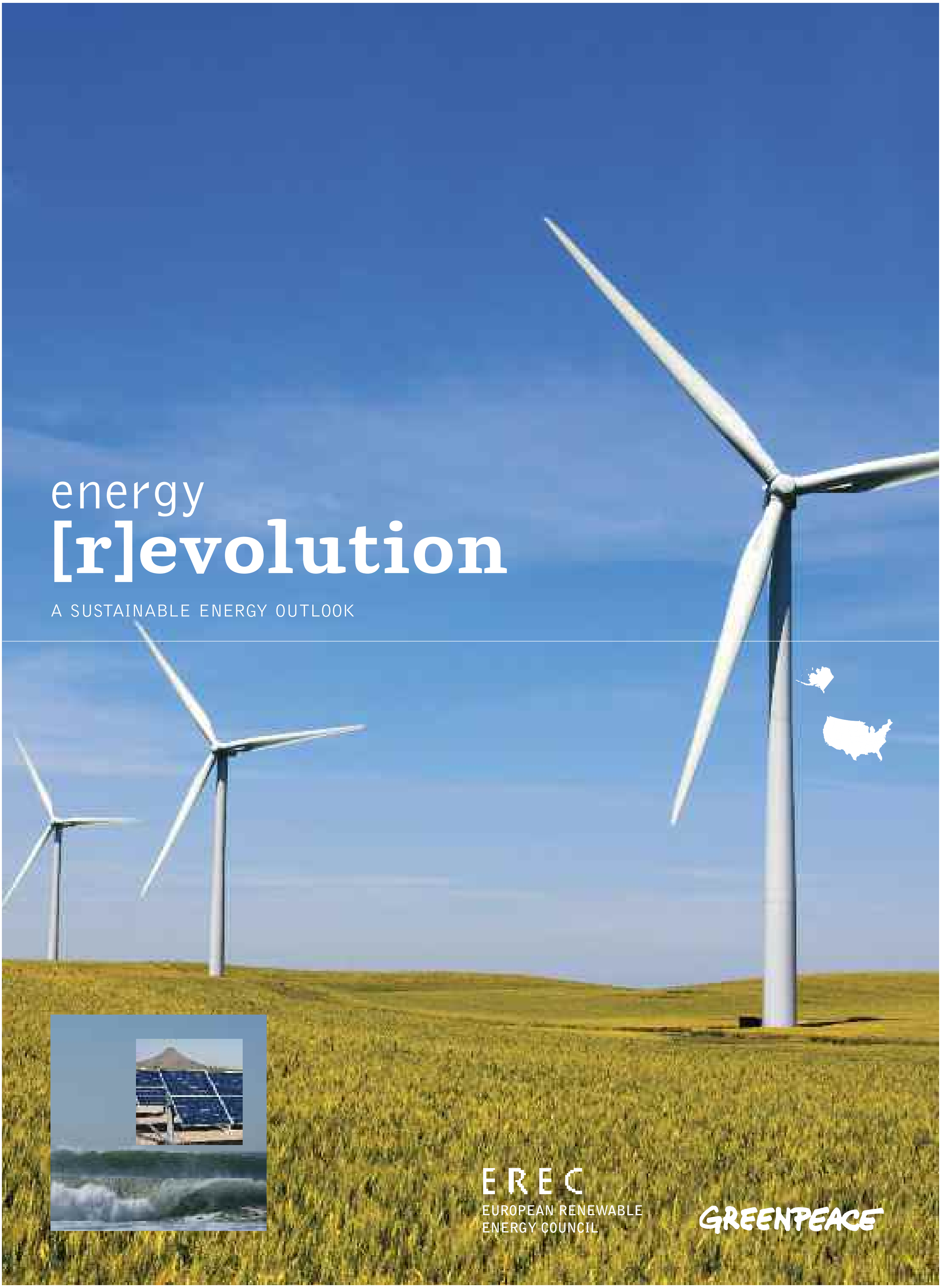
energy [r]evolution

A SUSTAINABLE ENERGY OUTLOOK



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report 2010 usa energy scenario

partners

Greenpeace International, European Renewable Energy Council (EREC)

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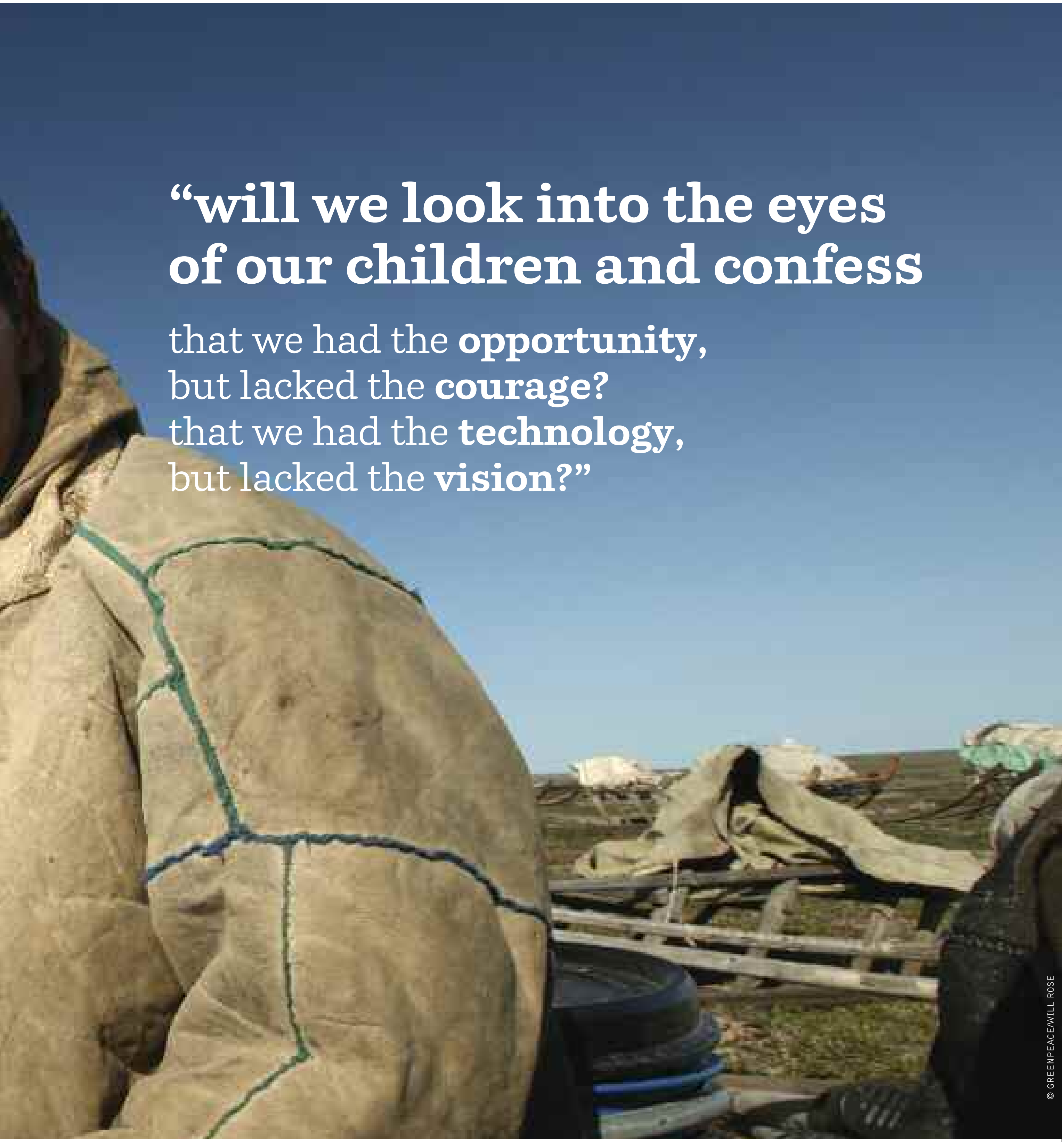
image THE INDIGENOUS NENETS PEOPLE MOVE EVERY 3 OR 4 DAYS SO THAT THEIR REINDEER DO NOT OVER GRAZE THE GROUND AND THEY DO NOT OVER FISH THE LAKES. THE YAMAL PENINSULA IS UNDER HEAVY THREAT FROM GLOBAL WARMING AS TEMPERATURES INCREASE AND RUSSIA'S ANCIENT PERMAFROST MELTS.



"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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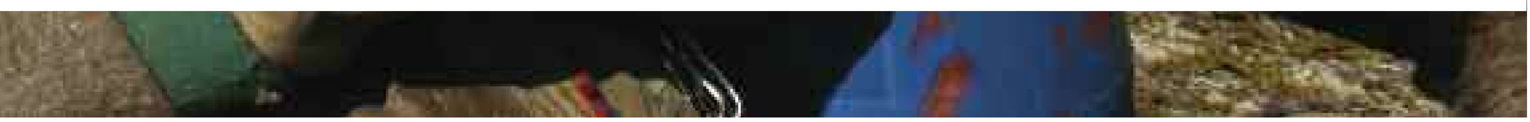

for further information about the global, regional and national scenarios please visit the energy [r]evolution website: **www.energyblueprint.info/**
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foreword

As I write, oil from a deepwater BP well is washing up on the sandy beaches and marshes of the Gulf Coast. At the same time, families in West Virginia are mourning the loved ones they lost in an explosion at a Massey Energy mine that claimed 29 lives—the worst mining disaster in the US in a generation. Sadly, these inestimable tragedies are only the recent headline-getters.

Every day, millions of people whose stories you won't hear are suffering the direct effects of our addiction to fossil fuels. Asthma, cancer, mutilated ecosystems, devastated communities—these are the hidden costs of our backward energy system, and we're paying those costs right now, whether we know it or not. Unfortunately, the worst is yet to come. According to the Nobel-prize winning Intergovernmental Panel on Climate Change, we must peak global warming pollution by 2015 and nearly eliminate it by mid-century.

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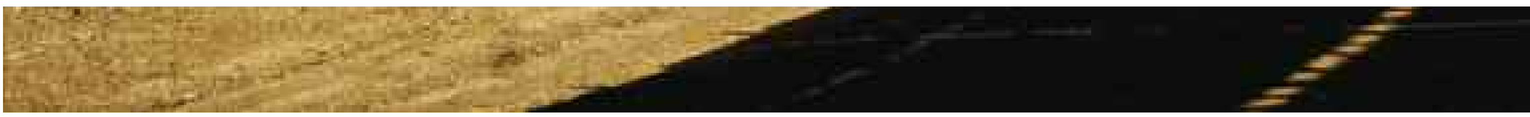

ANDASOL 1 SOLAR POWER STATION SUPPLIES UP TO 200,000 PEOPLE WITH CLIMATE-FRIENDLY ELECTRICITY AND SAVES ABOUT 149,000 TONNES OF CARBON DIOXIDE PER YEAR COMPARED WITH A MODERN COAL POWER PLANT.

If we fail to do so, we risk crossing tipping points in the climate system that could bring about devastating droughts, floods, sea level rise, storms, and wildfires. We are altering the fundamental systems that make our planet habitable. We can't politick our way out of this reality. Rhetoric won't keep our cities from flooding or ecosystems from collapsing. We must decide that enough is enough, and we must take real, bold, immediate action.

We are lucky, in the face of these grim realities, that we have the ability to save ourselves and preserve a livable planet for our children and grandchildren. Using technologies that already exist today—from wind turbines to super-efficient appliances to electric cars--we can continue to grow our economies while reversing the deep damage that fossil fuels have done. By taking simple steps like retrofitting our buildings to make them efficient, we can create millions of jobs and save millions of dollars. By investing in massive renewable energy and efficiency projects we can provide ourselves with energy security and ensure our leadership role in a new global economy. We can continue to thrive, without risking disasters like the Gulf oil spill or the catastrophe promised by unchecked climate change. This Energy [R]evolution is our roadmap.

Industry lobbyists and their PR people would have us believe that these things aren't possible. They've spent millions in campaign contributions and advertising to spin the idea that fossil fuels and nuclear power are a necessary part of our economic success. But you must ignore the politicians that parrot their talking points and the attractive ads, because it is a lie. When our leaders in government find the courage to force polluters to account for the true cost of fossil fuels, and find the wisdom to invest in solutions like renewables and efficiency, that lie will be exposed.

We cannot survive without an energy revolution. The keys to our future have been in the wrong hands for too long, and it will take all our strength to take them back. I hope you will join us.

Phil Radford
EXECUTIVE DIRECTOR
GREENPEACE USA
JUNE 2010

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introduction

"FOR THE SAKE OF A SOUND ENVIRONMENT, POLITICAL STABILITY AND THRIVING ECONOMIES, NOW IS THE TIME TO COMMIT TO A TRULY SECURE AND SUSTAINABLE ENERGY FUTURE."

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).

Energy policy has a dramatic impact across the social, political and economic spectrum. Governments and businesses must focus on the fact that energy is the lifeblood of the economy. For scientists, the crucial matter is the threat of climate change brought about by burning fossil fuels. NGO's concentrate on the environmental and social impacts, and economists on the potential of a shift in the way our energy is produced. For engineers, the task is developing new technologies to supply and consume energy in a smarter way. But at the end of the day, we are all consumers and we all must deal with the full reality of our energy system—from volatile prices to oil spills. Access to sufficient energy is vital to making our economies work but at the same time, our demand for energy has become the main source of the greenhouse gas emissions that put our climate at risk. Something needs to change.

While the last climate change summit in Copenhagen failed to produce an agreement, international negotiations to address the issue remain high on the political agenda. At the same time, highly volatile fossil fuel prices are creating more and more uncertainty for the global economy, creatingan indirect incentive for investing in renewable energy technologies, which are now booming. Against this backdrop, the third edition of the Energy [R]evolution analysis takes a deep plunge into what's possible in terms of energy supply strategies for the future and how to develop a sustainable energy and climate policy.

Access to energy is of strategic importance for every country in the world. Over the past few years oil prices have gone up and down like a rollercoaster, jumping to a record high in July 2008 of $147.27 and then falling back again to $33.87 in December. Even so, over the whole of 2009 the average oil price was still between $60 and $80 per barrel. At the same time, with gas prices in Europe rising in line with the price of oil, the impact on both the heating and power sectors has been huge.

Security of energy supply is not only influenced by the cost of fuels, however, but by their long term physical availability. Countries without their own fossil fuel supplies have increasingly shown interest in renewable energy sources, not only because of the price stability this brings but because they are indigenous and locally produced.

Renewable energy technologies 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, has 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. In 2009 the total level of annual investment in clean energy was $145 billion, only a 6.5% drop from the record previous year, while the global wind power market grew by an annual 41.5%. In the US

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

alone, the wind industry grew by nearly 40%. The renewable energy industry now employs around two million people worldwide and has become a major feature of national industrial development plans. In the US, wind already employs more people than coal. Meanwhile, the economics of renewables are expected to further improve as they develop technically, and as the price of fossil fuels continues to rise and as their saving of carbon dioxide emissions is given a monetary value. These cost comparisons, already favorable to renewables, don't even account for the massive externalized costs of fossil fuels such as the oil spill in the Gulf of Mexico.

Despite the small drop in fossil fuel emissions in the industrialized world as a result of the economic crisis, globally the level of energy related carbon dioxide continues to grow. This means that a recovered economy will result in increasing CO_2 emissions once again, further contributing to the greenhouse gases which threaten our planet. A shift in energy policy is needed so that a growing economy and reduced CO_2 emissions can go hand in hand. The Energy [R]evolution analysis shows how this is possible.

Although the Copenhagen climate change conference at the end of 2009 was a huge disappointment, it should not lead to a feeling that nothing can happen. A change in energy policy has to be connected to a change of climate policy. The United Nations (UNFCCC) climate talks therefore still remain central to the survival of our planet and a global regime for CO_2 reduction. Placing a price on carbon, as well as a long term agreement on CO_2 reduction, are both of vital importance for the uptake of renewables and energy efficiency. The achievement of a new 'fair, ambitious and legally binding' (FAB) deal relies fundamentally on legally binding emissions reduction obligations, on common guidelines for accounting rules, on a compliance regime and on agreed carbon trading mechanisms.

energy [r]evolution 2010

This is the third edition of the global Energy [R]evolution scenario since the first one was published in January 2007, each analysis deeper than the last. In the second edition we introduced specific research for the transport sector and an investigation of the pathway to future investment in renewable energies. Since then we have published country-specific scenarios for over 30 countries and regions, added a study of the employment implications of the scenarios and a detailed examination of how the grid network needs to be improved and adapted.

This new edition has broken fresh ground again. The 2010 Energy [R]evolution not only includes the financial analysis and employment calculations in parallel with the basic projections, we have also added a second, more ambitious Energy [R]evolution scenario. This was considered vital because rapid improvements in climate science made it clear during 2009 that a global 50% reduction in energy related CO_2 emissions by 2050 might not be enough to keep the global mean temperature rise below +2°C. An even greater reduction may be needed if runaway climate change is to be avoided.

The advanced Energy [R]evolution scenario has changed five parameters compared to the basic version. These mean that the economic lifetime of coal power stations has been reduced from 40 to 20 years, the growth rate of renewables has taken the advanced projections of the renewable industry into account, the use of electric drives in the transport sector will take off ten years earlier, the expansion of smart grids will happen quicker, and last but not least, the expansion of fossil fuel based energy will stop after 2015.

A drastic reduction in CO_2 levels and a share of over 80% renewables in the world energy supply are both possible goals by 2050. Of course this will be a technical challenge, but the main obstacle is political. We need to kick start the Energy [R]evolution with long lasting reliable policy decisions within the next few years. It took more than a decade to make politicians aware of the climate crisis; we do not have another decade to agree on the changes needed in the energy sector. Greenpeace and the renewables industry present the Energy [R]evolution scenario as a practical but ambitious blueprint. For the sake of a sound environment, political stability and thriving economies, now is the time to commit to a truly secure and sustainable energy future – a future built on energy efficiency and renewable energy, economic development and the creation of millions of new jobs for the next generation.

Christine Lins
SECRETARY GENERAL
EUROPEAN RENEWABLE
ENERGY COUNCIL (EREC)
JUNE 2010

Sven Teske
CLIMATE & ENERGY UNIT
GREENPEACE INTERNATIONAL

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, a political declaration agreed by many key countries at the 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 gigatons of carbon dioxide equivalents 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 drought, heat waves and floods, along with other adverse impacts such as increased water stress for up to 1.7 billion people, wildfire frequency and flood risks, 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 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.

references
1 COPENHAGEN ACCORD PLEDGES ARE PALTRY-JOERI ROGELJ, MALTE MEINSHAUSEN, APRIL 2010.
2 W. L. HARE. A SAFE LANDING FOR THE CLIMATE. STATE OF THE WORLD. WORLDWATCH INSTITUTE. 2009.

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

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 economic, with devastating consequences for the local environment. What is certain is that the days of 'cheap oil' 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 in 2008 and 2009 and is a testament to the inherent attractiveness of renewable technology.

Last year (2009) Bloomberg New Energy Finance reported the total level of annual investment in clean energy as $145 billion, only a 6.5% drop from the record previous year. The global wind industry defied the economic downturn and saw its annual market grow by 41.5% over 2008, and total global wind power capacity increase by 31.7% to 158 GW at the end of 2009.[4] More grid-connected solar PV capacity was added worldwide than in the boom year of 2008. And the economics of renewables will further improve as they develop technically, as the price of fossil fuels continues to rise and as their saving of carbon dioxide emissions is given a monetary value.

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.

In contrast to the explosive growth and promise of renewables and efficiency, nuclear energy is a relatively minor industry with major problems. The average age of operating commercial nuclear reactors is 23 years, so more power stations are being shut down than started. In 2008, world nuclear production fell by 2 % compared to 2006, and the number of operating reactors as of January 2010 was 436, eight less than at the historical peak of 2002. Although nuclear power produces little carbon dioxide, there are multiple threats to people and the environment from its operations. These include the risks and environmental damage from uranium mining, processing and transport, the risk of nuclear weapons proliferation, the unsolved problem of nuclear waste and the potential hazard of a serious accident. As a result, nuclear power is discounted in this analysis.

the energy [r]evolution

The threat of climate change demands nothing short of an Energy Revolution--a transformation that has already started, as renewable energy markets exhibit huge and steady growth. 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:

the five key principles behind this shift will be to:

- Implement renewable solutions, especially through decentralized 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

Decentralized 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.

greenhouse development rights

Although the Energy Revolution envisages a clear technological pathway, it is only likely to be turned into reality if its corresponding investment costs are shared fairly under some kind of global climate regime. To demonstrate one such possibility, we have utilized the Greenhouse Development Rights framework, designed by EcoEquity and the Stockholm Environment Institute, as a way of evening up the inherently unequal abilities of countries to respond to the climate crisis in their energy polices.

The Greenhouse Development Rights (GDR) framework calculates national shares of global greenhouse gas obligations based on a combination of responsibility (contribution to climate change) and capacity (ability to pay). Crucially, GDRs take inequality within countries into account and calculate national obligations on the basis of the estimated capacity and responsibility of individuals. Individuals

references

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.

4 GLOBAL WIND 2009 REPORT, GWEC, MARCH 2010, S. SAWYER, A. ZERVOS.

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

with incomes below a ‘development threshold’ – specified in the default case as $7,500 per capita annual income, PPP adjusted – are exempted from climate-related obligations. Individuals with incomes above that level are expected to contribute to the costs of global climate policy in proportion to their capacity (amount of income over the threshold) and responsibility (cumulative CO_2 emissions).

The result, of these calculations is that rich countries like the United States, which is also responsible for a large proportion of global greenhouse gas emissions, will contribute much more towards the costs of implementing global climate policies (such as increasing the proportion of renewables) than a country like India. Based on a ‘Responsibility and Capacity Indicator’, the US, accounting for 36.8% of the world’s responsibility for climate change, will in turn be responsible for funding 36.3% of the required global emissions reductions.

The GDR framework therefore represents a good mechanism for helping developing countries to leapfrog over fossil fuel dependence and into a sustainable energy supply, with the help of industrialized countries--while maintaining economic growth and the need to satisfy their growing energy needs. Greenpeace has taken this concept on board as a means of achieving equity within the climate debate and as a practical solution to kick-starting the renewable energy market in developing countries.

methodology and assumptions

Three global scenarios up to the year 2050 are outlined in this report: a Reference scenario, an Energy [R]evolution scenario with a target to reduce energy related CO_2 emissions by 50%, from their 1990 levels, and an advanced Energy [R]evolution version which envisages a fall of 82% in CO_2 by 2050.

The Reference Scenario is based on the reference scenario in the International Energy Agency’s 2009 World Energy Outlook (WEO 2009) analysis, extrapolated forward from 2030. Compared to the previous (2007) IEA projections, WEO 2009 assumes a slightly lower average annual growth rate of world Gross Domestic Product (GDP) of 3.1%, instead of 3.6%, over the period 2007-2030. At the same time, it expects final energy consumption in 2030 to be 6%% lower than in the 2007 report. China and India are expected to grow faster than other regions, followed by the Other Developing Asia group of countries, Africa and the Transition Economies (mainly the former Soviet Union). The OECD share of global purchasing power parity (PPP) adjusted GDP will decrease from 55% in 2007 to 29% by 2050.

The Energy [R]evolution Scenario has a key target for the reduction of worldwide carbon dioxide emissions down to a level of around 10 Gigatons per year by 2050. A second objective is the global phasing out of nuclear energy. To achieve these goals the scenario is characterized by significant efforts to fully exploit the large potential for energy efficiency. At the same time, all cost-effective renewable energy sources are used for heat and electricity generation, as well as the production of bio fuels. The general framework parameters for population and GDP growth remain unchanged from the Reference scenario.

The Advanced Energy [R]evolution Scenario takes a much more radical approach to the climate crisis facing the world. In order to pull the emergency brake on global emissions it therefore assumes much shorter technical lifetimes for coal-fired power plants - 20 years instead of 40 years. This reduces global CO_2 emissions even faster and takes the latest evidence of greater climate sensitivity into account. To fill the resulting gap, the annual growth rates of renewable energy sources, especially solar photovoltaics, wind and concentrating solar power plants, have therefore been increased.

Apart from that, the advanced scenario takes on board all the general framework parameters of population and economic growth from the basic version, as well as most of the energy efficiency roadmap. In the transport sector, however, there is 56% lower final energy demand due to a combination of simply less driving and instead increase use of public transport and a faster uptake of efficient combustion vehicles and – after 2025 – a larger share of electric vehicles.

Within the heating sector there is a faster expansion of CHP in the industry sector, more electricity for process heat and a faster growth of solar and geothermal heating systems. Combined with a larger share of electric drives in the transport sector, this results in a higher overall demand for power. Even so, the overall global electricity demand in the advanced Energy [R]evolution scenario is still lower than in the Reference scenario.

In the advanced scenario the latest market development projections of the renewable industry[5] have been calculated for all sectors (see Chapter 5, Table 5.13: Annual growth rates of renewable energy technologies). The speedier uptake of electric vehicles, combined with the faster implementation of smart grids and expanding super grids (about ten years ahead of the basic version) allows a higher share of fluctuating renewable power generation (photovoltaic and wind). The threshold of a 40% proportion of renewables in global primary energy supply is therefore passed just after 2030 (also ten years ahead). By contrast, the quantity of biomass and large hydro power remain the same in both Energy [R]evolution scenarios, for sustainability reasons.

towards a renewable future

Today, renewable energy sources account for 5.4% of the USA´s primary energy demand. Biomass, which is mostly used in the heat sector, is the main source. The share of renewable energies for electricity generation is 8.6%, while their contribution to heat supply is around 11.6% (to a large extent accounted for by traditional uses such as collected firewood). About 80% 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:

- Exploitation of existing large energy efficiency potentials will ensure that final energy demand decreases significantly - from the current 66,935 PJ/a (2007) to 46,897 PJ/a in 2050, compared to 72,483 PJ/a in the Reference scenario. This dramatic reduction is a crucial prerequisite for achieving a significant

references
5 SEE EREC, RE-THINKING 2050, GWEC, EPIA *ET AL.*

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

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.

- 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 8.6% and by 2050 to over 91%. More public transport systems also use electricity, as well as there being a greater shift in transporting freight from road to rail.
- 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 limits the further expansion of CHP.
- The electricity sector will be the pioneer of renewable energy utilization. By 2050, around 98% of electricity will be produced from renewable sources. A capacity of 2,533 GW will produce 6,446 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.
- In the heat supply sector, the contribution of renewables will increase to 98% 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.
- 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 bio fuels 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.
- By 2050, 87.4% 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. Climate infrastructure such as district heating systems, smart- and supergrids for renewable power generation as well as more R&D in storage technologies for electricity are from great importance to turn this scenario into reality. The successful implementation of smart grids is vital for the advanced Energy [R]evolution from 2020 onwards.

It is also important to highlight that in the advanced Energy [R]evolution 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 from 2040 onwards. To support the building of capacity in developing countries significant new public financing, especially from industrialized countries, will be needed. It is vital that specific funding mechanisms such as the "Greenhouse Development Rights" (GDR) and "Feed-in tariff" schemes (see chapter 2) are developed under the international climate negotiations that can assist the transfer of financial support to climate change mitigation, including technology transfer.

future costs

Renewable energy will initially cost more to implement than existing fuels. The slightly higher electricity generation costs under the advanced Energy [R]evolution scenario will be compensated for, however, by reduced demand for fuels in other sectors such as heating and transport. Assuming average costs of 3 cents/kWh for implementing energy efficiency measures, the additional cost for electricity supply under the advanced Energy [R]evolution scenario will amount to a maximum of $42 billion/a in 2030. These additional costs, which represent society's investment in an environmentally benign, safe and economic energy supply, continue to decrease after 2030. By 2050 the annual costs of electricity supply will be $183 billion/a below those in the Reference scenario. It is assumed that average crude oil prices will increase from $97 per barrel in 2008 to $130 per barrel in 2020, and continue to rise to $150 per barrel in 2050. Natural gas import prices are expected to increase by a factor of four between 2008 and 2050, while coal prices will continue to rise, reaching $172 per tonne in 2050. A CO_2 'price adder' is applied, which rises from $20 per ton of CO_2 in 2020 to $50 per ton in 2050.

future investment

It would require until 2030 $5.1 trillion in investment for the advanced Energy [R]evolution scenario to become reality - approximately 160% higher than in the Reference scenario ($2.0 trillion). Until 2050 investments sum up to $8.4 trillion in the advanced scenario compared to $3.2 trillion in the reference case. Under the advanced scenario, however, the world shifts about 80% of investment towards renewables and cogeneration; by 2050 the fossil fuel share of power sector investment would be focused mainly on combined heat and power and efficient gas-fired power plants. The average annual investment in the power sector under the advanced Energy [R]evolution scenario between 2007 and 2050 would be approximately $196 billion.

Because renewable energy has no fuel costs (except biomass), however, the fuel cost savings in the advanced Energy [R]evolution scenario reach a total of $1.3 trillion, or $55 billion per year until 2030 and a total of $6.3 trillion, or $146 billion per year until 2050.

This means that under the Reference scenario the additional costs for fossil fuels from 2007 until the year 2050 are as high as $6.3 trillion, which is significantly higher than the entire additional 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. Part of this money could be used to cover stranded investments in fossil-fuelled power stations in developing countries.

"Worldwide we would see more direct jobs created in the energy sector if we shift to either of the Energy [R]evolution scenarios than if we continue business as usual."

future global employment

Worldwide, we would see more direct jobs created in the energy sector if we shifted to either of the Energy [R]evolutions. The Energy [R]evolution scenarios lead to more energy sector jobs in USA at every stage of the projection.

- There are 1.1 million energy sector jobs in the Energy [R]evolution scenario and 1.4 in the advanced version by 2015, compared to 0.47 million in the Reference scenario.
- By 2020 job numbers reach 1.17 million in the Energy [R]evolution scenario (1.34 million in the advanced version), twice as much as in the Reference scenario.
- By 2030 job numbers in the renewable energy sector reach 834,000 in the Energy [R]evolution scenario, 1.1 million in the advanced version) and reach only 231,000 in the Reference scenario.

development of CO_2 emissions

While US emissions of CO_2 will decrease by 4% under the Reference scenario, under the Energy [R]evolution scenario they will decrease from 5,742 million tons in 2007 to 728 million tons in 2050, 86% below 1990 levels. Annual per capita emissions will drop from 18.6 tons/capita to 1.8 tons/capita. In spite of the phasing out of nuclear energy and a growing electricity demand, CO_2 emissions will decrease enormously in the electricity sector. In the long run efficiency gains and the increased use of renewable electric vehicles, as well as a sharp expansion in public transport, will even reduce CO_2 emissions in the transport sector. With a share of 48% of total emissions in 2050, the transport sector will reduce significantly but remain the largest source of CO_2 emissions - followed by industry and power generation.

The advanced Energy [R]evolution scenario reduces energy related CO2 emissions over a period ten to 15 years faster than the basic scenario, leading to 5.9 t per capita by 2030 and 0.3 t by 2050.

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. Internalize the external (social and environmental) costs of energy production through emissions trading and regulation.
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, with programs like feed-in tariffs.
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 three scenarios

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

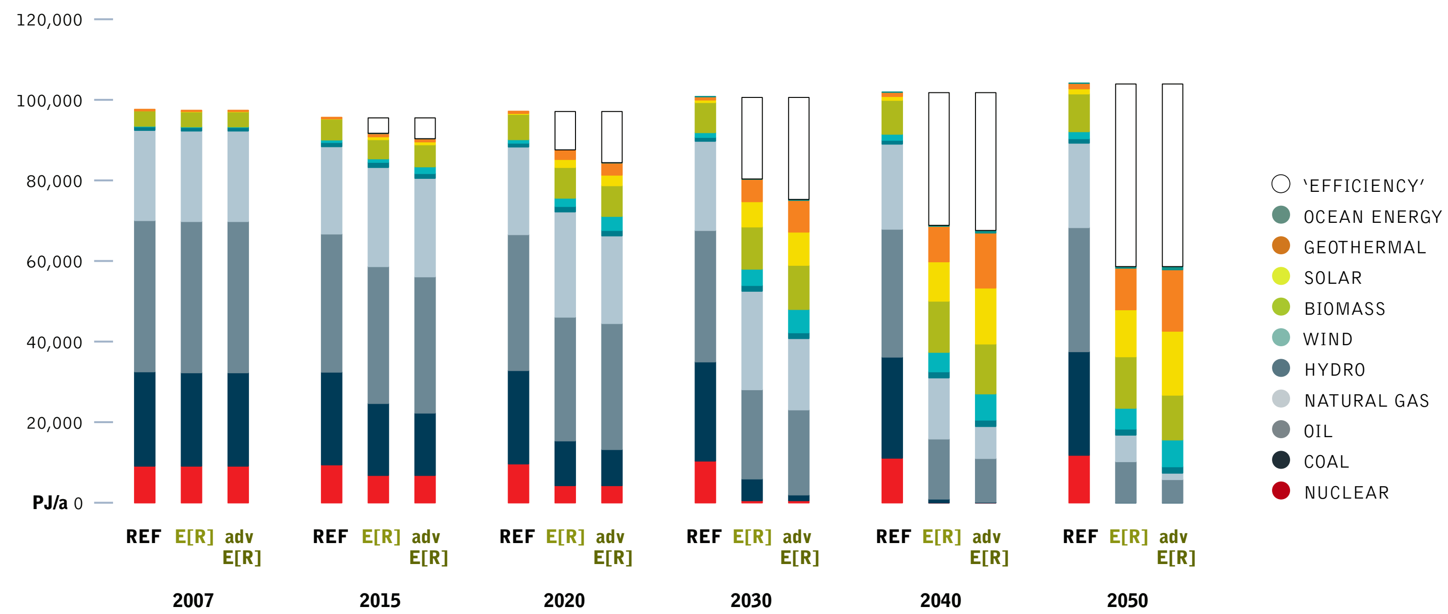

image CONSTRUCTION OF THE OFFSHORE WINDFARM AT MIDDELGRUNDEN NEAR COPENHAGEN, DENMARK.

table 0.1: energy [r]evolution: summary for policy makers

	POLICY	WHO	2010	2015	2020	2025	2030	2035	2040	2045	2050
	Climate										
targets	• Peak global temperature rise well below 2°C	UNFCCC									
targets	• Reduce ghg emissions by 40% by 2020 (as compared to 1990) in developed countries	UNFCCC									
targets	• Reduce ghg emissions by 15 to 30% of projected growth by 2020 in developing countries	UNFCCC									
targets	• Achieve zero deforestation globally by 2020	UNFCCC									
targets	• 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									
targets	• G8: min 20% renewable energy by 2020	G8									
targets	• No new construction permits for new coal power plants in Annex 1 countries by 2012	G8									
targets	• Priority access to the grid for renewables	G8									
targets	• Establish efficiency targets and strict standards for electric applications	National Governments									
targets	• Strict efficiency target for vehicles: 80g CO_2/km by 2020	National Governments									
targets	• Build regulations with mandatory renewable energy shares (e.g. solar collectors)	National Governments									
targets	• Co-generation law for industry and district heating support program	National Governments									
	Finance										
mechanisms	• Phase-out subsidies for fossil and nuclear fuels	G20									
mechanisms	• Put in place a Climate Fund under the auspices of the UNFCCC	UNFCCC									
mechanisms	• Provide at least 140 billion USD/year to the Climate Fund by 2020	UNFCCC									
mechanisms	• Ensure priority access to the fund for vulnerable countries and communities	UNFCCC									
mechanisms	• Establish feed-in law for renewable power generation in Annex 1 countries	National Governments									
mechanisms	• Establish feed-in law with funding from Annex 1 countries for dev. countries	G8 + G77									
	ENERGY [R]EVOLUTION RESULTS										
	Renewables & Supply										
power	Global Renewable Power Generation										
power	• Shares (max = adv. ER - Min = ER): **30%** / **50%** / **75%** / over **90%**	Utilities & RE Industry									
power	• Implementation of Smart Grids (**Policy**/**Planning**/**Construction**)	National Governments									
power	• Smart Grids interconnection to Super Grids (**Policy**/**Planning**/**Construction**)	Gov & Grid Operator									
power	• Renewables cost competive (max = worst case - min = best case)	RE - Industry									
power	• Phase out of coal power plants in OECD countries	Utilities									
power	• Phase out of nuclear power plants in OECD countries	Utilities									
heating	Global Renewable Heat supply shares										
heating	• Shares (max = adv. ER - Min = ER): **30%** / **50%** / **75%** / over **90%**	RE Industry									
heating	• Implementation of district heating (**Policy**/**Planning**/**Construction**)	National Governments									
heating	• Renewables cost competive (max = worst case - min = best case)	RE Industry									
final energy	Global Renewable Final Energy shares										
final energy	• Shares (max = adv. ER - Min = ER): **30%** / **50%** / **75%** / over **90%**										
final energy	• Consumer and business (Other Sectors)										
final energy	• Industry										
final energy	• Transport										
final energy	• Total Final Energy										
	Efficiency & Demand										
consumer	Global Statonary Energy Use										
consumer	• Efficiency standards reduce OECD household demand to 550 kWh/a per person	Cusumer Product Dev.									
consumer	• Power demand for IT equipment stablized and start to decrease	IT Industry									
consumer	• National energy intensity drops to 3 MJ/$GDP (Japan's level today)	Industry + Gov.									
transport	Global Transport Development										
transport	• Shift fright from road to rail and where possible from aviation to ships	Gov. + Logistic Industry									
transport	• Shift towards more public transport	Regional Governments									
transport	• Efficient cars become mainstream	Car-Industry									
emissions	**Energy Related CO_2 Emissions**										
emissions	• Global CO_2 reductions (min = adv. ER - Max = ER): **Emission peak** / **-30%** / **-50%** / **-80%**										
emissions	• Annex 1 CO_2 reductions (min = adv. ER - Max = ER): **Emission peak** / **-30%** / **-50%** / **-80%**										
emissions	• Non Annex 1 CO_2 reductions (min = adv. ER - Max = ER): **Emission peak** / **-30%** / **-50%** / **-80%**										

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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.”

GREENPEACE INTERNATIONAL
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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.

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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. As a result, climate change is already impacting on our lives, and is expected to destroy the livelihoods of many people in the developing world, as well as ecosystems and species, in 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 opinionon climate change, the world's temperature could potentially increase over the next hundred years by up to 6.4° Celsius. This is much faster than anything experienced so far in human history. The goal of climate policy should be to avoid dangerous climate change, which is being translated in limiting global mean temperature rise, as compared to pre-industrial levels, well below 2°C above, or even below 1.5°C. Above these tresholds, we will reach dangerous tipping points and 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 2015.

Climate change is already harming people and ecosystems. Its reality can be seen in disintegrating polar ice, thawing permafrost, dying coral reefs, 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 the impacts of climate change. An average global warming of 1.5°C threatens millions of people with an increased risk of hunger, malaria, 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 stop global warming, the damage could become irreversible. This can only happen through a rapid reduction in the emission of greenhouse gases into the atmosphere.

This 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 heatwaves, droughts and floods. Already, the global incidence of drought has doubled over the past 30 years.
- Severe regional impacts. In Europe, river flooding will increase, as well as coastal flooding, erosion and wetland loss. Flooding will also severely affect low-lying areas in developing countries such as Bangladesh and South China.
- Natural systems, including glaciers, coral reefs, mangroves, alpine ecosystems, boreal forests, tropical forests, prairie wetlands and native grasslands will be severely threatened.
- 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 decline in agricultural production.

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

"climate change has moved from being a predominantly physical phenomenon to being a social one" (hulme, 2009)."

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 190 member countries meet 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 the signatories from developed countries 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 has 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 failed and governments will continue negotiating in 2010 and possibly beyond to reach a new fair, ambitous and legally binding deal. Such a deal will need to ensure industrialized countries reduce their emissions on average by at least 40% by 2020, as compared to 1990 emissions. They will further need to provide at least $US 140 billion a year to developing countries to enable them to adapt to climate change, to protect their forests and to achieve the energy revolution. Developing countries should reduce their greenhouse gas emissions by 15 to 30% as compared to the projected growth of their emissions by 2020.

This new FAB deal will need to incoporate 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 ambitions to reduce emissions and need to even more invest in making the energy revolution happening. Greenpeace believes that it is feasible to reach a FAB deal in Cancun at the end of this year, if their would be sufficient political will to conclude such an agreement. That political will seems to be absent at the moment, but even if a FAB deal could not be finalised in COP16, due to lack of ambition and commitment of some countries, major parts of the deal must be put in place in Cancun, specifically those related to long term finance commitments, forest protection and overall ambition of emission reductions, so that by the Environment and Development Summit in Brazil in 2012 we can celebrate a deal that keeps the world well below 2 degrees warming with good certainty.

international energy policy

At present, renewable energy generators have to compete with old nuclear and fossil fuel power stations which produce electricity at marginal costs because consumers and taxpayers have already paid the interest and depreciation on the original investments. 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.

renewable energy targets

In recent years, in order to reduce greenhouse gas 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 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 of renewable energy.

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[6], the European Solar Thermal Power Industry Association[7] and the Global Wind Energy Council[8], 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.

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8 'GLOBAL WIND ENERGY OUTLOOK 2008', OCTOBER 2008.

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.

demands for the energy sector

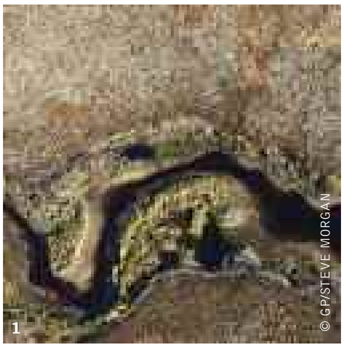
Greenpeace and the renewables industry have a clear agenda for the policy changes which need to be made to encourage a shift to renewable sources.

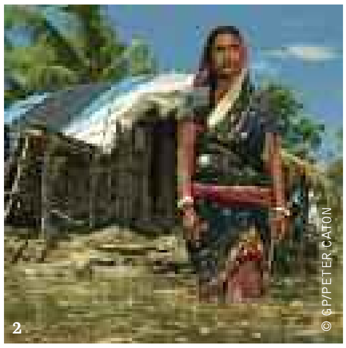
The main demands are:

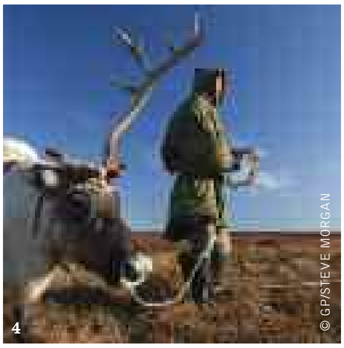
1. Phase out all subsidies for fossil fuels and nuclear energy.
2. Internalise external (social and environmental) costs through 'cap and trade' emissions trading.
3. Mandate strict efficiency standards for all energy consuming appliances, buildings and vehicles.
4. Establish legally binding targets 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 through feed-in tariff payments.
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[9] 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 would not only save taxpayers' money. It would also dramatically reduce the need for renewable energy support.

> **"If we do not take urgent and immediate action to protect the climate the damage could become irreversible."**







images 1. AN AERIAL VIEW OF PERMAFROST TUNDRA IN THE YAMAL PENINSULA. THE ENTIRE REGION IS UNDER HEAVY THREAT FROM GLOBAL WARMING AS TEMPERATURES INCREASE AND RUSSIA'S ANCIENT PERMAFROST MELTS. **2.** SOVARANI KOYAL LIVES IN SATJELLIA ISLAND AND IS ONE OF THE MANY PEOPLE AFFECTED BY SEA LEVEL RISE: "NOWADAYS, HEAVY FLOODS ARE GOING ON HERE. THE WATER LEVEL IS INCREASING AND THE TEMPERATURE TOO. WE CANNOT LIVE HERE, THE HEAT IS BECOMING UNBEARABLE. WE HAVE RECEIVED A PLASTIC SHEET AND HAVE COVERED OUR HOME WITH IT. DURING THE COMING MONSOON WE SHALL WRAP OUR BODIES IN THE PLASTIC TO STAY DRY. WE HAVE ONLY A FEW GOATS BUT WE DO NOT KNOW WHERE THEY ARE. WE ALSO HAVE TWO CHILDREN AND WE CANNOT MANAGE TO FEED THEM." **3.** WANG WAN YI, AGE 76, SITS INSIDE HIS HOME WHERE 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. **4.** INDIGENOUS NENETS PEOPLE WITH THEIR REINDEER. THE NENETS PEOPLE MOVE EVERY 3 OR 4 DAYS SO THAT THEIR HERDS DO NOT OVER GRAZE THE GROUND. THE ENTIRE REGION AND ITS INHABITANTS ARE UNDER HEAVY THREAT FROM GLOBAL WARMING AS TEMPERATURES INCREASE AND RUSSIA'S ANCIENT PERMAFROST MELTS. **5.** A BOY HOLDS HIS MOTHER'S HANDS WHILST IN A QUEUE FOR EMERGENCY RELIEF SUPPLY. SCIENTISTS ESTIMATE THAT OVER 70,000 PEOPLE, LIVING EFFECTIVELY ON THE FRONT LINE OF CLIMATE CHANGE, WILL BE DISPLACED FROM THE SUNDARBANS DUE TO SEA LEVEL RISE BY THE YEAR 2030.

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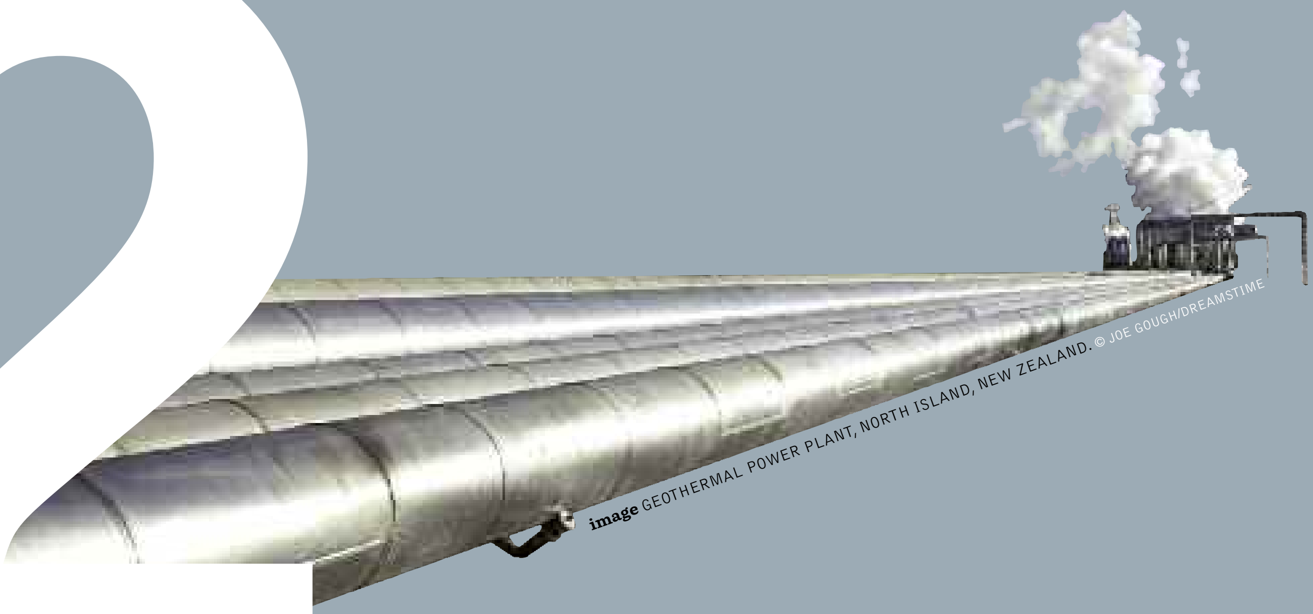

image GEOTHERMAL POWER PLANT, NORTH ISLAND, NEW ZEALAND. © JOE GOUGH/DREAMSTIME

"bridging the gap."

GREENPEACE INTERNATIONAL
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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 energy [r]evolution 2010 – u.s. policy brief

federal policies

the 2009 federal stimulus package The American Recovery and Reinvestment Act of 2009 (ARRA), designed to stimulate the national economy, provides $16.8 billion for renewable energy and energy efficiency, allocates another $3.5 billion for smart-grid investments and provides $4 billion of loan guarantees for renewable energy projects. Naturally, only a small portion of these amounts have been spent, but there are signs that these funds will have a significant impact on investment in the very near future.

One potentially significant aspect of the stimulus is the provision for a cash grant from the treasury in place of the production tax credit (for wind, geothermal, and closed-loop biomass) and the investment tax credit (mostly solar and small wind projects). This is important because developers had difficulty before ARRA in securing financing against potential tax equity. Now, ARRA provides the certainty needed to get projects going again. That means that construction is underway, or soon will be, on many projects that otherwise would have remained dormant.

The coal and nuclear industries are not entirely left out in the cold. $3.5 billion is provided for CCS demonstration under ARRA. The Administration also announced in February 2010 a $8.33 billion loan guarantee for two new nuclear reactors in Georgia.

climate-specific legislation Cap-and-trade legislation (Waxman-Markey) was passed by the house in June 2009 , albeit with too weak a 2020 target and other problematic provisions that included subsidies for coal. The Senate has been unable to finalize its own legislation, and the direction has been toward a set of policies even weaker than passed by the House.

renewable electricity A national Renewable Electricity Standard was passed by the House as part of Waxman-Markey, but, though approved by the more bipartisan Senate Energy and Natural Resources Committee it remains blocked in the Senate.

The Investment Tax Credit (mostly important for solar) has been extended through 2016. The Production Tax Credit has been extended through 2012 under ARRA, which also allows developers to take the ITC in place of the PTC on projects that begin construction before the end of this year.

biofuels The U.S. EPA is establishing changes to the Renewable Fuels Standard Program, which will increase the share of renewable sources in transportation fuel. The total renewable fuel requirement will increase to 8.25 percent of transportation fuel or 12.95 billion gallons in 2010 (from 9 billion gallons in 2008). This amount is to rise to 36 billion gallons by 2022. Last month, the Senate passed a bill reinstating a biodiesel blenders' tax credit that expired at the end of 2009 but final passage is uncertain. Also, to the chagrin of Archer Daniels Midland, tax credits specifically for ethanol, plus an import tariff on same, also remain uncertain beyond 2010.

state policies - PACE financing

Property-Assessed Clean Energy (PACE) financing is a growing trend. PACE programs allow low-interest funding of renewable energy installations by property owners, usually to be repaid through additional property tax assessments. At last count, the laws of nineteen states allowed local governments to form PACE programs to facilitate and encourage renewable energy installations in their municipalities. The latest addition (April 2010) was the state of Maine, passing a law specifically authorizing municipalities to collect special assessments to repay the PACE loans.

renewable portfolio standards Three additional states implemented an RPS in 2008 (MI, MO, and OH) and one in 2009 (KS), for a total of 29 states plus the District of Columbia with some form of a renewable portfolio standard.[10] A larger number of states, six in 2008 and seven in 2009, modified existing RPS provisions, mostly expanding targets and carving out a larger role for solar.

Many states are making special provisions for solar and distributed generation within RPS mandates. Nine states and DC made new provisions specific to solar in 2009.[11] One of these states is Nevada, which raised its RPS from 20 percent in 2020 to 25 percent in 2025, but also modestly increased the solar share to 1.5% of total sales by 2025 and added a credit multiplier for solar generation. As of April 2010, 16 states and DC have special provisions for solar and distributed generation, sometimes combined with credit multipliers. So far, RPS programs predominantly drive wind power development while other sources (solar, biomass and geothermal) are expected to gain ground.

investment incentives (such as direct rebates, tax credits or rebates, and loans) As noted above, Federal stimulus money helped boost incentive programs for renewables and energy efficiency. Still, some states did not increase available funding or even reduced funding due to budget constraints. In 2009, about forty new solar programs were launched at the state level. Significant new incentive programs included the Alaska Energy Authority Renewable Energy Grant Program and the Pennsylvania Sunshine Solar Rebate Program, each topping $100 million in funding for 2009. Many states increased tax incentives in various ways, such as increasing caps on tax credits, increasing the size of systems eligible for consideration, expanding programs to include additional renewable technologies, or extending program duration. Only two states, Hawaii and Vermont, placed new restrictions on their tax incentives.

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production incentives (such as FITs and REC purchase programs) As of late 2009, there were 39 production-based incentives in 28 states, with 15 new programs created last year.[12] But many of those are utility-based programs rather than state or municipal policies. Many states are considering FITs and a handful have enacted legislation. One municipality in Florida (Gainesville) has its own FIT, effective March 2009, with a variable rate and a 20-year contract requirement.

According to the Interstate Renewable Energy Council, it is the relative "maturity" of the U.S. solar market that is now driving states to consider more production-based incentives rather than relying only on rebates and other investment-based incentives, with 15 new production-based incentives created last year.

It is perhaps a sign of that perceived maturity, or more simply, the fact that system costs have declined significantly, that some states lowered their incentive payments, per watt installed or per watt-hour produced, or by reducing the cap on each incentive payment. This does not mean that overall program budgets always declined. Only three states appear to have reduced program funding last year, mostly to cover state budget deficits.

net metering Two states, Kansas and Nebraska, implemented net metering last year, for a total of 42 states with net metering programs. Twenty states modified their net metering rules last year. Some of these changes address concerns such as the treatment of excess generation, namely whether to credit at retail rates or average avoided cost and whether to allow monthly or indefinite rollover of excess. Some utilities remain concerned that self-generating customers are unduly compensated at anything above average avoided cost but the regulators and legislators seem to be increasingly convinced that the value of distributed renewable generation is indeed higher, and that this value should be no lower than the retail rate. Net metering program caps relative to peak load have also been increased in some states as well as system capacity limits. For example, some states have no system size limits as long as the system reflects the customer's average annual demand.

renewable heating A number of states now have incentives for renewable heating in place, particularly water heating and geothermal heat pumps. In June 2008, Hawaii was the first state to enact mandates in this area, requiring that all new homes be outfitted with solar water heating systems. The law prohibits the issuing of building permits for single-family homes that do not have solar water heaters starting January 1, 2010.

notable at the state level The State of Maine has set an 8,000-MW wind power goal by 2030, with 3,000 MW to come from off-shore resources. The Maine Public Utilities Commission is expected to get started this year by issuing a request for proposals for 25 MW of deepwater floating turbines as well as 5 MW of tidal power. In early 2010, the Obama administration approved the first American offshore wind farm—Cape Wind in Nantucket Sound. These 130 turbines will provide 420 megawatts of energy, or three quarters of the electricity for Cape Cod, Martha's Vineyard and Nantucket. And California continues to lead the way at the state level, with its progressive climate change policies.

references
12 IREC, 3.

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

2.2 ftsm: a support scheme for renewable power in developing countries

This section outlines a Greenpeace proposal for a feed-in tariff system in developing countries whose additional costs would be financed by developed nations. The financial resources for this could come from a combination of innovative sources, could be managed by the Copenhagen Green Climate Fund (that still needs to be established), and the level of contributions should be set through the GDR framework (see 2.3).

Both Energy [R]evolution scenarios show that renewable electricity generation has huge environmental and economic benefits. However its investment and generation costs, especially in developing countries, will remain higher than those of existing coal or gas-fired power stations for the next five to ten years. To bridge this cost gap a specific support mechanism for the power sector is needed. The **Feed-in Tariff Support Mechanism (FTSM)** is a concept conceived by Greenpeace International.[13] The aim is the rapid expansion of renewable energy in developing countries with financial support from industrialised nations.

Since the FTSM concept was first presented in 2008, the idea has received considerable support from a variety of different stakeholders. The Deutsche Bank Group´s Climate Change Advisors, for example, have developed a proposal based on FTSM called "GET FiT". Announced in April 2010, this took on board major aspects of the Greenpeace concept.

bankable renewable energy support schemes

Since the early development of renewable energies within the power sector, there has been an ongoing debate about the best and most effective type of support scheme. The European Commission published a survey in December 2005 which provided a good overview of the experience so far. This concluded that feed-in tariffs are by far the most efficient and successful mechanism. A more recent update of this report, presented in March 2010 at the IEA Renewable Energy Workshop by the Fraunhofer Institute[14], underscores this conclusion. The Stern Review on the Economics of Climate Change also concluded that feed-in tariffs "achieve larger deployment at lower costs". Globally more than 40 countries have adopted some version of the system.

Although the organisational form of these tariffs differs from country to country, there are certain clear criteria which emerge as essential for creating a successful renewable energy policy. At the heart of these is a reliable, bankable support scheme for renewable projects which provides long term stability and certainty[15]. Bankable support schemes result in lower cost projects because they lower the risk for both investors and equipment suppliers. The cost of wind-powered electricity in Germany is up to 40% cheaper than in the United Kingdom[16], for example, because the support system is more secure and reliable.

experience of feed-in tariffs

- Feed-in tariffs are seen as the best way forward, especially in developing countries. By 2009 this system had incentivised 75% of PV capacity worldwide and 45% of wind capacity.
- Based on experience, feed-in tariffs are the most effective mechanism to create a stable framework to build a domestic market for renewables. They have the lowest investment risk, highest technology diversity, lowest windfall profits for mature technologies and attract a broad spectrum of investors.[17]
- The main argument against them is the increase in electricity prices for households and industry, as the extra costs are shared across all customers. This is particularly difficult for developing countries, where many people can't afford to spend more money for electricity services.

For developing countries, feed-in laws would be an ideal mechanism to support the implementation of new renewable energies. The extra costs, however, which are usually covered in Europe, for example, by a very minor increase in the overall electricity price for consumers, are still seen as an obstacle. In order to enable technology transfer from Annex 1 countries to developing countries, a mix of a feed-in law, international finance and emissions trading could be used to establish a locally based renewable energy infrastructure and industry with the assistance of OECD countries.

Finance for renewable energy projects is one of the main obstacles in developing countries. While large scale projects have fewer funding problems, there are difficulties for small, community based projects, even though they have a high degree of public support. The experiences from micro credits for small hydro projects in Bangladesh, for example, as well as wind farms in Denmark and Germany, show how both strong local participation and acceptance can be achieved. The main reasons for this are the economic benefits flowing to the local community and careful project planning based on good local knowledge and understanding. When the community identifies the project rather than the project identifying the community, the result is generally faster bottom-up growth of the renewables sector.

The four main elements for successful renewable energy support schemes are therefore:

- A clear, bankable pricing system.
- Priority access to the grid with clear identification of who is responsible for the connection, and how it is incentivised.
- Clear, simple administrative and planning permission procedures.
- Public acceptance/support.

The first is fundamentally important, but it is no good if you don't have the other three elements as well.

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15 'THE SUPPORT OF ELECTRICITY FROM RENEWABLE ENERGY SOURCES', EUROPEAN COMMISSION, 2005.
16 SEE ABOVE REPORT, P. 27, FIGURE 4.
17 EFFECTIVE AND EFFICIENT LONG-TERM ORIENTED RE SUPPORT POLICIES, FRAUNHOFER INSTITUTE, MARIO RAGWITZ, MARCH 2010.

the feed-in tariff support mechanism

The basic aim of the FTSM is to facilitate the introduction of feed-in laws in developing countries by providing additional financial resources on a scale appropriate to the circumstances of each country. For those countries with higher levels of potential renewable capacity, the creation of a new sectoral no-lose mechanism generating emission reduction credits for sale to Annex I countries, with the proceeds being used to offset part of the additional cost of the feed-in tariff system, could be appropriate. For others there would need to be a more directly funded approach to paying for the additional costs to consumers of the tariff. The ultimate objective would be to provide bankable and long term stable support for the development of a local renewable energy market. The tariffs would bridge the gap between conventional power generation costs and those of renewable generation.

the key parameters for feed in tariffs under FTSM are:

- Variable tariffs for different renewable energy technologies, depending on their costs and technology maturity, paid for 20 years.
- Payments based on actual generation in order to achieve properly maintained projects with high performance ratios.
- Payment of the 'additional costs' for renewable generation based on the German system, where the fixed tariff is paid minus the wholesale electricity price which all generators receive.
- Payment could include an element for infrastructure costs such as grid connection, grid re-enforcement or the development of a smart grid. A specific regulation needs to define when the payments for infrastructure costs are needed in order to achieve a timely market expansion of renewable power generation.

A developing country which wants to take part in the FTSM would need to establish clear regulations for the following:

- Guaranteed access to the electricity grid for renewable electricity projects.
- Establishment of a feed-in law based on successful examples.
- Transparent access to all data needed to establish the feed-in tariff, including full records of generated electricity.
- Clear planning and licensing procedures.

The average additional costs for introducing the FTSM between 2010 and 2020 under the Energy [R]evolution scenario are estimated to be between 5 and 3 cents/kWh and 5 and 2 cents/kWh under the advanced version. The cost per tonne of CO_2 avoided would therefore be around $25.

The design of the FTSM would need to ensure that there were stable flows of funds to renewable energy suppliers. There may therefore need to be a buffer between fluctuating CO_2 emission prices and stable long term feed-in tariffs. This would be possible through the proposed Greenhouse Development Rights scheme, which would create a stable income for non-OECD countries (see Chapter 2.3, Table 2.7 and 2.8). The FTSM will need to secure payment of the required feed-in tariffs over the whole lifetime (about 20 years) of each project.

In order to be eligible, all renewable energy projects must have a clear set of environmental criteria which are part of the national licensing procedure in the country where the project will generate electricity. Those criteria will have to meet a minimum environmental standard defined by an independent monitoring group. If there are already acceptable criteria developed these should be adopted rather than reinventing the wheel. The members of the monitoring group would include NGOs, energy and finance experts as well as members of the governments involved. Funding will not be made available for speculative investments, only as soft loans for FTSM projects.

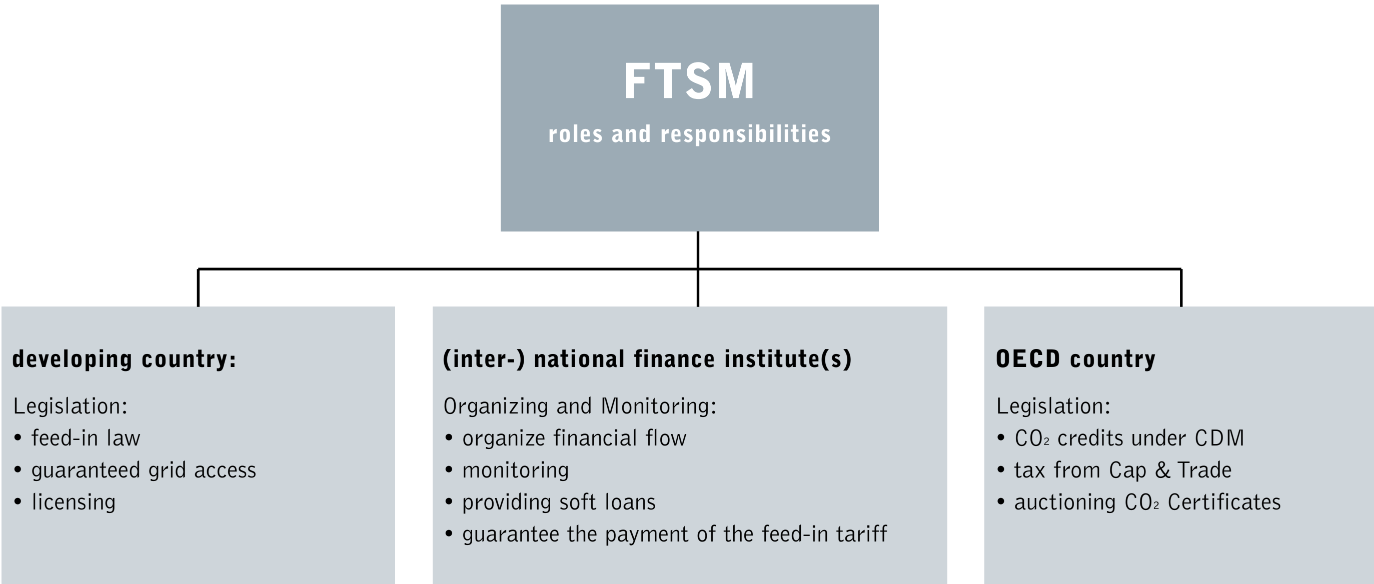
The FTSM would also seek to create the conditions for private sector actors, such as local banks and energy service companies, to gain experience in technology development, project development, project financing and operation and maintenance in order to develop track records which would help reduce barriers to further renewable energy development.

the key parameters for the FTSM fund will be:

- The mechanism will guarantee payment of the feed-in tariffs over a period of 20 years as long as the project is operated properly.
- The mechanism will receive annual income from emissions trading or from direct funding.
- The mechanism will pay feed-in tariffs annually only on the basis of generated electricity.
- Every FTSM project must have a professional maintenance company to ensure high availability.
- The grid operator must do its own monitoring and send generation data to the FTSM fund. Data from the project managers and grid operators will be compared regularly to check consistency.

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.

figure 2.1: ftsm scheme



financing the energy [r]evolution with FTSM

Based on both Energy [R]evolution Scenarios for developing (non-OECD) countries, a calculation has been done to estimate the costs and benefits of an FTSM programme using the following assumptions:

power generation costs The average level of feed-in tariffs, excluding solar, has been calculated on the assumption that the majority of renewable energy sources require support payments of between 7 and 15 cents per kilowatt-hour. While wind and bio energy power generation can operate on tariffs of below 10 cents per kWh, other technologies, such as geothermal and concentrated solar power, will need slightly more. Exact tariffs should be calculated on the basis of specific market prices within each country. The feed-in tariff for solar photovoltaic projects reflects current market price projections. The average conventional power generation costs are based on new coal and gas power plants without direct or indirect subsidies.

specific CO_2 reduction per kWh The assumed CO_2 reduction per kWh from switching to renewables is crucial for calculating the specific cost per tonne of CO_2 saved. In non-OECD countries the current level of CO_2 emissions for power generation averages 871 gCO_2/kWh, and will reduce to 857 gCO_2/kWh by 2030 (see Reference scenario Chapter 6). The average level of CO_2 emissions over the period from 2010 to 2020 is therefore 864 gCO_2/kWh.

table 2.1: assumptions for ftsm calculations

KEY PARAMETER	AVERAGE FEED-IN TARIFF EXCL. SOLAR PV (ct/kWh)	AVERAGE FEED-IN TARIFF FOR SOLAR PV (ct/kWh)
2010	12	20
2020	11	15
2030	10	10

financial parameters From the beginning of the financial crisis in mid-2008 it became clear that inflation rates and capital costs were likely to change very fast. The cost calculations in this programme do not take into account changes in interest rates, capital costs or inflation; all cost parameters are nominal based on 2009 levels.

key results The FTSM programme would cover 624TWh by 2015 and 4,960 TWh by 2030 of new renewable electricity generation and save 77.6 $GtCO_2$ between 2010 and 2030. This works out at 3.8 $GtCO_2$ per year under the basic Energy [R]evolution scenario and 82 $GtCO_2$ or 4.1 $GtCO_2$ per year under the advanced version. With an average CO_2 price of $23.1 per tonne, the total programme would cost $1.62 trillion. This works out at $76.3 billion annually under the basic version and $1.29 trillion or $61.4 billion annually under the advanced scenario.

Under the GDR scheme, this would mean that the EU-27 countries would need to cover 22.4% ($ billion 289) of these costs, or $14.4 annually. The costs for the USA would amount to $24.9 billion each year. India, on the other hand, would receive $13 billion per year between 2010 and 2030 to finance the domestic uptake of renewable power generation.

The FTSM will bridge the gap between now and 2030, when electricity generation costs for all renewable energy technologies are projected to be lower than conventional coal and gas power plants. However, this case study has calculated even lower generation costs for conventional power generation than we have assumed in our price projections for the Energy [R]evolution scenario (see Chapter 5, page 52, Table 5.3.). This is because we have excluded CO_2 emission costs. If these are taken into account coal power plants would have generation costs of 10.8 $cents/kWh by 2020 and 12.5 cents/kWh by 2030, as against the FTSM assumption of 10 cents/kWh over the same timescale. However, the advanced Energy [R]evolution case takes those higher costs into account and reaches economies of scale for renewable power generation around 5 years earlier. Therefore, in the second period in the advanced case, the annual costs of the FTSM programm drop significantly under the basic version even with much higher renewable electricity volume.

As the difference between renewable and coal electricity generation costs are projected to decrease, more renewable electricity can be financed with roughly the same amount of money.

for developing countries

Overall, the FTSM for non-OECD countries will bring more than 1,700 GW (2,300 GW in the advanced version) of new renewable energy power plants on line, creating about 5 million jobs with an annual cost of under $15,000 per job per year.

more than 1700 GW renewables

figure 2.2: feed-in tariffs versus conventional power generation

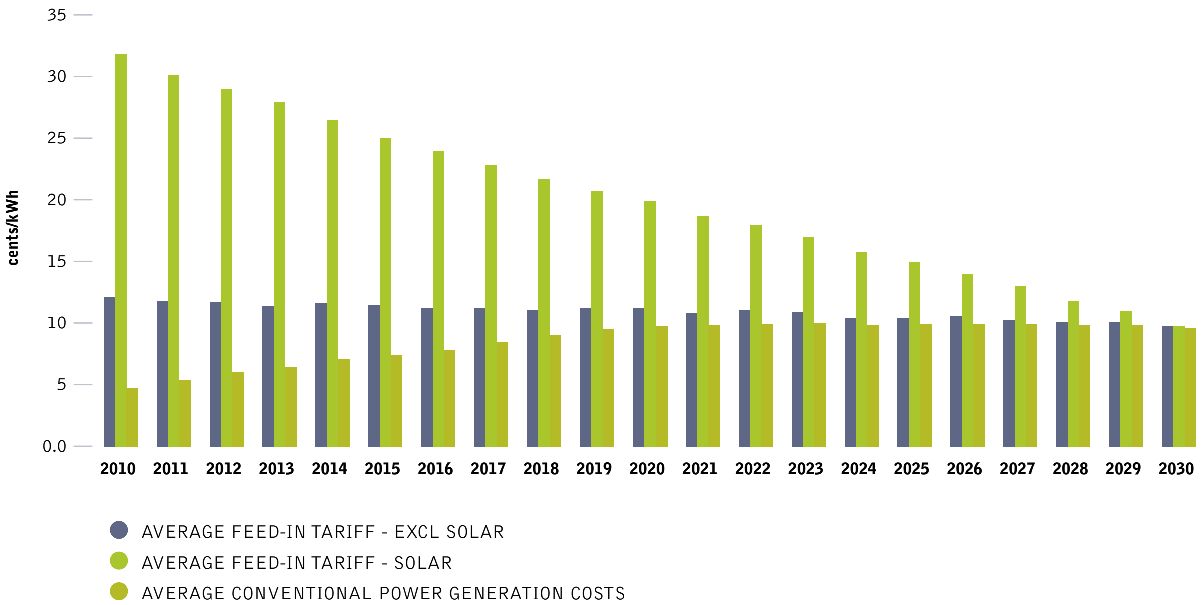


table 2.2: ftsm key parameters - Energy [R]evolution

KEY PARAMETER	CONVENTIONAL POWER GENERATION COSTS (ct/kWh)	INTEREST RATES (%)	SPECIFIC REDUCTION PER KWH (gCO2/kWh)
2010	7	4	0.7
2020	10	4	0.7
2030	10	4	0.7

table 2.3: ftsm key parameters - adv Energy [R]evolution

KEY PARAMETER	CONVENTIONAL POWER GENERATION COSTS (ct/kWh)	INTEREST RATES (%)	SPECIFIC REDUCTION PER KWH (gCO2/kWh)
2010	7	4	0.7
2020	11	4	0.7
2030	12.5	4	0.7

table 2.4: ftsm programme

KEY RESULTS TOTAL NON-OECD	YEAR	AVERAGE CO_2 COST PER TONNE [$/ TCO_2]	AVERAGE ANNUAL CO_2 EMISSION CREDITS (MILLION T CO_2)	TOTAL ANNUAL COSTS (BILLION US$)	TOTAL CO_2 CERTIFICATES PER PERIODE (MILLION T CO_2)	TOTAL COSTS PER PERIOD (BILLION $)
Period 1 E[R]	2010-2019	27.8	2,080.4	57.9	20,804	579
Period 1 adv E[R]	2010-2019	26.3	2,199.3	57.9	21,993	579
Period 2 E[R]	2020-2030	18.3	5,165.8	94.7	56,824	1,042
Period 2 adv E[R]	2020-2030	11.9	5,461.0	64.8	60,071	713
Period 1+2 E[R]	2010-2030	23.1	3,623.1	76.3	77,628	1,621
Period 1+2 adv E[R]	2010-2030	19.1	3,830.1	61.4	82,064	1,292

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

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table 2.5: renewable power for non-oecd countries under ftsm programme

ELECTRICITY GENERATION (TWh/a)	2007	2015	2020	2030	INSTALLED CAPACITY (GW)	2007	2015	2020	2030
Wind E[R]	23.6	307.0	854.5	2,238.0	Wind E[R]	15	138	347	865
PV E[R]	0.2	22.0	105.4	673.0	PV E[R]	0	14	59	383
Biomass E[R]	41.2	218.0	488.5	950.0	Biomass E[R]	7	44	100	173
Geothermal E[R]	21.6	50.5	111.0	251.0	Geothermal E[R]	4	9	19	44
Solar Thermal E[R]	0.0	21.7	112.1	798.0	Solar Thermal E[R]	0	9	36	130
Ocean Energy E[R]	0.0	4.6	27.4	48.5	Ocean Energy E[R]	0	1	8	14
Total - new RE E[R]	**86.7**	**623.8**	**1,699.0**	**4,958.5**	**Total - new RE E[R]**	**26.2**	**214.1**	**570.7**	**1,610.3**
Wind adv E[R]	23.6	312.0	1,092.0	2,949.0	Wind adv E[R]	15	140	443	1,142
PV adv E[R]	0.2	22.0	204.0	998.0	PV adv E[R]	0	14	114	560
Biomass adv E[R]	41.2	218.0	487.0	946.0	Biomass adv E[R]	7	44	100	173
Geothermal adv E[R]	21.6	55.4	164.0	715.0	Geothermal adv E[R]	4	10	28	117
Solar Thermal adv E[R]	0.0	24.7	281.0	1,550.0	Solar Thermal adv E[R]	0	10	91	255
Ocean Energy adv E[R]	0.0	4.6	67.0	237.0	Ocean Energy adv E[R]	0	1	20	70
Total - new RE adv E[R]	**86.7**	**636.7**	**2,295.0**	**7,395.0**	**Total - new RE adv E[R]**	**26.2**	**218.1**	**795.1**	**2,316.2**

2.3 greenhouse development rights

The Energy [R]evolution scenarios present a range of pathways towards a future based on an increasing proportion of renewable energy, but such routes are only likely to be followed if their corresponding investment costs are shared fairly under some form of global climate regime. To demonstrate how this would be possible we have used the Greenhouse Development Rights framework, designed by EcoEquity and the Stockholm Environment Institute, as a potential basis for implementing the Energy [R]evolution .

Greenpeace advocates for industrialized countries, as a group, to reduce their emissions by at least 40% by 2020 (as compared to 1990 emissions) and for developing countries, as a group, to reduce their emissions by at least 15% by 2020 as compared to their projected growth in emissions. On top of these commitments Greenpeace urges industrialized countries to provide financial resources of at least $US140 billion per year to fund the cost of climate change mitigation and adaptation in developing countries. The Greenhouse Development Rights framework provides a tool for distributing both this emission reduction and finance target equally amongst countries. Below we show how this will work for implementing the Energy [R]evolution scenarios.

the greenhouse development rights framework

The **Greenhouse Development Rights (GDR)** framework calculates national shares of global greenhouse gas obligations based on a combination of responsibility (contribution to climate change) and capacity (ability to pay). Crucially, GDRs take inequality within countries into account and calculate national obligations on the basis of the estimated capacity and responsibility of individuals. Individuals with incomes below a 'development threshold' – specified in the default case as $7,500 per capita annual income, PPP adjusted – are exempted from climate-related obligations. Individuals with incomes above that level are expected to contribute to the costs of global climate policy in proportion to their capacity (amount of income over the threshold) and responsibility (cumulative CO_2 emissions since 1990, excluding emissions corresponding to consumption below the threshold).

The calculations of capacity and responsibility are then combined into a joint **Responsibility and Capacity Indicator (RCI)** by taking the average of the two values. Thus, for example, as shown in Table 2.6 below, the United States of America, with 4.5% of the world's population, has 35.8% of the world's capacity in 2010, 36.8% of the world's responsibility and 36.3% of the calculated RCI. This means that in 2010, the USA would be responsible for 36.3% of the costs of global climate policy.

Because the system calculates obligations based on the characteristics of individuals, and all countries have at least some individuals with incomes over the development threshold, GDRs would eliminate the overarching formal distinction in the Kyoto Protocol between Annex I and non-Annex I countries. There would of course still be key differences between rich and poor countries, as rich countries would be expected to pay for reductions made in other countries as well as making steep domestic emissions reductions, while poor countries could expect the majority of the incremental costs for emissions reductions required within their borders to be paid for by wealthier countries. Similarly, the national obligations calculated through GDRs could be used to allocate contributions to a global adaptation fund; again, even poor countries would have some positive obligations to contribute, but they would expect to be net recipients of adaptation funds, while rich countries would be net contributors.

table 2.6: population, income, capacity, responsibility and RCI calculated for 2010 for IEA regions and selected countries, plus projected 2020 and 2030 RCI.

REGION/COUNTRY	POPULATION (2010)	INCOME USD /A (2010)	CAPACITY (2010)	RESPONSIBILITY (2010)	RCI (2010)	RCI (2020)	RCI (2030)
OECD	**17.6%**	**32,413**	**86.6%**	**75.3%**	**80.9%**	**72.8%**	**63.7%**
North America	6.6%	37,128	39.8%	41.5%	40.6%	36.9%	32.9%
United States	4.5%	45,640	35.8%	36.8%	36.3%	32.7%	28.9%
Mexico	1.6%	12,408	1.3%	1.6%	1.5%	1.5%	1.5%
Canada	0.5%	38,472	2.6%	3.1%	2.9%	2.7%	2.5%
Europe	8.0%	29,035	29.3%	22.2%	25.8%	23.2%	20.1%
Pacific	3.0%	30,961	17.5%	11.5%	14.5%	12.7%	10.7%
Japan	1.9%	33,422	14.3%	7.3%	10.8%	9.2%	7.4%
Non-OECD	**82.4%**	**5,137**	**13.4%**	**24.7%**	**19.1%**	**27.2%**	**36.3%**
E.Europe/Eurasia	4.9%	11,089	1.5%	7.8%	4.7%	5.2%	5.7%
Russia	2.0%	15,031	0.9%	5.9%	3.4%	3.5%	3.8%
Asia	52.5%	4,424	5.6%	7.2%	6.4%	12.7%	20.1%
China	19.7%	5,899	2.9%	4.3%	3.6%	8.3%	13.6%
India	17.2%	2,818	0.1%	0.1%	0.1%	0.5%	1.3%
Middle East	14.9%	2,617	0.8%	2.0%	1.4%	1.7%	2.0%
Africa	3.1%	12,098	2.4%	4.8%	3.6%	4.3%	4.8%
Latin America	7.0%	8,645	3.1%	2.9%	3.0%	3.3%	3.6%
Brazil	2.9%	9,442	1.5%	1.1%	1.3%	1.4%	1.4%
World	**100.0%**	**9,929**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**
European Union	**7.3%**	**30,471**	**28.1%**	**21.8%**	**25.0%**	**22.6%**	**19.6%**

A more detailed description of the GDR framework can be found in "The Greenhouse Development Right Framework" published in November 2008.[18] For this study, the standard GDR framework has been slightly modified to account for the most recent IEA World Energy Outlook 2009 baseline emissions and economic growth scenario up to 2030, and for the target pathways defined by the Energy [R]evolution and advanced Energy [R]evolution scenarios (for more details see Chapter 6). Because the GDR framework calculates the share of global climate obligation for each country, it can therefore be used to calculate (against a baseline) the amount of reductions required for each country to meet an international target. In Figure 2.3 we show the global obligation required to move from the IEA baseline to the emissions pathway in the Energy [R]evolution scenario (declining to 25 $GtCO_2$ in 2020 and 21 $GtCO_2$ in 2030), with the reduction divided into "wedges" proportional to each country's share.

Figure 2.4 shows the global emissions reductions required under the advanced Energy [R]evolution scenario, also divided into "wedges" proportional to each country or region's Responsibility and Capacity Indicator. Note that the size of each wedge in percentage terms changes over time, consistent with Table 2.6. The largest share is for the US, followed by Europe, while the wedges for India and China increase over time. Africa and Developing Asia have the smallest wedges.

figure 2.3: energy [r]evolution wedges

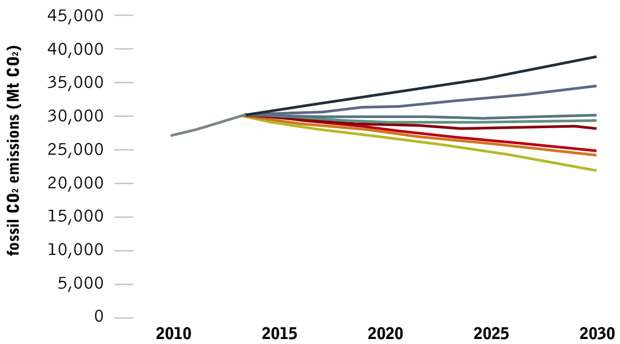

figure 2.4: advanced energy [r]evolution wedges

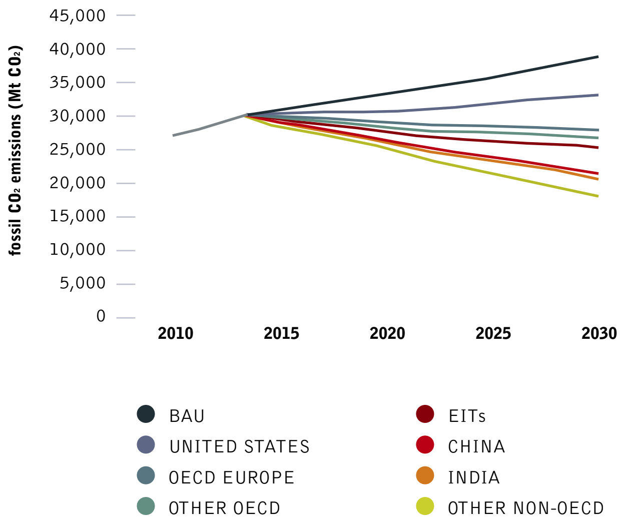

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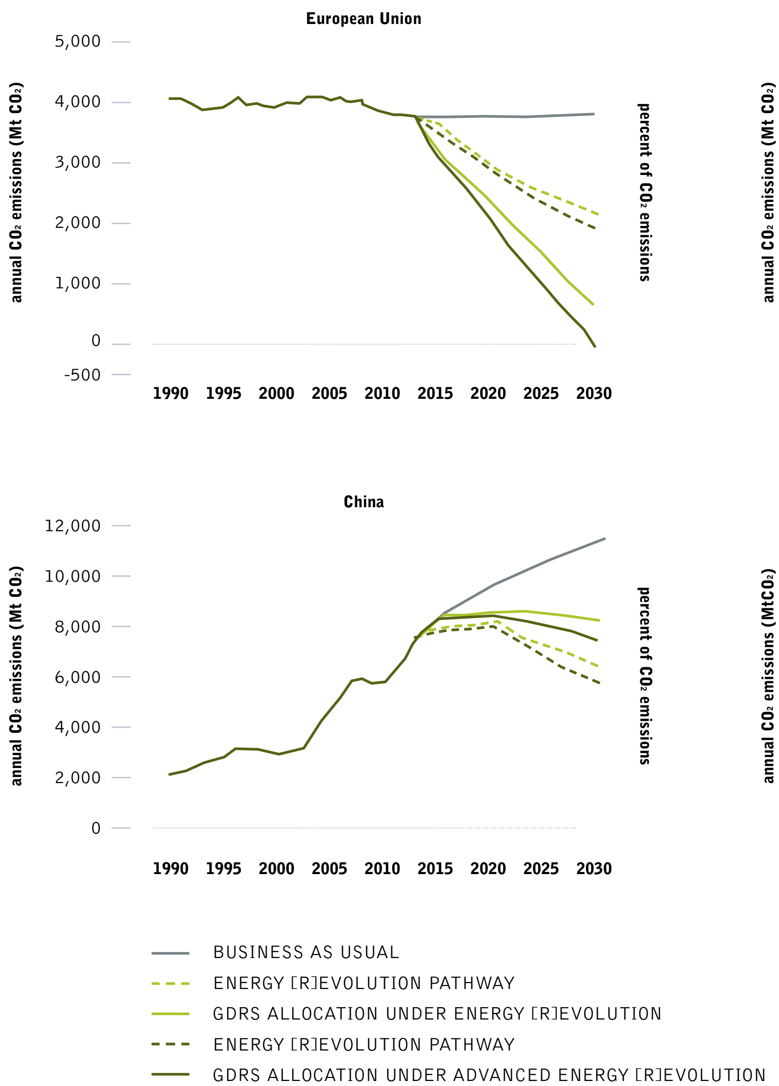
image WIND TURBINES AT THE NAN WIND FARM IN NAN'AO. GUANGDONG PROVINCE HAS ONE OF THE BEST WIND RESOURCES IN CHINA AND IS ALREADY HOME TO SEVERAL INDUSTRIAL SCALE WIND FARMS.

The charts in Figure 2.5 show for the US, EU, India and China, the relationship between domestic emissions reductions under the Energy [R]evolution scenarios and the allocation of responsibility through the GDR framework. For the EU and the US, the allocations (solid blue and green lines) are well below the estimated emissions (dotted blue and green lines), with the difference resulting from an international obligation to fund reductions in other countries. In India and China, by contrast, the allocation of permits is greater than the estimated emissions, indicating that other countries will need to support a reduction from the level indicated by the allocation (solid lines) and projected emissions (dashed lines).

Because the forward calculation of the Responsibility and Capacity Indicator (RCI) depends on the budget that is allocated, the percentage reductions of different countries and regions are slightly different under the Energy [R]evolution and advanced Energy [R]evolution pathways. Nevertheless, because neither capacity nor responsibility from 1990-2010 vary in the two scenarios, the RCIs for specific countries are still quite similar, and thus the actual allocations going forward differ between the two scenarios primarily because of the stricter targets in the advanced scenario.

It is also important to note that because GDRs allocate obligations as a percentage of the global commitment, measured in $MtCO_2$ in this example, a country with lower per capita emissions will appear to have a more stringent reduction target, when their target is stated in terms of a percentage of 1990 emissions by 2020 or 2030. However, it should be borne in mind that the GDR calculation does not specify the split between domestic and internationally supported reductions. Since we assume that emissions trading or a similar mechanism will lead to a rough equalisation of the marginal cost of reductions, it is in essence the "per capita tonnes of reductions", and thus per capita costs, which are made comparable (not equal) through the calculation of the RCI. With this in mind, we can see under the Energy [R]evolution scenario that the OECD nations have a global responsibility equal to a reduction to 45% below 1990 levels in 2020 and 2% of 1990 levels in 2030.

figure 2.5: annual ghg emissions and reduction pathways allocated under the GDR system for the USA, Europe, China and India



Based on the Energy [R]evolution pathway for the three OECD regions the total domestic emissions would add up to 9.9 $GtCO_2$ by 2020 and 7.2 $GtCO_2$ by 2030

Under the GDR scheme the OECD regions would have an emissions budget of 8.14 $GtCO_2$ by 2020 and 2.9 $GtCO_2$ by 2030. Therefore the richer nations have to finance the saving of 1.7 $GtCO_2$ by 2020 and 4.3 $GtCO_2$ by 2030 in non-OECD countries.

The non-OECD countries would in aggregate see their emissions allocation rise from 195% of 1990 levels in 2020 to 200% in 2030. In $MtCO_2$, China's emissions allocation would rise from about 8,200 in 2015 to about 8,500 in 2020 and grow only slightly more by 2030. India by contrast would see its allocation rise from 1,600 $MtCO_2$ today to about 2,000 by 2020 and 2,800 $MtCO_2$ in 2030. Within the OECD, the US allocation would fall to 52% of 1990 levels by 2020 and 2% by 2030, while the EU's allocation would fall from 84% today to 33% of 1990 levels in 2020 and -3% of 1990 levels by 2030. (A negative emissions allocation is simply a requirement to buy a larger quantity of emission permits/support a larger amount of mitigation internationally.)

Under the advanced Energy [R]evolution scenario, which has global emissions falling to 25 $GtCO_2$ in 2020, instead of 27 $GtCO_2$ in the basic version, and then to 18 $GtCO_2$ instead of 22 $GtCO_2$ in 2030, reductions are correspondingly steeper. The OECD countries' allocation of emissions falls to 19% of 1990 levels in 2020 and -22% in 2030, with the US share being 20% and -24% respectively and the EU's share 12% and -22%. China's emissions allocation peaks at 8,300 $MtCO_2$ (instead of 8,500 under the basic scenario) and falls to 7,300 $MtCO_2$ by 2030; India, however, changes little from its allowances under the less stringent global pathway.

For an interesting comparison in terms of relatively wealthy "developing" countries, which are currently completely excluded from binding targets under the Kyoto protocol, consider Brazil and Mexico; both see their allocation falling immediately below their 2010 levels. In the Energy [R]evolution scenario, the drop is about a 15% reduction below 2010 levels by 2020; in the advanced scenario, the drop is about a 30% reduction below 2010 levels.

Table 2.7 presents an overview of the CO_2 emission allocations by country and/or region based on the global Energy [R]evolution pathway towards a level of 27 $GtCO_2$ in 2020 and 21.9 $GtCO_2$ in 2030. The advanced version shown in Table 2.8 has a stricter reduction pathway, falling to 18.3 $GtCO_2$ by 2030, a bit more than ten years ahead of the basic scenario. The GDR system allocates the same emission allocations for each country under the advanced Energy [R]evolution pathway, but this scenario also results in a faster uptake of renewable energy, enabling developing countries to leapfrog from conventional to renewables faster. This pathway might also reduce stranded investments resulting from closed fossil fuel power stations, as developing countries will be able to build up the energy infrastructure with new technologies from the very beginning.

In total, all the OECD countries will have cumulative emissions allocations between 1990 and 2030 of 8.14 $GtCO_2$ and 7.35 $GtCO_2$ under the advanced Energy [R]evolution scenario. The scenarios show that 21% (basic version) or 27% (advanced) of those emission reductions will have to come from international actions, as domestic emissions are still too high. In summary, the OECD countries will have to finance a saving of 45 $GtCO_2$ for non-OECD countries. A possible mechanism to support the introduction of renewable power generation in those countries - crucial to the Energy [R]evolution scenarios - would be the feed-in tariff support system described below.

applying GDR to the energy [r]evolution

It is obvious that, given the huge responsibility and large capacity of industrialised countries, they have a high RCI. Their responsibility for implementing emission reductions should therefore go well beyond the domestic reductions they can achieve by implementing the Energy [R]evolution. Tables 2.7 and 2.8 show the difference between their emissions under the two ER scenarios and the emission reductions they would be responsible for if the RCI is used to distribute their global obligations more equitably.

The difference between their domestic emissions in the ER scenarios and the levels under the RCI system defines the responsibility that these countries will have to fund the implementation of the Energy [R]evolution scenario in developing countries

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.

table 2.7: greenhouse development emission allocation - energy [r]evolution base case

FOSSIL CO_2 EMISSION IN [MT CO_2]	1990	2015			2020			2030		
		GDR EMISSION RIGHTS	DOMESTIC EMISSION RIGHTS UNDER ADV. E[R]	MITIGATION FUND	GDR EMISSION RIGHTS	DOMESTIC EMISSION RIGHTS UNDER ADV. E[R]	MITIGATION FUND	GDR EMISSION RIGHTS	DOMESTIC EMISSION RIGHTS UNDER ADV. E[R]	MITIGATION FUND
OECD	**11,405**	**10,834**	**11,716**	**-882**	**8,143**	**9,919**	**-1,775**	**2,926**	**7,253**	**-4,327**
North America	5,756	5,732	6,094	-361	4,357	5,223	-865	1,740	3,655	-1,915
United States	5,009	4,847	5,183	-336	3,618	4,393	-775	1,278	3,043	-1,765
Mexico	302	406	394	12	361	363	-2	276	279	-2
Canada	445	479	516	-37	378	466	-88	186	334	-148
Europe	4,026	3,263	3,642	-379	2,394	2,947	-553	648	2,209	-1,561
Pacific	1,623	1,838	1,980	-142	1,392	1,749	-357	538	1,389	-851
Non-OECD	**9,542**	**18,023**	**28,308**	**885**	**18,587**	**16,810**	**1,777**	**19,037**	**14,707**	**4,330**
Transition Economies	4,158	2,598	2,382	216	2,418	1,931	487	2,077	1,440	637
Asia	3,596	11,734	11,170	564	12,498	11,526	972	13,284	10,252	3,032
China	2,277	8,226	7,830	396	8,503	8,033	470	8,065	6,557	1,508
India	607	1,712	1,626	86	2,054	1,807	247	2,861	2,035	826
Other Asia	712	1,796	1,714	82	1,940	1,686	254	2,358	1,660	698
Africa	566	962	1,001	39	922	1,013	91	887	1,031	143
Middle East	608	1,661	1,555	105	1,768	1,439	329	1,978	1,248	730
Latin America	613	1,069	1,030	39	981	901	80	811	736	75
World	**20,947**	**28,857**	**28,854**		**26,730**	**26,729**		**21,963**	**21,960**	

table 2.8: greenhouse development emission allocation - advanced energy [r]evolution base case

FOSSIL CO_2 EMISSION IN [MT CO_2]	1990	2015			2020			2030		
		GDR EMISSION RIGHTS	DOMESTIC EMISSION RIGHTS UNDER ADV. E[R]	MITIGATION FUND	GDR EMISSION RIGHTS	DOMESTIC EMISSION RIGHTS UNDER ADV. E[R]	MITIGATION FUND	GDR EMISSION RIGHTS	DOMESTIC EMISSION RIGHTS UNDER ADV. E[R]	MITIGATION FUND
OECD	**11,405**	**10,524**	**11,317**	**-793**	**7,359**	**9,327**	**-1,969**	**911**	**5,941**	**-5,029**
North America	5,756	5,575	5,841	-266	3,956	4,749	-793	694	2,724	-2,030
United States	5,009	4,709	4,942	-233	3,267	3,965	-698	370	2,188	-1,818
Mexico	302	399	396	3	341	350	-9	218	246	-29
Canada	445	468	503	-36	349	434	-85	106	290	-184
Europe	4,026	3,160	3,488	-328	2,134	2,908	-774	-11	1,931	-1,942
Pacific	1,623	1,789	1,988	-199	1,269	1,671	-402	229	1,286	-1,057
Non-OECD	**9,542**	**17,892**	**17,109**	**783**	**18,161**	**16,179**	**1,983**	**17,459**	**12,436**	**5,022**
Transition Economies	4,158	2,571	2,382	189	2,342	1,906	436	1,837	1,303	534
Asia	3,596	11,671	11,142	529	12,266	11,067	1,199	12,301	8,485	3,817
China	2,277	8,178	7,813	366	8,323	7,875	448	7,324	5,744	1,580
India	607	1,709	1,620	90	2,039	1,524	515	2,742	1,332	1,410
Other Asia	712	1,784	1,709	74	1,904	1,667	236	2,236	1,409	827
Africa	566	953	998	44	895	970	74	804	889	85
Middle East	608	1,646	1,571	75	1,729	1,393	336	1,857	1,124	733
Latin America	613	1,051	1,016	34	929	843	86	659	636	23
World	**20,947**	**28,417**	**28,426**		**25,520**	**25,506**		**18,370**	**18,377**	

nuclear power and climate protection

GLOBAL

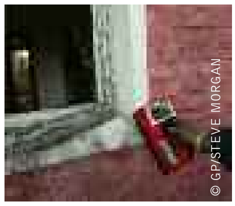
3

image SIGN ON A RUSTY DOOR AT CHERNOBYL ATOMIC STATION.

"safety and security risks, radioactive waste, nuclear proliferation..."

GREENPEACE INTERNATIONAL
CLIMATE CAMPAIGN

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



© GP/STEVE MORGAN

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 23 years, so more power stations are being shut down than started. In 2008, world nuclear production fell by 2% compared to 2006, and the number of operating reactors as of January 2010 was 436, eight 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.

a solution to climate protection?

The promise of nuclear energy to contribute to both climate protection and energy supply needs to be checked against reality. In the most recent Energy Technology Perspectives report published by the International Energy Agency[19], 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 32 large reactors (1,000 MWe each) would have to be built every year from now until 2050. This would be unrealistic, expensive, hazardous and too late to make a difference. Even so, according to the IEA scenario, such a massive nuclear expansion would cut carbon emissions by less than 5%.

unrealistic: Such a rapid 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.[20] 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. The Wall Street Journal has reported that the cost index for nuclear components has risen by 173% since 2000 – a near tripling over the past eight years.[21] 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, 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 spent fuel (assuming they are 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.

Most of the expected electricity demand growth by 2050 will occur in non-OECD countries. This means that a large proportion of the new reactors would need to be built in those countries in order to have a global impact on emissions. At the moment, the list of countries with announced nuclear ambitions is long and worrying in terms of their political situation and stability, especially with the need to guarantee against the hazards of accidents and proliferation for many decades. The World Nuclear Association listed the Emerging Nuclear Energy Countries in February 2010. In Europe this included Italy, Albania, Serbia, Portugal, Norway, Poland, Belarus, Estonia, Latvia, Ireland and Turkey. In the Middle East and North Africa: Iran, Gulf states including UAE, Yemen, Israel, Syria, Jordan, Egypt, Tunisia, Libya, Algeria and Morocco. In central and southern Africa: Nigeria, Ghana, Uganda and Namibia. In South America: Chile, Ecuador and Venezuela. In central and southern Asia: Azerbaijan, Georgia, Kazakhstan, Mongolia and Bangladesh. In South East Asia: Indonesia, Philippines, Vietnam, Thailand, Malaysia, Australia and New Zealand.

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 an 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.

references
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20 PLATTS, 2008; *ENERGY BIZ*, MAY/JUNE 2008
21 *WALL STREET JOURNAL*, 29 MAY 2008

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 be only 4.6% - less than 3% of the global overall reduction required.

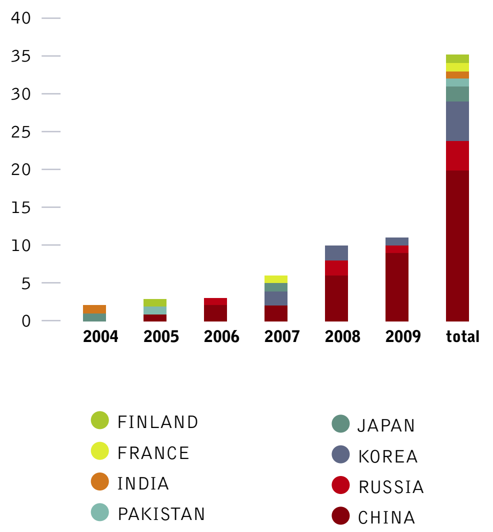
There are other technologies that can deliver much larger emission reductions, and much faster. Their investment costs are lower and they do not create global security risks. Even the IEA finds that the combined potential of efficiency savings and renewable energy to cut emissions by 2050 is more than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

nuclear power in the energy [r]evolution scenario

For the reasons explained above, the 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 will be finally put into operation.

figure 3.1: new reactor construction starts in past six years. OUT OF 35 NEW REACTORS WHOSE CONSTRUCTION HAS STARTED SINCE 2004, ONLY TWO ARE LOCATED IN EUROPE (FINLAND AND FRANCE).



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:

- Nuclear Proliferation
- Nuclear Waste
- Safety Risks

These are the background to why nuclear power has been discounted as a future technology in the Energy [R]evolution Scenario.

1. 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 protect a large reprocessing plant in order to 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 Director General of the International Atomic Energy Agency, Mohamed El Baradei, 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".[22]

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".[23] Even without fast reactors, 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.

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23 IPCC WORKING GROUP II, 'IMPACTS, ADAPTATIONS AND MITIGATION OF CLIMATE CHANGE: SCIENTIFIC-TECHNICAL ANALYSES', 1995

image NUCLEAR REACTOR IN LIANYUNGANG, CHINA.

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.

2. nuclear waste

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.

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.[24] No country in the world has a solution for high level waste.

The IAEA recognises that, despite its international safety requirements, "...radiation doses to individuals in the future can only be estimated and that the uncertainties associated with these estimates will increase for times farther into the future."

The least damaging option for waste already created at the current time is to store it above ground, in dry storage at the site of origin, although this option also presents major challenges and threats. The only real solution is to stop producing the waste.

3. safety risks

Windscale (1957), Three Mile Island (1979), Chernobyl (1986) and Tokaimura (1999) are only a few of the hundreds of nuclear accidents which have occurred to date.

- A simple power failure at a Swedish nuclear plant in 2006 highlighted our vulnerability to nuclear catastrophe. 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 was not restored there could have been a major incident within hours. A former director of the Forsmark plant later said that "it was pure luck there wasn't a meltdown". The closure of the plants removed at a stroke roughly 20% of Sweden's electricity supply.
- 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 life from the 30 years or so they were originally designed for 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.

"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."

references

24 'WASTE MANAGEMENT IN THE NUCLEAR FUEL CYCLE', WORLD NUCLEAR ASSOCIATION, INFORMATION AND ISSUE BRIEF, FEBRUARY 2006 (WWW.WORLD-NUCLEAR.ORG/INFO/INF04.HTM)

figure 3.2: **the nuclear fuel chain**

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 accident to date happened at Chernobyl in the then Soviet Union in 1986. 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.

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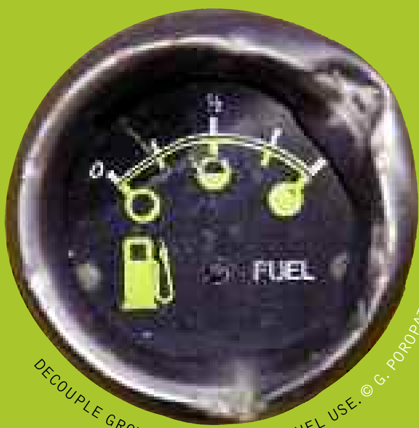

DECOUPLE GROWTH FROM FOSSIL FUEL USE. © G. POROPAT/DREAMSTIME

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

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

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

key principles

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

1. **respect natural limits – phase out fossil fuels by the end of this century** We must learn to respect natural limits. There is only so much carbon that the atmosphere can absorb. Each year we 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.

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

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

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

   The Energy [R]evolution 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.

from principles to practice

In 2007, renewable energy sources accounted for 13% of the world's primary energy demand. Biomass, which is mostly used for heating, was the main renewable energy source. The share of renewable energy in electricity generation was 18%. The contribution of renewables to primary energy demand for heat supply was around 24%. About 80% of primary energy supply today still comes from fossil fuels, and 6% from nuclear power.[25]

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

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

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

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

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

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

a development pathway

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

step 1: energy efficiency

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

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

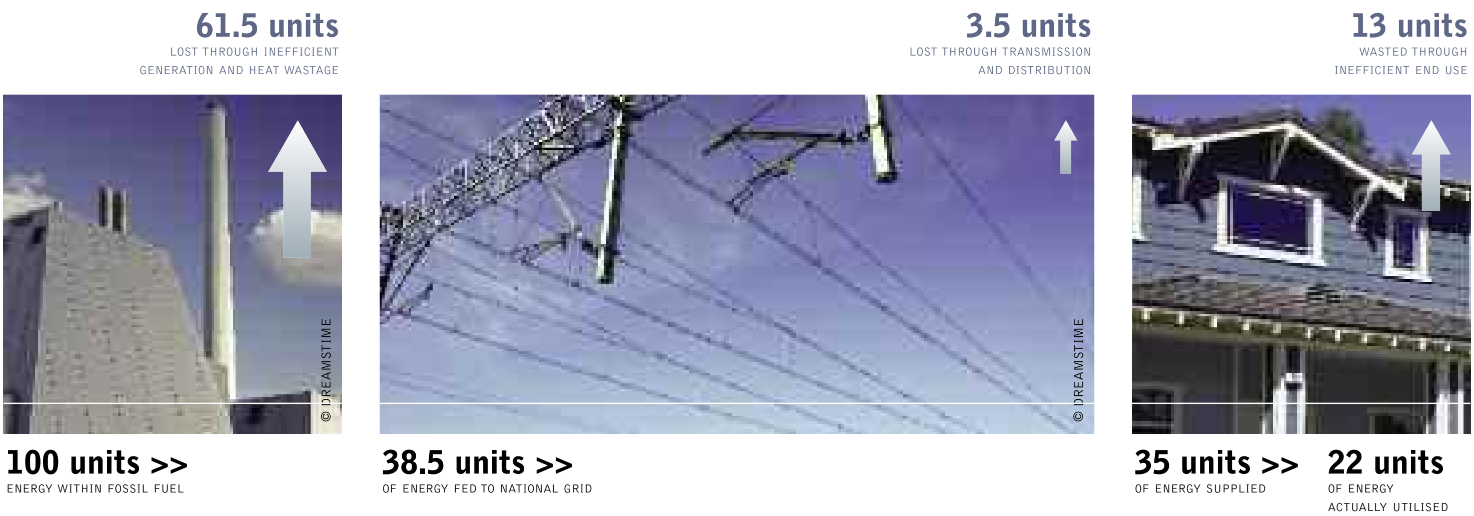
A dramatic reduction in primary energy demand compared to the IEA's Reference scenario (see chapter 6) – but with the same GDP and population development - is a crucial prerequisite for achieving a significant share of renewable energy sources in the overall energy supply system, compensating for the phasing out of nuclear energy and reducing the consumption of fossil fuels.

step 2: the renewable energy [r]evolution

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

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

figure 4.1: centralised energy infrastructures waste more than two thirds of their energy



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

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

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

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

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

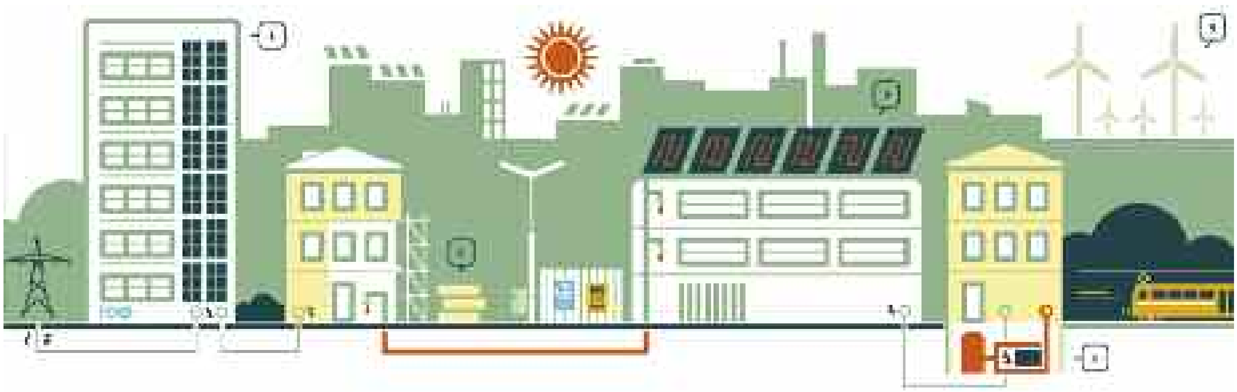
transport Before new technologies, including hybrid or electric cars and new fuels such as bio fuels, can play a substantial role in the transport sector, the existing large efficiency potentials have to be exploited. In this study, biomass is primarily committed to stationary applications; the use of bio fuels for transport is limited by the availability of sustainably grown biomass.[26] Electric vehicles will therefore play an even more important role in improving energy efficiency in transport and substituting for fossil fuels.

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

figure 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
26 SEE CHAPTER 13

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

new business model

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

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

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

table 4.2: utilities today

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

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

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

table 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								

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

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

rural electrification[27] 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.

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

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

We already have the sun, wind, geothermal sources and running rivers available right now, whilst ocean energy, biomass and efficient gas turbines are all set to make a massive contribution in the future. Clever technologies can track and manage energy use patterns, provide flexible power that follows demand through the day, use better storage options and group customers together to form 'virtual batteries'. With all these solutions we can secure the renewable energy future needed to avert catastrophic climate change. Renewable energy 24/7 is technically and economically possible, it just needs the right policy and the commercial investment to get things moving and 'keep the lights on'.[28]

the new electricity grid

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

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

references
27 SUSTAINABLE ENERGY FOR POVERTY REDUCTION: AN ACTION PLAN', IT POWER/GREENPEACE INTERNATIONAL, 2002.
28 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.

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

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).

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

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

hybrid systems

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

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

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

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

elements in the new power system architecture

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

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

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

smart grids

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

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

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

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

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

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

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

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

To develop a power system based almost entirely on renewable energy sources will require a new overall power system architecture, including smart grid technology. This concept will need substantial amounts of further work to fully emerge.[29] 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.[30] 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.[31] Together the combination ensures sufficient electricity supply to cover demand.

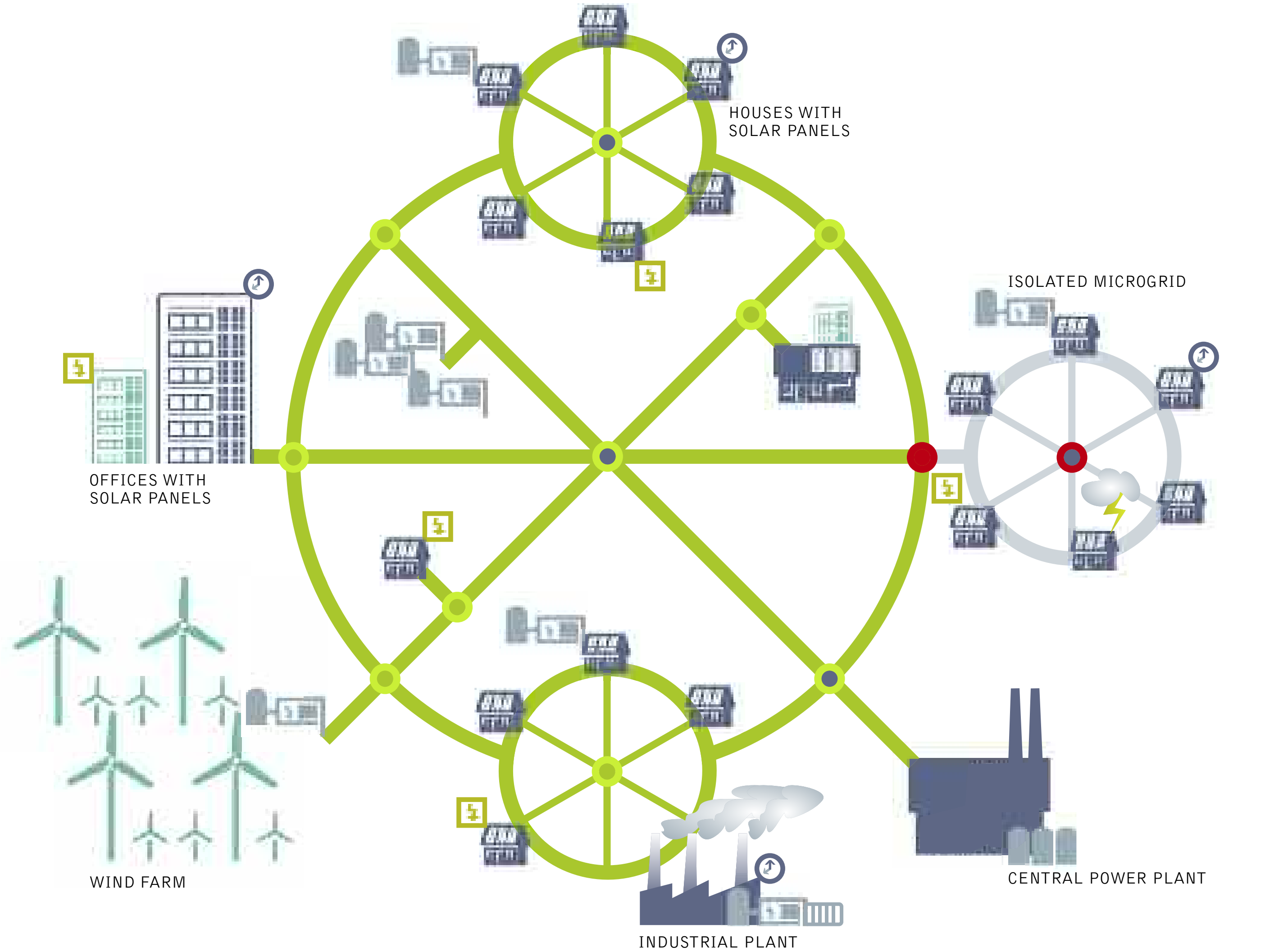
A number of mature and emerging technologies are viable options for **storing electricity**. Of these, pumped storage can be considered the most established technology. Pumped storage is a type of hydroelectric power station that can store energy. Water is pumped from a lower elevation reservoir to a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

references
29 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
30 SEE ALSO HTTP://WWW.KOMBIKRAFTWERK.DE/INDEX.PHP?ID=27
31 SEE ALSO HTTP://WWW.SOLARSERVER.DE/SOLARMAGAZIN/ANLAGEJANUAR2008_E.HTML

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.

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

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

references

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

scenarios for a future energy supply

GLOBAL

5

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

"towards a sustainable global energy supply system."

GREENPEACE INTERNATIONAL
CLIMATE CAMPAIGN

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 reference scenario published by the International Energy Agency (IEA) in World Energy Outlook 2009 (WEO 2009).[33] This only takes existing international energy and environmental policies into account. Its assumptions include, for example, continuing progress in electricity and gas market reforms, the liberalisation of cross-border energy trade and recent policies designed to combat environmental pollution. The Reference scenario does not include additional policies to reduce greenhouse gas emissions. As the IEA's projection only covers a time horizon up to 2030, it has also been extended by extrapolating its key macroeconomic and energy indicators forward to 2050. This provides a baseline for comparison with the Energy [R]evolution scenario.

The **Energy [R]evolution Scenario** has a key target to reduce worldwide carbon dioxide emissions down to a level of around 10 Gigatonnes per year by 2050 in order to keep the increase in global temperature under +2°C. A second objective is the global phasing out of nuclear energy. First published in 2007, then updated and expanded in 2008, this latest revision also serves as a baseline for the more ambitious "advanced" Energy [R]evolution scenario. To achieve its targets, the scenario is characterised by significant efforts to fully exploit the large potential for energy efficiency, using currently available best practice technology. At the same time, all cost-effective renewable energy sources are used for heat and electricity generation as well as the production of bio fuels. The general framework parameters for population and GDP growth remain unchanged from the Reference Scenario.

The **Advanced Energy [R]evolution Scenario** is aimed at an even stronger decrease in CO_2 emissions, especially given the uncertainty that even 10 Gigatonnes might be too much to keep global temperature rises at bay. All general framework parameters such as population and economic growth remain unchanged. The efficiency pathway for industry and "other sectors" is also the same as in the basic Energy [R]evolution scenario. What is different is that the advanced scenario incorporates a stronger effort to develop better technologies to achieve CO_2 reduction. So the transport sector factors in lower demand (compared to the basic scenario), resulting from a change in driving patterns and a faster uptake of efficient combustion vehicles and – after 2025 – a larger share of electric and plug-in hybrid vehicles.

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

In all sectors, the latest market development projections of the renewables industry[34] have been taken into account (see table 5.13 Annual growth rates of RE energy technologies). In developing countries in particular, a shorter operational lifetime for coal power plants, of 20 instead of 40 years, has been assumed in order to allow a faster uptake of renewables. The speedier introduction of electric vehicles, combined with the implementation of smart grids and faster expansion of super grids (about ten years ahead of the basic Energy [R]evolution scenario) - allows a higher share of fluctuating renewable power generation (photovoltaic and wind) to be employed. The 30% mark for the proportion of renewables in the global energy supply is therefore passed just after 2020 (ten years ahead of the basic Energy [R]evolution scenario).

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

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

scenario background

The scenarios in this report were jointly commissioned by Greenpeace and the European Renewable Energy Council from the Institute of Technical Thermodynamics, part of the German Aerospace Center (DLR). The supply scenarios were calculated using the MESAP/PlaNet simulation model adopted in the previous Energy [R]evolution studies.[35] Some detailed analyses carried out during preparation of the 2008 Energy [R]evolution study were also used as input to this update. The energy demand projections were developed for the 2008 study by Ecofys Netherlands, based on an analysis of the future potential for energy efficiency measures. The biomass potential, judged according to Greenpeace sustainability criteria, has been developed especially for this scenario by the German Biomass Research Centre. The future development pathway for car technologies is based on a special report produced in 2008 by the Institute of Vehicle Concepts, DLR for Greenpeace International. These studies are described briefly below.

references

33 INTERNATIONAL ENERGY AGENCY, 'WORLD ENERGY OUTLOOK 2007', 2007
34 SEE EREC, RE-THINKING 2050, GWEC, EPIA ET AL
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1. oil and gas price projections

The recent dramatic fluctuations in global oil prices have resulted in slightly 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 $34 per barrel was assumed in 2030. More recent projections of oil prices by 2030 in the IEA's WEO 2009 range from $2008 80/bbl in the lower prices sensitivity case up to $2008 150/bbl in the higher prices sensitivity case. The reference scenario in WEO 2009 predicts an oil price of $2008 115/bbl.

Since the first Energy [R]evolution study was published in 2007, however, the actual price of oil has moved over $100/bbl for the first time, and in July 2008 reached a record high of more than $140/bbl.

Although oil prices fell back to $100/bbl in September 2008 and around $80/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 5.3).

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 $24-29/GJ by 2050.

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/tCO_2 in 2015, rising to $50/tCO_2 by 2050. Additional CO_2 costs are applied in Kyoto Protocol Non-Annex B (developing) countries only after 2020.

table 5.3: development projections for fossil fuel prices in $2008

	UNIT	2000	2005	2007	2008	2010	2015	2020	2025	2030	2040	2050
Crude oil imports												
IEA WEO 2009 "Reference"	barrel	34.30	50.00	75.00	97.19		86.67	100	107.5	115		
USA EIA 2008 "Reference"	barrel					86.64		69.96		82.53		
USA EIA 2008 "High Price"	barrel					92.56		119.75		138.96		
Energy [R]evolution 2010	barrel						110.56	130.00	140.00	150.00	150.00	150.00
Natural gas imports												
IEA WEO 2009 "Reference"												
United States	GJ	5.00	2.32	3.24	8.25		7.29	8.87	10.04	11.36		
Europe	GJ	3.70	4.49	6.29	10.32		10.46	12.10	13.09	14.02		
Japan LNG	GJ	6.10	4.52	6.33	12.64		11.91	13.75	14.83	15.87		
Energy [R]evolution 2010												
United States	GJ			3.24		8.70		10.70	12.40	14.38	18.10	23.73
Europe	GJ			6.29		10.89		16.56	17.99	19.29	22.00	26.03
Japan LNG	GJ			6.33		13.34		18.84	20.37	21.84	24.80	29.30
Hard coal imports												
OECD steam coal imports												
Energy [R]evolution 2010	tonne			69.45		120.59	116.15	135.41	139.50	142.70	160.00	172.30
IEA WEO 2009 "Reference"	tonne	41.22	49.61	69.45		120.59	91.05	104.16	107.12	109.4		
Biomass (solid)												
Energy [R]evolution 2010												
OECD Europe	GJ			7.4		7.7	8.2	9.2		10.0	10.3	10.5
OECD Pacific and North America	GJ			3.3		3.4	3.5	3.8		4.3	4.7	5.2
Other regions	GJ			2.7		2.8	3.2	3.5		4.0	4.6	4.9

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

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

table 5.4: 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**

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.[36]

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

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

Cost estimates for CCS vary considerably, depending on factors such as power station configuration, technology, fuel costs, size of project and location. One thing is certain, however: CCS is expensive. It requires significant funds to construct the power stations and the necessary infrastructure to transport and store carbon. The IPCC assesses costs at $15-75 per tonne of captured CO_2[37], while a recent US Department of Energy report found installing carbon capture systems to most modern plants resulted in a near doubling of costs.[38] These costs are estimated to increase the price of electricity in a range from 21-91%.[39]

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.[40] 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.[41]

The Intergovernmental Panel on Climate Change (IPCC) estimates a cost range for pipelines of $1-8/tonne of CO_2 transported. A United States Congressional Research Services report calculated capital costs for an 11 mile pipeline in the Midwestern region of the US at approximately $6 million. The same report estimates that a dedicated interstate pipeline network in North Carolina would cost upwards of $5 billion due to the limited geological sequestration potential in that part of the country.[42] Storage and subsequent monitoring and verification costs are estimated by the IPCC to range from $0.5-8/t$CO_2$ (for storage) and $0.1-0.3/t$CO_2$ (for monitoring). The overall cost of CCS could therefore serve as a major barrier to its deployment.[43]

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

Table 5.5 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 5.5: 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 ($/kW)	1,320	1,230	1,190	1,160	1,130	**1,100**
	Electricity generation costs including CO_2 emission costs ($cents/kWh)	6.6	9.0	10.8	12.5	14.2	**15.7**
	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 ($/kW)	1,570	1,440	1,380	1,350	1,320	**1,290**
	Electricity generation costs including CO_2 emission costs ($cents/kWh)	5.9	6.5	7.5	8.4	9.3	**10.3**
	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 ($/kW)	690	675	645	610	580	**550**
	Electricity generation costs including CO_2 emission costs ($cents/kWh)	7.5	10.5	12.7	15.3	17.4	**18.9**
	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.

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36 'GREENPEACE INTERNATIONAL BRIEFING: CARBON CAPTURE AND STORAGE', GOERNE, 2007.
37 ABANADES, J C ET AL., 2005, PG 10.
38 NATIONAL ENERGY TECHNOLOGY LABORATORIES, 2007.
39 RUBIN ET AL., 2005A, PG 40.
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42 PARFOMAK, P & FOLGER, P, 2008, PG 5 AND 12.
43 RUBIN ET AL., 2005B, PG 4444.

4. cost projections for renewable energy technologies

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

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

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

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

Assumptions on future costs for renewable electricity technologies in the Energy [R]evolution scenario are derived from a review of learning curve studies, for example by Lena Neij and others[44], from the analysis of recent technology foresight and road mapping studies, including the European Commission funded NEEDS project (New Energy Externalities Developments for Sustainability)[45] or the IEA Energy Technology Perspectives 2008, projections by the European Renewable Energy Council published in April 2010 ("RE-thinking 2050") and discussions with experts from a wide range of different sectors of the renewable energy industry.

photovoltaics (pv)

The worldwide photovoltaics (PV) market has been growing at over 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 1000 GW between 2030 and 2040 in the basic Energy [R]evolution scenario, and with an electricity output of 1400 TWh/a , 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 1,000 GW by 2025 – five years ahead of the basic scenario.

table 5.6: 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 ($/kWp)	3,746	2,610	1,776	1,027	785	**761**
Operation & maintenance costs ($/kW/a)	66	38	16	13	11	**10**
Advanced Energy [R]evolution						
Global installed capacity (GW)	6	108	439	1,330	2,959	**4,318**
Investment costs ($/kWp)	3,746	2,610	1,776	1,027	761	**738**
Operation & maintenance costs ($/kW/a)	66	38	16	13	11	**10**

44 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.
45 WWW.NEEDS-PROJECT.ORG

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

concentrating solar power

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

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

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

wind power

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

table 5.7: 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 ($/kW)*	7,250	5,576	5,044	4,263	4,200	**4,160**
Operation & maintenance costs ($/kW/a)	300	250	210	180	160	**155**
Advanced Energy [R]evolution						
Global installed capacity (GW)	1	28	225	605	1,173	**1,643**
Investment costs ($/kW)*	7,250	5,576	5,044	4,200	4,160	**4,121**
Operation & maintenance costs ($/kW/a)	300	250	210	180	160	**155**

* INCLUDING HIGH TEMPERATURE HEAT STORAGE.

table 5.8: 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 ($/kWp)	1,510	1,255	998	952	906	**894**
O&M costs ($/kW/a)	58	51	45	43	41	**41**
Wind offshore						
Investment costs ($/kWp)	2,900	2,200	1,540	1,460	1,330	**1,305**
O&M costs ($/kW/a)	166	153	114	97	88	**83**
Advanced Energy [R]evolution						
Installed capacity (on+offshore)	95	494	1,140	2,241	3,054	**3,754**
Wind onshore						
Investment costs ($/kWp)	1,510	1,255	998	906	894	**882**
O&M costs ($/kW/a)	58	51	45	43	41	**41**
Wind offshore						
Investment costs ($/kWp)	2,900	2,200	1,540	1,460	1,330	**1,305**
O&M costs ($/kW/a)	166	153	114	97	88	**83**

biomass

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

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

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

geothermal

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

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

table 5.9: 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 ($/kW)	2,818	2,452	2,435	2,377	2,349	**2,326**
O&M costs ($/kW/a)	183	166	152	148	147	**146**
Biomass (CHP)						
Global installed capacity (GW)	18	67	150	261	413	**545**
Investment costs ($/kW)	5,250	4,255	3,722	3,250	2,996	**2,846**
O&M costs ($/kW/a)	404	348	271	236	218	**207**
Advanced Energy [R]evolution						
Biomass (electricity only)						
Global installed capacity (GW)	28	50	64	78	83	**81**
Investment costs ($/kW)	2,818	2,452	2,435	2,377	2,349	**2,326**
O&M costs ($/kW/a)	183	166	152	148	147	**146**
Biomass (CHP)						
Global installed capacity (GW)	18	65	150	265	418	**540**
Investment costs ($/kW)	5,250	4,255	3,722	3,250	2,996	**2,846**
O&M costs ($/kW/a)	404	348	271	236	218	**207**

table 5.10: 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 ($/kW)	12,446	10,875	9,184	7,250	6,042	**5,196**
O&M costs ($/kW/a)	645	557	428	375	351	**332**
Geothermal (CHP)						
Global installed capacity (GW)	1	3	13	37	83	**134**
Investment costs ($/kW)	12,688	11,117	9,425	7,492	6,283	**5,438**
O&M costs ($/kW/a)	647	483	351	294	256	**233**
Advanced Energy [R]evolution						
Geothermal (electricity only)						
Global installed capacity (GW)	10	21	57	191	337	**459**
Investment costs ($/kW)	12,446	10,875	9,184	5,196	4,469	**3,843**
O&M costs ($/kW/a)	645	557	428	375	351	**332**
Geothermal (CHP)						
Global installed capacity (GW)	0	3	13	47	132	**234**
Investment costs ($/kW)	12,688	11,117	9,425	7,492	6,283	**5,438**
O&M costs ($/kW/a)	647	483	351	294	256	**233**

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

- for conventional geothermal power, from 7 $cents/kWh to about 2 $cents/kWh;
- for EGS, despite the presently high figures (about 20 $cents/kWh), electricity production costs - depending on the payments for heat supply - are expected to come down to around 5 $cents/kWh in the long term.

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

ocean energy

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

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

Because of the early development stage any future cost estimates for ocean energy systems are uncertain. Present cost estimates are based on analysis from the European NEEDS project.[46]

hydro power

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

table 5.11: ocean energy cost assumptions

Energy [R]evolution	2007	2015	2020	2030	2040	**2050**
Global installed capacity (GW)	0	9	29	73	168	**303**
Investment costs ($/kW)	7,216	3,892	2,806	2,158	1,802	**1,605**
Operation & maintenance costs ($/kW/a)	360	207	117	89	75	**66**
Advanced Energy [R]evolution						
Global installed capacity (GW)	0	9	58	180	425	**748**
Investment costs ($/kW)	7,216	3,892	2,806	1,802	1,605	**1,429**
Operation & maintenance costs ($/kW/a)	360	207	117	89	75	**66**

table 5.12: hydro power cost assumptions

Energy [R]evolution	2007	2015	2020	2030	2040	**2050**
Global installed capacity (GW)	922	1,043	1,206	1,307	1,387	**1,438**
Investment costs ($/kW)	2,705	2,864	2,952	3,085	3,196	**3,294**
Operation & maintenance costs ($/kW/a)	110	115	123	128	133	**137**
Advanced Energy [R]evolution						
Global installed capacity (GW)	922	1,111	1,212	1,316	1,406	**1,451**
Investment costs ($/kW)	2,705	2,864	2,952	3,085	3,196	**3,294**
Operation & maintenance costs ($/kW/a)	110	115	123	128	133	**137**

46 WWW.NEEDS-PROJECT.ORG

summary of renewable energy cost development

Figure 5.2 summarises the cost trends for renewable energy technologies as derived from the respective learning curves. It should be emphasised that the expected cost reduction is basically not a function of time, but of cumulative capacity, so dynamic market development is required. Most of the technologies will be able to reduce their specific investment costs to between 30% and 70% of current levels by 2020, and to between 20% and 60% once they have achieved full maturity (after 2040).

Reduced investment costs for renewable energy technologies lead directly to reduced heat and electricity generation costs, as shown in Figure 5.3. Generation costs today are around 8 to 26 $cents/kWh for the most important technologies, with the exception of photovoltaics. In the long term, costs are expected to converge at around 5-12 $cents/kWh. These estimates depend on site-specific conditions such as the local wind regime or solar irradiation, the availability of biomass at reasonable prices or the credit granted for heat supply in the case of combined heat and power generation.

assumed growth rates in different scenarios

In scientific literature[47] quantitative scenario modelling approaches are broadly separated into two groups: "top-down" and "bottom-up" models. While this classification might have made sense in the past, it is less appropriate today, since the transition between the two categories is continuous, and many models, while being rooted in one of the two traditions - macro-economic or energy-engineering - incorporate aspects from the other approach and thus belong to the class of so-called hybrid models.[48] In the energy-economic modelling community, macro-economic approaches are traditionally classified as top-down models and energy-engineering models as bottom-up. The Energy [R]evolution scenario is a "bottom-up" (technology driven) scenario and the assumed growth rates for renewable energy technology deployment are important drivers.

Around the world, however, energy modelling scenario tools are under constant development and in the future both approaches are likely to merge into one, with detailed tools employing both a high level of technical detail and economic optimisation. The Energy [R]evolution scenario uses a "classical" bottom-up model which has been constantly developed, and now includes calculations covering both the investment pathway and the employment effect (see Chapter 7).

figure 5.2: future development of renewable energy investment costs (NORMALISED TO CURRENT COST LEVELS) FOR RENEWABLE ENERGY TECHNOLOGIES

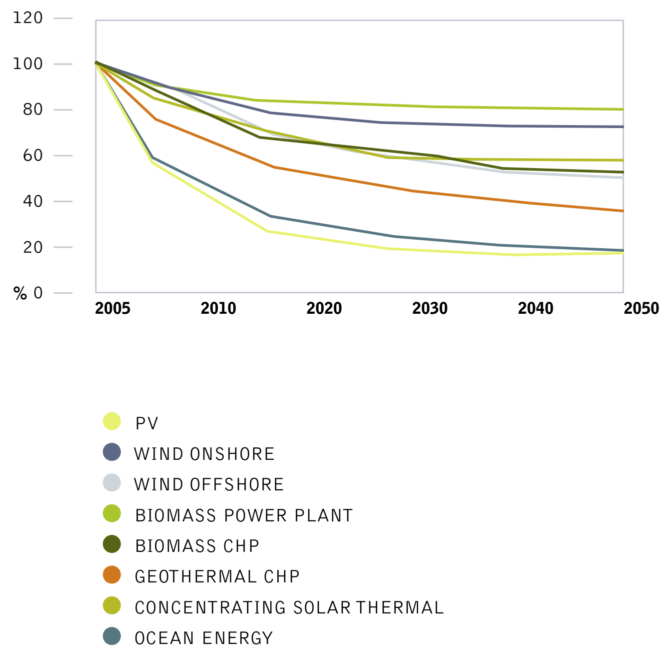
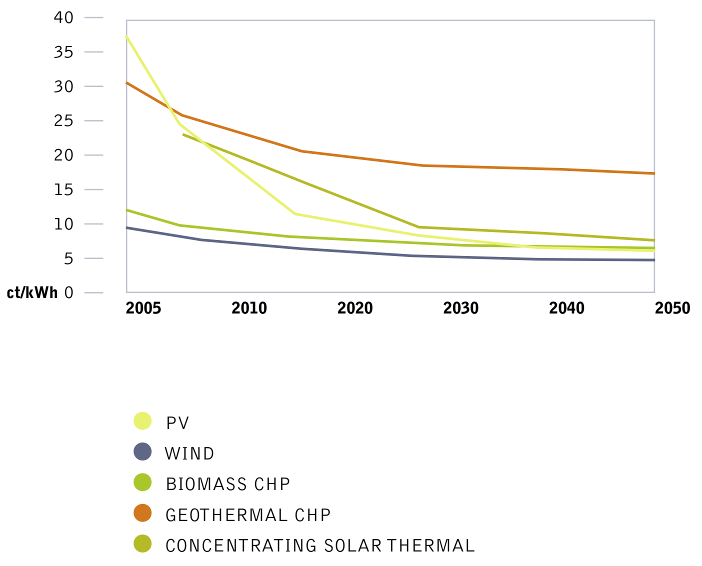


figure 5.3: expected development of electricity generation costs EXAMPLE FOR OECD NORTH AMERICA



47 HERZOG *ET AL.*, 2005; BARKER *ET AL.*, 2007.
48 VAN VUUREN *ET AL.*; HOURCADE *ET AL.*, 2006.

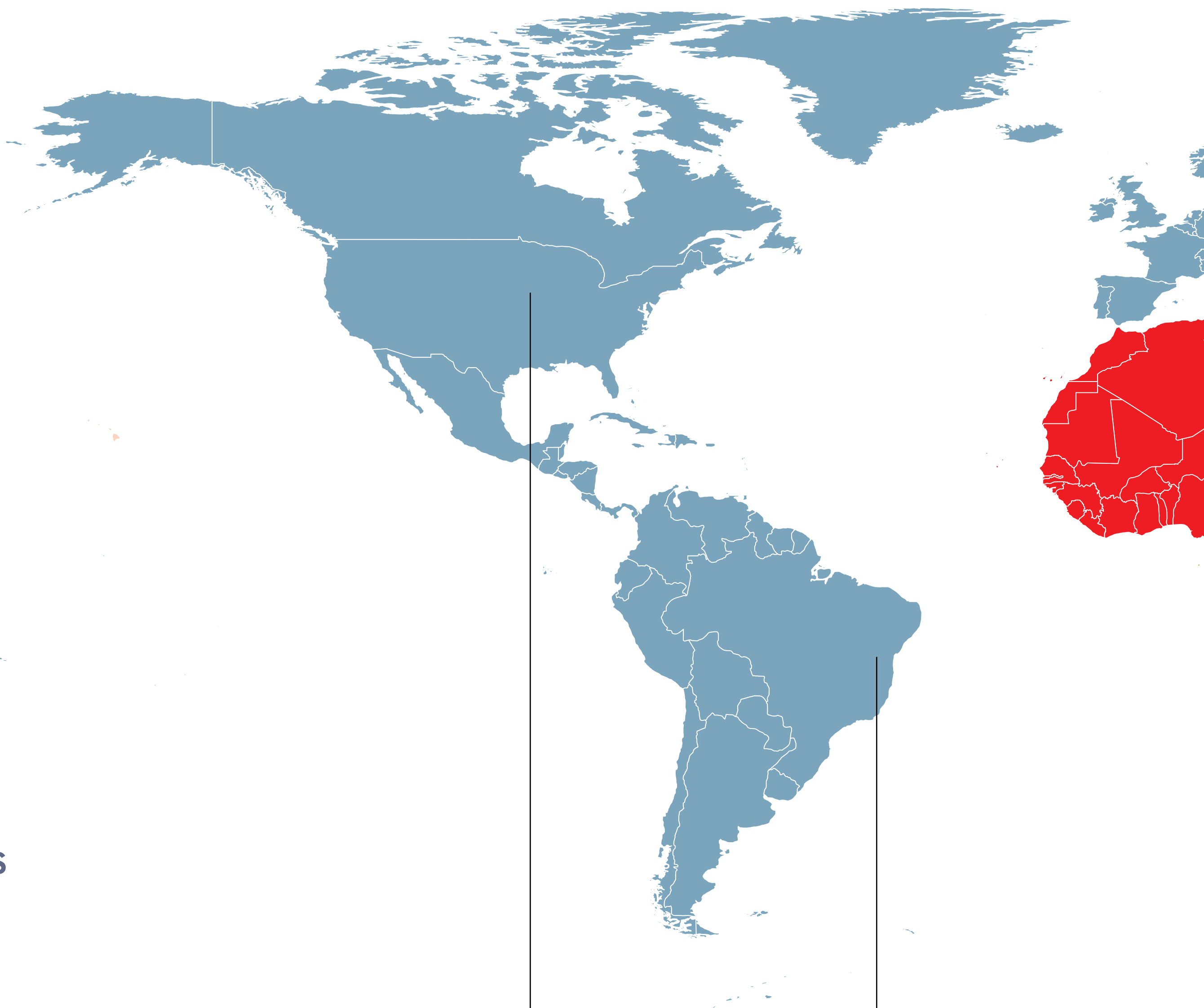
image CONSTRUCTION OF WIND TURBINES.

table 5.13: assumed global annual average growth rates for renewable technologies

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

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

MIDDLE EAST

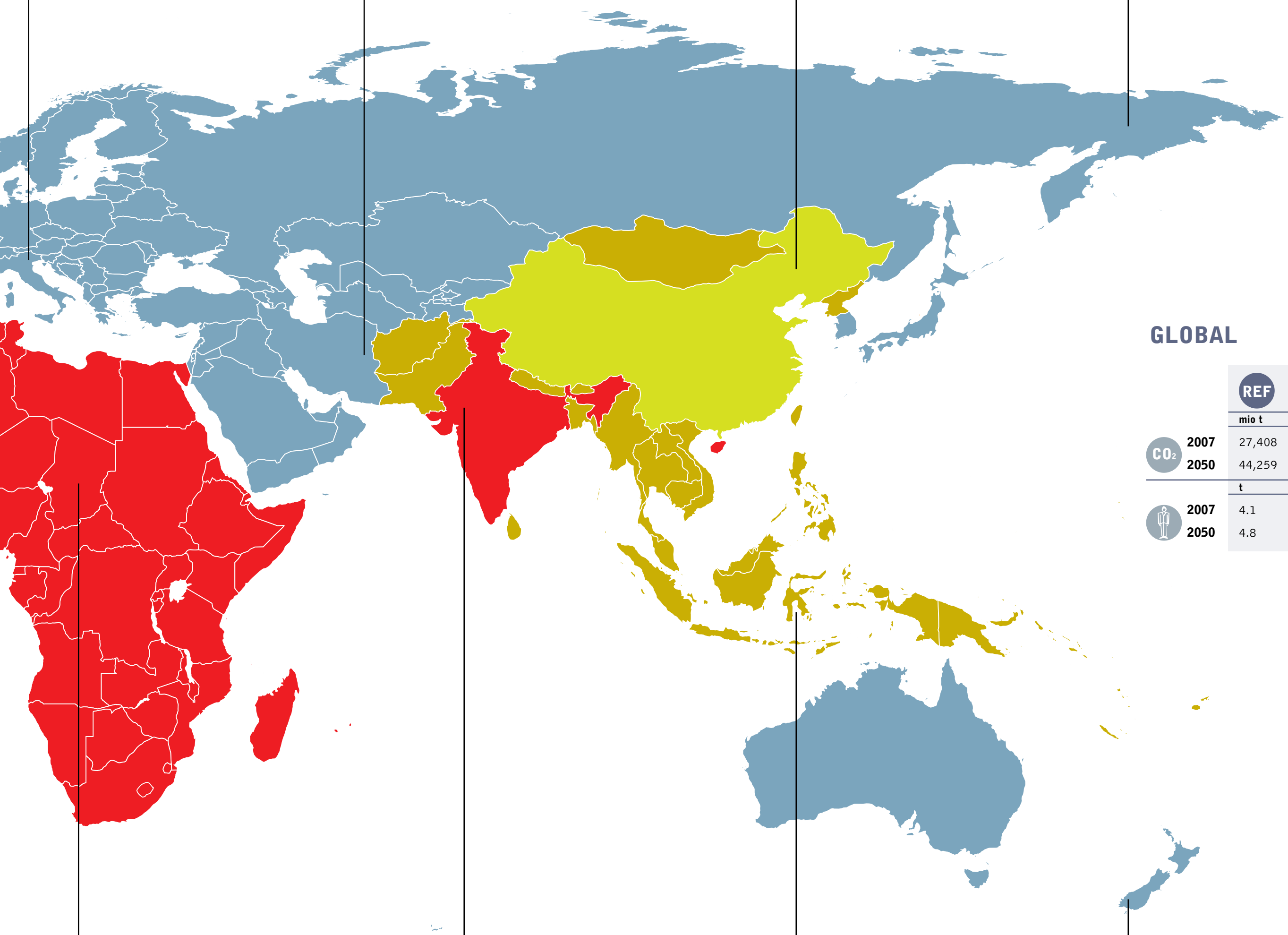
		REF mio t	%	E[R] mio t	%
CO_2	2007	1,374	234	1,374	234
	2050	3,208	546	122	21
		t		t	
per capita	2007	6.79M		6.79	
	2050	9.08		0.35	

CHINA

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

TRANSITION ECONOMIES

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



GLOBAL

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

AFRICA

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

INDIA

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

DEVELOPING ASIA

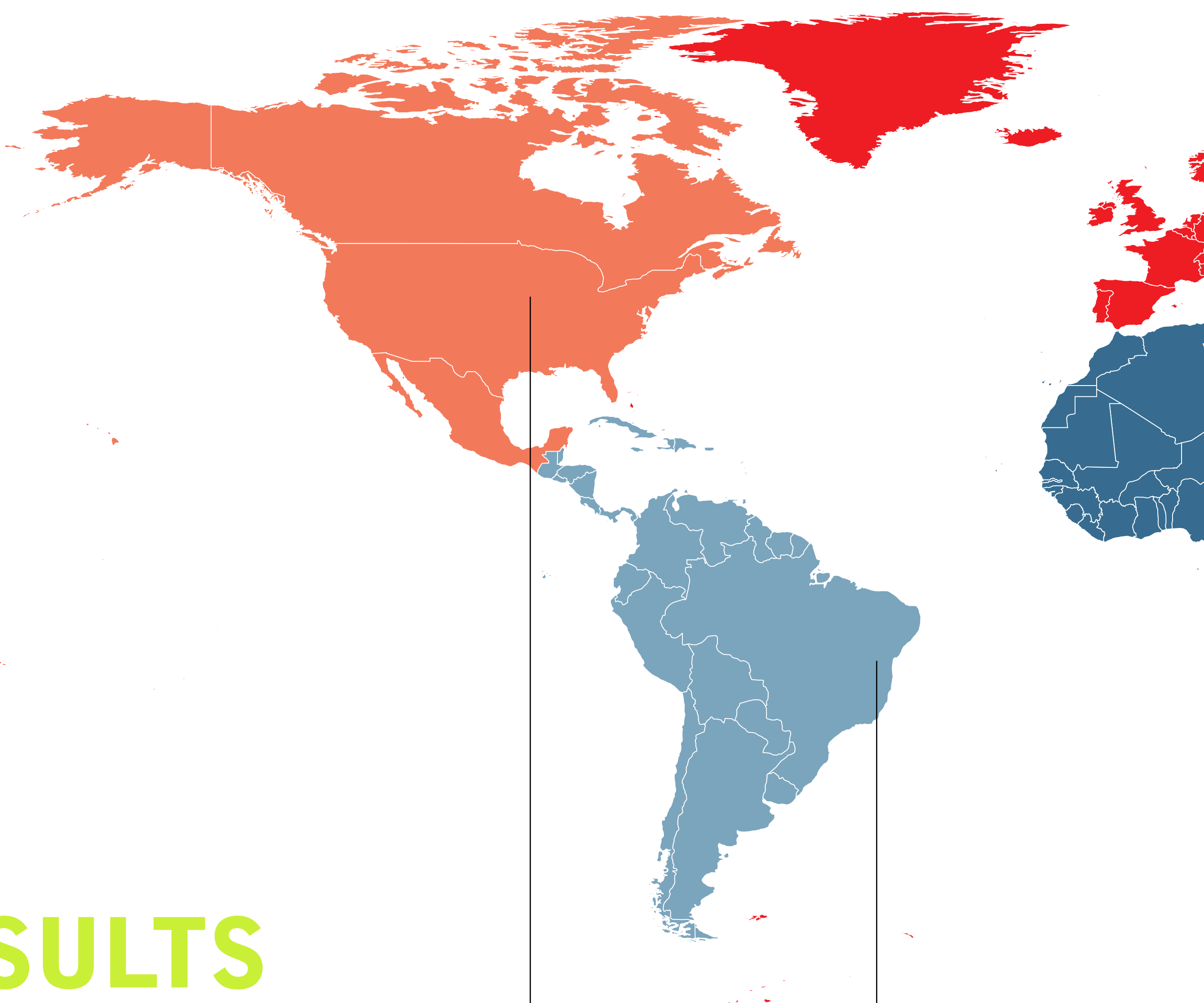
		REF mio t	%	E[R] mio t	%
CO_2	2007	1,488	216	1,488	216
	2050	3,846M	557	428	62
		t		t	
per capita	2007	1.47		1.47	
	2050	2.54		0.28	

OECD PACIFIC

		REF mio t	%	E[R] mio t	%
CO_2	2007	2,144	136	2,144	136
	2050	1,822	116	74	5
		t		t	
per capita	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

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

0 — 1000 KM

REF REFERENCE SCENARIO

E[R] ADVANCED ENERGY [R]EVOLUTION SCENARIO

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 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
		%		%	
Renewables	2007	7	15	7	15
	2050	15	25	85	98
		%		%	
Fossil fuels	2007	85	67M	85	67M
	2050	75	59M	9	2
		%		%	
Nuclear	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
		%		%	
Renewables	2007	29	70H	29	70H
	2050	28	57H	88H	98
		%		%	
Fossil fuels	2007	70L	28L	70L	28L
	2050	69	40L	12L	2
		%		%	
Nuclear	2007	1	2	NUCLEAR POWER PHASED OUT BY 2030	
	2050	3	2		

OECD EUROPE

	REF		E[R]	
	PE PJ	EL TWh	PE PJ	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

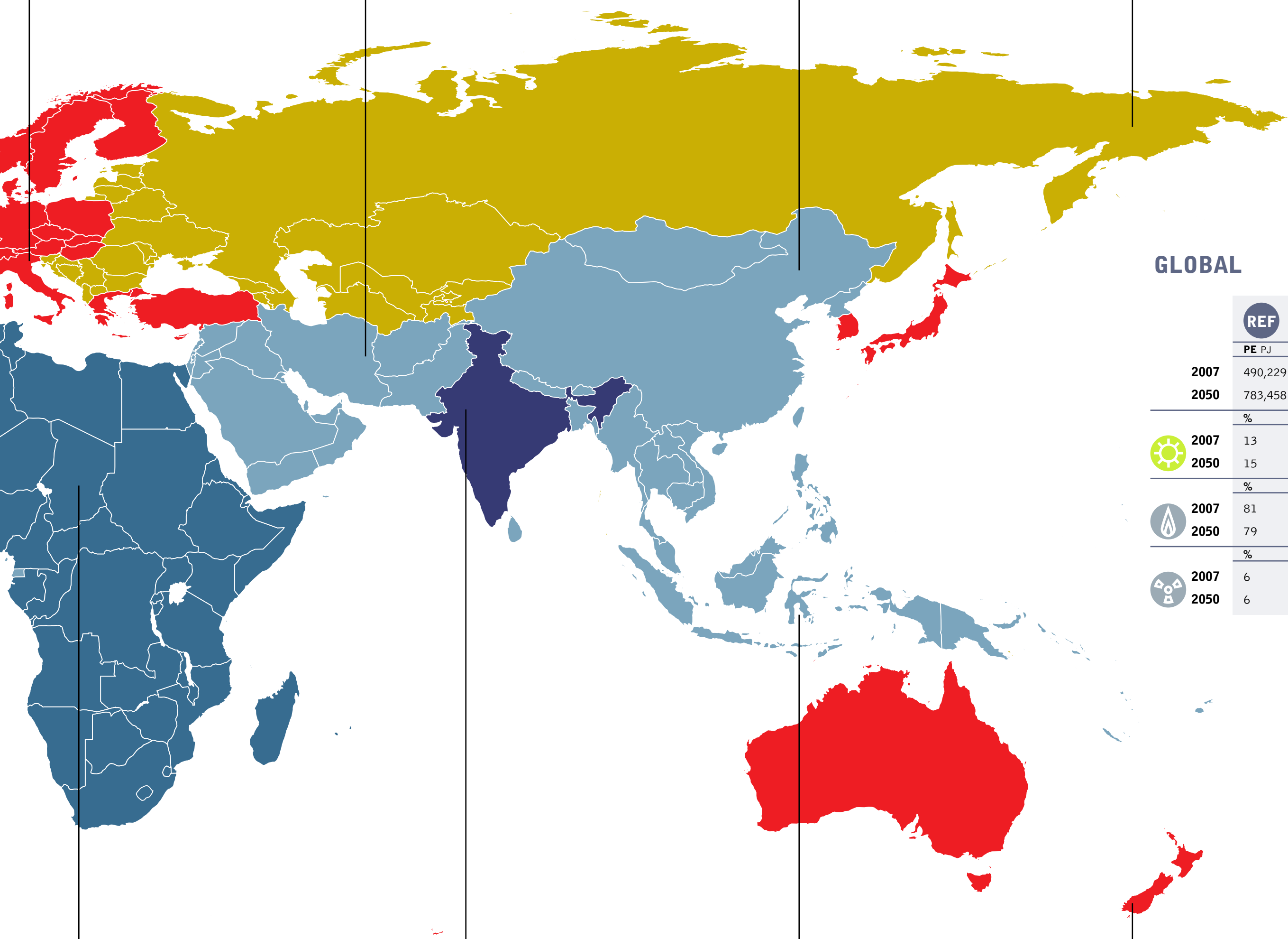
	REF		E[R]	
	PE PJ	EL TWh	PE PJ	EL TWh
2007	21,372	715	21,372	715
2050	51,281	2,404	27,475	2,786L
	%		%	
2007	1L	3	1L	3L
2050	2L	7	76	99H
	%		%	
2007	99H	97	99H	97H
2050	97H	92	23	1L
	%		%	
2007	0L	0	NO NUCLEAR ENERGY DEVELOPMENT	
2050	0L	0		

CHINA

	REF		E[R]	
	PE PJ	EL TWh	PE PJ	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		E[R]	
	PE PJ	EL TWh	PE PJ	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		E[R]	
	PE PJ	EL TWh	PE PJ	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		E[R]	
	PE PJ	EL TWh	PE PJ	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		E[R]	
	PE PJ	EL TWh	PE PJ	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		E[R]	
	PE PJ	EL TWh	PE PJ	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		E[R]	
	PE PJ	EL TWh	PE PJ	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 usa energy [r]evolution scenario

USA

6

image SOLAR PANEL. © BERND JUERGENS/DREAMSTIME

"its effects are giving rise to a frighteningly new global phenomenon: the man-made natural disaster."

BARACK OBAMA
PRESIDENT OF THE UNITED STATES

image AERIAL PHOTO OF THE ANDASOL 1 SOLAR POWER STATION, EUROPE'S FIRST COMMERCIAL PARABOLIC TROUGH SOLAR POWER PLANT. ANDASOL 1 WILL SUPPLY UP TO 200,000 PEOPLE WITH CLIMATE-FRIENDLY ELECTRICITY AND SAVE ABOUT 149,000 TONNES OF CARBON DIOXIDE PER YEAR COMPARED WITH A MODERN COAL POWER PLANT.

image MAINTENANCE WORKERS FIX THE BLADES OF A WINDMILL AT GUAZHOU WIND FARM NEAR YUMEN IN GANSU PROVINCE, CHINA.

energy demand by sector

Combining the projections on population development, GDP growth and energy intensity results in future development pathways for the USA's final energy demand. These are shown in Figure 6.1 for the Reference and both Energy [R]evolution scenarios. Under the Reference scenario total primary energy demand increases by more than 7% from the current 97,394 PJ/a to 103,577 PJ/a in 2050. In the Energy [R]evolution scenario, energy demand decreases by 40% compared to current consumption and is expected to reach 58,651 PJ/a by 2050. In the advanced version, transport sector demand in the USA is 13% lower by 2050 than in the basic Energy [R]evolution scenario; other sectors remain approximately the same.

Under the Energy [R]evolution scenario electricity demand is expected to decrease in the industry sector but to grow in the transport sector, whereas in the residential and service sectors electricity demand remains nearly constant (see Figure 6.2). Total electricity demand will rise to 4,636 TWh/a by the year 2050. Compared to the Reference scenario, efficiency measures in industry and other sectors avoid the generation of about 2,178 TWh/a. This reduction can be achieved in particular by introducing highly efficient electronic devices using the best available technology in all demand sectors.

Efficiency gains in the heat supply sector are even larger. Under the Energy [R]evolution scenario demand for heat supply will grow up to 2030 but can then even be reduced to below the current level of demand (see Figure 6.3). Compared to the Reference scenario, consumption equivalent to 2,517 PJ/a is avoided through efficiency gains by 2050 in both Energy [R]evolution scenarios. 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 services will be accompanied by a much lower future energy demand.

In the transport sector, it is assumed under the Energy [R]evolution scenario that energy demand will decrease by half to 13,505 PJ/a by 2050, saving 49% 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 behavior patterns. The advanced version will further decrease demand - through lifestyle changes, increased efficiency in transport systems and a higher share of electric drives - to 56% below the reference case

figure 6.1: projection of total final energy demand by sector (REF, E[R] & advanced E[R])

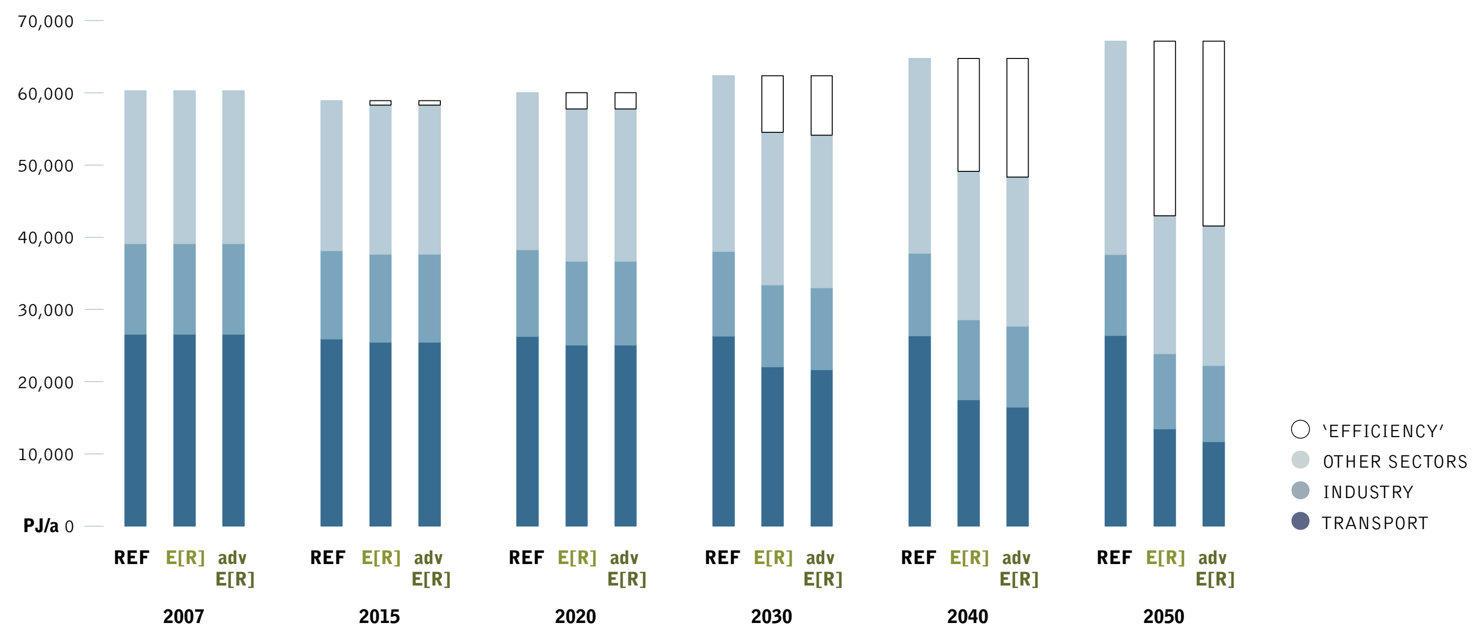
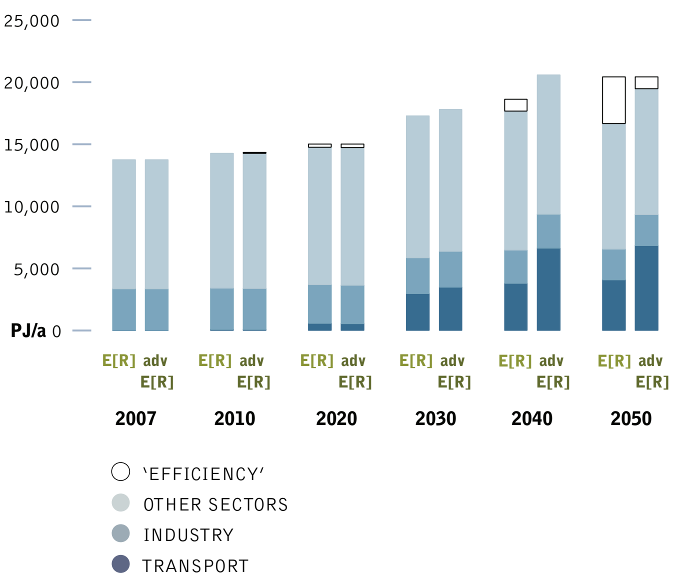


figure 6.2: development of electricity demand by sector (REF, E[R] & advanced E[R])



heating and cooling supply

Today, renewables meet 12% of the USA's primary energy demand for heat supply, the main contribution coming from the use of biomass. The lack of district heating networks is a severe structural barrier to the large scale utilisation of geothermal and solar thermal energy. Dedicated support instruments are required to ensure a dynamic development.

In the Energy [R]evolution scenario, renewables provide 74% of the USA's total heating demand by 2050.

- Energy efficiency measures help to reduce the currently growing demand for heating and cooling, in spite of improving living standards.
- In the industry sector solar collectors, biomass/biogas and geothermal energy are increasingly substituted for conventional fossil-fuelled heating systems.
- A shift from coal and oil to natural gas in the remaining conventional applications leads to a further reduction of CO_2 emissions.

In the Energy [R]evolution scenario 2,517 PJ/a is saved by 2050, or 13% compared to the Reference scenario. The advanced version introduces renewable heating systems around five years ahead of the basic scenario. Solar collectors and geothermal heating systems achieve economies of scale via ambitious support programmes five to ten years earlier, resulting in a renewables share of 53% by 2030 and 98% by 2050.

figure 6.3: development of heat demand by sector

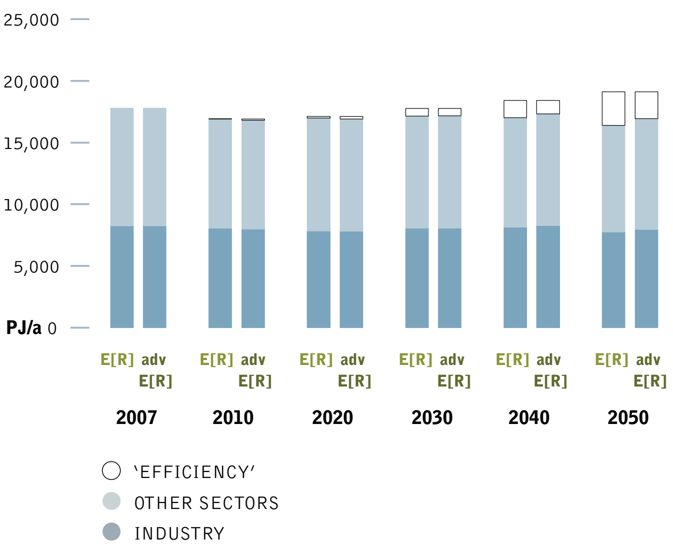


figure 6.4: development of heat supply structure under 3 scenarios

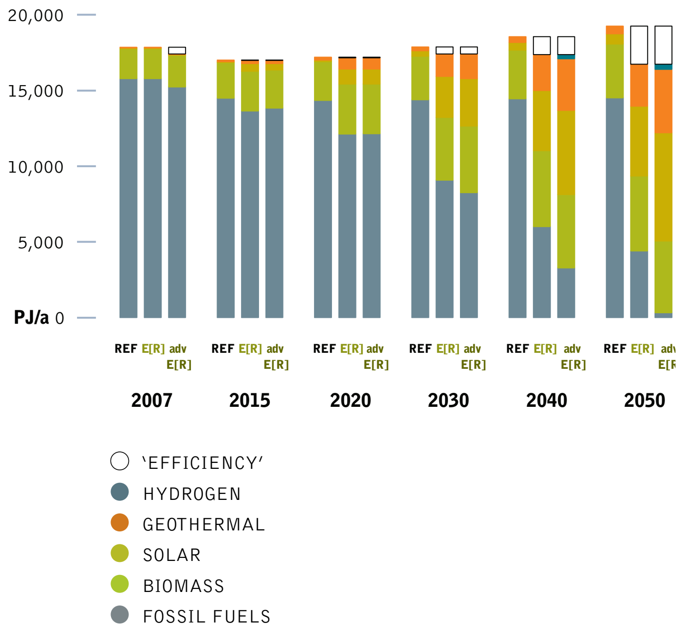


image CONTROL ROOM OF LUZ SOLAR POWER PLANT, CALIFORNIA, USA.

image LUZ INTERNATIONAL SOLAR POWER PLANT, CALIFORNIA, USA.

electricity generation

The development of the electricity supply sector is characterized by a dynamically growing renewable energy market and an increasing share of renewable electricity. 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, 96% of the electricity produced in the USA will come from renewable energy sources. 'New' renewables – mainly wind, solar thermal energy and PV – will contribute over 75% of electricity generation. The advanced Energy [R]evolution scenario will not increase this share significantly. By 2030 78% and by 2050 99% will come from renewables, but the overall installed capacity of renewable generation (2533 GW) will be higher than in the basic version.

Table 6.1 shows the comparative evolution of different renewable technologies over time. Up to 2020, hydro power, photovoltaics (PV), and wind will remain the main contributors. After 2020, the continuing growth of wind will and PV be complemented by electricity from biomass, ocean, geothermal, and solar thermal (CSP) energy.

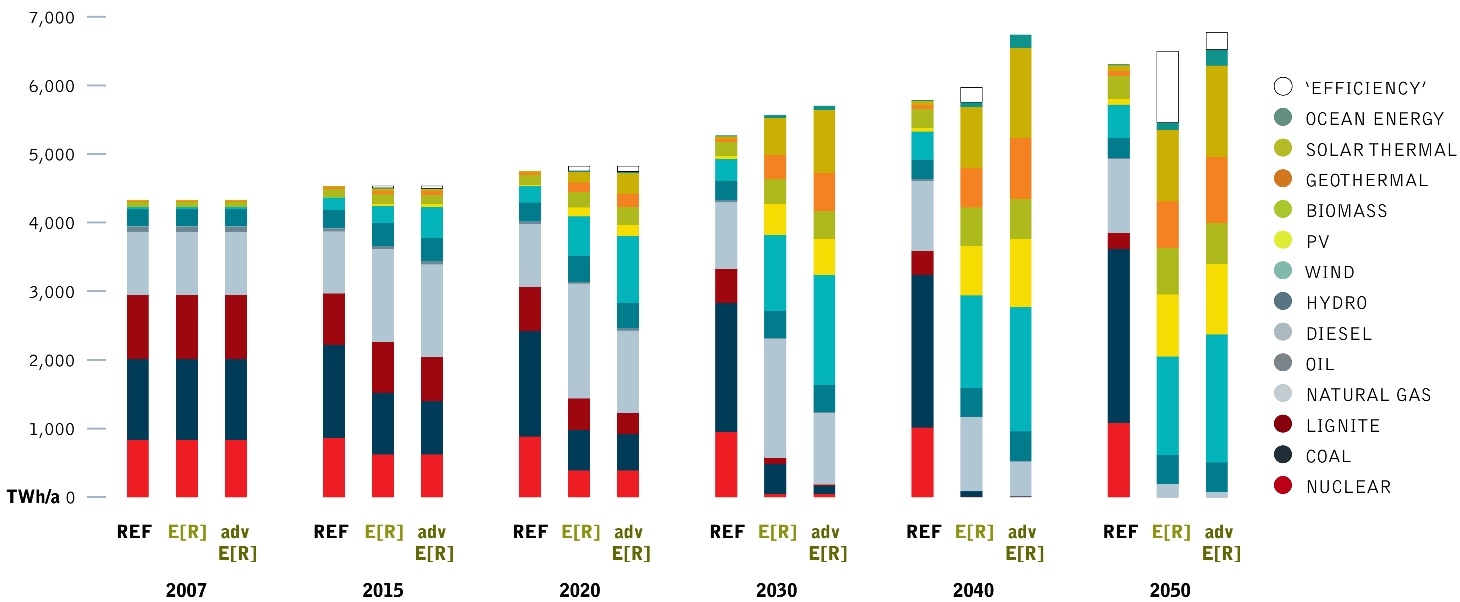
table 6.1: projection of renewable electricity generation capacity under both energy [r]evolution scenarios

IN GW

		2007	2020	2030	2040	2050
Hydro	E[R]	100	138	146	152	153
	advanced E[R]	100	138	146	158	158
Biomass	E[R]	12	38	64	101	119
	advanced E[R]	12	43	71	102	107
Wind	E[R]	17	220	401	491	521
	advanced E[R]	17	370	584	657	678
Geothermal	E[R]	3	21	49	78	93
	advanced E[R]	3	29	75	124	134
PV	E[R]	1	114	387	626	787
	advanced E[R]	1	141	450	868	896
CSP	E[R]	0	52	167	255	261
	advanced E[R]	0	100	282	373	335
Ocean energy	E[R]	0	8	27	71	108
	advanced E[R]	0	18	57	189	225
Total	**E[R]**	**132**	**590**	**1,240**	**1,774**	**2,043**
	advanced E[R]	**132**	**838**	**1,664**	**2,471**	**2,533**

figure 6.5: development of electricity generation structure under 3 scenarios

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



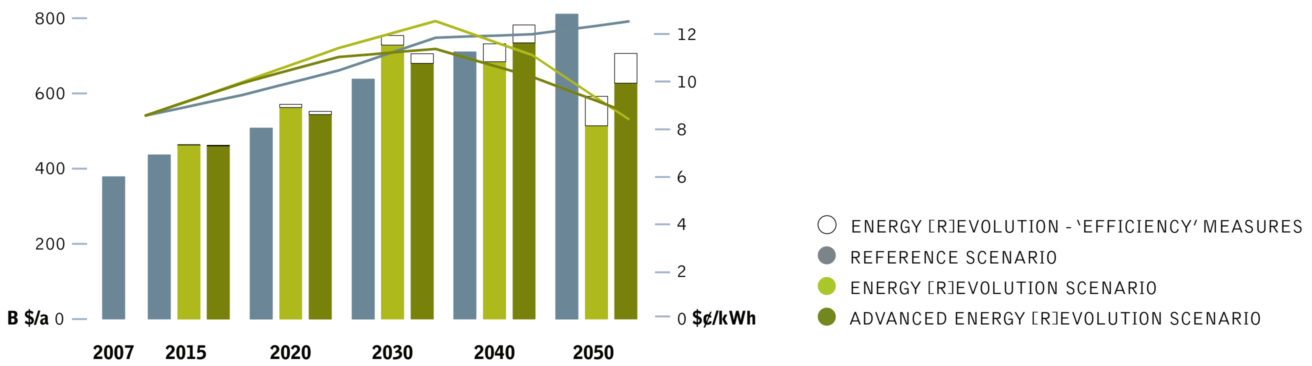
future costs of electricity generation

Figure 6.6 shows that the introduction of renewable technologies under the Energy [R]evolution scenario significantly decreases the future costs of electricity generation compared to the Reference scenario. Because of the lower CO_2 intensity of electricity generation, costs will become economically favorable under the Energy [R]evolution scenario and by 2050 will be more than 4 cents/kWh below those in the Reference version.

Under the Reference scenario, on the other hand, unchecked growth in demand, an increase in fossil fuel prices and the cost of CO_2 emissions result in total electricity supply costs rising from today's $379 billion per year to more than $811 billion in 2050. Figure 6.6 shows that the Energy [R]evolution scenario not only complies with the USA CO_2 reduction targets but also helps to stabilize energy costs and relieve the economic pressure on society. Increasing energy efficiency and shifting energy supply to renewables leads to long term costs for electricity supply that are one third lower than in the Reference scenario.

Due to the significantly smaller share of gas power plants in the advanced version, the overall supply costs in 2030 are $49 billion lower than in the basic Energy [R]evolution scenario. Due to the increased demand for electricity, especially in the transport and industry sectors, the overall supply costs in 2050 in the advanced version are $114 billion higher than in the basic Energy [R]evolution.

figure 6.6: development of total electricity supply costs & development of specific electricity generation costs under 3 scenarios



job results

The Energy [R]evolution scenarios lead to more energy sector jobs in USA at every stage of the projection.

- There are 1.1 million energy sector jobs in the Energy [R]evolution scenario and 1.4 in the advanced version by 2015, compared to 0.47 million in the Reference scenario.
- By 2020 job numbers reach 1.17million in the Energy [R]evolution scenario (1.34 million in the advanced version), twice as much as in the Reference scenario.
- By 2030 job numbers in the renewable energy sector reach 834,000 in the Energy [R]evolution scenario, 1.1 million in the advanced version) and reach only 231,000 in the Reference scenario.

Table 6.2 shows the increase in job numbers under both Energy [R]evolution scenarios for each technology up to 2020 and up to 2030. Both scenarios show losses in coal generation, but these are outweighed by employment growth in renewable technologies and gas. Wind shows particularly strong growth in both Energy [R]evolution scenarios by 2020, but by 2030 there is significant employment across a range of renewable technologies.

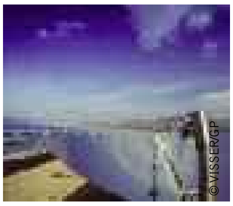


image CONCENTRATING SOLAR POWER (CSP) AT A SOLAR FARM IN DAGGETT, CALIFORNIA, USA.

image AN OFFSHORE DRILLING RIG DAMAGED BY HURRICANE KATRINA, GULF OF MEXICO.

table 6.2: employment & investment

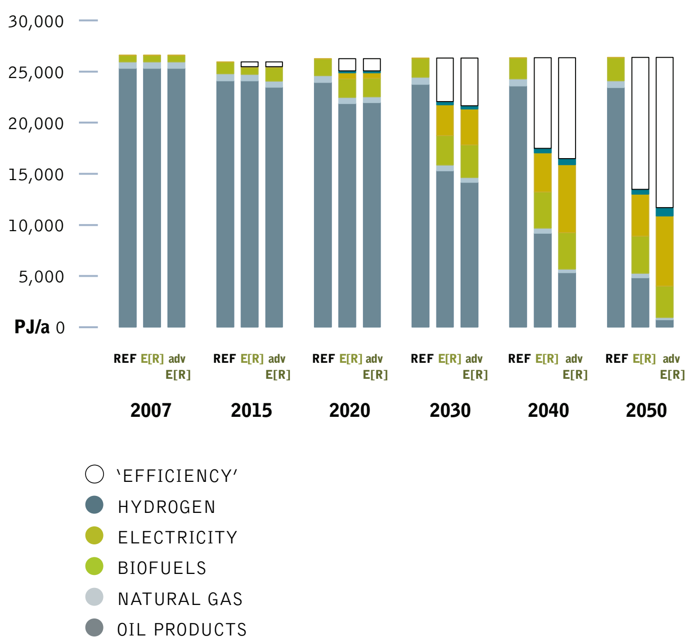
	REFERENCE			ENERGY [R]EVOLUTION			ADVANCED ENERGY [R]EVOLUTION		
	2015	2020	2030	2015	2020	2030	2015	2020	2030
Jobs									
Construction & installation	77,275	64,942	60,238	434,323	420,379	243,081	546,621	501,219	399,299
Manufacturing	60,255	41,933	35,079	330,750	270,940	143,907	487,420	327,949	180,877
Operations & maintenance	150,873	168,011	209,943	181,292	264,388	413,168	199,086	314,617	488,107
Fuel	181,332	186,004	202,736	204,582	213,436	233,260	210,632	196,220	201,204
Coal and gas export	763	878	1,401	416	218	19	361	121	11
Total Jobs	**470,498**	**461,767**	**509,396**	**1,151,363**	**1,169,361**	**1,033,434**	**1,444,121**	**1,340,126**	**1,269,497**
Coal	109,954	104,239	114,937	63,904	40,551	20,056	55,283	32,591	5,597
Gas, oil and diesel	118,234	119,625	122,193	185,298	172,467	177,478	172,422	143,192	133,852
Nuclear	33,940	36,904	41,097	18,470	12,024	1,712	18,470	12,024	1,712
Renewables	208,370	200,999	231,168	883,691	944,319	834,188	1,197,945	1,152,319	1,128,336
Total Jobs	**470,498**	**461,767**	**509,396**	**1,151,363**	**1,169,361**	**1,033,434**	**1,444,121**	**1,340,126**	**1,269,497**

transport

A key target in the USA is to introduce incentives for people to drive smaller cars, something almost completely absent today. In addition, it is vital to shift transport use to efficient modes like rail, light rail and buses, especially in the expanding large metropolitan areas. Together with rising prices for fossil fuels, these changes reduce the huge growth in car sales projected under the Reference scenario. Energy demand from the transport sector is reduced to 51% in the Energy [R]evolution scenario and to 44% in the advanced version compared to the Reference Scenario.

Highly efficient propulsion technology with hybrid, plug-in hybrid and battery-electric power trains will bring large efficiency gains. By 2030, electricity will provide 14% of the transport sector's total energy demand in the Energy [R]evolution scenario, while in the advanced version the share will already reach 16% in 2030 and 59% by 2050

figure 6.7: transport under 3 scenarios



development of CO_2 emissions

Whilst the USA's emissions of CO_2 will decrease by 4% under the Reference scenario, under the Energy [R]evolution scenario they will decrease from 5,742 million tons in 2007 to 728 million tons in 2050. Annual per capita emissions will drop from 18.6 t to 1.8 t. In spite of the phasing out of nuclear energy and increasing demand, CO_2 emissions will decrease in the electricity sector. In the long run efficiency gains and the increased use of renewable electricity in the transport sector will even reduce CO_2 emissions

With a share of 48% of total CO_2, the transport sector will be the largest source of emissions in 2050. The advanced Energy [R]evolution scenario reduces energy related CO_2 emissions over a period ten to 15 years faster than the basic scenario, leading to 5.9 t per capita by 2030 and 0.3 t by 2050. By 2050, the USA's CO_2 emissions are 97% below 1990 levels.

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 6.9. Compared to the Reference Scenario, overall primary energy demand will be reduced by 57% in 2050. Around 71% of the remaining demand will be covered by renewable energy sources.

The advanced version phases out coal and oil about ten to 15 years faster than the basic scenario. This is made possible mainly by the replacement of new coal power plants with renewables after a 20 rather than 40 year lifetime and a faster introduction of electric vehicles in the transport sector to replace oil combustion engines. This leads to an overall renewable energy share of 46% in 2030 and 87% in 2050. Nuclear power is phased out in both Energy [R]evolution scenarios soon after 2040.

figure 6.8: development of CO_2 emissions by sector under both energy [r]evolution scenarios

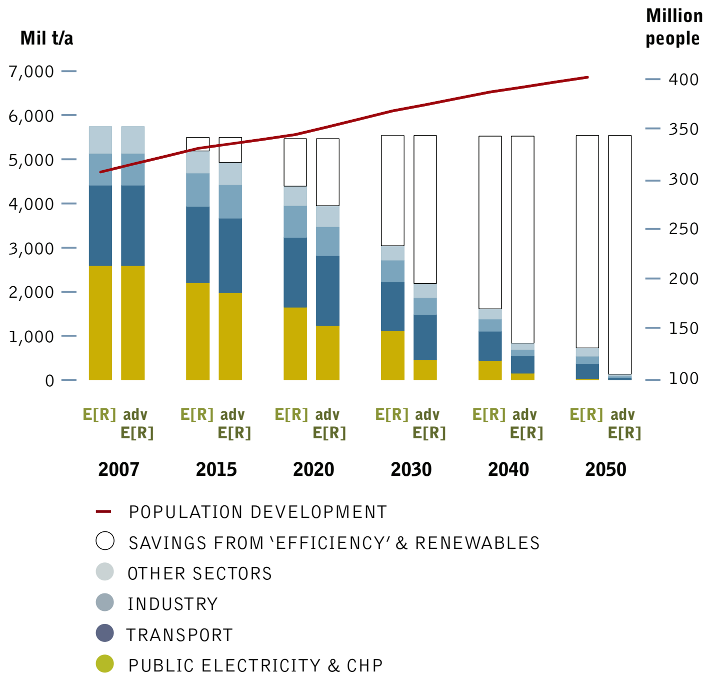


figure 6.9: development of primary energy consumption under three scenarios

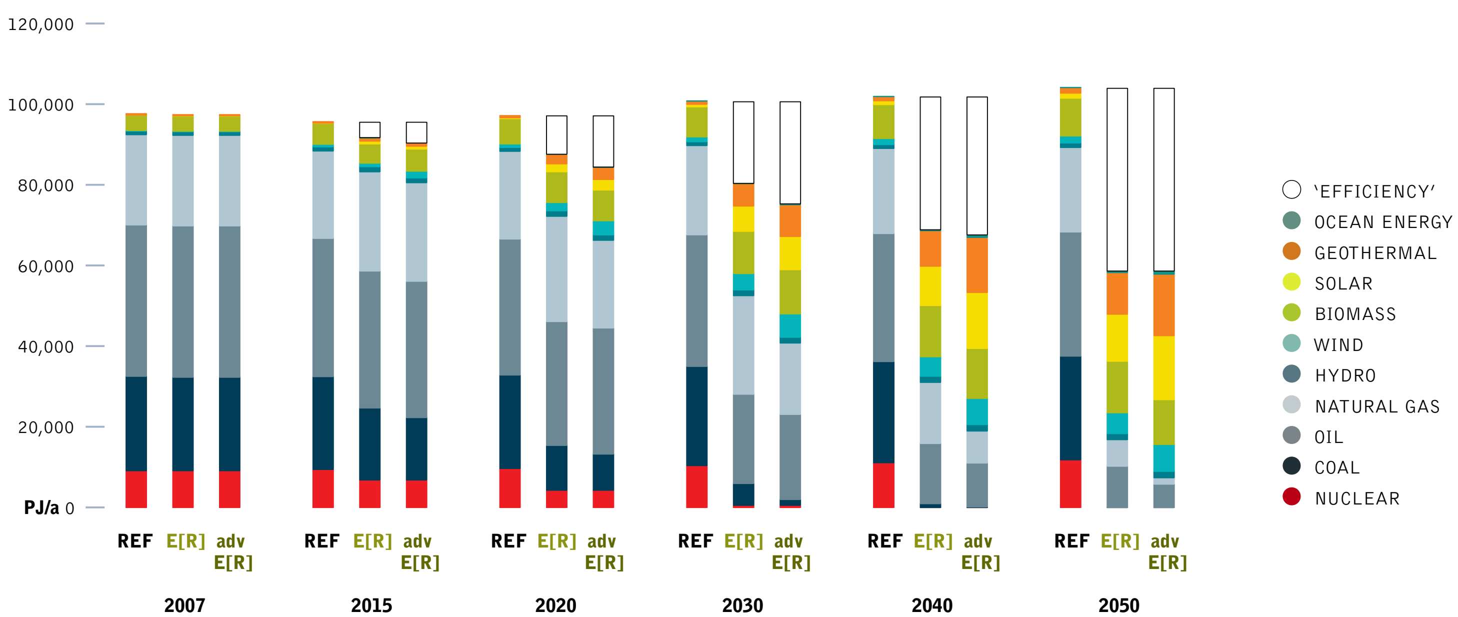


image SUN SETTING OFF THE GULF OF MEXICO.

image CONCENTRATING SOLAR POWER (CSP) AT A SOLAR FARM IN DAGGETT, CALIFORNIA, USA.

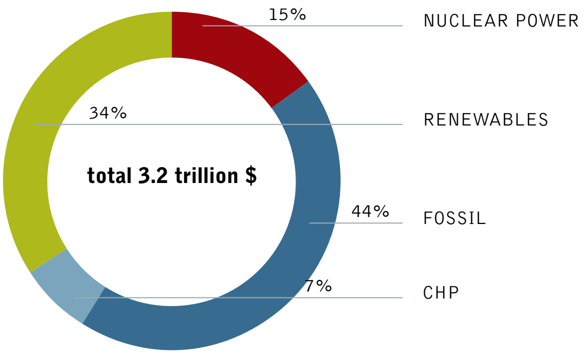
future investment

investment in new power plants The overall level of investment required in new power plants "up to 2050 will be in the region of $3.2 to 8.4 trillion. A major driving force for investment in new generation capacity will be the ageing fleet of power plants. Utilities must choose which technologies to opt for within the next five to ten years based on national energy policies, in particular market liberalization, renewable energy and CO_2 reduction targets. A possible cap & trade scheme could have a major impact on whether the majority of investment goes into fossil fuelled power plants or renewable energy and co-generation. Such a scheme will play a major role in future technology choices, as well as whether the investment costs for renewable energy become competitive with conventional power plants. In regions with a good wind regime, for example, wind farms can already produce electricity at the same cost levels as coal or gas power plants.

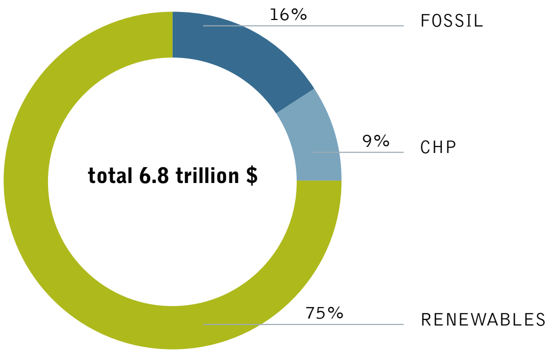
It would require $6.8 trillion in investment for the Energy [R]evolution scenario to become reality – approximately 110% higher than in the Reference scenario ($3.2 trillion). The advanced Energy [R]evolution scenario would need $8.4 trillion, approximately 25% over the basic version. While over 50 percent of investment under the reference scenario will go into fossil fuels and nuclear power plants, at about $1.7 trillion, the Energy [R]evolution Scenarios, however, the USA shifts about 80% of investment towards renewables and cogeneration, whilst the advanced version makes the shift approximately five to ten years earlier. By then, the fossil fuel share of power sector investment would be focused mainly on combined heat and power and efficient gas-fired power plants.

figure 6.10: investment shares - reference versus energy [r]evolution

reference scenario 2007 - 2050



energy [r]evolution scenario 2007 - 2050



advanced energy [r]evolution scenario 2007 - 2050

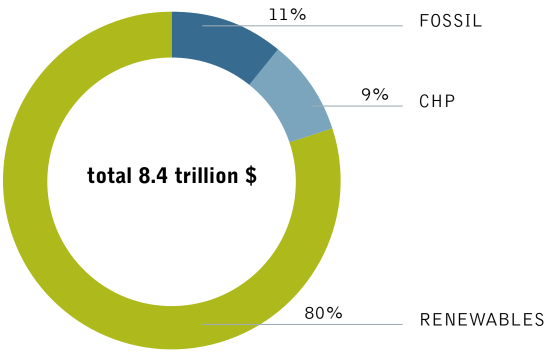
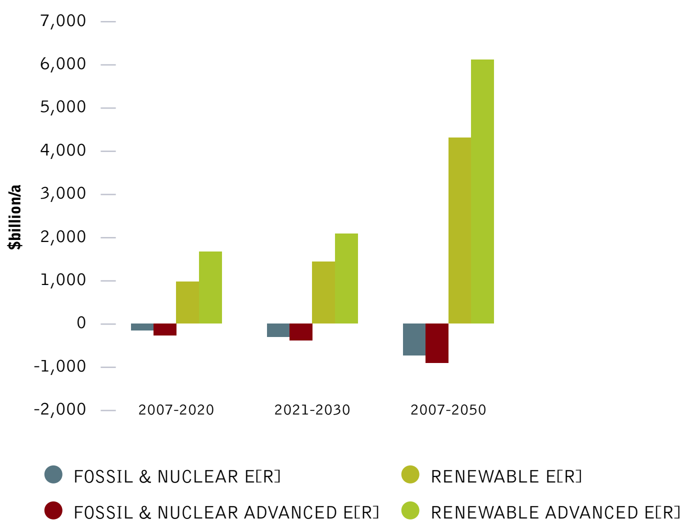


figure 6.11: change in cumulative power plant investment in both energy [r]evolution scenarios



fossil fuel power generation investment Under the Reference scenario, investment in renewable electricity generation will be $1.2 trillion. This compares to $7.2 trillion in the advanced Energy [R]evolution scenario. How investment is divided between the different renewable power generation technologies depends on their level of technical development and regionally available resources. Technologies such as wind power, which in many regions is already cost competitive with existing power plants, will take a larger investment volume and a bigger market share. The market volume attributed to different technologies also depends on local resources and policy frameworks within the U.S. states. Figure 6.12 provides an overview of the investment required for each technology. For solar photovoltaic, the primary market will remain in southern states and sunny states like California for years to come, but should soon expand to other U.S. states. Because solar photovoltaic energy is a highly modular and decentralized technology that can be used almost anywhere, its market will eventually spread across the entire U.S. Solar photovoltaic is expected to reach grid parity (generation costs on the same level as consumer electricity prices) by 2012 to 2015.

Concentrated solar power systems, on the other hand, can only be operated in U.S. states with more than 2000 hours of direct sunlight. The main investment in this technology will therefore take place in California, Arizona and New Mexico. The main development of the wind industry will take place especially in coastal areas, but also areas further inland such as Texas, Nebraska, and the Dakotas. Offshore wind technology will take a larger share from around 2015 onwards. The main offshore wind development will take place around the Atlantic coast. Bio energy power plants will be distributed across the U.S., as there is potential almost everywhere for biomass and/or biogas (cogeneration) power plants.

figure 6.12: renewable energy investment costs

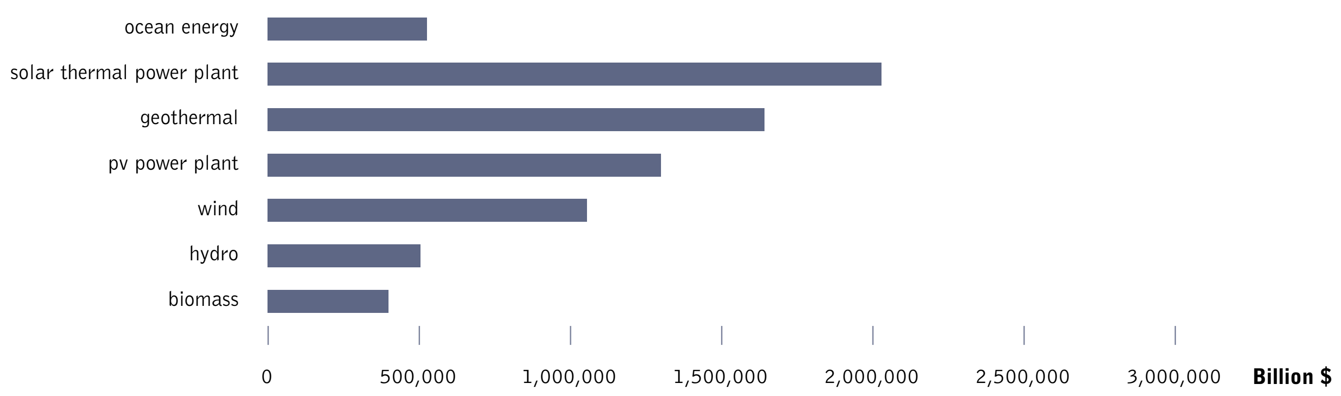


image A LOCAL WOMAN WORKS WITH TRADITIONAL AGRICULTURE PRACTICES JUST BELOW 21ST CENTURY ENERGY TECHNOLOGY. THE JILIN TONGYU TONGFA WIND POWER PROJECT, WITH A TOTAL OF 118 WIND TURBINES, IS A GRID CONNECTED RENEWABLE ENERGY PROJECT.

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fuel cost savings with renewable energy The total fuel cost savings in the Energy [R]evolution scenario reach a total of $3.8 trillion, or $89 billion per year. The advanced Energy [R]evolution has even higher fuel cost savings of $6.3 trillion, or $146 billion per year. This is because renewable energy has no fuel costs.

So in both cases the additional investment for renewable power plants refinance entirely via the fuel cost savings, which add up to $3.8 trillion ($6.3 trillion advanced) from today until 2050. This is enough to compensate for the entire investment in renewable and cogeneration capacity required to implement both of the Energy [R]evolution scenarios.

table 6.3: fuel cost savings and investment costs under the reference, energy[r]evolution and advanced energy [r]evolution

INVESTMENT COST	DOLLAR	2007-2020	2021-2030	2007-2050	2007-2050 AVERAGE PER YEAR
USA (2010) DIFFERENCE E[R] VERSUS REF					
Conventional (fossil & nuclear)	billion $	-134	-278	-734	-17
Renewables (incl. CHP)	billion $	1,011	1,446	4,314	100
Total	billion $	877	1,168	3,580	83
USA (2010) DIFFERENCE ADV E[R] VERSUS REF					
Conventional (fossil & nuclear)	billion $	-279	-368	-907	-21
Renewables (incl. CHP)	billion $	1,672	2,099	6,117	142
Total	billion $	1,393	1,732	5,211	121
CUMULATED FUEL COST SAVINGS					
SAVINGS E[R] CUMULATED IN $					
Fuel oil	billion $/a	1	15	77	2
Gas	billion $/a	-319	-774	-1,001	-23
Hard coal	billion $/a	334	997	4,570	106
Lignite	billion $/a	9	50	170	4
Total	billion $/a	24	289	3,815	89
SAVINGS ADV E[R] CUMULATED IN $					
Fuel oil	billion $/a	-7	10	60	1
Gas	billion $/a	-206	-174	1,044	24
Hard coal	billion $/a	385	1,166	4,975	116
Lignite	billion $/a	24	67	206	5
Total	billion $/a	195	1,068	6,285	146

energy resources & security of supply

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

7

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.”

GREENPEACE INTERNATIONAL
CLIMATE CAMPAIGN

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

status of global fuel supplies

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

the reserves chaos

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

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

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

non-conventional oil reserves

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

One of the worst examples of environmental degradation resulting from the exploitation of unconventional oil reserves is the oil sands that lie beneath the Canadian province of Alberta and form the world's second-largest proven oil reserves after Saudi Arabia. Producing crude oil from these 'tar sands' - a heavy mixture of bitumen, water, sand and clay found beneath more than 54,000 square miles[50] of prime forest in northern Alberta, an area the size of England and Wales - generates up to four times more carbon dioxide, the principal global warming gas, than conventional drilling. The booming oil sands industry will produce 100 million tonnes of CO_2 a year (equivalent to a fifth of the UK's entire annual emissions) by 2012, ensuring that Canada will miss its emission targets under the Kyoto treaty. The oil rush is also scarring a wilderness landscape: millions of tonnes of plant life and top soil are scooped away in vast opencast mines and millions of litres of water diverted from rivers. Up to five barrels of water are needed to produce a single barrel of crude and the process requires huge amounts of natural gas. It takes two tonnes of the raw sands to produce a single barrel of oil.

gas

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

49 '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.
50 *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 ones have been almost constant since 1980 because discoveries have roughly matched production.

shale gas[51]

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

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

coal

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

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

table 7.1: 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.

51 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 7.2: assumptions on fossil fuel use in the energy [r]evolution scenario

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

nuclear

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

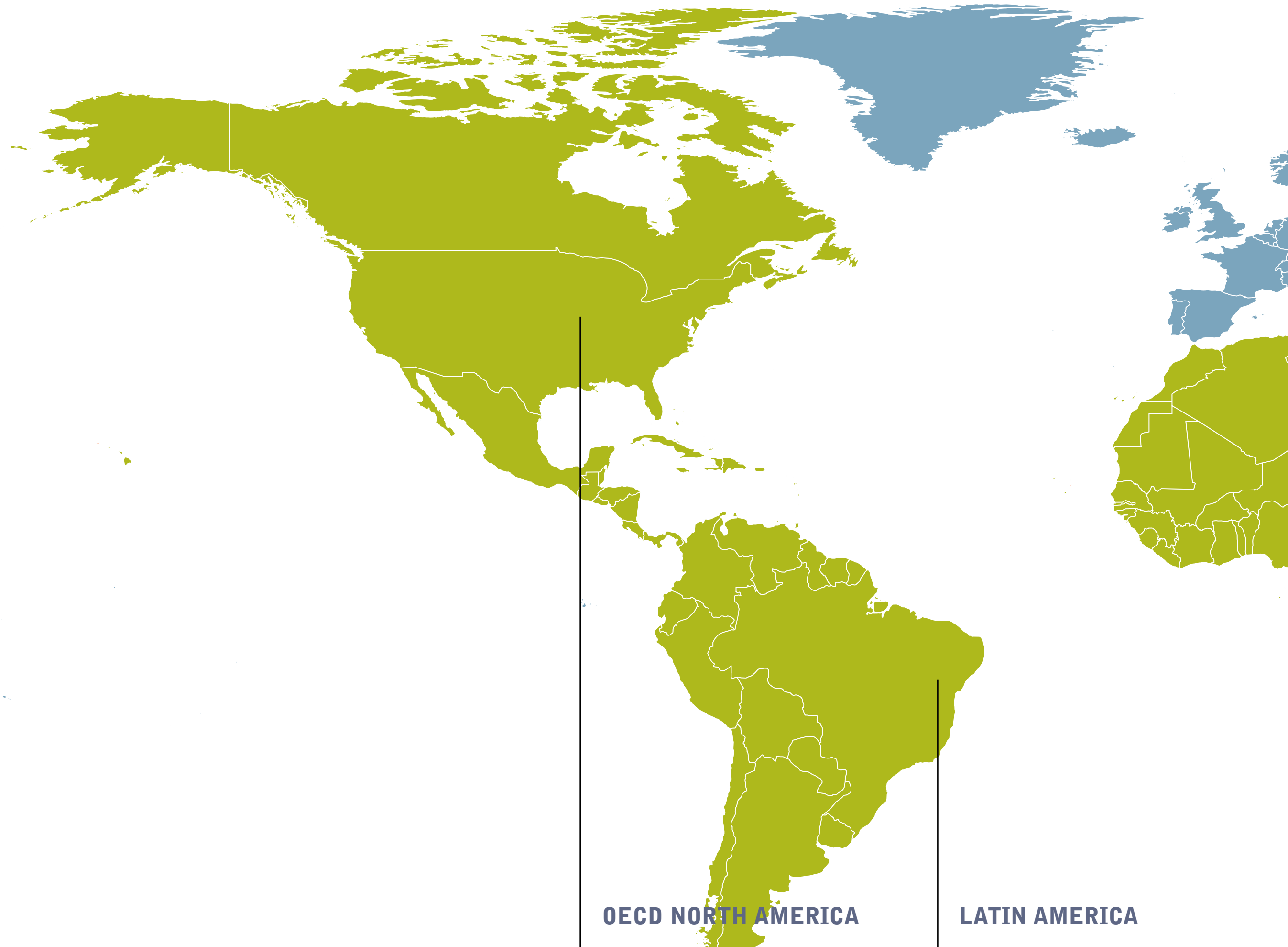
Secondary sources, such as old deposits, currently make up nearly half of worldwide uranium reserves. These will soon be used up, however. Mining capacities will have to be nearly doubled in the next few years to meet current needs.

A joint report by the OECD Nuclear Energy Agency and the International Atomic Energy Agency[52] 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.

52 'URANIUM 2003: RESOURCES, PRODUCTION AND DEMAND'

map 7.1: oil reference scenario and the advanced energy [r]evolution scenario

WORLDWIDE SCENARIO



OECD NORTH AMERICA

		REF		E[R]	
		TMB	%	TMB	%
Reserves	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	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]

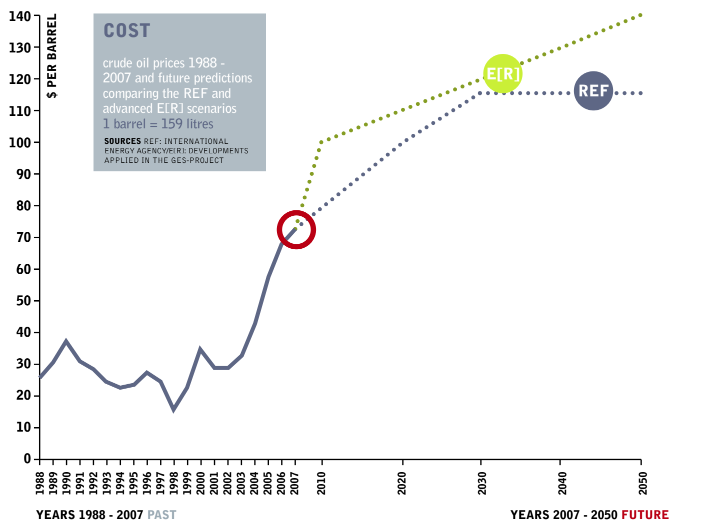
CONSUMPTION PER PERSON LITERS [L]

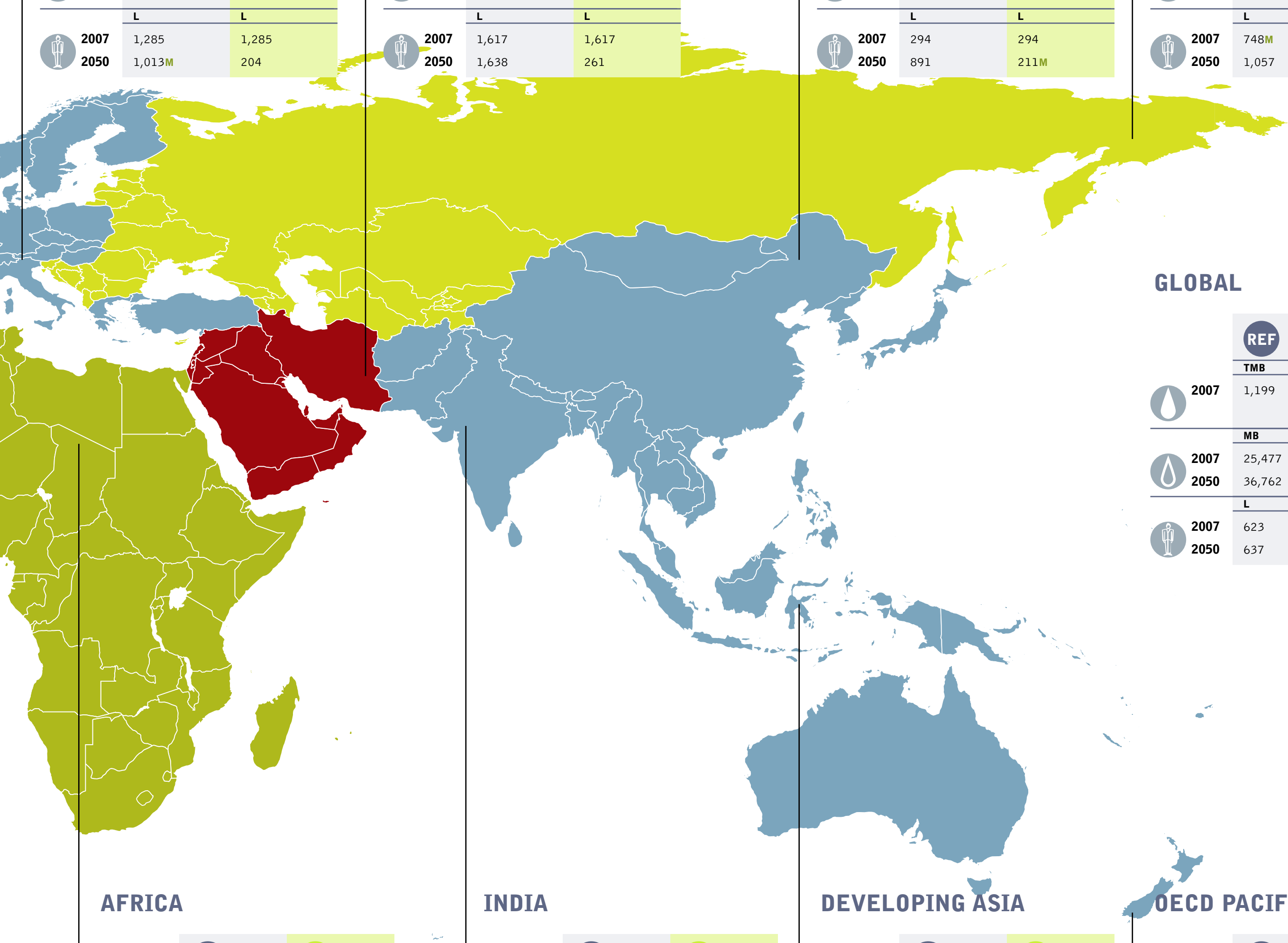
H HIGHEST | **M** MIDDLE | **L** LOWEST

COST

crude oil prices 1988 - 2007 and future predictions comparing the REF and advanced E[R] scenarios
1 barrel = 159 litres

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





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	

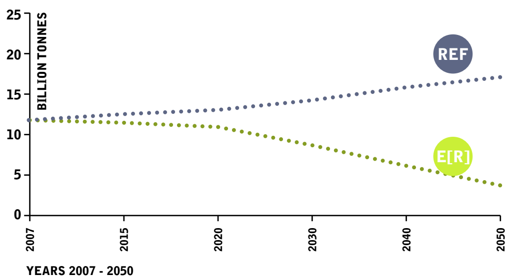
OECD PACIFIC

		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

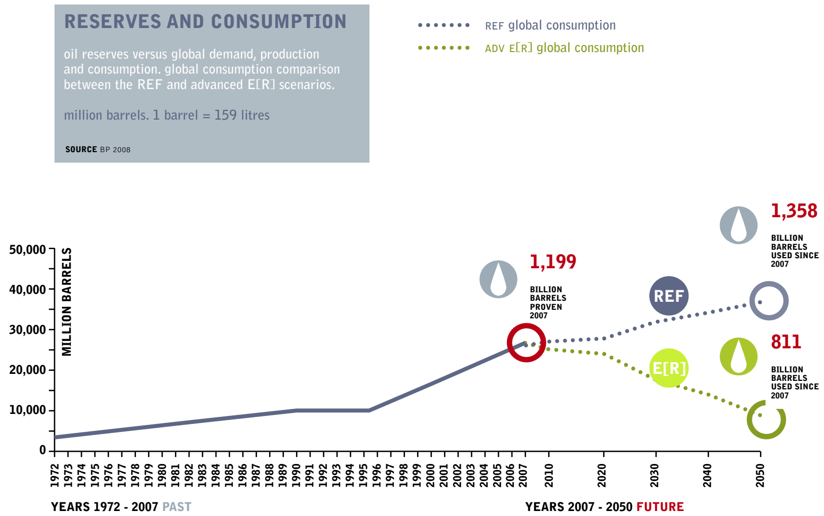


RESERVES AND CONSUMPTION

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



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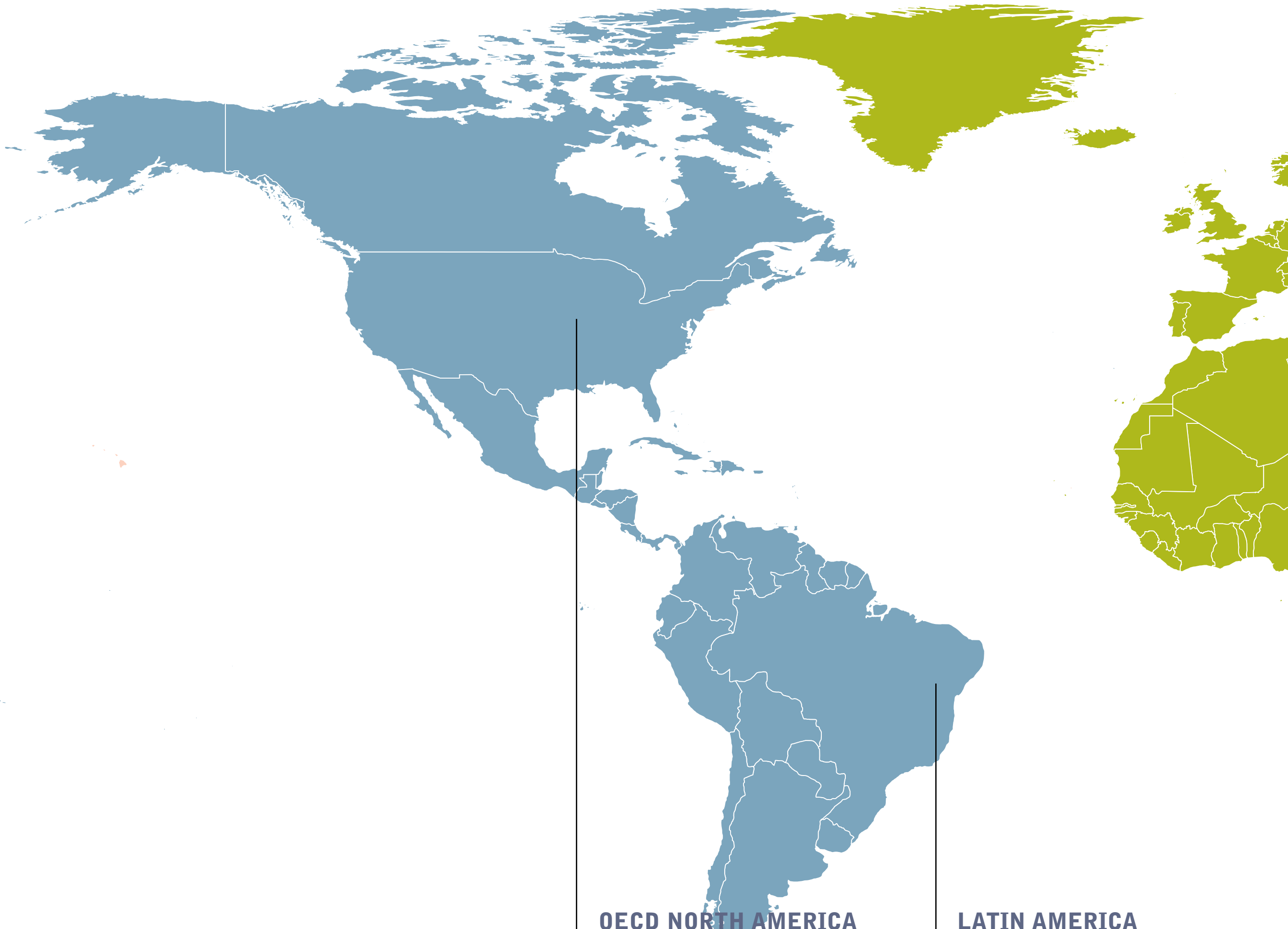
map 7.2: gas reference scenario and the advanced energy [r]evolution scenario

WORLDWIDE SCENARIO



NON RENEWABLE RESOURCE

GAS

OECD NORTH AMERICA

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

LATIN AMERICA

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

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

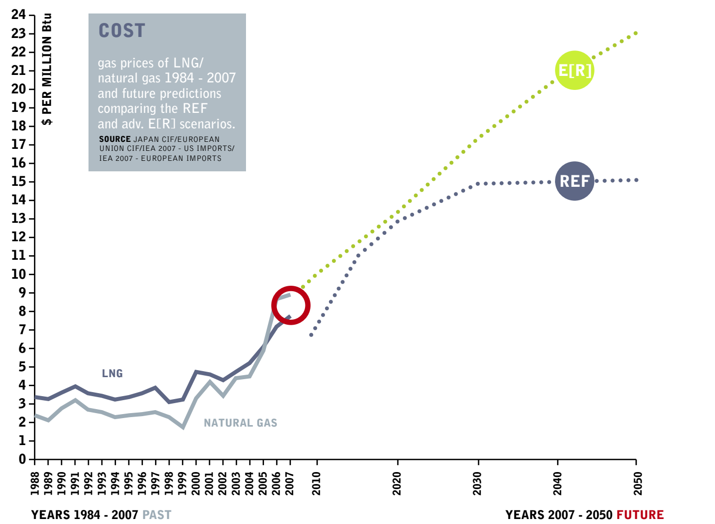
0 1000 KM

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



OECD EUROPE

	REF tn m³	REF %	E[R] tn m³	E[R] %
2007	9.8	5.4%	9.8	5.4%
	bn m³	**PJ**	**bn m³**	**PJ**
2007	504	19,170	504	19,170
2050	644	24,469	69	2,613
	m³		**m³**	
2007	934		934	
2050	1,120M		120	

MIDDLE EAST

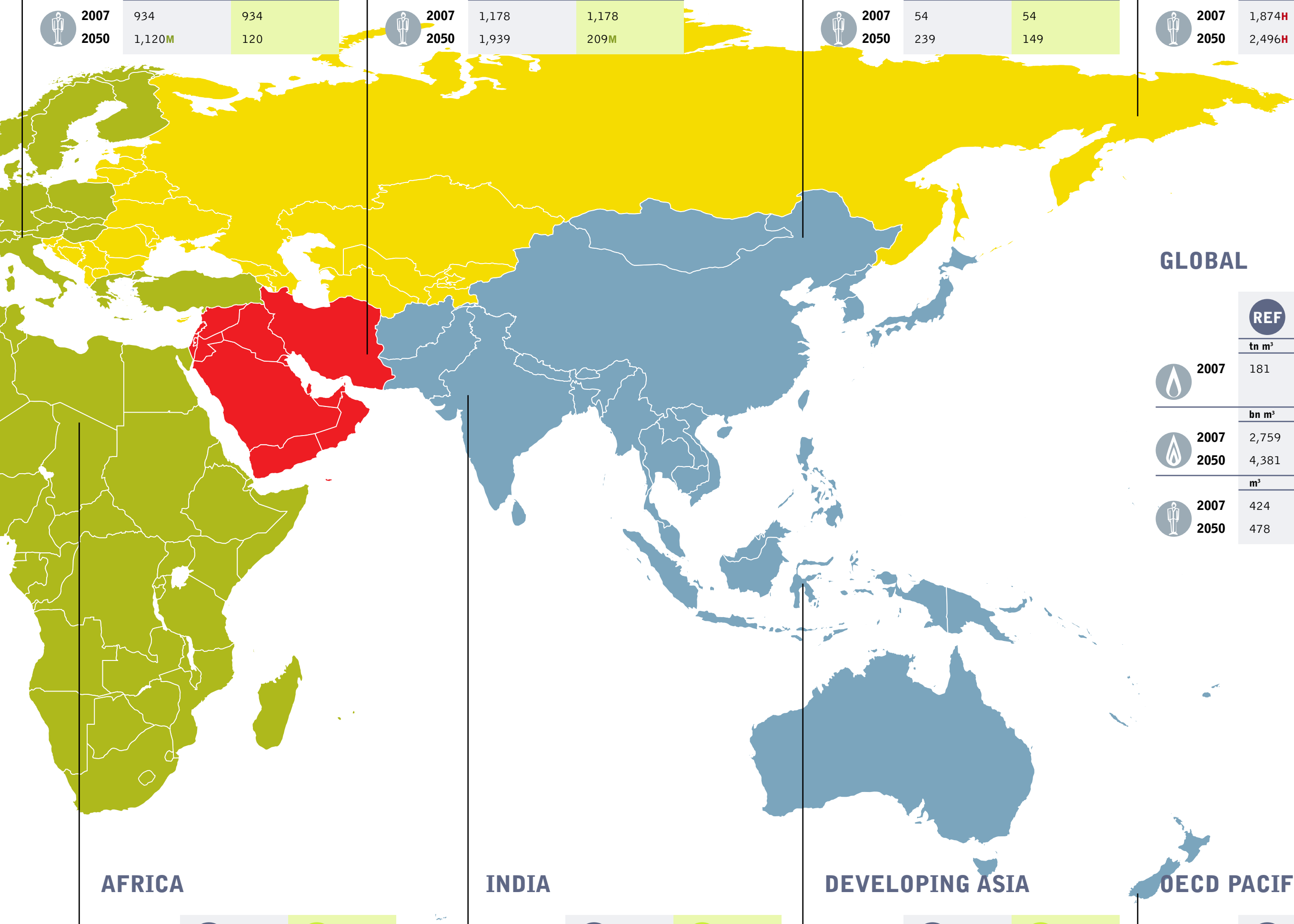
	REF tn m³	REF %	E[R] tn m³	E[R] %
2007	73.2H	40.4%H	73.2H	40.4%H
	bn m³	**PJ**	**bn m³**	**PJ**
2007	238M	9,056M	239	9,056
2050	685	26,034	74	2,805
	m³		**m³**	
2007	1,178		1,178	
2050	1,939		209M	

CHINA

	REF tn m³	REF %	E[R] tn m³	E[R] %
2007	1.9	1.0%	1.9	1.0%
	bn m³	**PJ**	**bn m³**	**PJ**
2007	71	2,716	71	2,716
2050	341	12,953	212	8,061
	m³		**m³**	
2007	54		54	
2050	239		149	

TRANSITION ECONOMIES

	REF tn m³	REF %	E[R] tn m³	E[R] %
2007	53.3	29.4%	53.3	29.4%
	bn m³	**PJ**	**bn m³**	**PJ**
2007	638	24,225	638	24,225
2050	776	29,478	138	5,248
	m³		**m³**	
2007	1,874H		1,874H	
2050	2,496H		444H	



GLOBAL

	REF tn m³	REF %	E[R] tn m³	E[R] %
2007	181	100%	181	100%
	bn m³	**PJ**	**bn m³**	**PJ**
2007	2,759	104,846	2,759	104,846
2050	4,381	166,489	902	34,285
	m³		**m³**	
2007	424		424	
2050	478		99	

AFRICA

	REF tn m³	REF %	E[R] tn m³	E[R] %
2007	14.6M	8.0%M	14.6M	8.0%M
	bn m³	**PJ**	**bn m³**	**PJ**
2007	91	3,472	91	3,472
2050	167	6,338	65	2,456
	m³		**m³**	
2007	95		95	
2050	83		32L	

INDIA

	REF tn m³	REF %	E[R] tn m³	E[R] %
2007	1.1L	0.6%L	1.1L	0.6%L
	bn m³	**PJ**	**bn m³**	**PJ**
2007	37L	1,397L	37L	1,397L
2050	164L	6,227L	107M	4,075M
	m³		**m³**	
2007	32L		32L	
2050	102L		66	

DEVELOPING ASIA

	REF tn m³	REF %	E[R] tn m³	E[R] %
2007	8.6	4.8%	8.6	4.8%
	bn m³	**PJ**	**bn m³**	**PJ**
2007	184	6,998	184	6,998
2050	422	16,020	115	4,368
	m³		**m³**	
2007	182		182	
2050	278		76	

OECD PACIFIC

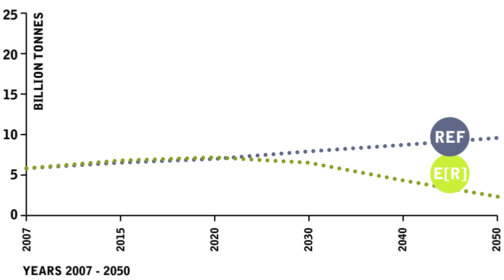
	REF tn m³	REF %	E[R] tn m³	E[R] %
2007	2.9	1.6%	2.9	1.6%
	bn m³	**PJ**	**bn m³**	**PJ**
2007	156	5,912	156	5,912
2050	170	6,467	18L	667L
	m³		**m³**	
2007	776M		776M	
2050	946		98	

CO_2 EMISSIONS FROM GAS

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

billion tonnes

SOURCE GPI/EREC

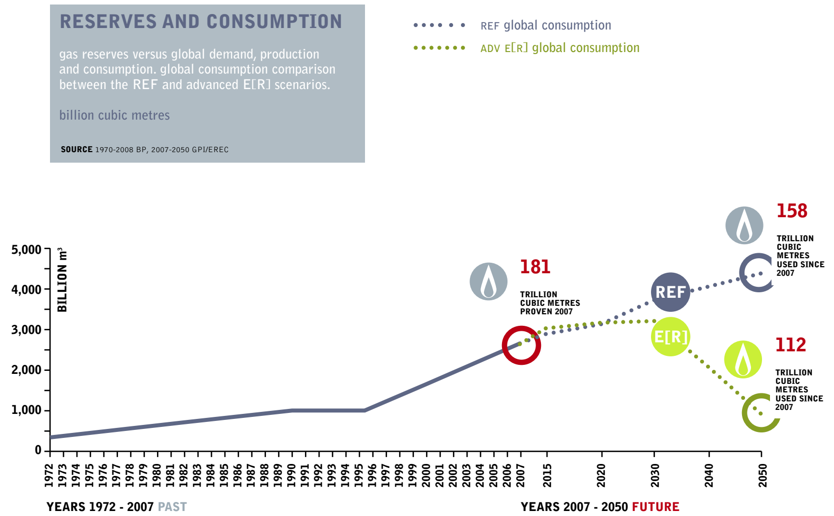


RESERVES AND CONSUMPTION

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



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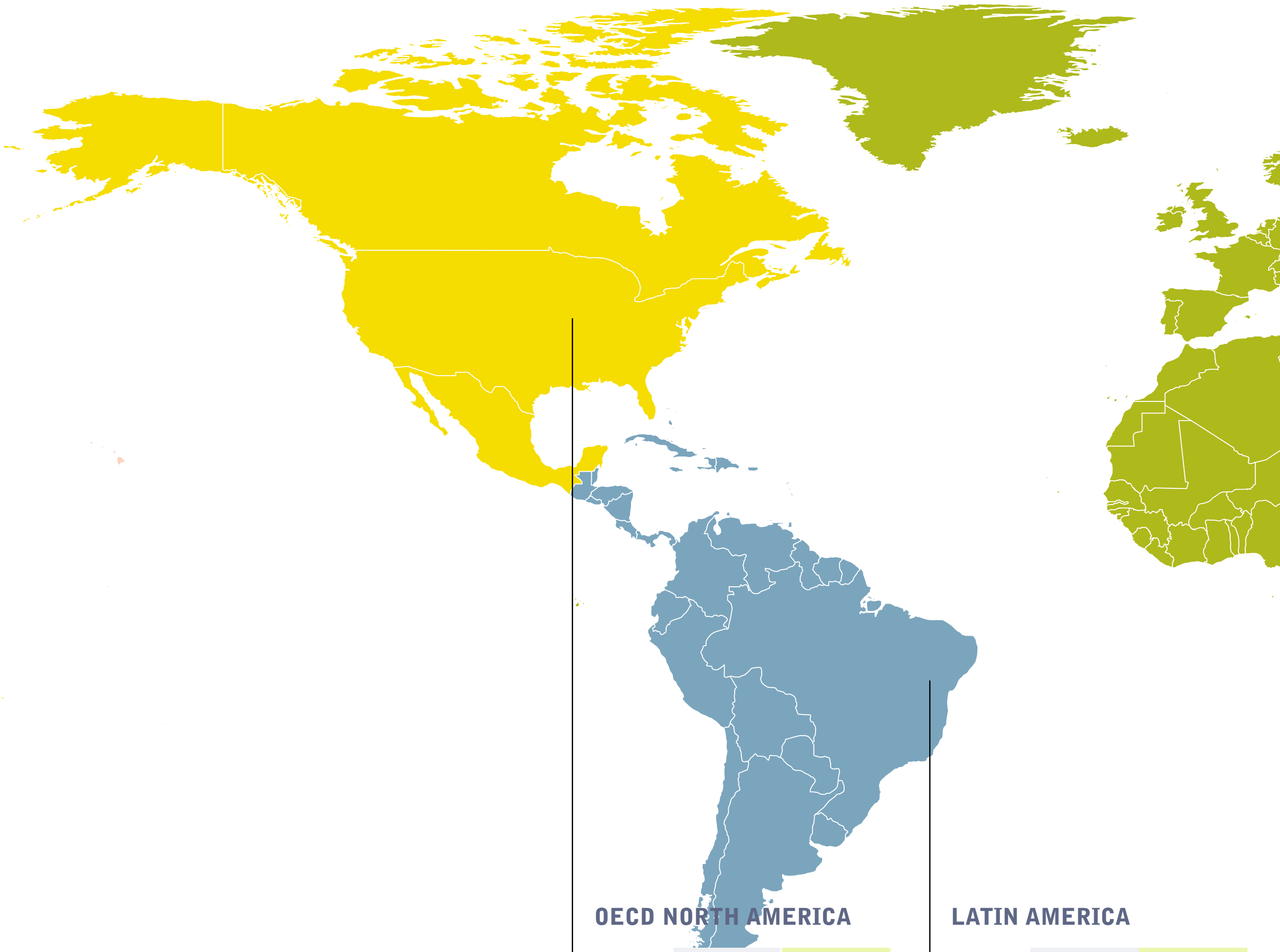
map 7.3: coal reference scenario and the advanced energy [r]evolution scenario

WORLDWIDE SCENARIO



OECD NORTH AMERICA

		REF		E[R]	
		mn t	%	mn t	%
Reserves	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		E[R]	
		mn t	%	mn t	%
Reserves	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

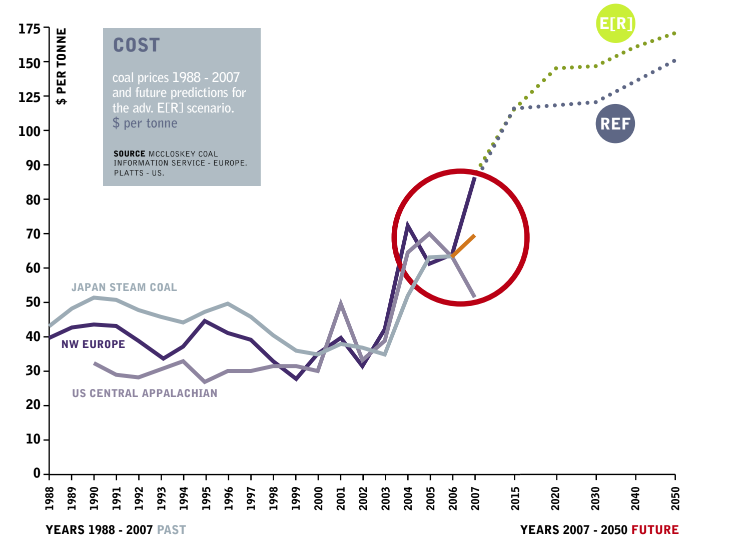
0 — 1000 KM

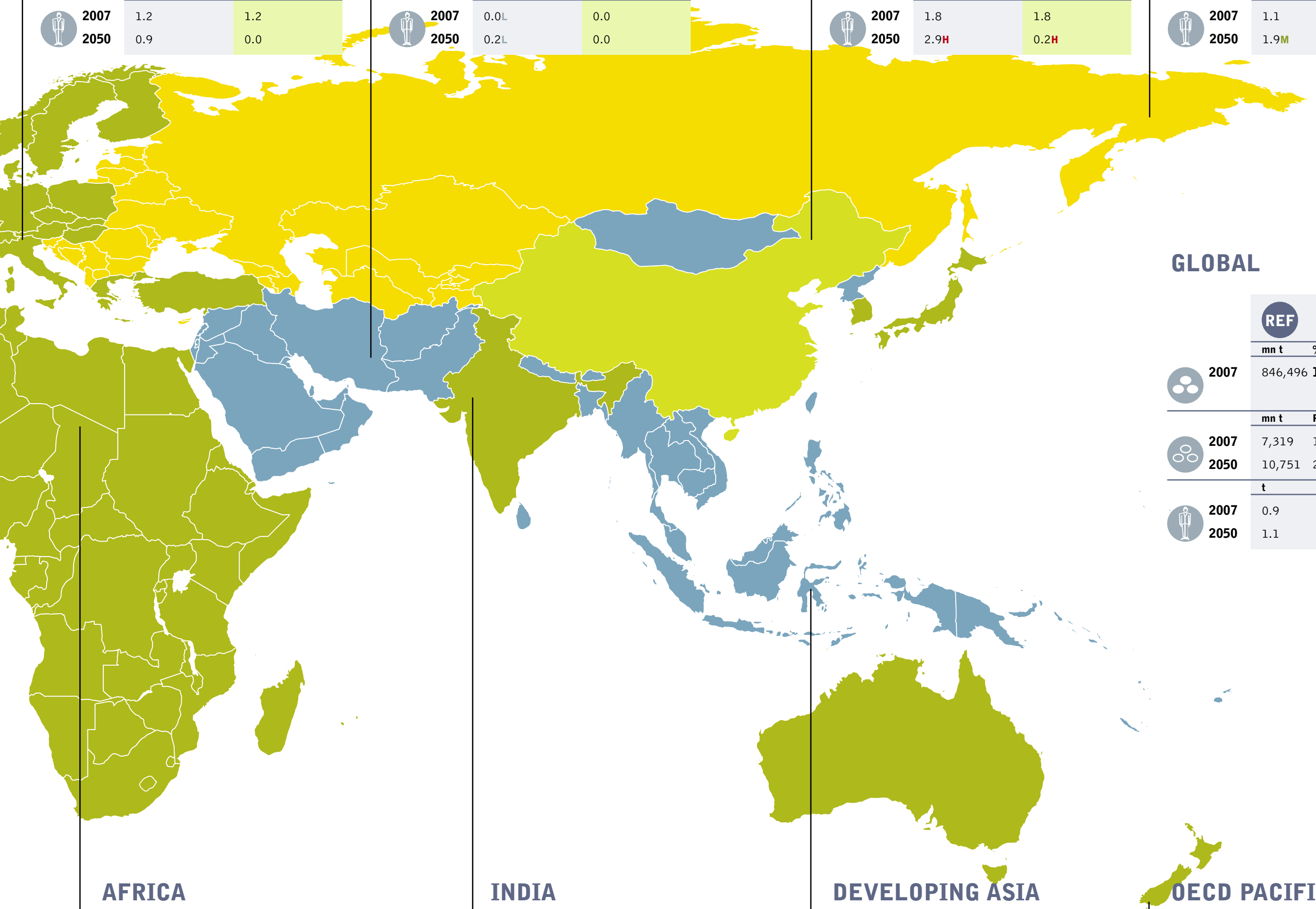
RESERVES TOTAL MILLION TONNES [mn t] | SHARE IN % OF GLOBAL TOTAL [END OF 2007]

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

CONSUMPTION PER PERSON TONNES [t]

H HIGHEST | M MIDDLE | L LOWEST





OECD EUROPE

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

MIDDLE EAST

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

CHINA

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

TRANSITION ECONOMIES

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

GLOBAL

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

AFRICA

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

INDIA

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

DEVELOPING ASIA

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

OECD PACIFIC

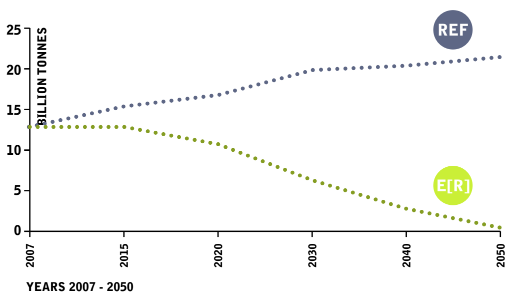
	REF		E[R]	
	mn t	%	mn t	%
2007	77,661	9%	77,661	9%
	mn t	PJ	mn t	PJ
2007	565	10,652	565	10,652
2050	518	10,097	1L	27
	t		t	
2007	2.3		2.3	
2050	2.4		0.0	

CO_2 EMISSIONS FROM COAL

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

billion tonnes

SOURCE GPI/EREC

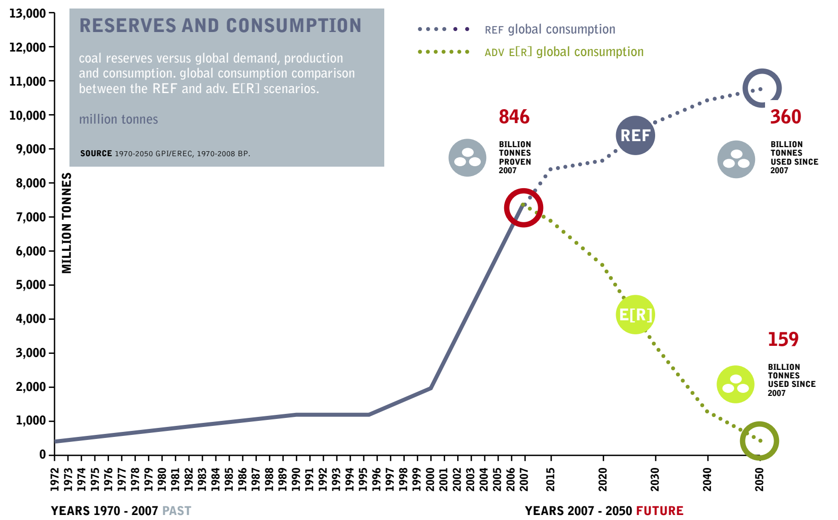


RESERVES AND CONSUMPTION

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

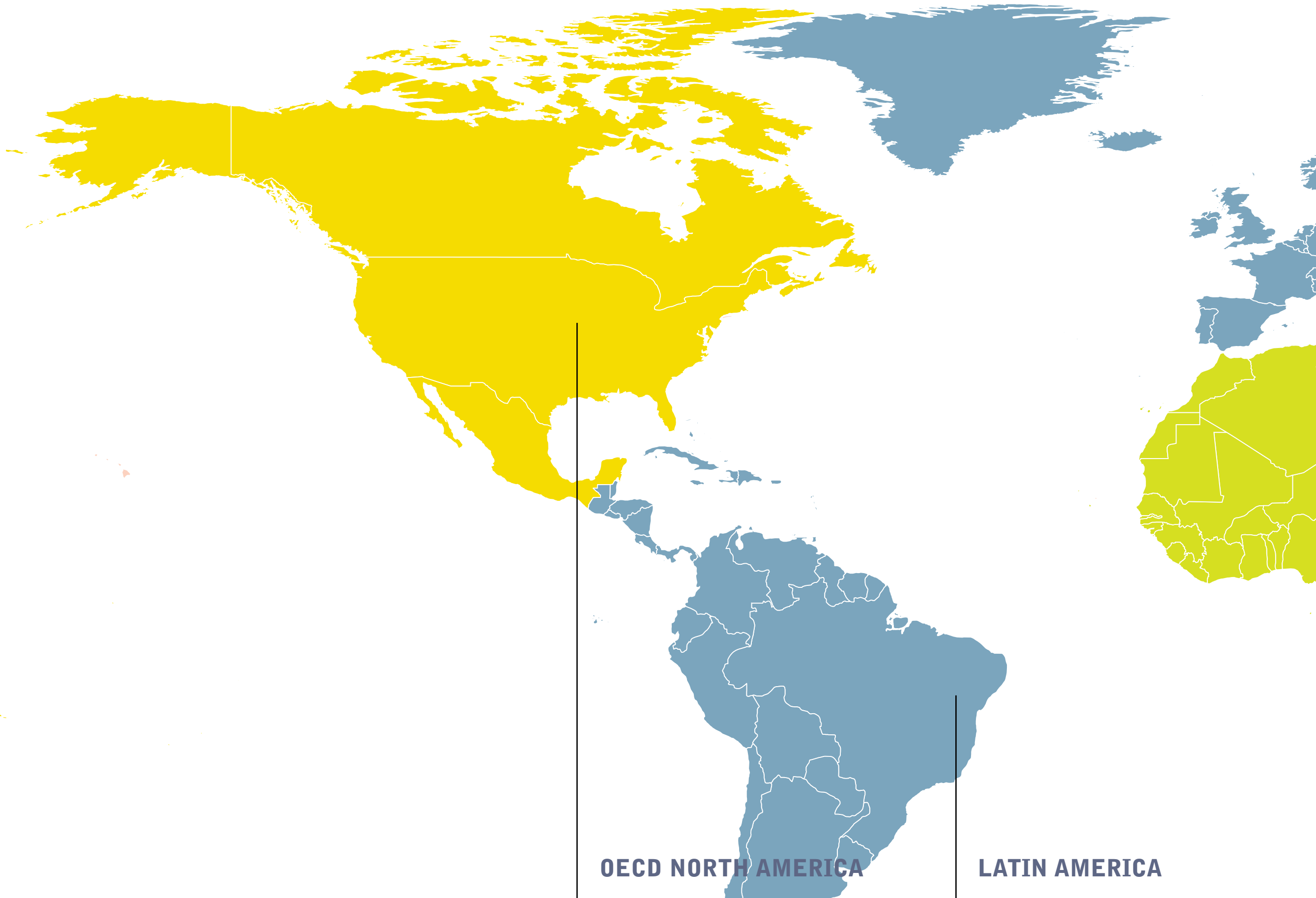
million tonnes

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



map 7.4: 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 per region	2007	10,260H		10,260H	
	2050	13,735H		0	
		kWh		kWh	
Consumption 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 per region	2007	214		214	
	2050	655		0	
		kWh		kWh	
Consumption 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

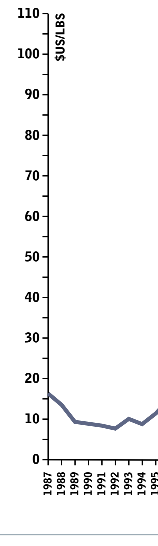
RESERVES TOTAL TONNES | SHARE IN % OF GLOBAL TOTAL [END OF 2007]

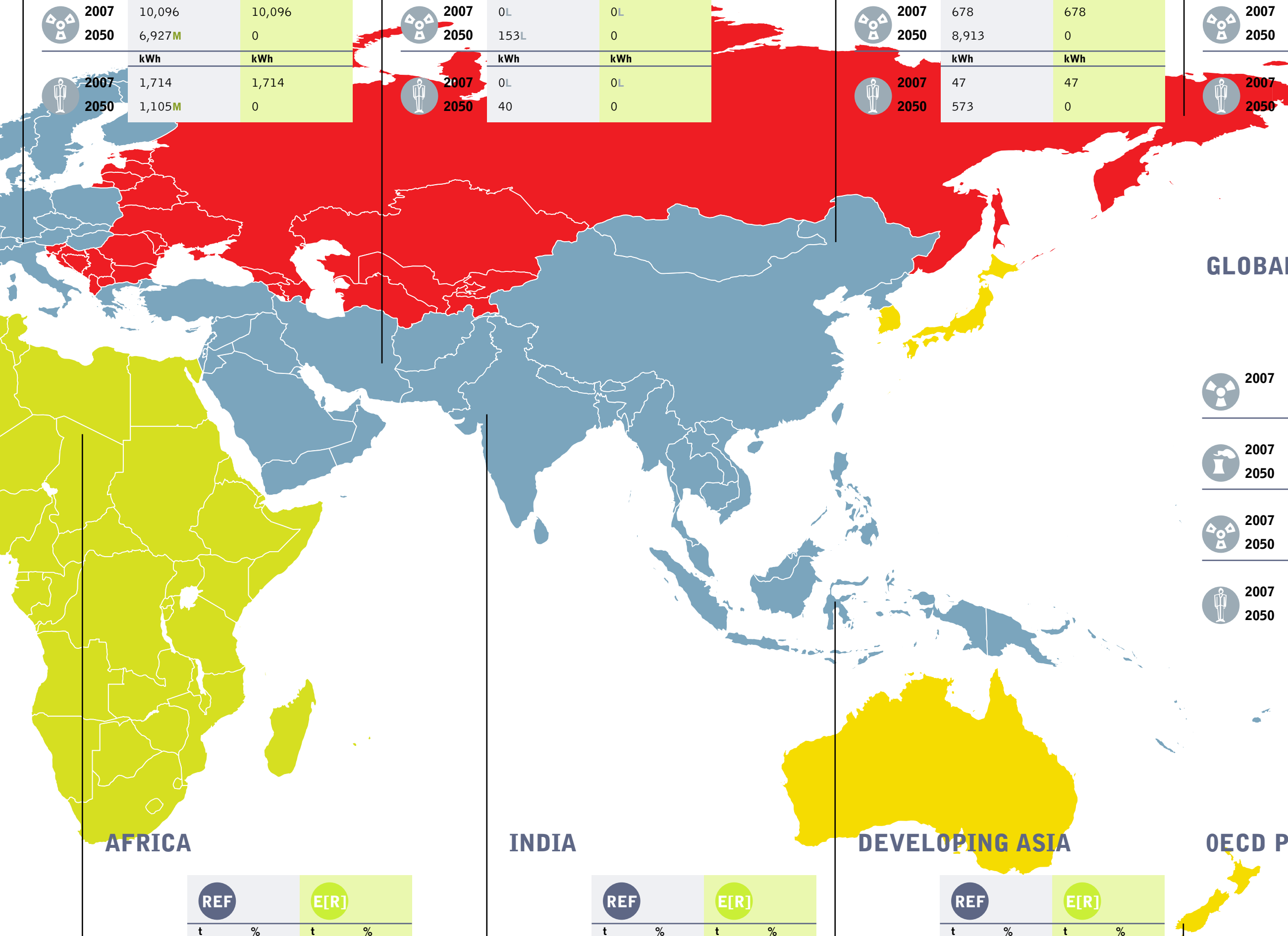
GENERATION PER REGION TERAWATT HOURS [TWh]

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
TWh	2050	635M	
PJ	2007	10,096	10,096
PJ	2050	6,927M	0
kWh	2007	1,714	1,714
kWh	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
TWh	2050	14L	
PJ	2007	0L	0L
PJ	2050	153L	0
kWh	2007	0L	0L
kWh	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
TWh	2050	817	
PJ	2007	678	678
PJ	2050	8,913	0
kWh	2007	47	47
kWh	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
TWh	2050	463	
PJ	2007	3,197M	3,197M
PJ	2050	5,051	0
kWh	2007	861M	861M
kWh	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
TWh	2050	4,413	
PJ	2007	29,664	29,664
PJ	2050	48,142	0
kWh	2007	418	418
kWh	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
TWh	2050	45	
PJ	2007	123	123
PJ	2050	491	0
kWh	2007	12	12
kWh	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
TWh	2050	172	
PJ	2007	183	183
PJ	2050	1,876	0
kWh	2007	17	17
kWh	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
TWh	2050	80	
PJ	2007	476	476
PJ	2050	873	0
kWh	2007	43	43
kWh	2050	53	0

OECD PACIFIC

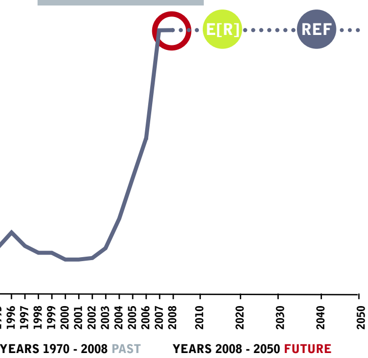
	Year	REF	E[R]
t / %	2007	741,600 23.4%	741,600 23.4%
TWh	2007	407	NUCLEAR POWER PHASED OUT BY 2045
TWh	2050	868	
PJ	2007	4,437	4,437
PJ	2050	9,469	0
kWh	2007	2,030	2,030
kWh	2050	4,827H	0

COST

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

tonnes

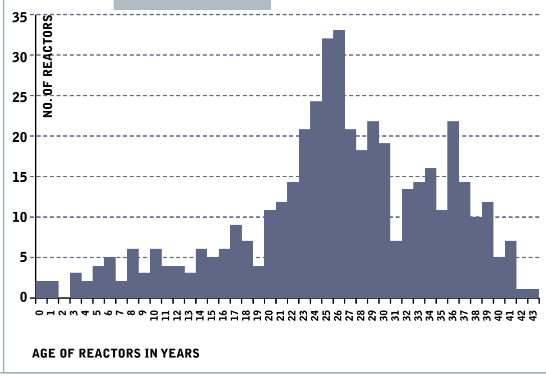
SOURCES REF: INTERNATIONAL ENERGY AGENCY/E[R]: DEVELOPMENTS APPLIED IN THE GES-PROJECT



REACTORS

age and number of reactors worldwide

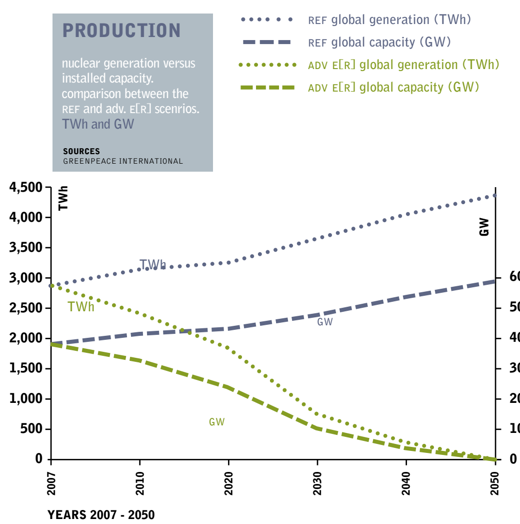
SOURCES IAEA



PRODUCTION

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

SOURCES GREENPEACE INTERNATIONAL



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

renewable energy

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

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

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

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

The meta study by the DLR (German Aerospace 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.[54] 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 7.3).

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[53]

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.

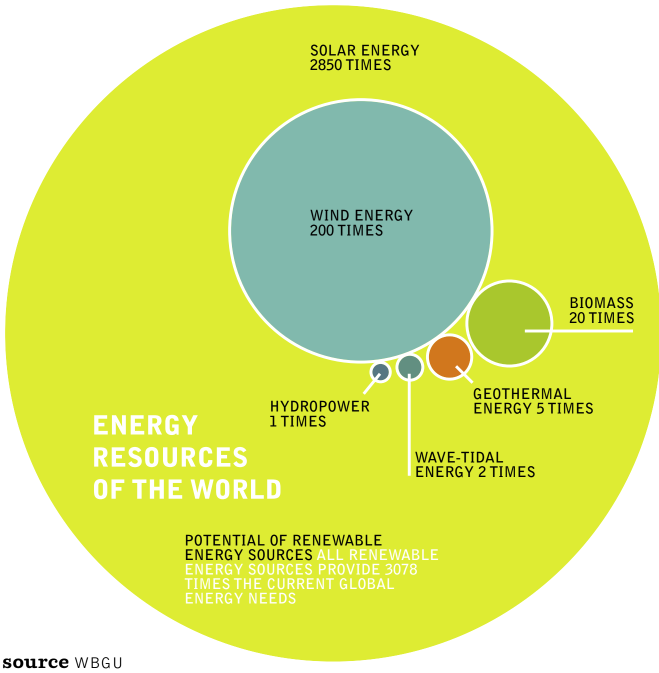
conversion potential This is derived from the annual efficiency of the respective conversion technology. It is therefore not a strictly defined value, since the efficiency of a particular technology depends on technological progress.

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 7.1: energy resources of the world



source WBGU

53 WBGU (GERMAN ADVISORY COUNCIL ON GLOBAL CHANGE).
54 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 7.3: technical potential by renewable energy technology for 2020, 2030 and 2050

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

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

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

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

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

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

the global potential for sustainable biomass

As part of background research for the Energy [R]evolution 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.[55]

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.

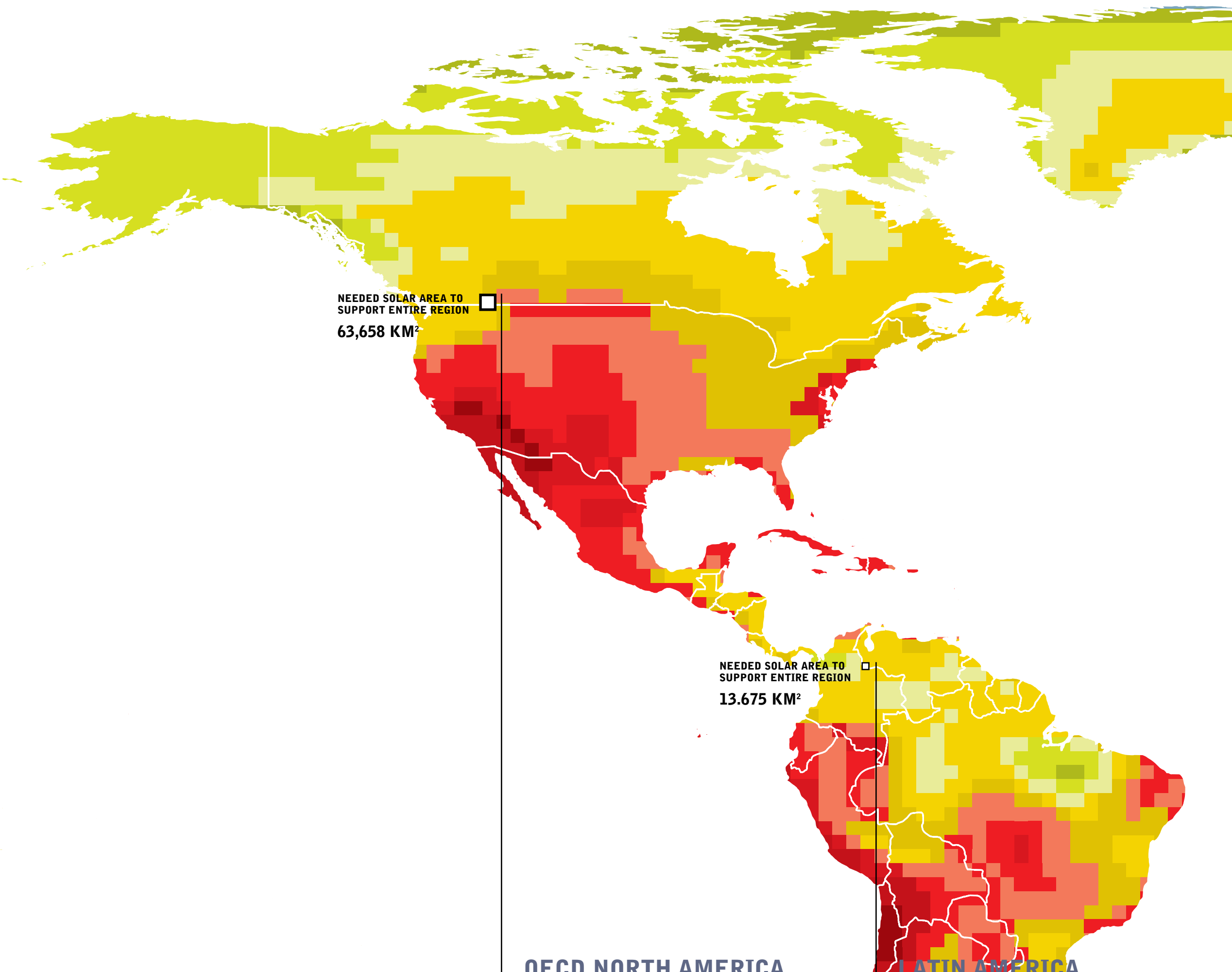
Data from 18 studies has been examined, with a concentration on those which report the potential for biomass residues. Among these there were ten comprehensive assessments with more or less detailed documentation of the methodology. The majority focus on the long-term potential for 2050 and 2100. Little information is available for 2020 and 2030. Most of the studies were published within the last ten years. Figure 7.2 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.

55 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.

map 7.5: solar reference scenario and the advanced energy [r]evolution scenario

WORLDWIDE SCENARIO



RENEWABLE RESOURCE

SOLAR

OECD NORTH AMERICA

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

LATIN AMERICA

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

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 kWh/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]

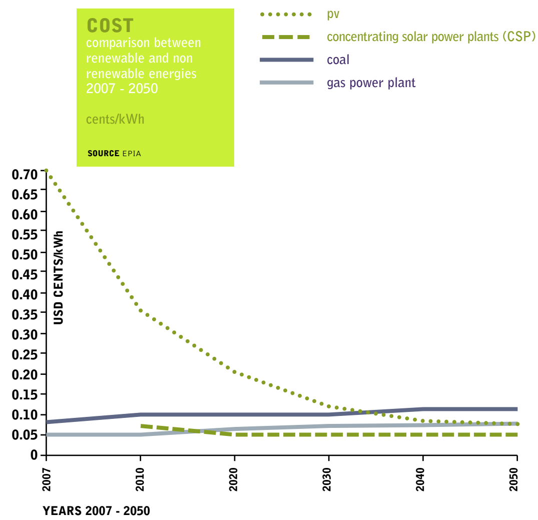
H HIGHEST | **M** MIDDLE | **L** LOWEST

COST

comparison between renewable and non renewable energies 2007 - 2050

cents/kWh

SOURCE EPIA

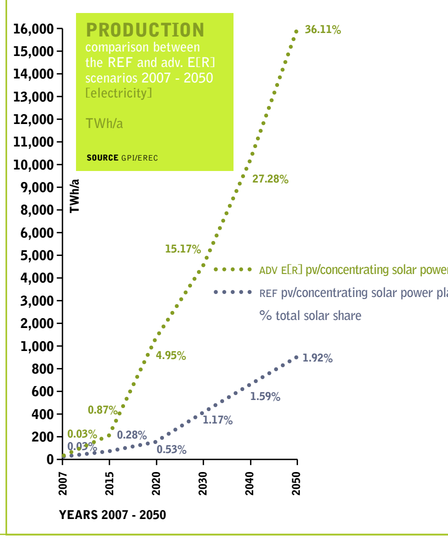


PRODUCTION

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

TWh/a

SOURCE GPI/EREC



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

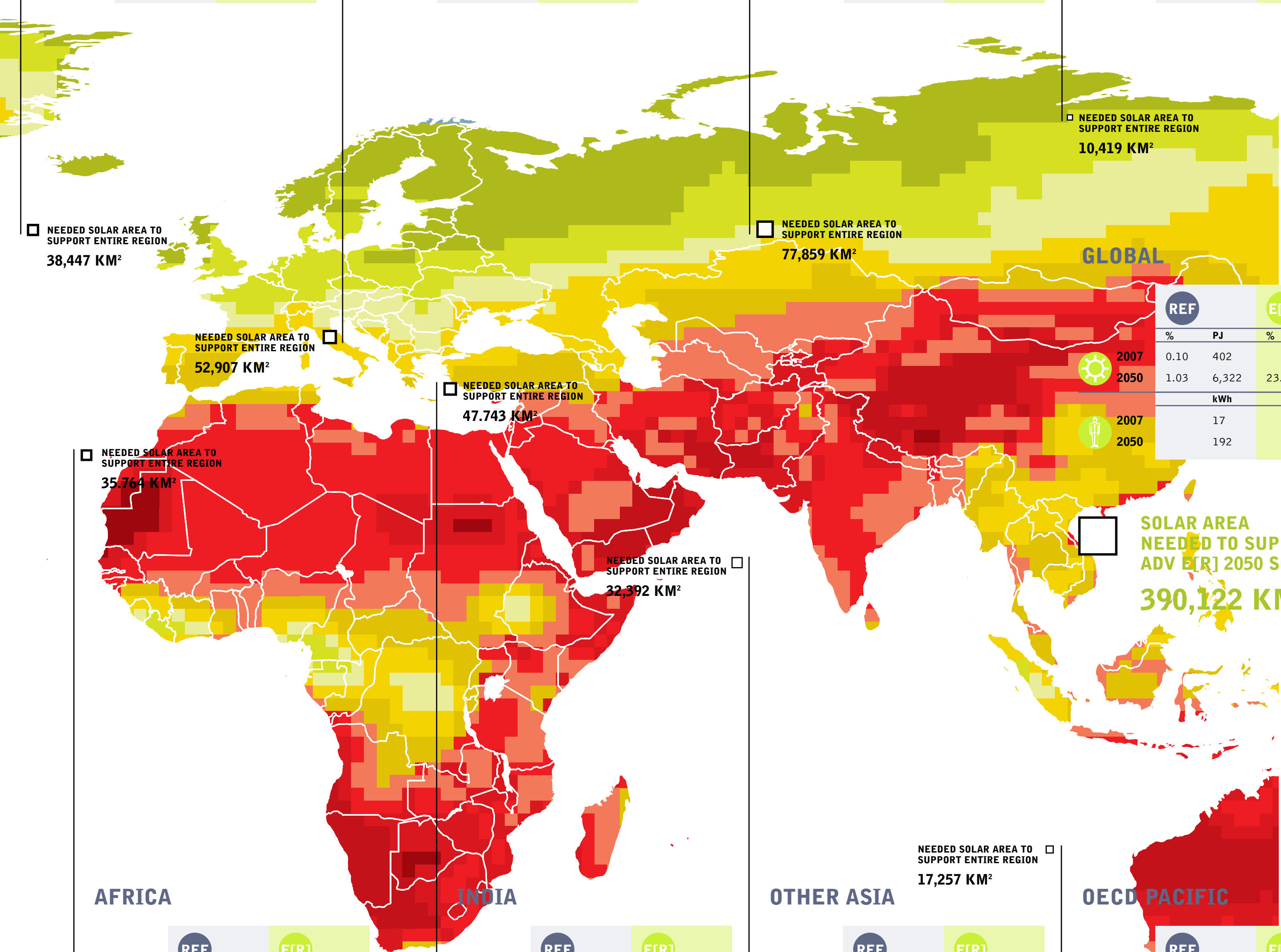
	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.17H	36		
2050	0.62	319	53H	14,696
		kWh		kWh
2007		50H		
2050		251		11,552H

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

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

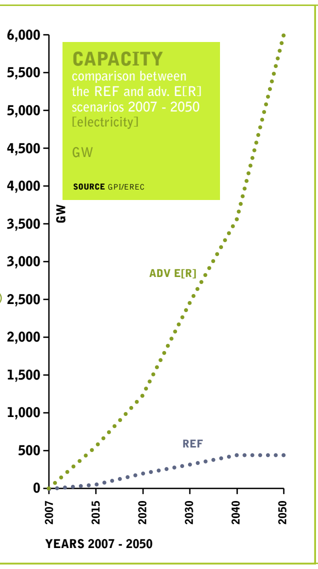
	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.02L	6L		
2050	0.23	182	24	13,262M
		kWh		kWh
2007		1		
2050		31		2,282

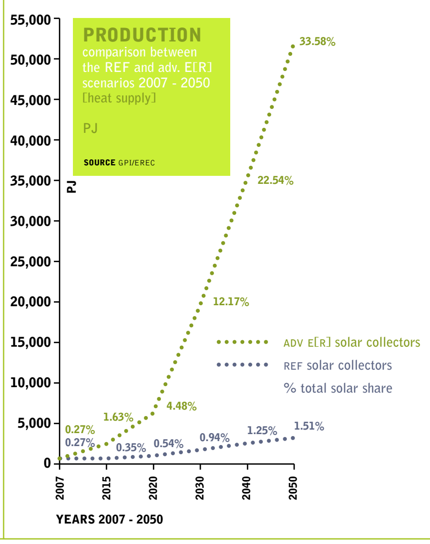
OTHER ASIA

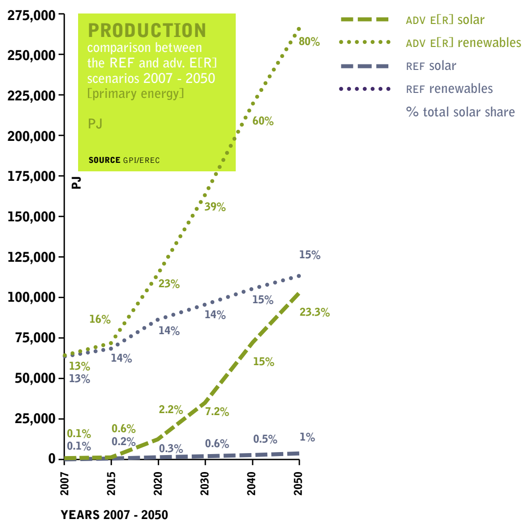
	REF %	REF PJ	E[R] %	E[R] PJ
2007	0.01L	4L		
2050	0.58	405	22	8,998
		kWh		kWh
2007		1L		
2050		74		1,649L

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

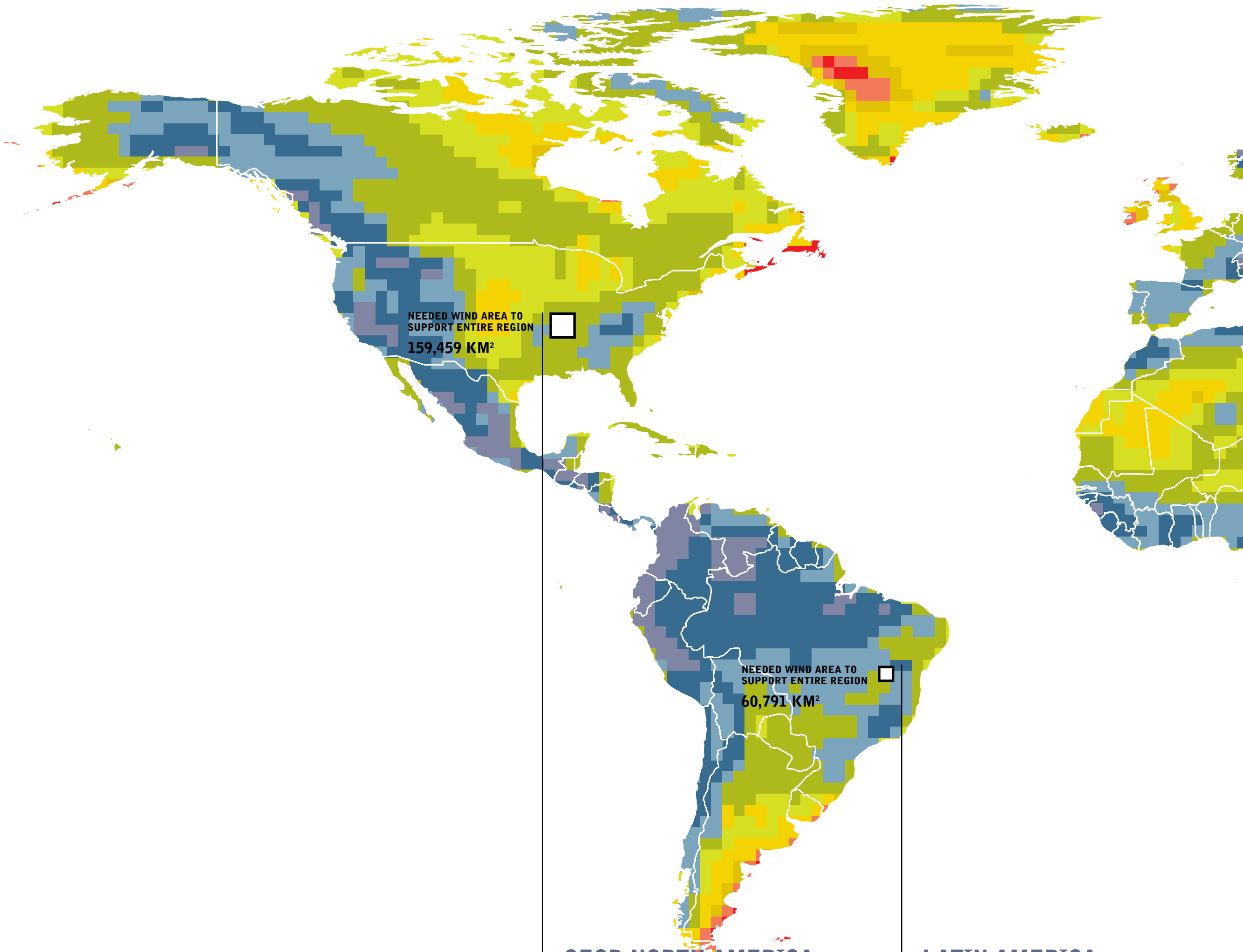






map 8.6: wind reference scenario and the advanced energy [r]evolution scenario

WORLDWIDE SCENARIO



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

RENEWABLE RESOURCE

WIND

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

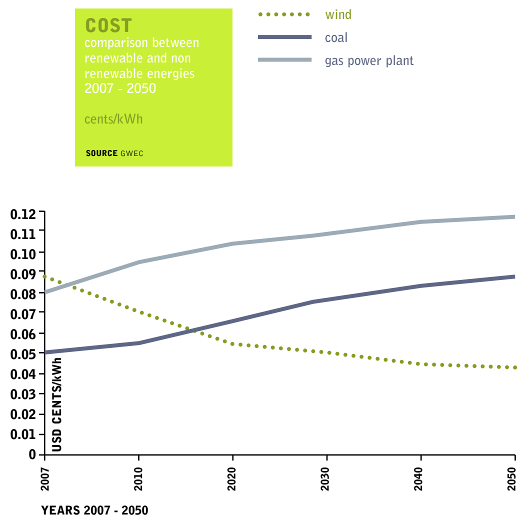
E[R] ADVANCED ENERGY [R]EVOLUTION SCENARIO

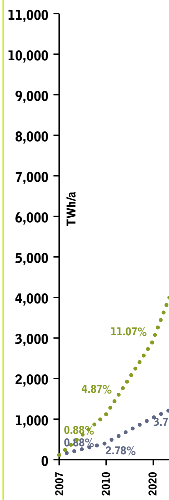
0 1000 KM

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

PRODUCTION PER PERSON KILOWATT HOUR [kWh]

H HIGHEST | M MIDDLE | L LOWEST





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

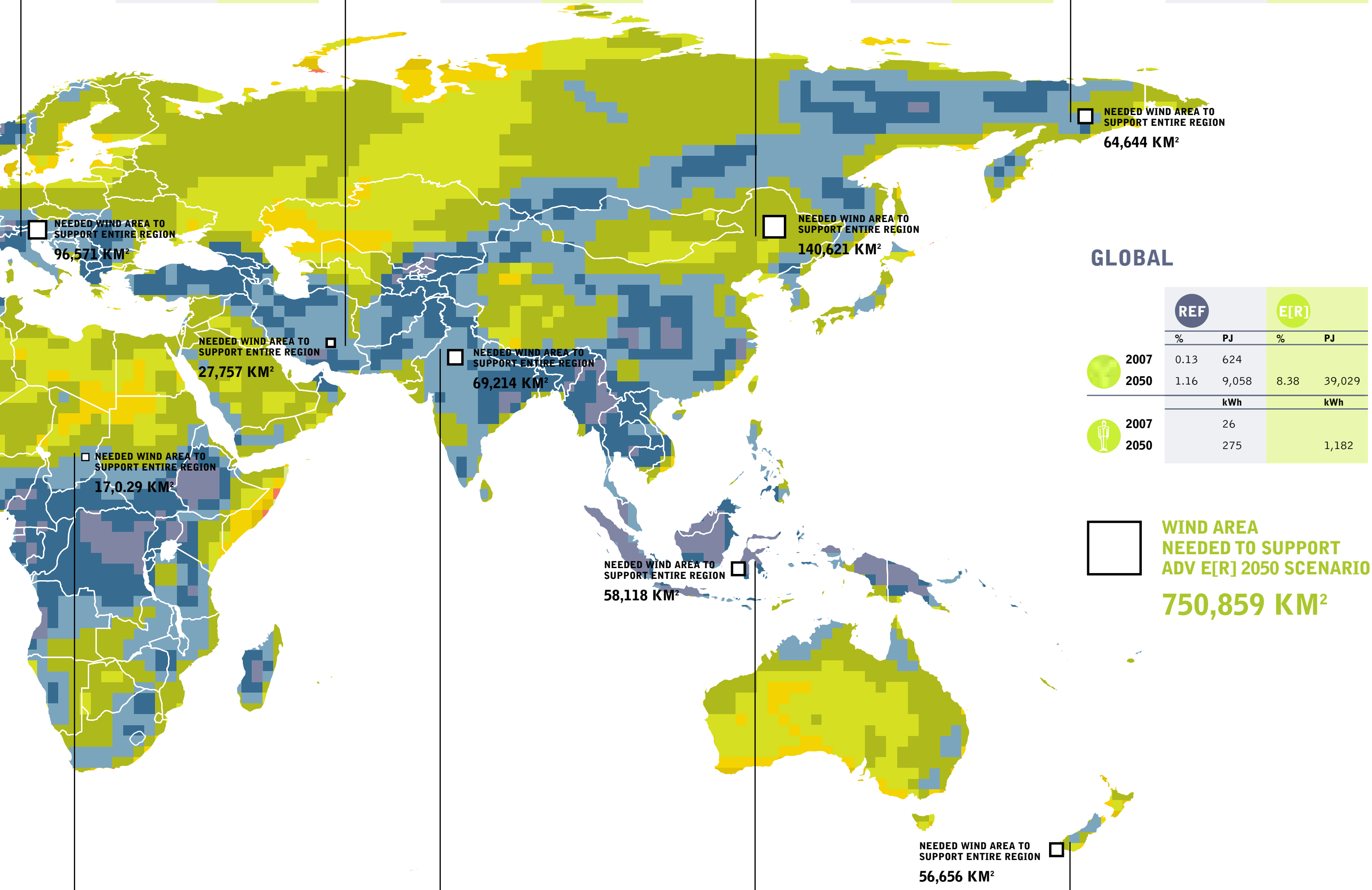
		REF %	REF PJ	E[R] %	E[R] PJ
	2007	0.00L	1L		
	2050	0.26L	133L	4.78	1,314
			kWh		kWh
	2007		1		
	2050		105		1,033

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

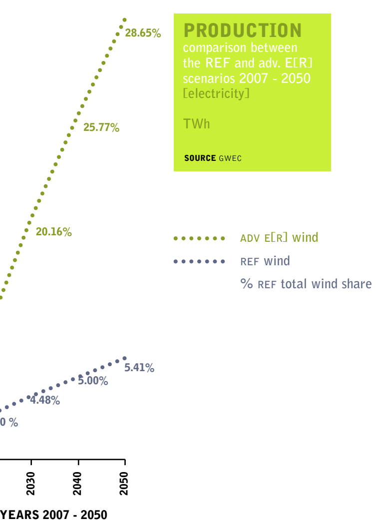
		REF %	REF PJ	E[R] %	E[R] PJ
	2007	0.17	42M		
	2050	0.48	374	6.38	3,488
			kWh		kWh
	2007		10		
	2050		64		600

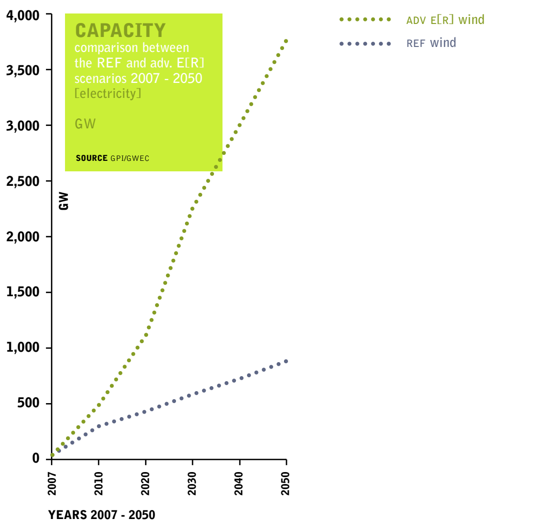
ASIA

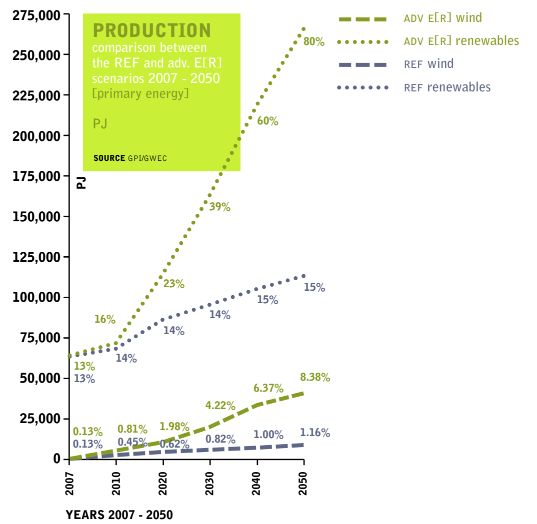
		REF %	REF PJ	E[R] %	E[R] PJ
	2007	0.01	2L		
	2050	0.69	475	8.75	3,557
			kWh		kWh
	2007		0L		
	2050		87		652

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

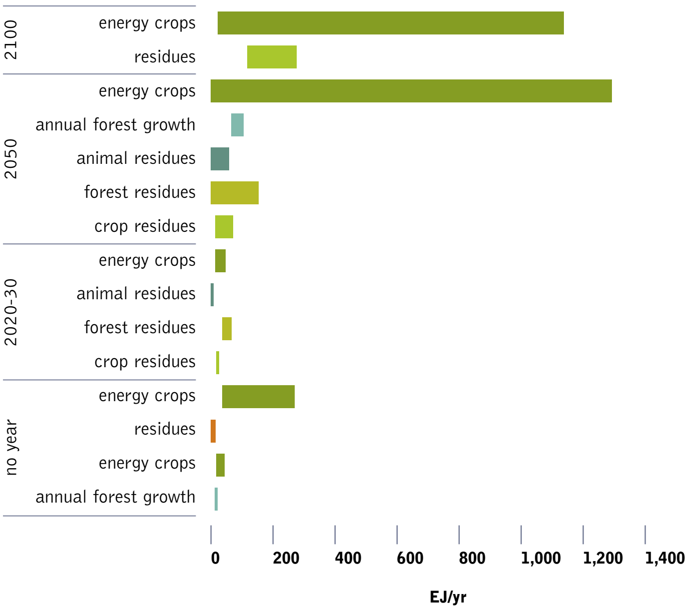






GREENPEACE DESIGN WWW.ONEHEMISPHERE.SE CONCEPT SVEN TESKE/GREENPEACE INTERNATIONAL.

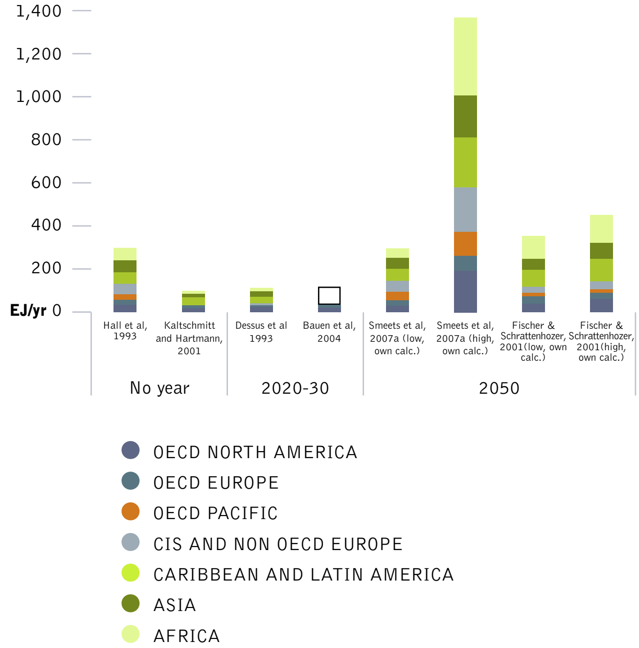
figure 7.2: ranges of potential for different biomass types



source GERMAN BIOMASS RESEARCH CENTRE (DBFZ)

figure 7.3: bio energy potential analysis from different authors

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



source GERMAN BIOMASS RESEARCH CENTRE (DBFZ)

potential of energy crops

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

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

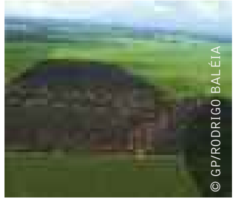
In a next step the surpluses of agricultural areas were classified either as arable land or grassland. On grassland, hay and grass silage are produced, on arable land fodder silage and Short Rotation Coppice (such as fast-growing willow or poplar) are cultivated. Silage of green fodder and grass are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

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

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

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.



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 7.4: world wide energy crop potentials in different scenarios

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

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

energy technologies

GLOBAL

8

“the technology is here, all we need is political will.”

CHRIS
SUPORTER, AUSTRALIA

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

This chapter describes the range of technologies available now and in the future to satisfy the world's energy demand. The Energy [R]evolution scenario is focused on the potential for energy savings and renewable sources, primarily in the electricity and heat generating sectors.

fossil fuel technologies

The most commonly used fossil fuels for power generation around the world are coal and gas. Oil is still used where other fuels are not readily available, for example islands or remote sites, or where there is an indigenous resource. Together, coal and gas currently account for over half of global electricity supply.

coal combustion technologies In a conventional coal-fired power station, pulverised or powdered coal is blown into a combustion chamber where it is burned at high temperature. The resulting heat is used to convert water flowing through pipes lining the boiler into steam. This drives a steam turbine and generates electricity. Over 90% of global coal-fired capacity uses this system. Coal power stations can vary in capacity from a few hundred megawatts up to several thousand.

A number of technologies have been introduced to improve the environmental performance of conventional coal combustion. These include coal cleaning (to reduce the ash content) and various 'bolt-on' or 'end-of-pipe' technologies to reduce emissions of particulates, sulphur dioxide and nitrogen oxide, the main pollutants resulting from coal firing apart from carbon dioxide. Flue gas desulphurisation (FGD), for example, most commonly involves 'scrubbing' the flue gases using an alkaline sorbent slurry, which is predominantly lime or limestone based.

More fundamental changes have been made to the way coal is burned to both improve its efficiency and further reduce emissions of pollutants. These include:

- **integrated gasification combined cycle:** Coal is not burned directly but reacted with oxygen and steam to form a synthetic gas composed mainly of hydrogen and carbon monoxide. This is cleaned and then burned in a gas turbine to generate electricity and produce steam to drive a steam turbine. IGCC improves the efficiency of coal combustion from 38-40% up to 50%.
- **supercritical and ultrasupercritical:** These power plants operate at higher temperatures than conventional combustion, again increasing efficiency towards 50%.
- **fluidised bed combustion:** Coal is burned in a reactor comprised of a bed through which gas is fed to keep the fuel in a turbulent state. This improves combustion, heat transfer and the recovery of waste products. By elevating pressures within a bed, a high-pressure gas stream can be used to drive a gas turbine, generating electricity. Emissions of both sulphur dioxide and nitrogen oxide can be reduced substantially.
- **pressurised pulverised coal combustion:** Mainly being developed in Germany, this is based on the combustion of a finely ground cloud of coal particles creating high pressure, high temperature steam for power generation. The hot flue gases are used to generate electricity in a similar way to the combined cycle system.

Other potential future technologies involve the increased use of coal gasification. Underground Coal Gasification, for example, involves converting deep underground unworked coal into a combustible gas which can be used for industrial heating, power generation or the manufacture of hydrogen, synthetic natural gas or other chemicals. The gas can be processed to remove CO_2 before it is passed on to end users. Demonstration projects are underway in Australia, Europe, China and Japan.

gas combustion technologies Natural gas can be used for electricity generation through the use of either gas or steam turbines. For the equivalent amount of heat, gas produces about 45% less carbon dioxide during its combustion than coal.

Gas turbine plants use the heat from gases to directly operate the turbine. Natural gas fuelled turbines can start rapidly, and are therefore often used to supply energy during periods of peak demand, although at higher cost than baseload plants.

Particularly high efficiencies can be achieved through combining gas turbines with a steam turbine in combined cycle mode. In a **combined cycle gas turbine (CCGT)** plant, a gas turbine generator produces electricity and the exhaust gases from the turbine are then used to make steam to generate additional electricity. The efficiency of modern CCGT power stations can be more than 50%. Most new gas power plants built since the 1990s have been of this type.

At least until the recent increase in global gas prices, CCGT power stations have been the cheapest option for electricity generation in many countries. Capital costs have been substantially lower than for coal and nuclear plants and construction time shorter.

carbon reduction technologies Whenever a fossil fuel is burned, carbon dioxide (CO_2) is produced. Depending on the type of power plant, a large quantity of the gas will dissipate into the atmosphere and contribute to climate change. A hard coal power plant discharges roughly 720 grammes of carbon dioxide per kilowatt hour, a modern gas-fired plant about 370g CO_2/kWh. One method, currently under development, to mitigate the CO_2 impact of fossil fuel combustion is called carbon capture and storage (CCS). It involves capturing CO_2 from power plant smokestacks, compressing the captured gas for transport via pipeline or ship and pumping it into underground geological formations for permanent storage.

While frequently touted as the solution to the carbon problem inherent in fossil fuel combustion, CCS for coal-fired power stations is unlikely to be ready for at least another decade. Despite the 'proof of concept' experiments currently in progress, as a fully integrated process the technology remains unproven in relation to all of its operational components. Suitable and effective capture technology has not been developed and is unlikely to be commercially available any time soon; effective and safe long-term storage on the scale necessary has not been demonstrated; and serious concerns attach to the safety aspects of transport and injection of CO_2 into designated formations, while long term retention cannot reliably be assured.

Deploying the technology on coal power plants is likely to double construction costs, increase fuel consumption by 10-40%, consume more water, generate more pollutants and ultimately require the public sector to ensure that the CO_2 stays where it has been buried. In a similar way to the disposal of nuclear waste, CCS envisages creating a scheme whereby future generations monitor in perpetuity the climate pollution produced by their predecessors.

carbon dioxide storage In order to benefit the climate, captured CO_2 has to be stored somewhere permanently. Current thinking is that it can be pumped under the earth's surface at a depth of over 3,000 feet into geological formations, such as saline aquifers. However, the volume of CO_2 that would need to be captured and stored is enormous - a single coal-fired power plant can produce 7 million tonnes of CO_2 annually.

It is estimated that a single 'stabilisation wedge' of CCS (enough to reduce carbon emissions by 1 billion metric tonnes per year by 2050) would require a flow of CO_2 into the ground equal to the current flow out of the ground - and in addition to the associated infrastructure to compress, transport and pump it underground. It is still not clear that it will be technically feasible to capture and bury this much carbon, both in terms of the number of storage sites and whether they will be located close enough to power plants.

Even if it is feasible to bury hundreds of thousands of megatons of CO_2 there is no way to guarantee that storage locations will be appropriately designed and managed over the timescales required. The world has limited experience of storing CO_2 underground; the longest running storage project at Sleipner in the Norweigian North Sea began operation only in 1996. This is particularly concerning because as long as CO_2 is present in geological sites, there is a risk of leakage. Although leakages are unlikely to occur in well-characterised, managed and monitored sites, permanent storage stability cannot be guaranteed since tectonic activity and natural leakage over long timeframes are impossible to predict.

Sudden leakage of CO_2 can be fatal. Carbon dioxide is not itself poisonous, and is contained (approx. 0.04%) in the air we breathe. But as concentrations increase it displaces the vital oxygen in the air. Air with concentrations of 7 to 8% CO_2 by volume causes death by suffocation after 30 to 60 minutes.

There are also health hazards when large amounts of CO_2 are explosively released. Although the gas normally disperses quickly after leaking, it can accumulate in depressions in the landscape or closed buildings, since carbon dioxide is heavier than air. It is equally dangerous when it escapes more slowly and without being noticed in residential areas, for example in cellars below houses.

The dangers from such leaks are known from natural volcanic CO_2 degassing. Gas escaping at the Lake Nyos crater lake in Cameroon, Africa in 1986 killed over 1,700 people. At least ten people have died in the Lazio region of Italy in the last 20 years as a result of CO_2 being released.

carbon storage and climate change targets Can carbon storage contribute to climate change reduction targets? In order to avoid dangerous climate change, global greenhouse gas emissions need to peak by between 2015 and 2020 and fall dramatically thereafter. Power plants capable of capturing and storing CO_2 are still being developed, however, and won't become a reality for at least another decade, if ever. This means that even if CCS works, the technology would not make any substantial contribution towards protecting the climate before 2020.

Power plant CO_2 storage will also not be of any great help in attaining the goal of at least an 80% greenhouse gas reduction by 2050 in OECD countries. Even if CCS were to be available in 2020, most of the world's new power plants will have just finished being modernised. All that could then be done would be for existing power plants to be retrofitted and CO_2 captured from the waste gas flow. Retrofitting power plants would be an extremely expensive exercise. 'Capture ready' power plants are equally unlikely to increase the likelihood of retrofitting existing fleets with capture technology.

The conclusion reached in the Energy [R]evolution scenario is that renewable energy sources are already available, in many cases cheaper, and lack the negative environmental impacts associated with fossil fuel exploitation, transport and processing. It is renewable energy together with energy efficiency and energy conservation – and not carbon capture and storage – that has to increase worldwide so that the primary cause of climate change – the burning of fossil fuels like coal, oil and gas – is stopped.

Greenpeace opposes any CCS efforts which lead to:

- Public financial support to CCS, at the expense of funding renewable energy development and investment in energy efficiency.
- The stagnation of renewable energy, energy efficiency and energy conservation improvements
- Inclusion of CCS in the Kyoto Protocol's Clean Development Mechanism (CDM) as it would divert funds away from the stated intention of the mechanism, and cannot be considered clean development under any coherent definition of this term.
- The promotion of this possible future technology as the only major solution to climate change, thereby leading to new fossil fuel developments – especially lignite and black coal-fired power plants, and an increase in emissions in the short to medium term.

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

nuclear technologies

Generating electricity from nuclear power involves transferring the heat produced by a controlled nuclear fission reaction into a conventional steam turbine generator. The nuclear reaction takes place inside a core and surrounded by a containment vessel of varying design and structure. Heat is removed from the core by a coolant (gas or water) and the reaction controlled by a moderating element or "moderator".

Across the world over the last two decades there has been a general slowdown in building new nuclear power stations. This has been caused by a variety of factors: fear of a nuclear accident, following the events at Three Mile Island, Chernobyl and Monju, increased scrutiny of economics and environmental factors, such as waste management and radioactive discharges.

nuclear reactor designs: evolution and safety issues At the beginning of 2005 there were 441 nuclear power reactors operating in 31 countries around the world. Although there are dozens of different reactor designs and sizes, there are three broad categories either currently deployed or under development. These are:

Generation I: Prototype commercial reactors developed in the 1950s and 1960s as modified or enlarged military reactors, originally either for submarine propulsion or plutonium production.

Generation II: Mainstream reactor designs in commercial operation worldwide.

Generation III: New generation reactors now being built.

Generation III reactors include the so-called Advanced Reactors, three of which are already in operation in Japan, with more under construction or planned. About 20 different designs are reported to be under development[56], most of them 'evolutionary' designs developed from Generation II reactor types with some modifications, but without introducing drastic changes. Some of them represent more innovative approaches. According to the World Nuclear Association, reactors of Generation III are characterised by the following:

- A standardised design for each type to expedite licensing, reduce capital cost and construction time.
- A simpler and more rugged design, making them easier to operate and less vulnerable to operational upsets.
- Higher availability and longer operating life, typically 60 years.
- Reduced possibility of core melt accidents.
- Minimal effect on the environment.
- Higher burn-up to reduce fuel use and the amount of waste.
- Burnable absorbers ('poisons') to extend fuel life.

To what extent these goals address issues of higher safety standards, as opposed to improved economics, remains unclear.

Of the new reactor types, the European Pressurised Water Reactor (EPR) has been developed from the most recent Generation II designs to start operation in France and Germany.[57] Its stated goals are to improve safety levels - in particular to reduce the probability of a severe accident by a factor of ten, achieve mitigation from severe accidents by restricting their consequences to the plant itself, and reduce costs. Compared to its predecessors, however, the EPR displays several modifications which constitute a reduction of safety margins, including:

- The volume of the reactor building has been reduced by simplifying the layout of the emergency core cooling system, and by using the results of new calculations which predict less hydrogen development during an accident.
- The thermal output of the plant has been increased by 15% relative to existing French reactors by increasing core outlet temperature, letting the main coolant pumps run at higher capacity and modifying the steam generators.
- The EPR has fewer redundant pathways in its safety systems than a German Generation II reactor.

Several other modifications are hailed as substantial safety improvements, including a 'core catcher' system to control a meltdown accident. Nonetheless, in spite of the changes being envisaged, there is no guarantee that the safety level of the EPR actually represents a significant improvement. In particular, reduction of the expected core melt probability by a factor of ten is not proven. Furthermore, there are serious doubts as to whether the mitigation and control of a core melt accident with the core catcher concept will actually work.

Finally, **Generation IV** reactors are currently being developed with the aim of commercialisation in 20-30 years.

56 IAEA 2004; WNO 2004A.
57 HAINZ 2004.

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.

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.

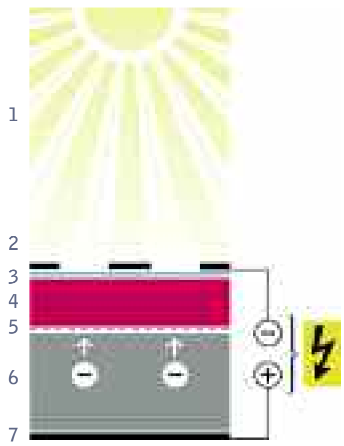
technologies

- **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.

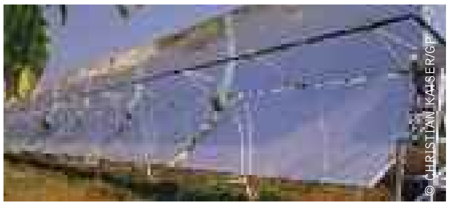
figure 9.1: photovoltaics technology



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

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.



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).

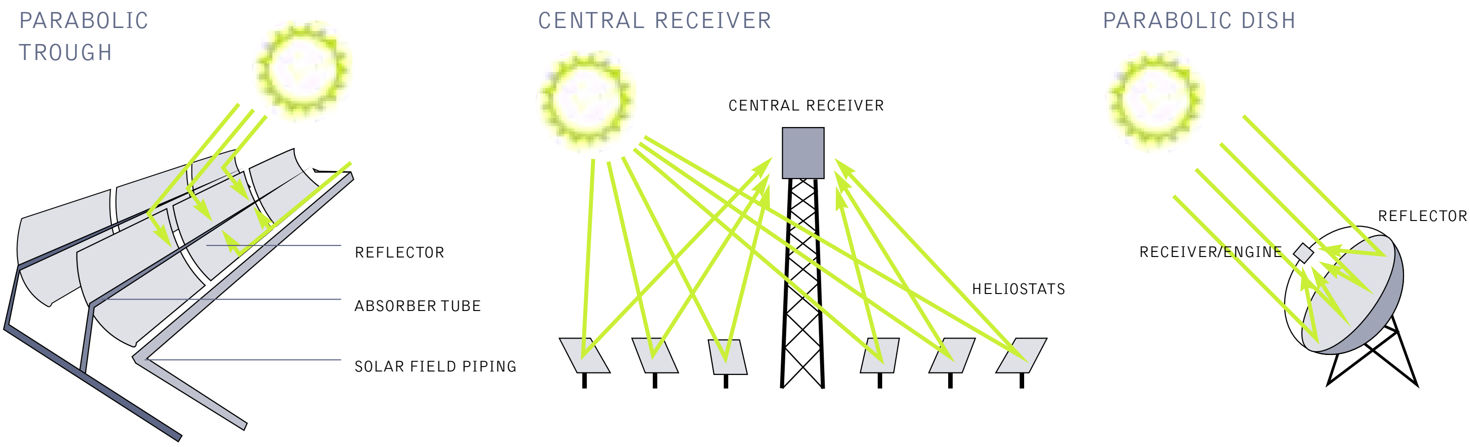
- **central receiver or solar tower** A circular array of heliostats (large individually tracking mirrors) is used to concentrate sunlight on to a central receiver mounted at the top of a tower. A heat-transfer medium absorbs the highly concentrated radiation reflected by the heliostats and converts 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



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

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.

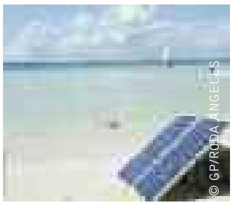
Smaller wind turbines can produce power efficiently in areas that otherwise have no access to electricity. This power can be used directly or stored in batteries. New technologies for using the wind's power are also being developed for exposed buildings in densely populated cities.

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.

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.



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.

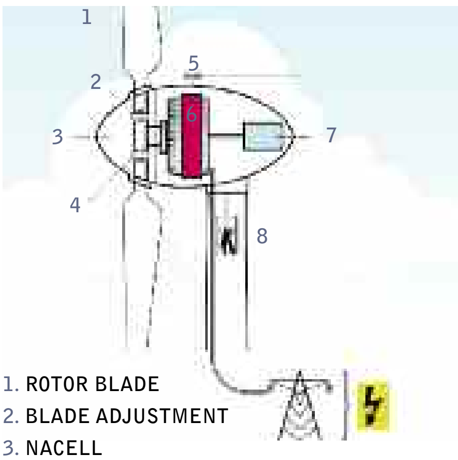
biomass energy Biomass is a broad term used to describe material of recent biological origin that can be used as a source of energy. This includes wood, crops, algae and other plants as well as agricultural and forest residues. Biomass can be used for a variety of end uses: heating, electricity generation 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.

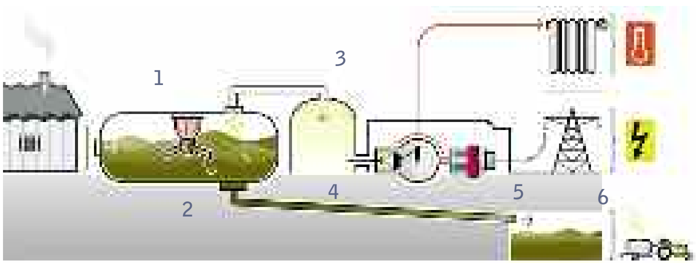
biomass technology A number of processes can be used to convert energy from biomass. These divide into thermal systems, which involve direct combustion of solids, liquids or a gas via pyrolysis or gasification, and biological systems, which involve decomposition of solid biomass to liquid or gaseous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

- **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.[58]

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 bio fuels can be produced from any biological carbon source, although the most common are photosynthetic plants. Various plants and plant-derived materials are used for bio fuel production.

Globally bio fuels are most commonly used to power vehicles, but can also be used for other purposes. The production and use of bio fuels 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 bio fuels 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.

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

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

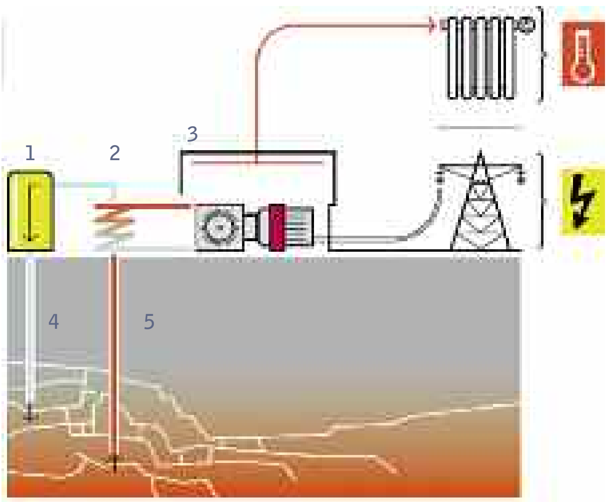
geothermal energy Geothermal energy is heat derived from deep underneath the earth's crust. In most areas, this heat reaches the surface in a very diffuse state. However, due to a variety of geological processes, some areas, including the western part of the USA, west and central Eastern Europe, Iceland, 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.

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.

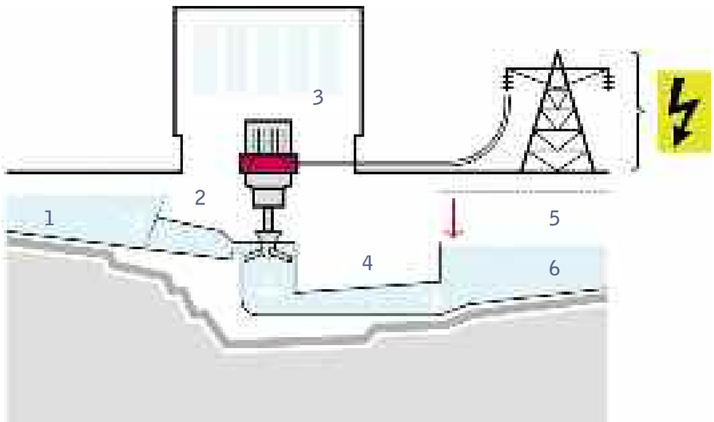
The main requirement for hydro power is to create an artificial head so that water, diverted through an intake channel or pipe into a turbine, discharges back into the river downstream. Small hydro power is mainly 'run-of-the-river' and does not collect significant amounts of stored water, requiring 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

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.


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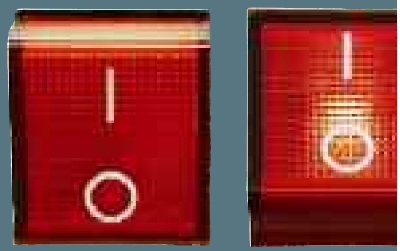
images 1. BIOMASS CROPS. **2.** OCEAN ENERGY. **3.** CONCENTRATING SOLAR POWER (CSP).

GLOBAL

9



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.

"...so I urge the government to act and to act quickly."

LYN ALLISON
LEADER OF THE AUSTRALIAN DEMOCRATS, SENATOR 2004-2008

If the Energy [R]evolution is to happen, then governments around the world need to play a major part. Their contribution will include regulating the energy market, both on the supply and demand side, educating everyone from consumers to industrialists, and stimulating the market for renewable energy and energy efficiency by a range of economic mechanisms. They can also build on the successful policies already adopted by other countries.

To start with they need to agree on further binding emission reduction commitments in the second phase of the Kyoto Protocol. Only by setting stringent greenhouse gas emission reduction targets will the cost of carbon become sufficiently high to properly reflect its impact on society. This will in turn stimulate investments in renewable energy. Through massive funding for mitigation and technology cooperation, industrialised countries will also stimulate the development of renewable energy and energy efficiency in developing countries.

Alongside these measures specific support for the introduction of feed-in tariffs in the developing world - the extra costs of which could be funded by industrialised countries - could create similar incentives to those in countries like Germany and Spain, where the growth of renewable energy has boomed. Energy efficiency measures should be more strongly supported through the Kyoto process and its financial mechanisms.

Carbon markets can also play a distinctive role in making the Energy [R]evolution happen, although the functioning of the carbon market needs a thorough revision in order to ensure that the price of carbon is sufficiently high to reflect its real cost. Only then can we create a level playing field for renewable energy and be able to calculate the economic benefits of energy efficiency.

Industrialised countries should ensure that all financial flows to energy projects in developing countries are targeted towards renewable energy and energy efficiency. All financial assistance, whether through grants, loans or trade guarantees, directed towards supporting fossil fuel and nuclear power production, should be phased out in the next two to five years. International financial institutions, export credit agencies and development agencies should provide the required finance and infrastructure to create systems and networks to deliver the seed capital, institutional support and capacity to facilitate the implementation of the Energy [R]evolution in developing countries.

While any energy policy needs to be adapted to the local situation, we are proposing the following policies to encourage the Energy [R]evolution that all countries should adopt.

1. climate policy

Policies to limit the effects of climate change and move towards a renewable energy future must be based on penalising energy sources that contribute to global pollution.

Action: Phase out subsidies for fossil fuel and nuclear power production and inefficient energy use

The United Nations Environment Programme (UNEP) estimates (August 2008) the annual bill for worldwide energy subsidies at about $300 billion, or 0.7% of global GDP.[59] Approximately 80% of this is spent on funding fossil fuels and more than 10% to support nuclear energy. The lion's share is used to artificially lower the real price of fossil fuels. Subsidies (including loan guarantees) make energy efficiency less attractive, keep renewable energy out of the market place and prop up non-competitive and inefficient technologies.

Eliminating direct and indirect subsidies to fossil fuels and nuclear power would help move us towards a level playing field across the energy sector. Scrapping these payments would, according to UNEP, reduce greenhouse gas emissions by as much as 6% a year, while contributing 0.1% to global GDP. Many of these seemingly well intentioned subsidies rarely make economic sense anyway, and hardly ever address poverty, thereby challenging the widely held view that such subsidies assist the poor.

Instead, governments should use subsidies to stimulate investment in energy-saving measures and the deployment of renewable energy by reducing their investment costs. Such support could include grants, favourable loans and fiscal incentives, such as reduced taxes on energy efficient equipment, accelerated depreciation, tax credits and tax deductions.

The G-20 countries, meeting in Philadelphia in September 2009, called for world leaders to eliminate fossil fuel subsidies, but hardly any progress has been made since then towards implementing the resolution.

Action: Introduce the "polluter pays" principle

A substantial indirect form of subsidy comes from the fact that the energy market does not incorporate the external, societal costs of the use of fossil fuels and nuclear power. Pricing structures in the energy markets should reflect the full costs to society of producing energy.

This requires that governments apply a 'polluter pays' system that charges the emitters accordingly, or applies suitable compensation to non-emitters. Adoption of polluter pays taxation to electricity sources, or equivalent compensation to renewable energy sources, and exclusion of renewables from environment-related energy taxation, is essential to achieve fairer competition in the world's electricity markets.

references
59 "REFORMING ENERGY SUBSIDIES: OPPORTUNITIES TO CONTRIBUTE TO THE CLIMATE CHANGE AGENDA", UNEP, 2008.

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.

The real cost of conventional energy production includes expenses absorbed by society, such as health impacts and local and regional environmental degradation - from mercury pollution to acid rain – as well as the global negative impacts of climate change. Hidden costs include the waiving of nuclear accident insurance that is too expensive to be covered by the nuclear power plant operators. The Price Anderson Act, for instance, limits the liability of US nuclear power plants in the case of an accident to an amount of up to $98 million per plant, and only $15 million per year per plant, with the rest being drawn from an industry fund of up to $10 billion. After that the taxpayer becomes responsible.[60]

Although environmental damage should, in theory, be rectified by forcing polluters to pay, the environmental impacts of electricity generation can be difficult to quantify. How do you put a price on lost homes on Pacific Islands as a result of melting icecaps or on deteriorating health and human lives?

An ambitious project, funded by the European Commission - ExternE – has tried to quantify the full environmental costs of electricity generation. It estimates that the cost of producing electricity from coal or oil would double and that from gas would increase by 30% if external costs, in the form of damage to the environment and health, were taken into account. If those environmental costs were levied on electricity generation according to its impact, many renewable energy sources would not need any support. If, at the same time, direct and indirect subsidies to fossil fuels and nuclear power were removed, the need to support renewable electricity generation would seriously diminish or cease to exist.

One way to achieve this is by a carbon tax that ensures a fixed price is paid for each unit of carbon that is released into the atmosphere. Such taxes have, or are being, implemented in countries such as Sweden and the state of British Columbia. Another approach is through cap and trade, as operating in the European Union and planned in New Zealand and several US states. This concept gives pollution reduction a value in the marketplace.

In theory, cap and trade prompts technological and process innovations that reduce pollution down to the required levels. A stringent cap and trade can harness market forces to achieve cost-effective greenhouse gas emission reductions. But this will only happen if governments implement true 'polluter pays' cap and trade schemes that charge emitters accordingly.

Government programmes that allocate a maximum amount of emissions to industrial plants have proved to be effective in promoting energy efficiency in certain industrial sectors. To be successful, however, these allowances need to be strictly limited and their allocation auctioned.

2. energy policy and market regulation

Essential reforms are necessary in the electricity sector if new renewable energy technologies are to be implemented more widely.

Action: Reform the electricity market to allow better integration of renewable energy technologies

Complex licensing procedures and bureaucratic hurdles constitute one of the most difficult obstacles faced by renewable energy in many countries. A clear timetable for approving renewable energy projects should be set for all administrations at all levels, and they should receive priority treatment. Governments should propose more detailed procedural guidelines to strengthen the existing legislation and at the same time streamline the licensing procedures.

Other barriers include the lack of long term and integrated resource planning at national, regional and local level; the lack of predictability and stability in the markets; the grid ownership by vertically integrated companies and the absence of (access to) grids for large scale renewable energy sources, such as offshore wind power or concentrating solar power plants. The International Energy Agency has identified Denmark, Spain and Germany as example of best practice in a reformed electricity market that supports the integration of renewable energy.

In order to remove these market barriers, governments should:

- streamline planning procedures and permit systems and integrate least cost network planning;
- ensure access to the grid at fair and transparent prices;
- ensure priority access and transmission security for electricity generated from renewable energy resources, including fina;
- unbundle all utilities into separate generation, distribution and selling companies;
- ensure that the costs of grid infrastructure development and reinforcement are borne by the grid management authority rather than individual renewable energy projects;
- ensure the disclosure of fuel mix and environmental impact to end users;
- establish progressive electricity and final energy tariffs so that the price of a kWh costs more for those who consume more;
- set up demand-side management programmes designed to limit energy demand, reduce peak loads and maximise the capacity factor of the generation system. Demand-side management should also be adapted to facilitate the maximum possible share of renewable energies in the power mix;
- introduce pricing structures in the energy markets to reflect the full costs to society of producing energy.

references
60 HTTP://EN.WIKIPEDIA.ORG/WIKI/PRICE-ANDERSON_NUCLEAR_INDUSTRIES_INDEMNITY_ACT

3. targets and incentives for renewables

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 which guarantee stable tariffs over a period of up to 20 years.

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

Support mechanisms for different sectors and technologies can vary according to regional characteristics, priorities or starting points, but some general principles should apply. These are:

- **Long term stability:** Policy makers need to make sure that investors can rely on the long-term stability of any support scheme. It is absolutely crucial to avoid stop-and-go markets by changing the system or the level of support frequently.
- **Encouraging local and regional benefits and public acceptance:** A support scheme should encourage local/regional development, employment and income generation. It should also encourage public acceptance of renewables, including increased stakeholder involvement.

Incentives can be provided for renewable energy through both targets and price support mechanisms.

Action: Establish legally binding targets for renewable energy and combined heat and power generation

An increasing number of countries have established targets for renewable energy, either as a general target or broken down by sector for power, transport and heating. These are either expressed in terms of installed capacity or as a percentage of energy consumption. China and the European Union have a target for 20% renewable energy by 2020, for example, and New Zealand has a 90% by 2025 target.

Although these targets are not always legally binding, they have served as an important catalyst for increasing the share of renewable energy throughout the world. The electricity sector clearly needs a long term horizon, as investments are often only paid back after 20 to 40 years. Renewable energy targets therefore need to have short, medium and long term stages and must be legally binding in order to be effective. In order for the proportion of renewable energy to increase significantly, targets must also be set in accordance with the potential for each technology (wind, solar, biomass etc) and taking into account existing and planned infrastructure. Every government should carry out a detailed analysis of the potential and feasibility of renewable energies in its own country, and define, based on that analysis, the deadline for reaching, either individually or in cooperation with other countries, a 100% renewable energy supply.

Action: Provide a stable return for investors through price support mechanisms

Price support mechanisms for renewable energy are a practical means of correcting market failures in the electricity sector. Their aim is to support market penetration of those renewable energy technologies, such as wind and solar thermal, that currently suffer from unfair competition due to direct and indirect support to fossil fuel use and nuclear energy, and to provide incentives for technology improvements and cost reductions so that technologies such as PV, wave and tidal can compete with conventional sources in the future.

Overall, there are two types of incentive to promote the deployment of renewable energy. These are Fixed Price Systems where the government dictates the electricity price (or premium) paid to the producer and lets the market determine the quantity, and Renewable Quota Systems (in the USA referred to as Renewable Portfolio Standards) where the government dictates the quantity of renewable electricity and leaves it to the market to determine the price. Both systems create a protected market against a background of subsidised, depreciated conventional generators whose external environmental costs are not accounted for. Their aim is to provide incentives for technology improvements and cost reductions, leading to cheaper renewables that can compete with conventional sources in the future.

The main difference between quota based and price based systems is that the former aims to introduce competition between electricity producers. However, competition between technology manufacturers, which is the most crucial factor in bringing down electricity production costs, is present regardless of whether government dictates prices or quantities. Prices paid to wind power producers are currently higher in many European quota based systems (UK, Belgium, Italy) than in fixed price or premium systems (Germany, Spain, Denmark).

The European Commission has concluded that fixed price systems are to be preferred above quota systems. If implemented well, fixed price systems are a reliable, bankable support scheme for renewable energy projects, providing long term stability and leading to lower costs. In order for such systems to achieve the best possible results, however, priority access to the grid must be ensured.

fixed price systems

Fixed price systems include investment subsidies, fixed feed-in tariffs, fixed premium systems and tax credits.

- **Investment subsidies** are capital payments usually made on the basis of the rated power (in kW) of the generator. It is generally acknowledged, however, that systems which base the amount of support on generator size rather than electricity output can lead to less efficient technology development. There is therefore a global trend away from these payments, although they can be effective when combined with other incentives.
- **Fixed feed-in tariffs (FITs)** widely adopted in Europe, have proved extremely successful in expanding wind energy in

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

Germany, Spain and Denmark. Operators are paid a fixed price for every kWh of electricity they feed into the grid. In Germany the price paid varies according to the relative maturity of the particular technology and reduces each year to reflect falling costs. The additional cost of the system is borne by taxpayers or electricity consumers.

The main benefit of a FIT is that it is administratively simple and encourages better planning. Although the FIT is not associated with a formal Power Purchase Agreement, distribution companies are usually obliged to purchase all the production from renewable installations. Germany has reduced the political risk of the system being changed by guaranteeing payments for 20 years. The main problem associated with a fixed price system is that it does not lend itself easily to adjustment – whether up or down - to reflect changes in the production costs of renewable technologies.

- **Fixed premium systems** sometimes called an "environmental bonus" mechanism, operate by adding a fixed premium to the basic wholesale electricity price. From an investor perspective, the total price received per kWh is less predictable than under a feed-in tariff because it depends on a constantly changing electricity price. From a market perspective, however, it is argued that a fixed premium is easier to integrate into the overall electricity market because those involved will be reacting to market price signals. Spain is the most prominent country to have adopted a fixed premium system.
- **Tax credits** as operated in the US and Canada, offer a credit against tax payments for every kWh produced. In the United States the market has been driven by a federal Production Tax Credit (PTC) of approximately 1.8 cents per kWh. It is adjusted annually for inflation.

renewable quota systems

Two types of renewable quota systems have been employed - tendering systems and green certificate systems.

- **Tendering systems** involve competitive bidding for contracts to construct and operate a particular project, or a fixed quantity of renewable capacity in a country or state. Although other factors are usually taken into account, the lowest priced bid invariably wins. This system has been used to promote wind power in Ireland, France, the UK, Denmark and China. The downside is that investors can bid an uneconomically low price in order to win the contract, and then not build the project. Under the UK's NFFO (Non-Fossil Fuel Obligation) tender system, for example, many contracts remained unused. It was eventually abandoned. If properly designed, however, with long contracts, a clear link to planning consent and a possible minimum price, tendering for large scale projects could be effective, as it has been for offshore oil and gas extraction in Europe's North Sea.
- **Tradable green certificate (TGC) systems** operate by offering "green certificates" for every kWh generated by a renewable producer. The value of these certificates, which can be traded on a market, is then added to the value of the basic electricity. A green certificate system usually operates in combination with a rising quota of renewable electricity generation. Power companies are bound by law to purchase an increasing proportion of renewables input. Countries which have adopted this system include the UK and Italy in Europe and many individual states in the US, where it is known as a Renewable Portfolio Standard. Compared with a fixed tender price, the TGC model is more risky for the investor, because the price fluctuates on a daily basis, unless effective markets for long-term certificate (and electricity) contracts are developed. Such markets do not currently exist. The system is also more complex than other payment mechanisms.

4. renewables for heating and cooling

The crucial requirement for both heating and cooling is often forgotten in the energy mix. In many regions of the world, such as Europe, nearly half of the total energy demand is for heating/cooling. This demand can be met economically without relying on fossil fuels.

Policies should make sure that specific targets and appropriate measures to support renewable heating and cooling are part of any national renewables strategy. These should include financial incentives, awareness raising campaigns, training of installers, architects and heating engineers, and demonstration projects. For new buildings, and those undergoing major renovation, an obligation to cover a minimum share of heat consumption by renewables should be introduced, as already implemented in some countries. At the same time, increased R&D efforts should be undertaken, particularly in the fields of heat storage and renewable cooling.

Governments should also promote the development of combined heat and power generation in those industrial sectors that are most attractive for CHP - where there is a demand for heat either directly or through a local (existing or potential) district heating system. Governments should set targets and efficiency standards for CHP and provide financial incentives for investment in industrial installations.

5. energy efficiency and innovation

Action: Set stringent efficiency and emissions standards for appliances, buildings, power plants and vehicles

Policies and measures to promote energy efficiency exist in many countries. Energy and information labels, mandatory minimum energy performance standards and voluntary efficiency agreements are the most popular measures. Effective government policies usually contain two elements - those that push the market through standards and those that pull through incentives - and have proved to be an effective, low cost way to coordinate a transition to more energy efficiency.

The Japanese front-runner programme, for example, is a regulatory scheme with mandatory targets which gives incentives to manufacturers and importers of energy-consuming equipment to continuously improve the efficiency of their products. It operates by allowing today's best models on the market to set the level for future standards.

In the residential sector in industrialised countries, standby power consumption ranges from 20 to 60 watts per household, equivalent to 4 to 10% of total residential energy consumption. Yet the technology is available to reduce standby power to 1 watt. A global standard, as proposed by the IEA, could mandate this reduction. Japan, South Korea and the state of California have not waited for this international approach and have already adopted standby standards.

Governments should mandate the phase-out of incandescent and inefficient light bulbs and replace them with the most efficient lighting. Countries like Cuba, Venezuela and Australia have already banned incandescent light bulbs.

Governments should also set emissions standards for cars and power plants, such as those proposed in Europe for passenger cars of 120g CO_2/km and 350g/kWh for power plants. Similar emissions standards, as already implemented in China, Japan and the states of Washington and California, will support innovation and ensure that inefficient vehicles and power plants are outlawed.

Action: Support innovation in energy efficiency, low carbon transport systems and renewable energy production

Innovation will play an important role in making the Energy [R]evolution happen, and is needed to realise the ambition of ever-improving efficiency and emissions standards. Programmes supporting renewable energy and energy efficiency development and diffusion are a traditional focus of energy and environmental policies because energy innovations face barriers all along the energy supply chain (from R&D to demonstration projects to widespread deployment). Direct government support through a variety of fiscal instruments, such as tax incentives, is vital to hasten deployment of radically new technologies due to a lack of industry investment. This suggests that there is a role for the public sector in increasing investment directly and in correcting market and regulatory obstacles that inhibit investment in new technology

Governments need to invest in research and development for more efficient appliances and building techniques, in new forms of insulation, in new types of renewable energy production (such as tidal and wave power) as well as in a low carbon transport future, through the development of better batteries for plug-in electric cars or fuels for aviation from renewable sources. Governments need to engage in innovation themselves, both through publicly funded research and by supporting private research and development.

There are numerous ways to support innovation. The most important policies are those that reduce the cost of research and development, such as tax incentives, staff subsidies or project grants. Financial support for research and development on 'dead end' energy solutions such as nuclear fusion should be diverted to supporting renewable energy, energy efficiency and decentralised energy solutions.

Specific proposals for efficiency and innovation measures include:

appliances and lighting

Two types of renewable quota systems have been employed - tendering systems and green certificate systems.

- **Efficiency standards** Governments should set ambitious, stringent and mandatory efficiency standards for all energy consuming appliances that constantly respond to technical innovation and enforce the phase-out of the most inefficient appliances. These standards should allow the banning of inefficient products from the market, with penalties for non-compliance.
- **Consumer awareness** Governments should inform consumers and/or set up systems that compel retailers and manufacturers to do so, about the energy efficiency of the products they use and buy, including awareness-raising and educational programmes. Consumers often make their choices based on non-financial factors but lack the necessary information.
- **Energy labelling** Labels provide the means to inform consumers of the product's relative or absolute performance and energy operating costs. Governments should support the development of endorsement and comparison labels for electrical appliances.

buildings

- **Residential and commercial building codes** Governments should set mandatory building codes that require the use of a set share of renewable energy for heating and cooling and compliance with a limited annual energy consumption level. These codes should be regularly upgraded in order to make use of fresh products on the market and non-compliance should be penalised.
- **Financial incentives** Given that investment costs are often a barrier to implementing energy efficiency measures, in particular for retrofitting renewable energy options, governments should offer financial incentives including tax reductions schemes, investment subsidies and preferential loans.
- **Energy intermediaries and audit programmes** Governments should develop strategies and programmes to promote the education of architects, engineers and other professionals in the building sector as well as end-users about energy efficiency opportunities in new and existing buildings. As part of this strategy governments should invest in 'energy intermediaries' and energy audit programmes in order to assist professionals and consumers in identifying opportunities for improving the efficiency of their buildings.

transport

- **Emissions standards** Governments should regulate the efficiency of private cars and other transport vehicles in order to push manufacturers to reduce emissions through downsizing, design and technology improvement. Improvements in efficiency will reduce CO_2 emissions irrespective of the fuel used. After this further reductions could be achieved by using low-emission fuels. Emissions standards should provide for an average reduction of 5g CO_2/km/year in industrialised countries. These standards need to be mandatory. To dissuade car makers from overpowering high end cars a maximum CO_2 emissions limit for individual car models should be introduced.
- **Electric vehicles** Governments should develop incentives to promote the further development of electric cars and other efficient and sustainable low carbon transport technologies. Linking electric cars to a renewable energy grid is the best possible option to reduce emissions from the transport sector.
- **Transport demand management** Governments should invest in developing, improving and promoting low emission transport options, such as public and non-motorised transport, freight transport management programmes, teleworking and more efficient land use planning in order to limit journeys.

10

"because we use such inefficient lighting, 80 coal fired power plants are running day and night to produce the energy that is wasted."

GREENPEACE INTERNATIONAL
CLIMATE CAMPAIGN

image COAL FIRED POWER PLANT.

glossary of commonly used terms and abbreviations

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

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

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

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

conversion factors - fossil fuels

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

conversion factors - different energy units

FROM	TO: 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

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

definition of sectors

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

All definitions below are from the IEA Key World Energy Statistics

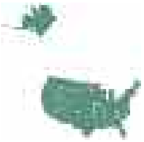
Industry sector: Consumption in the industry sector includes the following subsectors (energy used for transport by industry is not included -> see under "Transport")

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

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

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

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



usa: reference scenario

table 10.1: usa: electricity generation

TWh/a	2007	2015	2020	2030	2040	2050
Power plants	**3,992**	**4,182**	**4,379**	**4,826**	**5,285**	**5,740**
Coal	1,122	1,296	1,468	1,796	2,117	2,402
Lignite	937	750	650	500	350	231
Gas	702	697	703	723	755	786
Oil	51	19	8	6	5	5
Diesel	8	7	6	5	4	4
Nuclear	837	863	885	951	1,017	1,083
Biomass	32	63	78	122	171	219
Hydro	250	272	274	279	284	289
Wind	35	175	243	325	407	489
PV	1	8	18	40	60	80
Geothermal	17	27	34	45	56	67
Solar thermal power plants	0	5	12	34	58	82
Ocean energy	0	0	0	1	2	3
Combined heat & power production	**332**	**346**	**366**	**437**	**496**	**561**
Coal	56	60	66	83	107	135
Lignite	1	1	0	0	0	0
Gas	217	211	216	249	270	292
Oil	19	18	17	16	14	10
Biomass	39	54	64	84	99	115
Geothermal	0	1	2	4	5	9
Hydrogen	0	0	0	0	0	0
CHP by producer						
Main activity producers	185	190	194	237	260	283
Autoproducers	147	156	172	200	236	278
Total generation	**4,324**	**4,528**	**4,745**	**5,263**	**5,781**	**6,301**
Fossil	3,113	3,060	3,135	3,378	3,622	3,865
Coal	1,178	1,357	1,535	1,879	2,224	2,537
Lignite	938	751	650	500	350	231
Gas	919	908	919	972	1,025	1,078
Oil	70	37	25	22	19	15
Diesel	8	7	6	5	4	4
Nuclear	837	863	885	951	1,017	1,083
Hydrogen	0	0	0	0	0	0
Renewables	**374**	**605**	**725**	**934**	**1,142**	**1,353**
Hydro	250	272	274	279	284	289
Wind	35	175	243	325	407	489
PV	1	8	18	40	60	80
Biomass	72	117	142	206	270	334
Geothermal	17	28	36	49	61	76
Solar thermal	0	5	12	34	58	82
Ocean energy	0	0	0	1	2	3
Distribution losses	267	287	305	317	329	340
Own consumption electricity	262	282	300	311	323	334
Electricity for hydrogen production	0	0	0	0	0	0
Final energy consumption (electricity)	**3,825**	**3,992**	**4,176**	**4,678**	**5,179**	**5,682**
Fluctuating RES (PV, Wind, Ocean)	36	183	261	366	469	572
Share of fluctuating RES	0.8%	4.0%	5.5%	7.0%	8.1%	9.1%
RES share	**8.6%**	**13.4%**	**15.3%**	**17.7%**	**19.8%**	**21.5%**

table 10.2: usa: heat supply

PJ/A	2007	2015	2020	2030	2040	2050
District heating plants	**0**	**28**	**40**	**61**	**115**	**172**
Fossil fuels	0	28	40	61	115	172
Biomass	0	0	0	0	0	0
Solar collectors	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0
Heat from CHP	**831**	**833**	**867**	**987**	**1,089**	**1,221**
Fossil fuels	652	630	627	675	727	794
Biomass	179	199	234	301	344	387
Geothermal	0	4	7	12	18	40
Fuel cell (hydrogen)	0	0	0	0	0	0
Direct heating[1)]	**17,035**	**16,165**	**16,316**	**16,845**	**17,358**	**17,883**
Fossil fuels	15,141	13,851	13,700	13,660	13,631	13,572
Biomass	1,794	2,158	2,312	2,593	2,864	3,155
Solar collectors	56	54	113	345	508	674
Geothermal	44	102	192	247	355	482
Total heat supply[1)]	**17,866**	**17,027**	**17,223**	**17,893**	**18,562**	**19,276**
Fossil fuels	15,793	14,509	14,366	14,396	14,473	14,538
Biomass	1,973	2,357	2,545	2,894	3,208	3,543
Solar collectors	56	54	113	345	508	674
Geothermal	44	107	198	259	373	521
Fuel cell ((hydrogen)	0	0	0	0	0	0
RES share (including RES electricity)	**11.6%**	**14.8%**	**16.6%**	**19.5%**	**22.0%**	**24.6%**

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

table 10.3: usa: CO_2 emissions

MILL t/a	2007	2015	2020	2030	2040	2050
Condensation power plants	**2,474**	**2,374**	**2,370**	**2,491**	**2,509**	**2,539**
Coal	1,050	1,212	1,366	1,648	1,853	2,010
Lignite	1,069	844	693	529	338	205
Gas	310	299	302	307	312	317
Oil	40	14	6	4	3	3
Diesel	6	5	5	4	3	3
Combined heat & power production	**158**	**147**	**141**	**147**	**157**	**172**
Coal	51	50	48	50	55	65
Lignite	2	1	0	0	0	0
Gas	94	87	84	88	94	99
Oil	11	10	9	9	8	7
CO_2 emissions electricity & steam generation	**2,632**	**2,522**	**2,512**	**2,638**	**2,666**	**2,711**
Coal	1,101	1,262	1,414	1,698	1,908	2,076
Lignite	1,071	845	693	529	338	205
Gas	404	386	386	395	406	416
Oil & diesel	56	29	19	17	15	13
CO_2 emissions by sector	**5,742**	**5,495**	**5,467**	**5,537**	**5,528**	**5,541**
% of 1990 emissions	113%	108%	108%	109%	109%	109%
Industry	481	440	421	388	359	333
Other sectors	610	540	545	561	579	596
Transport	1826	1738	1726	1714	1702	1690
Electricity & steam generation	2,591	2,480	2,466	2,586	2,604	2,633
District heating	234	297	309	288	284	288
Population (Mill.)	309	332.3	346.2	370.0	388.9	403.9
CO_2 emissions per capita (t/capita)	**18.6**	**16.5**	**15.8**	**15.0**	**14.2**	**13.7**

table 10.4: usa: installed capacity

GW	2007	2015	2020	2030	2040	2050
Power plants	**939**	**975**	**1,017**	**1,101**	**1,211**	**1,321**
Coal	176	204	234	275	324	368
Lignite	147	118	103	77	54	35
Gas	326	320	323	329	343	357
Oil	45	24	8	6	5	5
Diesel	18	16	14	12	9	9
Nuclear	101	104	107	115	123	131
Biomass	5	9	11	17	23	30
Hydro	100	100	101	102	104	106
Wind	17	68	92	118	148	178
PV	1	7	16	35	52	70
Geothermal	3	4	5	6	7	9
Solar thermal power plants	0	2	4	10	17	21
Ocean energy	0	0	0	1	2	3
Combined heat & power production	**104**	**113**	**114**	**132**	**132**	**144**
Coal	10	11	12	14	19	24
Lignite	0	0	0	0	0	0
Gas	77	83	83	96	89	92
Oil	10	10	7	6	5	5
Biomass	7	9	11	15	18	21
Geothermal	0	0	0	1	1	1
Hydrogen	0	0	0	0	0	0
CHP by producer						
Main activity producers	67	71	67	77	82	87
Autoproducers	37	42	47	55	51	57
Total generation	**1,043**	**1,089**	**1,130**	**1,233**	**1,344**	**1,465**
Fossil	810	785	783	814	849	896
Coal	186	215	245	290	343	392
Lignite	147	118	103	77	54	35
Gas	403	402	406	425	433	449
Oil	55	34	15	11	10	10
Diesel	18	16	14	12	9	9
Nuclear	101	104	107	115	123	131
Hydrogen	0	0	0	0	0	0
Renewables	**132**	**199**	**240**	**304**	**372**	**437**
Hydro	100	100	101	102	104	106
Wind	17	68	92	118	148	178
PV	1	7	16	35	52	70
Biomass	12	18	22	32	41	51
Geothermal	3	4	5	7	8	10
Solar thermal	0	2	4	10	17	21
Ocean energy	0	0	0	1	2	3
Fluctuating RES (PV, Wind, Ocean)	18	75	108	154	202	250
Share of fluctuating RES	1.7%	6.9%	9.5%	12.5%	15.0%	17.1%
RES share	**12.7%**	**18.3%**	**21.2%**	**24.7%**	**27.7%**	**29.9%**

table 10.5: usa: primary energy demand

PJ/A	2007	2015	2020	2030	2040	2050
Total	**97,394**	**95,428**	**96,896**	**100,368**	**101,436**	**103,577**
Fossil	**83,057**	**78,725**	**78,325**	**78,964**	**77,465**	**76,997**
Hard coal	13,488	15,154	16,640	19,489	21,646	23,333
Lignite	9,652	7,613	6,240	4,762	3,043	1,848
Natural gas	22,382	21,706	21,706	22,093	21,078	21,014
Crude oil	37,535	34,252	33,740	32,621	31,698	30,801
Nuclear	**9,127**	**9,415**	**9,655**	**10,375**	**11,095**	**11,815**
Renewables	**5,210**	**7,289**	**8,917**	**11,029**	**12,876**	**14,766**
Hydro	899	979	986	1,004	1,022	1,040
Wind	125	630	875	1,170	1,465	1,760
Solar	60	100	221	612	933	1,257
Biomass	3,766	5,154	6,256	7,483	8,446	9,386
Geothermal	362	426	578	757	1,002	1,312
Ocean Energy	0	0	0	4	7	11
RES share	**5.4%**	**7.6%**	**9.2%**	**11.0%**	**12.7%**	**14.2%**

table 10.6: usa: final energy demand

PJ/a	2007	2015	2020	2030	2040	2050
Total (incl. non-energy use)	**66,935**	**64,700**	**65,752**	**67,977**	**70,218**	**72,483**
Total (energy use)	**60,303**	**58,922**	**60,058**	**62,409**	**64,775**	**67,166**
Transport	**26,611**	**25,958**	**26,293**	**26,335**	**26,377**	**26,419**
Oil products	25,330	24,116	23,949	23,781	23,614	23,447
Natural gas	633	680	680	680	680	680
Biofuels	619	1,130	1,632	1,841	2,050	2,259
Electricity	29	32	32	32	32	32
RES electricity	3	4	5	6	6	7
Hydrogen	0	0	0	0	0	0
RES share Transport	**2.3%**	**4.4%**	**6.2%**	**7.0%**	**7.8%**	**8.6%**
Industry	**12,541**	**12,190**	**12,024**	**11,731**	**11,450**	**11,195**
Electricity	3,344	3,317	3,271	3,158	3,036	2,922
RES electricity	289	444	500	560	600	627
District heat	677	680	726	851	987	1,153
RES district heat	59	75	107	171	199	232
Coal	1,066	983	816	618	447	261
Oil products	1,284	992	912	819	722	622
Gas	4,696	4,332	4,268	4,006	3,740	3,459
Solar	0	7	23	54	91	116
Biomass and waste	1,468	1,857	1,947	2,126	2,305	2,495
Geothermal	5	22	60	100	122	167
Hydrogen	0	0	0	0	0	0
RES share Industry	**14.5%**	**19.7%**	**21.9%**	**25.7%**	**29.0%**	**32.5%**
Other Sectors	**21,151**	**20,774**	**21,740**	**24,343**	**26,949**	**29,552**
Electricity	10,398	11,020	11,731	13,649	15,575	17,501
RES electricity	899	1,474	1,793	2,422	3,078	3,757
District heat	88	79	74	74	76	78
RES district heat	8	9	11	15	15	16
Coal	73	51	58	27	32	32
Oil products	2,349	1,629	1,588	1,472	1,346	1,219
Gas	7,607	7,343	7,476	7,963	8,428	8,893
Solar	56	46	90	291	417	558
Biomass and waste	540	542	626	758	885	1,012
Geothermal	39	62	98	108	189	258
RES share Other Sectors	**7.3%**	**10.3%**	**12.0%**	**14.8%**	**17.0%**	**19.0%**
Total RES	**3,984**	**5,672**	**6,893**	**8,451**	**9,957**	**11,505**
RES share	**6.6%**	**9.6%**	**11.5%**	**13.5%**	**15.4%**	**17.1%**
Non energy use	**6,632**	**5,778**	**5,694**	**5,568**	**5,443**	**5,317**
Oil	6,006	5,233	5,157	5,043	4,929	4,816
Gas	626	545	537	525	513	502
Coal	0	0	0	0	0	0

usa: energy [r]evolution scenario

table 10.7: usa: electricity generation

TWh/a	2007	2015	2020	2030	2040	2050
Power plants	**3,992**	**4,029**	**4,133**	**4,818**	**4,935**	**4,589**
Coal	1,122	845	528	409	67	0
Lignite	937	740	463	86	0	0
Gas	702	1,056	1,308	1,374	846	13
Oil	51	17	8	6	3	0
Diesel	8	6	4	2	1	0
Nuclear	837	623	393	53	7	0
Biomass	32	44	54	49	46	60
Hydro	250	340	375	398	417	420
Wind	35	249	580	1,105	1,351	1,436
PV	1	25	131	445	720	905
Geothermal	17	51	125	323	513	604
Solar thermal power plants	0	29	156	542	893	1,043
Ocean energy	0	4	8	27	71	108
Combined heat & power production	**332**	**475**	**619**	**740**	**823**	**876**
Coal	56	59	56	30	14	0
Lignite	1	1	0	0	0	0
Gas	217	294	366	364	235	182
Oil	19	21	15	0	0	0
Biomass	39	97	168	314	520	618
Geothermal	0	2	14	32	54	76
Hydrogen	0	0	0	0	0	0
CHP by producer						
Main activity producers	185	205	228	254	275	297
Autoproducers	147	270	391	486	548	579
Total generation	**4,324**	**4,504**	**4,752**	**5,558**	**5,758**	**5,465**
Fossil	3,113	3,039	2,749	2,270	1,166	195
Coal	1,178	904	584	438	81	0
Lignite	938	741	463	86	0	0
Gas	919	1,350	1,674	1,738	1,081	195
Oil	70	38	24	6	3	0
Diesel	8	6	4	2	1	0
Nuclear	837	623	393	53	7	0
Hydrogen	0	0	0	0	0	0
Renewables	**374**	**842**	**1,610**	**3,235**	**4,585**	**5,270**
Hydro	250	340	375	398	417	420
Wind	35	249	580	1,105	1,351	1,436
PV	1	25	131	445	720	905
Biomass	72	142	222	363	566	678
Geothermal	17	53	138	355	567	680
Solar thermal	0	29	156	542	893	1,043
Ocean energy	0	4	8	27	71	108
Distribution losses	267	286	293	308	322	314
Own consumption electricity	262	280	315	350	379	375
Electricity for hydrogen production	0	4	72	129	173	171
Final energy consumption (electricity)	**3,825**	**3,965**	**4,103**	**4,803**	**4,916**	**4,636**
Fluctuating RES (PV, Wind, Ocean)	36	278	719	1,577	2,142	2,449
Share of fluctuating RES	0.8%	6.2%	15.1%	28.4%	37.2%	44.8%
RES share	**8.6%**	**18.7%**	**33.9%**	**58.2%**	**79.6%**	**96.4%**
'Efficiency' savings (compared to Ref.)	**0**	**44**	**229**	**697**	**1,311**	**2,178**

table 10.8: usa: heat supply

PJ/A	2007	2015	2020	2030	2040	2050
District heating plants	**0**	**334**	**906**	**1,850**	**2,610**	**2,607**
Fossil fuels	0	0	0	0	0	0
Biomass	0	159	408	740	913	782
Solar collectors	0	92	272	647	1,044	1,173
Geothermal	0	83	227	462	652	652
Heat from CHP	**831**	**1,134**	**1,586**	**2,214**	**2,838**	**3,173**
Fossil fuels	652	767	891	896	653	531
Biomass	179	359	610	1112	1,839	2,191
Geothermal	0	7	84	205	345	450
Fuel cell (hydrogen)	0	0	0	0	0	0
Direct heating[1)]	**17,035**	**15,545**	**14,673**	**13,356**	**11,946**	**10,979**
Fossil fuels	15,141	12,902	11,240	8,201	5,369	3,891
Biomass	1,794	2,101	2,294	2,283	2,266	1,967
Solar collectors	56	403	714	2,071	2,935	3,448
Geothermal	44	139	425	801	1,376	1,674
Total heat supply[1)]	**17,866**	**17,013**	**17,165**	**17,420**	**17,393**	**16,759**
Fossil fuels	15,793	13,669	12,132	9,098	6,022	4,422
Biomass	1,973	2,619	3,312	4,135	5,018	4,940
Solar collectors	56	495	986	2,719	3,978	4,621
Geothermal	44	230	735	1,469	2,374	2,776
Fuel cell (hydrogen)	0	0	0	0	0	0
RES share (including RES electricity)	**11.6%**	**19.7%**	**29.3%**	**47.8%**	**65.4%**	**73.6%**
'Efficiency' savings (compared to Ref.)	**0**	**14**	**59**	**473**	**1,169**	**2,517**

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

table 10.9: usa: CO_2 emissions

MILL t/a	2007	2015	2020	2030	2040	2050
Condensation power plants	**2,474**	**2,093**	**1,554**	**1,055**	**411**	**5**
Coal	1,050	790	491	375	58	0
Lignite	1,069	833	493	91	0	0
Gas	310	453	561	583	350	5
Oil	40	12	6	4	2	0
Diesel	6	5	3	2	1	0
Combined heat & power production	**158**	**174**	**187**	**175**	**118**	**86**
Coal	51	46	41	19	8	0
Lignite	2	1	0	0	0	0
Gas	94	116	138	156	110	86
Oil	11	11	8	0	0	0
CO_2 emissions electricity & steam generation	**2,632**	**2,267**	**1,741**	**1,230**	**529**	**92**
Coal	1,101	837	532	394	66	0
Lignite	1,071	834	493	91	0	0
Gas	404	569	699	739	460	92
Oil & diesel	56	27	17	6	3	0
CO_2 emissions by sector	**5,742**	**5,187**	**4,395**	**3,044**	**1,613**	**728**
% of 1990 emissions	113%	102%	87%	60%	32%	14%
Industry	481	445	388	301	195	134
Other sectors	610	495	449	328	230	188
Transport	1826	1,738	1,579	1,105	665	350
Electricity & steam generation	2,591	2,199	1,651	1,118	441	20
District heating	234	310	328	191	82	36
Population (Mill.)	309	332	346	370	389	404
CO_2 emissions per capita (t/capita)	**18.6**	**15.6**	**12.7**	**8.2**	**4.1**	**1.8**

table 10.10: usa: installed capacity

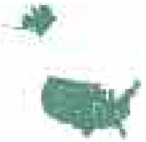
GW	2007	2015	2020	2030	2040	2050
Power plants	**939**	**1,117**	**1,380**	**1,894**	**2,112**	**1,927**
Coal	176	133	84	63	13	0
Lignite	147	116	74	13	0	0
Gas	326	484	600	624	423	7
Oil	45	21	8	6	3	0
Diesel	18	14	9	5	2	0
Nuclear	101	75	48	6	1	0
Biomass	5	6	7	7	6	8
Hydro	100	125	138	146	152	153
Wind	17	97	220	401	491	521
PV	1	23	114	387	626	787
Geothermal	3	8	18	43	68	81
Solar thermal power plants	0	11	52	167	255	261
Ocean energy	0	4	8	27	71	108
Combined heat & power production	**104**	**149**	**180**	**193**	**169**	**169**
Coal	10	11	10	5	2	0
Lignite	0	0	0	0	0	0
Gas	77	111	132	125	63	45
Oil	10	10	5	0	0	0
Biomass	7	17	30	57	94	111
Geothermal	0	0	2	6	9	13
Hydrogen	0	0	0	0	0	0
CHP by producer						
Main activity producers	67	76	77	73	58	55
Autoproducers	37	73	103	120	111	114
Total generation	**1,043**	**1,266**	**1,560**	**2,087**	**2,282**	**2,096**
Fossil	810	901	922	841	507	53
Coal	186	144	94	68	16	0
Lignite	147	117	74	13	0	0
Gas	403	595	732	749	486	53
Oil	55	32	14	6	3	0
Diesel	18	14	9	5	2	0
Nuclear	101	75	48	6	1	0
Hydrogen	0	0	0	0	0	0
Renewables	**132**	**290**	**590**	**1,240**	**1,774**	**2,043**
Hydro	100	125	138	146	152	153
Wind	17	97	220	401	491	521
PV	1	23	114	387	626	787
Biomass	12	23	38	64	101	119
Geothermal	3	8	21	49	78	93
Solar thermal	0	11	52	167	255	261
Ocean energy	0	4	8	27	71	108
Fluctuating RES (PV, Wind, Ocean)	18	123	342	815	1188	1416
Share of fluctuating RES	1.7%	9.8%	21.9%	39.1%	52.0%	67.6%
RES share	**12.7%**	**22.9%**	**37.8%**	**59.4%**	**77.7%**	**97.5%**

table 10.11: usa: primary energy demand

PJ/A	2007	2015	2020	2030	2040	2050
Total	**97,394**	**91,640**	**87,603**	**80,370**	**68,856**	**58,651**
Fossil	**83,057**	**76,421**	**67,885**	**51,980**	**30,944**	**16,846**
Hard coal	13,488	10,343	6,676	4,525	861	106
Lignite	9,652	7,512	4,445	819	0	0
Natural gas	22,382	24,572	26,036	24,475	15,108	6,608
Crude oil	37,535	33,994	30,729	22,161	14,974	10,132
Nuclear	**9,127**	**6,796**	**4,287**	**578**	**76**	**0**
Renewables	**5,210**	**8,422**	**15,431**	**27,812**	**37,836**	**41,805**
Hydro	899	1,224	1,350	1,433	1,501	1,511
Wind	125	896	2,088	3,978	4,864	5,170
Solar	60	689	2,019	6,272	9,785	11,634
Biomass	3,766	4,766	7,579	10,501	12,657	12,732
Geothermal	362	831	2,366	5,531	8,774	10,370
Ocean Energy	0	14	29	97	256	389
RES share	**5.4%**	**9.2%**	**17.7%**	**34.7%**	**55.0%**	**71.3%**
'Efficiency' savings (compared to Ref.)	**0**	**3,858**	**9,471**	**20,263**	**32,919**	**45,337**

table 10.12: usa: final energy demand

PJ/a	2007	2015	2020	2030	2040	2050
Total (incl. non-energy use)	**66,935**	**64,094**	**63,501**	**60,143**	**54,589**	**48,314**
Total (energy use)	**60,303**	**58,317**	**57,807**	**54,574**	**49,146**	**42,997**
Transport	**26,611**	**25,500**	**25,091**	**22,088**	**17,519**	**13,505**
Oil products	25,330	24,108	21,904	15,319	9,206	4,840
Natural gas	633	624	596	547	494	441
Biofuels	619	660	1,821	2,906	3,558	3,654
Electricity	29	97	593	2,991	3,806	4,107
RES electricity	3	18	201	1,741	3,031	3,960
Hydrogen	0	11	177	325	455	463
RES share Transport	**2.3%**	**2.7%**	**8.3%**	**21.9%**	**39.7%**	**59.7%**
Industry	**12,541**	**12,180**	**11,599**	**11,358**	**11,075**	**10,396**
Electricity	3,344	3,317	3,109	2,880	2,684	2,459
RES electricity	289	620	1,054	1,676	2,137	2,371
District heat	677	847	1,200	1,923	2,556	2,721
RES district heat	59	388	823	1,657	2,425	2,647
Coal	1,066	908	607	44	0	0
Oil products	1,284	1,000	751	383	112	80
Gas	4,696	4,286	3,896	3,574	2,634	1,902
Solar	0	228	357	768	1,009	1,120
Biomass and waste	1,468	1,570	1,474	1,442	1,462	1,352
Geothermal	5	24	205	345	617	762
Hydrogen	0	0	0	0	0	0
RES share Industry	**14.5%**	**23.2%**	**33.7%**	**51.8%**	**69.1%**	**79.4%**
Other Sectors	**21,151**	**20,636**	**21,117**	**21,128**	**20,552**	**19,097**
Electricity	10,398	10,860	11,070	11,420	11,206	10,124
RES electricity	899	2,029	3,751	6,646	8,923	9,762
District heat	88	512	1,112	1,856	2,521	2,683
RES district heat	8	235	762	1,600	2,391	2,610
Coal	73	55	33	22	0	0
Oil products	2,349	1,401	1,005	544	353	290
Gas	7,607	6,756	6,249	4,515	2,915	2,159
Solar	56	175	357	1,303	1,926	2,328
Biomass and waste	540	792	1,129	1,138	1,096	850
Geothermal	39	86	161	331	536	662
RES share Other Sectors	**7.3%**	**16.1%**	**29.2%**	**52.1%**	**72.4%**	**84.9%**
Total RES	**3,984**	**6,828**	**12,155**	**21,742**	**29,474**	**32,526**
RES share	**6.6%**	**11.7%**	**21.0%**	**39.8%**	**60.0%**	**75.6%**
Non energy use	**6,632**	**5,778**	**5,694**	**5,568**	**5,443**	**5,317**
Oil	6,006	5,233	5,157	5,043	4,929	4,816
Gas	626	545	537	525	513	502
Coal	0	0	0	0	0	0



usa: advanced energy [r]evolution scenario

table 10.13: usa: electricity generation

TWh/a	2007	2015	2020	2030	2040	2050
Power plants	**3,992**	**4,028**	**4,124**	**4,962**	**5,919**	**5,660**
Coal	1,122	723	485	96	0	0
Lignite	937	643	313	17	0	0
Gas	702	1,039	821	684	295	0
Oil	51	23	12	6	4	0
Diesel	8	6	4	2	1	0
Nuclear	837	623	393	53	7	0
Biomass	32	56	84	93	80	0
Hydro	250	335	375	398	433	433
Wind	35	457	976	1,607	1,810	1,868
PV	1	35	162	517	998	1,030
Geothermal	17	51	179	516	797	765
Solar thermal power plants	0	33	301	917	1,304	1,338
Ocean energy	0	4	18	57	189	225
Combined heat & power production	**332**	**475**	**619**	**740**	**823**	**876**
Coal	56	55	41	21	5	0
Lignite	1	0	0	0	0	0
Gas	217	312	377	360	214	73
Oil	19	21	15	2	0	0
Biomass	39	85	173	321	498	597
Geothermal	0	2	14	36	102	190
Hydrogen	0	0	0	0	4	17
CHP by producer						
Main activity producers	185	205	228	254	275	297
Autoproducers	147	270	391	486	548	579
Total generation	**4,324**	**4,503**	**4,743**	**5,702**	**6,742**	**6,536**
Fossil	3,113	2,822	2,069	1,187	520	73
Coal	1,178	778	526	116	6	0
Lignite	938	643	313	17	0	0
Gas	919	1,351	1,198	1,044	509	73
Oil	70	44	28	8	4	0
Diesel	8	6	4	2	1	0
Nuclear	837	623	393	53	7	0
Hydrogen	0	0	0	0	4	17
Renewables	**374**	**1,058**	**2,281**	**4,462**	**6,211**	**6,446**
Hydro	250	335	375	398	433	433
Wind	35	457	976	1,607	1,810	1,868
PV	1	35	162	517	998	1,030
Biomass	72	141	257	414	578	597
Geothermal	17	53	192	552	899	955
Solar thermal	0	33	301	917	1,304	1,338
Ocean energy	0	4	18	57	189	225
Distribution losses	267	286	293	308	322	314
Own consumption electricity	262	280	315	350	379	375
Electricity for hydrogen production	0	4	72	127	230	299
Final energy consumption (electricity)	**3,825**	**3,964**	**4,094**	**4,949**	**5,843**	**5,579**
Fluctuating RES (PV, Wind, Ocean)	36	496	1,156	2,181	2,997	3,123
Share of fluctuating RES	0.8%	11.0%	24.4%	38.2%	44.5%	47.8%
RES share	**8.6%**	**23.5%**	**48.1%**	**78.3%**	**92.1%**	**98.6%**
'Efficiency' savings (compared to Ref.)	**0**	**44**	**228**	**694**	**1,291**	**2,164**

table 10.14: usa: heat supply

PJ/A	2007	2015	2020	2030	2040	2050
District heating plants	**0**	**330**	**837**	**2,392**	**3,488**	**3,572**
Fossil fuels	0	0	0	0	0	0
Biomass	0	157	352	909	1,046	893
Solar collectors	0	91	268	837	1,465	1,679
Geothermal	0	83	218	646	977	1,000
Heat from CHP	**831**	**1,117**	**1,603**	**2,233**	**2,995**	**3,527**
Fossil fuels	652	795	892	878	582	217
Biomass	179	315	628	1,141	1,755	2,119
Geothermal	0	7	84	215	644	1,139
Fuel cell (hydrogen)	0	0	0	0	14	51
Direct heating[1]	**17,035**	**15,565**	**14,724**	**12,794**	**10,910**	**9,660**
Fossil fuels	15,141	13,061	11,260	7,386	2,701	107
Biomass	1,794	2,043	2,312	2,355	2,060	1,733
Solar collectors	56	322	720	2,286	4,088	5,467
Geothermal	44	138	431	768	1,791	2,047
Hydrogen	0	0	0	0	270	306
Total heat supply[1]	**17,866**	**17,013**	**17,165**	**17,420**	**17,393**	**16,759**
Fossil fuels	15,793	13,856	12,152	8,263	3,283	324
Biomass	1,973	2,515	3,291	4,406	4,862	4,746
Solar collectors	56	413	988	3,123	5,554	7,146
Geothermal	44	228	733	1,628	3,411	4,186
Fuel cell (hydrogen)	0	0	0	0	284	357
RES share (including RES electricity)	**11.6%**	**18.6%**	**29.2%**	**52.6%**	**81.0%**	**98.0%**
'Efficiency' savings (compared to Ref.)	**0**	**14**	**59**	**473**	**1,169**	**2,517**

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

table 10.15: usa: CO_2 emissions

MILL t/a	2007	2015	2020	2030	2040	2050
Condensation power plants	**2,474**	**1,867**	**1,149**	**402**	**126**	**0**
Coal	1,050	676	451	88	0	0
Lignite	1,069	724	334	18	0	0
Gas	310	446	352	290	122	0
Oil	40	17	9	4	3	0
Diesel	6	5	3	2	1	0
Combined heat & power production	**158**	**176**	**179**	**168**	**100**	**32**
Coal	51	42	28	13	3	0
Lignite	2	0	0	0	0	0
Gas	94	124	143	153	97	32
Oil	11	11	8	1	0	0
CO_2 emissions electricity & steam generation	**2,632**	**2,043**	**1,328**	**569**	**225**	**32**
Coal	1,101	718	479	101	3	0
Lignite	1,071	724	334	18	0	0
Gas	404	569	495	444	219	32
Oil & diesel	56	32	20	7	4	0
CO_2 emissions by sector	**5,742**	**4,926**	**3,950**	**2,187**	**834**	**129**
% of 1990 emissions	113%	97%	78%	43%	16%	3%
Industry	481	447	364	262	103	20
Other sectors	610	507	477	325	152	41
Transport	1826	1,693	1,584	1,022	386	54
Electricity & steam generation	2,591	1,973	1,237	456	157	1
District heating	234	307	288	121	37	12
Population (Mill.)	309	332	346	370	389	404
CO_2 emissions per capita (t/capita)	**18.6**	**14.8**	**11.4**	**5.9**	**2.1**	**0.3**

table 10.16: usa: installed capacity

GW	2007	2015	2020	2030	2040	2050
Power plants	**939**	**1,173**	**1,378**	**1,944**	**2,517**	**2,394**
Coal	176	114	77	15	0	0
Lignite	147	101	50	3	0	0
Gas	326	477	377	311	148	0
Oil	45	29	12	6	4	0
Diesel	18	14	9	5	2	0
Nuclear	101	75	48	6	1	0
Biomass	5	8	12	13	11	0
Hydro	100	123	138	146	158	158
Wind	17	178	370	584	657	678
PV	1	32	141	450	868	896
Geothermal	3	8	26	69	106	102
Solar thermal power plants	0	12	100	282	373	335
Ocean energy	0	4	18	57	189	225
Combined heat & power production	**104**	**154**	**183**	**193**	**172**	**158**
Coal	10	10	8	4	1	0
Lignite	0	0	0	0	0	0
Gas	77	118	136	124	62	15
Oil	10	10	5	0	0	0
Biomass	7	15	31	58	91	107
Geothermal	0	0	2	6	18	32
Hydrogen	0	0	0	0	1	3
CHP by producer						
Main activity producers	67	80	80	74	62	44
Autoproducers	37	74	103	119	110	114
Total generation	**1,043**	**1,327**	**1,561**	**2,137**	**2,689**	**2,552**
Fossil	810	873	675	467	216	15
Coal	186	124	85	19	1	0
Lignite	147	101	50	3	0	0
Gas	403	594	513	435	209	15
Oil	55	39	18	6	4	0
Diesel	18	14	9	5	2	0
Nuclear	101	75	48	6	1	0
Hydrogen	0	0	0	0	1	3
Renewables	**132**	**379**	**838**	**1,664**	**2,471**	**2,533**
Hydro	100	123	138	146	158	158
Wind	17	178	370	584	657	678
PV	1	32	141	450	868	896
Biomass	12	23	43	71	102	107
Geothermal	3	8	29	75	124	134
Solar thermal	0	12	100	282	373	335
Ocean energy	0	4	18	57	189	225
Fluctuating RES (PV, Wind, Ocean)	18	213	528	1,090	1,714	1,799
Share of fluctuating RES	1.7%	16.1%	33.9%	51.0%	63.7%	70.5%
RES share	**12.7%**	**28.6%**	**53.7%**	**77.8%**	**91.9%**	**99.3%**

table 10.17: usa: primary energy demand

PJ/A	2007	2015	2020	2030	2040	2050
Total	**97,394**	**90,342**	**84,409**	**75,296**	**67,624**	**58,673**
Fossil	**83,057**	**73,681**	**61,930**	**40,187**	**18,902**	**7,377**
Hard coal	13,488	9,010	5,943	1,279	121	54
Lignite	9,652	6,521	3,005	162	0	0
Natural gas	22,382	24,369	21,675	17,708	7,946	1,603
Crude oil	37,535	33,781	31,306	21,038	10,835	5,720
Nuclear	**9,127**	**6,796**	**4,287**	**578**	**76**	**0**
Renewables	**5,210**	**9,865**	**18,191**	**34,531**	**48,646**	**51,296**
Hydro	899	1,206	1,350	1,433	1,559	1,559
Wind	125	1,645	3,514	5,785	6,516	6,725
Solar	60	658	2,655	8,285	13,841	15,851
Biomass	3,766	5,512	7,619	10,942	12,390	11,096
Geothermal	362	829	2,988	7,880	13,660	15,255
Ocean Energy	0	14	65	205	680	810
RES share	**5.4%**	**10.9%**	**21.6%**	**45.9%**	**72.0%**	**87.4%**
'Efficiency' savings (compared to Ref.)	**0**	**5,149**	**12,665**	**25,336**	**34,151**	**45,316**

table 10.18: usa: final energy demand

PJ/a	2007	2015	2020	2030	2040	2050
Total (incl. non-energy use)	**66,935**	**64,081**	**63,502**	**59,742**	**53,774**	**46,897**
Total (energy use)	**60,303**	**58,304**	**57,808**	**54,173**	**48,331**	**41,580**
Transport	**26,611**	**25,500**	**25,091**	**21,688**	**16,519**	**11,705**
Oil products	25,330	23,504	21,989	14,192	5,347	749
Natural gas	633	600	550	450	350	200
Biofuels	619	1,292	1,816	3,218	3,579	3,095
Electricity	29	93	559	3,507	6,639	6,853
RES electricity	3	22	269	2,744	6,116	6,759
Hydrogen	0	11	177	321	603	807
RES share Transport	**2.3%**	**5.2%**	**8.6%**	**28.6%**	**62.1%**	**91.0%**
Industry	**12,541**	**12,167**	**11,599**	**11,355**	**11,188**	**10,571**
Electricity	3,344	3,317	3,111	2,887	2,756	2,506
RES electricity	289	780	1,496	2,259	2,539	2,472
District heat	677	828	1,342	2,303	3,075	3,461
RES district heat	59	359	905	2,053	2,935	3,455
Coal	1,066	900	507	22	0	0
Oil products	1,284	1,143	775	381	83	31
Gas	4,696	4,173	3,608	2,879	1,201	257
Solar	0	226	499	977	1,348	1,560
Biomass and waste	1,468	1,556	1,548	1,517	1,465	1,356
Geothermal	5	24	210	389	985	1,092
Hydrogen	0	0	0	0	275	309
RES share Industry	**14.5%**	**24.2%**	**40.2%**	**63.4%**	**85.1%**	**96.9%**
Other Sectors	**21,151**	**20,637**	**21,119**	**21,130**	**20,624**	**19,304**
Electricity	10,398	10,860	11,070	11,420	11,208	10,126
RES electricity	899	2,552	5,324	8,936	10,326	9,987
District heat	88	511	930	2,011	3,026	3,255
RES district heat	8	222	627	1,793	2,888	3,250
Coal	73	55	33	22	0	0
Oil products	2,349	1,604	1,398	587	231	106
Gas	7,607	6,688	6,236	4,394	1,799	106
Solar	56	96	222	1,309	2,740	4,088
Biomass and waste	540	738	1,070	1,142	1,111	866
Geothermal	39	86	160	245	509	756
RES share Other Sectors	**7.3%**	**17.9%**	**35.1%**	**63.5%**	**85.2%**	**98.2%**
Total RES	**3,984**	**7,954**	**14,232**	**26,834**	**37,351**	**39,835**
RES share	**6.6%**	**13.6%**	**24.6%**	**49.5%**	**77.3%**	**95.8%**
Non energy use	**6,632**	**5,778**	**5,694**	**5,568**	**5,443**	**5,317**
Oil	6,006	5,233	5,157	5,043	4,929	4,816
Gas	626	545	537	525	513	502
Coal	0	0	0	0	0	0

usa: total new investment by technology

table 10.19: usa: total investment

MILLION $	2007-2010	2011-2020	2021-2030	2007-2050	2007-2050 AVERAGE PER YEAR
Reference scenario					
Conventional (fossil & nuclear)	**228,432**	**555,576**	**564,788**	**1,988,374**	**46,241**
Renewables	**115,529**	**280,517**	**289,546**	**1,248,582**	**29,037**
Biomass	15,567	38,466	38,567	177,190	4,121
Hydro	23,590	83,560	88,012	339,964	7,906
Wind	39,228	74,020	69,145	335,001	7,791
PV	18,279	25,712	33,576	134,826	3,135
Geothermal	16,735	37,461	26,475	126,404	2,940
Solar thermal power plants	2,130	21,298	31,248	128,065	2,978
Ocean energy	0	0	2,522	7,131	166
Energy [R]evolution					
Conventional (fossil & nuclear)	**228,432**	**421,735**	**286,560**	**1,254,365**	**29,171**
Renewables	**115,529**	**1,291,437**	**1,735,294**	**5,562,494**	**129,360**
Biomass	15,567	73,770	73,522	376,096	8,746
Hydro	23,590	193,077	107,576	483,375	11,241
Wind	39,228	234,915	254,336	779,784	18,135
PV	18,279	244,509	398,625	1,127,792	26,228
Geothermal	16,735	228,150	307,560	1,090,201	25,354
Solar thermal power plants	2,130	285,859	545,759	1,458,011	33,907
Ocean energy	0	31,156	47,915	247,235	5,750
Advanced Energy [R]evolution					
Conventional (fossil & nuclear)	**228,432**	**276,838**	**197,147**	**1,081,663**	**25,155**
Renewables	**115,529**	**1,952,727**	**2,388,692**	**7,366,054**	**171,304**
Biomass	15,567	84,578	77,665	389,715	9,063
Hydro	23,590	193,244	107,576	499,850	11,624
Wind	39,228	427,868	292,818	1,043,906	24,277
PV	18,279	309,613	449,881	1,280,405	29,777
Geothermal	16,735	324,692	498,116	1,635,072	38,025
Solar thermal power plants	2,130	548,219	864,284	2,009,337	46,729
Ocean energy	0	64,513	98,352	507,770	11,809

notes

energy
[r]evolution

GREENPEACE

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

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

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EREC

european renewable energy council - [EREC]

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

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

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