**1,761**	**41**
Renewables	**10,330**	**43,592**	**34,996**			**152,091**	**3,537**
Biomass	3,767	8,649	6,016			28,929	673
Hydro	4,194	13,798	13,764			53,929	1,254
Wind	2,370	11,833	9,786			43,146	1,003
PV	0	6,797	3,040			14,798	344
Geothermal	0	2,336	2,187			10,062	234
Solar thermal power plants	0	0	0			0	0
Ocean energy	0	179	203			1,227	29

notes

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** COASTLINE NEAR GÖTEBORG, SWEDEN. © T. JOHANSSON/ISTOCK