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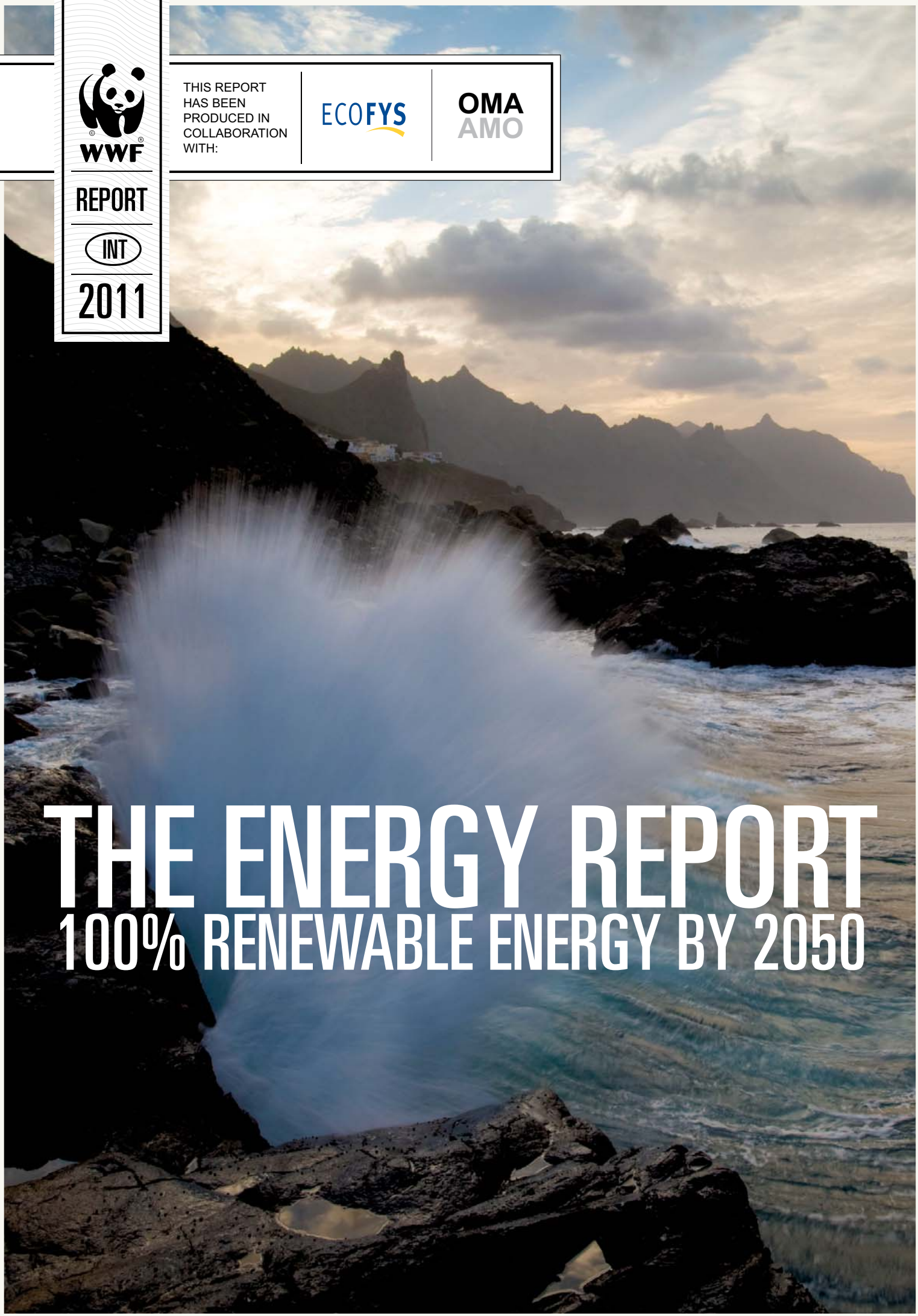

THE ENERGY REPORT

100% RENEWABLE ENERGY BY 2050

WWF

WWF is one of the world's largest and most experienced independent conservation organizations, with over 5 million supporters and a global Network active in more than 100 countries.
WWF's mission is to stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature, by conserving the world's biological diversity, ensuring that the use of renewable natural resources is sustainable, and promoting the reduction of pollution and wasteful consumption.

ECOFYS

Established in 1984 with the mission of achieving a sustainable energy supply for everyone, Ecofys has become a leader in energy saving, sustainable energy solutions and climate policies. The unique synergy between our fields of competence is the key to this success. We create smart, effective, practical and sustainable solutions for and with our clients.

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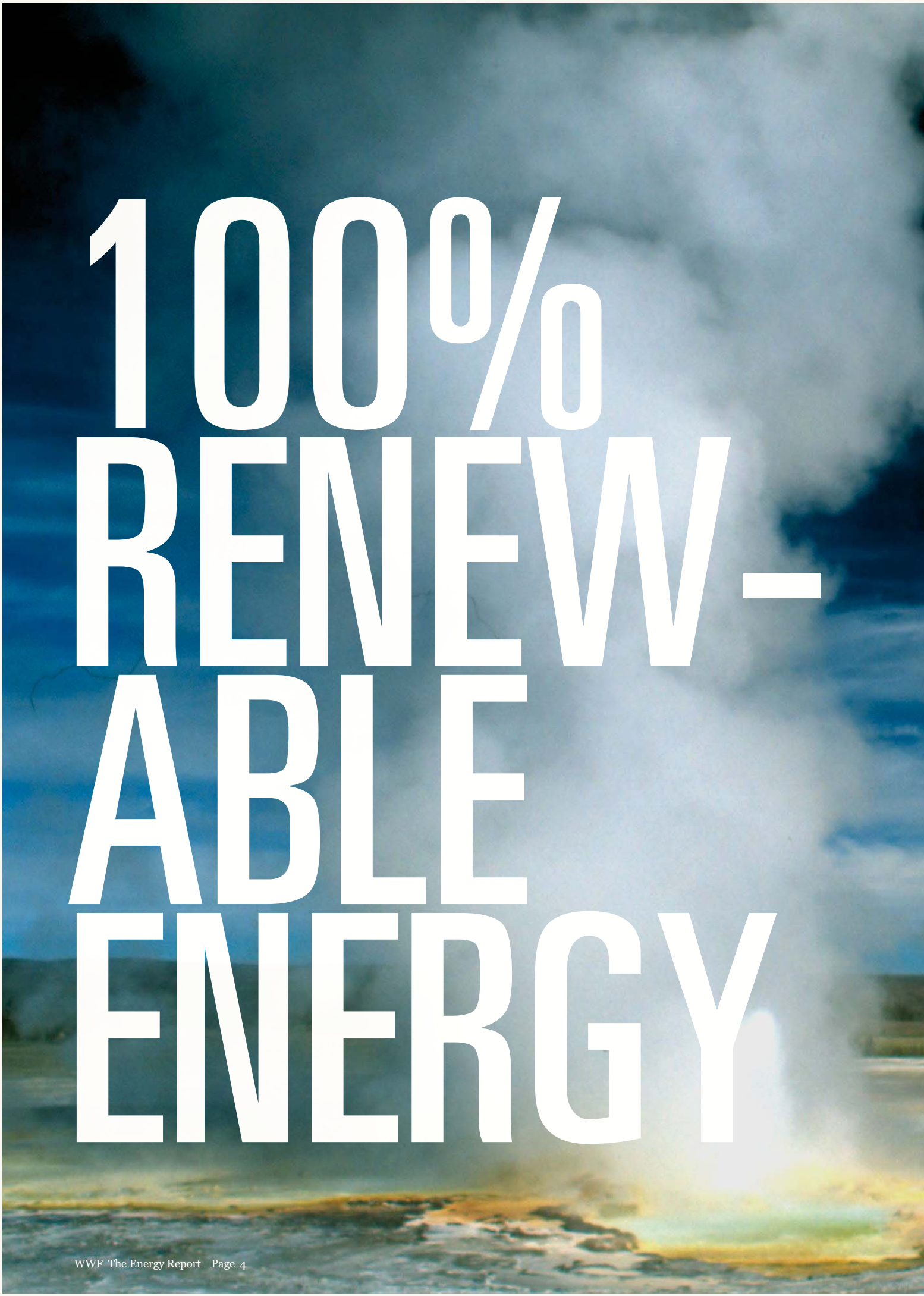
100%
RENEW-
ABLE
ENERGY

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Map 1: A new perspective on the world - looking towards 2050. *Global GIS Database: Complete GlobaL Set, 2002*
© AMO

"By 2050, we could get all the energy we need from renewable sources. This report shows that such a transition is not only possible but also cost-effective, providing energy that is affordable for all and producing it in ways that can be sustained by the global economy and the planet. The transition will present significant challenges, but I hope this report will inspire governments and business to come to grips with those challenges and, at the same time, to move boldly to bring the renewable economy into reality. There is nothing more important to our ability to create a sustainable future."

James P. Leape
Director General
WWF International

10 RECOMMENDATIONS FOR A 100% RENEWABLE ENERGY FUTURE

1.

CLEAN ENERGY: Promote only the most efficient products. Develop existing and new renewable energy sources to provide enough clean energy for all by 2050.

2.

GRIDS: Share and exchange clean energy through grids and trade, making the best use of sustainable energy resources in different areas.

3.

ACCESS: End energy poverty: provide clean electricity and promote sustainable practices, such as efficient cook stoves, to everyone in developing countries.

4.

MONEY: Invest in renewable, clean energy and energy-efficient products and buildings.

5.

FOOD: Stop food waste. Choose food that is sourced in an efficient and sustainable way to free up land for nature, sustainable forestry and biofuel production. Everyone has an equal right to healthy levels of protein in their diet – for this to happen, wealthier people need to eat less meat.

© Martin Harvey / WWF-Canon

6.

MATERIALS: Reduce, re-use, recycle – to minimize waste and save energy. Develop durable materials. And avoid things we don't need.

7.

TRANSPORT: Provide incentives to encourage greater use of public transport, and to reduce the distances people and goods travel. Promote electrification wherever possible, and support research into hydrogen and other alternative fuels for shipping and aviation.

8.

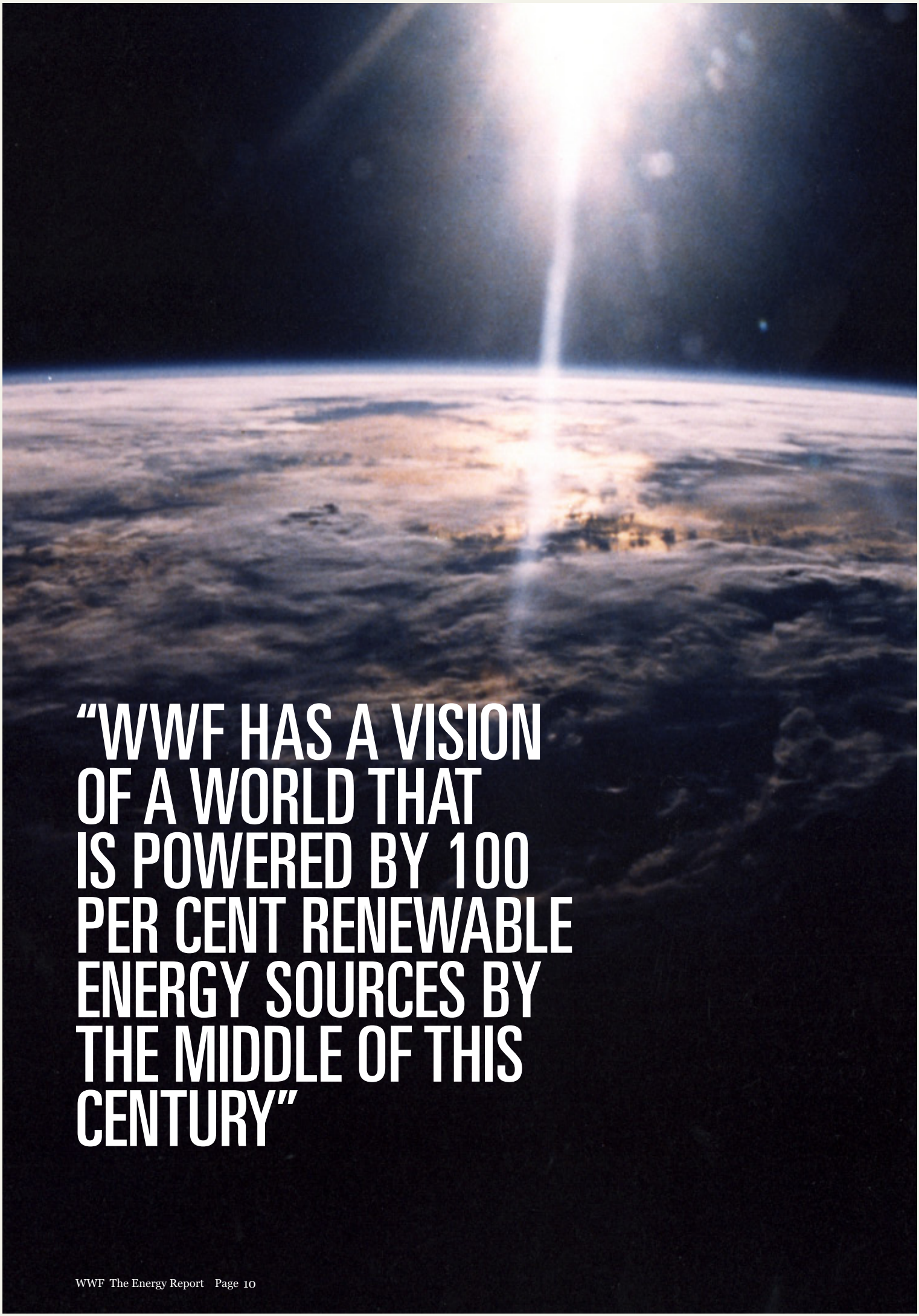
TECHNOLOGY: Develop national, bilateral and multilateral action plans to promote research and development in energy efficiency and renewable energy.

9.

SUSTAINABILITY: Develop and enforce strict sustainability criteria that ensure renewable energy is compatible with environmental and development goals.

10.

AGREEMENTS: Support ambitious climate and energy agreements to provide global guidance and promote global cooperation on renewable energy and efficiency efforts.



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"WWF HAS A VISION OF A WORLD THAT IS POWERED BY 100 PER CENT RENEWABLE ENERGY SOURCES BY THE MIDDLE OF THIS CENTURY"

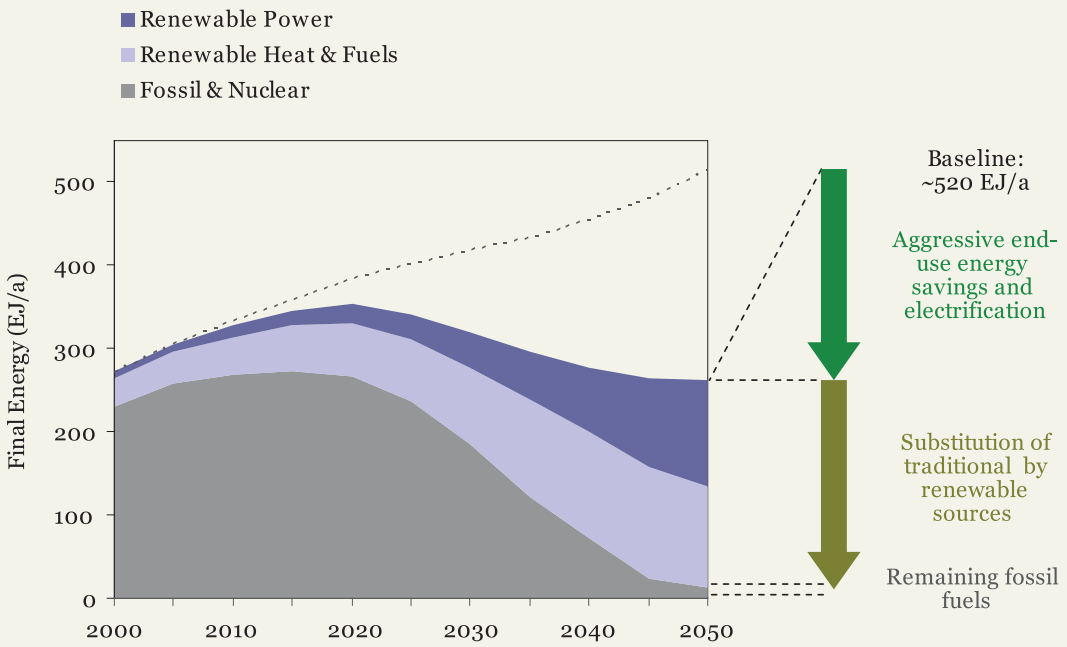

Figure 1
Evolution of energy supply in the Energy Scenario, showing the key developments.
Source: The Ecofys Energy Scenario, December 2010.

100 PER CENT RENEWABLE ENERGY BY 2050

WWF has a vision of a world that is powered by 100 per cent renewable energy sources by the middle of this century. Unless we make this transition, the world is most unlikely to avoid predicted escalating impacts of climate change.

But is it possible to achieve 100 per cent renewable energy supplies for everyone on the planet by 2050? WWF called upon the expertise of respected energy consultancy Ecofys to provide an answer to this question. In response, Ecofys has produced a bold and ambitious scenario - which demonstrates that it is technically possible to achieve almost 100 per cent renewable energy sources within the next four decades. The ambitious outcomes of this scenario, along with all of the assumptions, opportunities, detailed data and sources, are presented as Part 2 of this report.

The Ecofys scenario raises a number of significant issues and challenges. The Energy Report investigates the most critically important political, economic, environmental and social choices and challenges – and encourages their further debate.

How are we going to provide for all of the world's future needs, on energy, food, fibre, water and others, without running into such huge issues as: conflicting demands on land/water availability and use; rising, and in some cases, unsustainable consumption of commodities; nuclear waste; and regionally appropriate and adequate energy mixes?

The world needs to seriously consider what will be required to transition to a sustainable energy future, and to find solutions to the dilemmas raised in this report. Answering these challenges - the solutions to the energy needs of current and future generations – is one of the most important, challenging and urgent political tasks ahead.

"1.4 BILLION
PEOPLE HAVE
NO ACCESS
TO RELIABLE
ELECTRICITY"

© Cat Holloway / WWF-Canon

A RENEWABLE ENERGY FUTURE: WHY WE NEED IT

Switching to renewable energy isn't just the best choice. It's our only option.

The way we produce and use energy today is not sustainable. Our main fossil fuel sources – oil, coal and gas – are finite natural resources, and we are depleting them at a rapid rate. Furthermore they are the main contributors to climate change, and the race to the last 'cheap' fossil resources evokes disasters for the natural environment as seen recently in the case of the BP oil spill in the Gulf of Mexico. In the developing world, regional and local desertification is caused by depletion of fuelwood and other biomass sources that are often used very inefficiently causing substantive in-door pollution and millions of deaths annually. A fully sustainable renewable power supply is the only way we can secure energy for all and avoid environmental catastrophe.

ENERGY FACTS WE HAVE TO FACE

1.4 billion people have no access to reliable electricity[1].

While most of us take energy for granted as a basic right, a fifth of the world's population still has no access to reliable electricity – drastically reducing their chances of getting an education and earning a living. As energy prices increase, the world's poor will continue to be excluded.

At the same time, more than 2.7 billion people are dependent on traditional bioenergy (mainly from wood, crop residues and animal dung) as their main source of cooking and heating fuel[2] . This is often harvested unsustainably, causing soil erosion and increasing the risk of flooding, as well as threatening biodiversity and adding to greenhouse gas emissions. Traditional stoves are also a significant health problem: the World Health Organization (WHO) estimates that 2.5 million women and young children die prematurely each year from inhaling their fumes[3]. With many developing societies becoming increasingly urban, air quality in cities will decline further.

Finite and increasingly expensive fossil fuels are not the answer for developing countries. But renewable energy sources offer the potential to transform the quality of life and improve the economic prospects of billions.

1. IEA, World Energy Outlook (WEO) 2010, Paris
2. IEA, World Energy Outlook (WEO) 2010, Paris.
3. http://www.iaea.org/Publications/Magazines/Bulletin/Bull442/44204002429.pdf

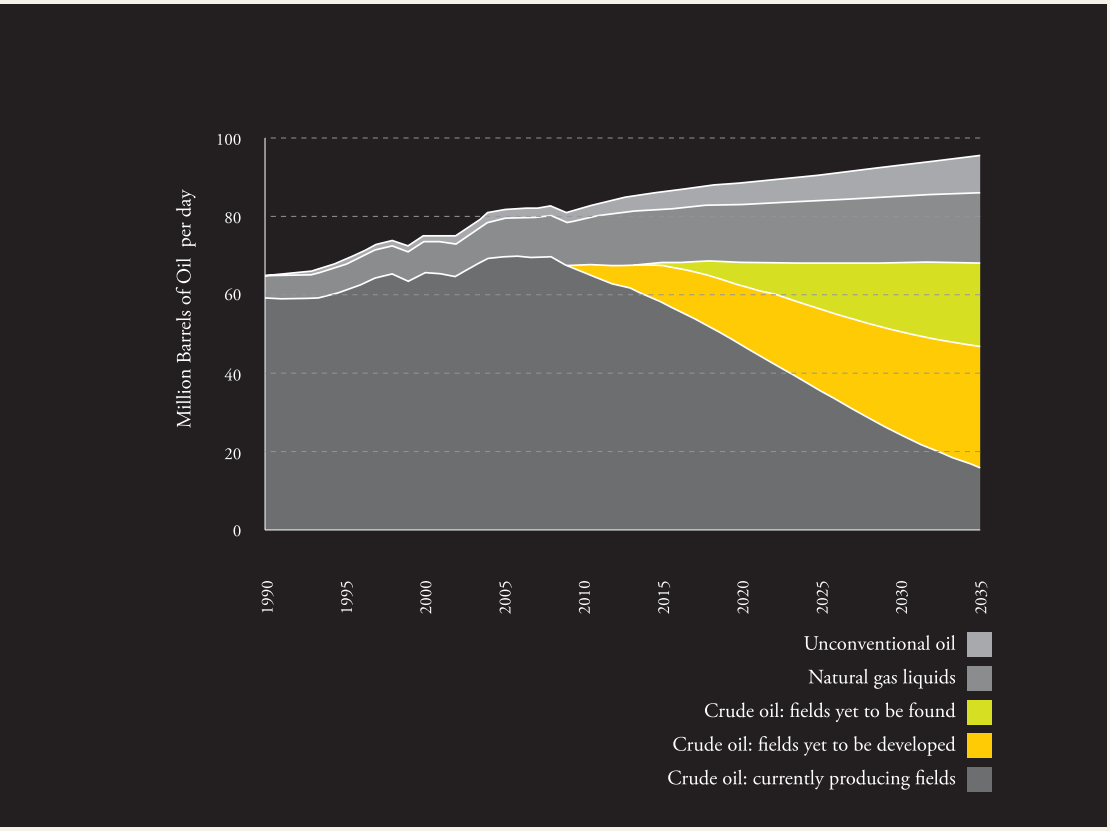

Figure 2: World oil production by type
http://www.worldenergyoutlook.org/docs/weo2010/key_graphs.pdf

"IF EVERYONE CONSUMED AS MUCH ENERGY AS THE AVERAGE SINGAPOREAN AND U.S. RESIDENT, THE WORLD'S OIL RESERVES WOULD BE DEPLETED IN 9 YEARS"*

OIL AND GAS ARE RUNNING OUT

Supplies of cheap, conventional oil and gas are declining while our energy demands continue to increase. It is clear that our reliance on fossil fuels cannot continue indefinitely. With the world's population projected to increase to over nine billion over the next 40 years, "business-as-usual" is not an option.

According to the International Energy Agency (IEA)[4] , production from known oil and gas reserves will fall by around 40-60 per cent by 2030. Yet the developed world's thirst for energy is unabated, while demand is rocketing in emerging economies, such as China, India and Brazil. If everyone in the world used oil at the same rate as the average Saudi, Singaporean or U.S. resident, the world's proven oil reserves would be used up in less than 10 years[5]. Competition for fossil fuel resources is a source of international tension, and potentially conflict.

Energy companies are increasingly looking to fill the gap with unconventional sources of oil and gas, such as shale gas, oil from deep water platforms like BP's Deepwater Horizon, or the Canadian tar sands. But these come at an unprecedented cost – and not just in economic terms. Many reserves are located in some of the world's most pristine places – such as tropical rainforests and the Arctic – that are vital for biodiversity and the ecosystem services that we all depend on, from freshwater to a healthy atmosphere. Extracting them is difficult and dangerous, and costly to businesses, communities and economies when things go wrong.

Processing and using unconventional fossil sources produces large quantities of greenhouse gasses and chemical pollution, and puts unsustainable demands on our freshwater resources, with severe impacts on biodiversity and ecosystem services.

4. IEA, World Energy Outlook (WEO), 2009, Paris.
5. Per capita oil consumption in the U.S. and Canada is about 3 tons annually, in Saudi Arabia about 5 tons and in Singapore 10 tons. Proven oil reserves are estimated at about 205 billion tons in 2010 (BP, Statistical Review, 2010)

*Proven oil reserves are estimated 1,349 billion barrels. Oil consumption in the U. S. 18.86 million barrels per day. World population is 6.9 billion.

FOSSIL FUEL SOURCING

Map 2: *Oil Claims in Africa : P. Hearn, Jr., T. Hare, et. al., Global GIS Database: Complete Global Set, 2002 © AMO*

CLIMATE CHANGE IS ALREADY A REALITY

Even if fossil fuel supplies were infinite, we would have another compelling reason for an urgent switch to renewable energy: climate change. Hundreds of millions of people worldwide are already affected by water shortages, crop failures, tropical diseases, flooding and extreme weather events – conditions that are likely to be made worse by increasing concentrations of greenhouse gasses in the Earth's atmosphere. The WHO estimates that climate change is already causing more than 150,000 deaths a year[6].

Global warming threatens the fragile balance of our planet's ecosystems, and could consign a quarter of all species to extinction[7]. The loss of ecological services from forests, coral reefs and other ecosystems will also have huge economic implications[8].The costs of adapting to climate change will be colossal: a recent report suggests that by 2030, the world may need to spend more than €200 billion a year on measures such as building flood defences, transporting water for agriculture and rebuilding infrastructure affected by climate change[9].To avoid devastating consequences, we must keep eventual global warming below 1.5°C compared to pre-Industrial temperatures. To have a chance of doing that, global greenhouse gas emissions need to start falling within the next five years, and we need to cut them by at least 80 per cent globally by 2050 (from 1990 levels) – and even further beyond that date.

The global energy sector holds the key. It is responsible for around two-thirds of global greenhouse gas emissions, an amount that is increasing at a faster rate than for any other sector. Coal is the most carbon-intensive fuel and the single largest source of global greenhouse gas emissions. Embracing renewable energy, along with ambitious energy-saving measures, is the best way to achieve the rapid emissions reductions we need.

6. http://www.who.int/globalchange/news/fsclimandhealth/en/index.html
7. http://www.nature.com/nature/journal/v427/n6970/abs/nature02121.html
8. For a report on the effects of climate change on ecosystem services, see The Economics of Ecosystems and Biodiversity (TEEB) TEEB Climate Issues Update. September 2009
9. Martin Parry, Nigel Arnell, Pam Berry, David Dodman, Samuel Fankhauser, Chris Hope, Sari Kovats, Robert Nicholls, David Satterthwaite, Richard Tiffin, Tim Wheeler (2009) Assessing the Costs of Adaptation to Climate Change: A Review of the UNFCCC and Other Recent Estimates, International Institute for Environment and Development and Grantham Institute for Climate Change, London.

CLIMATE CHANGE IS ALREADY A REALITY

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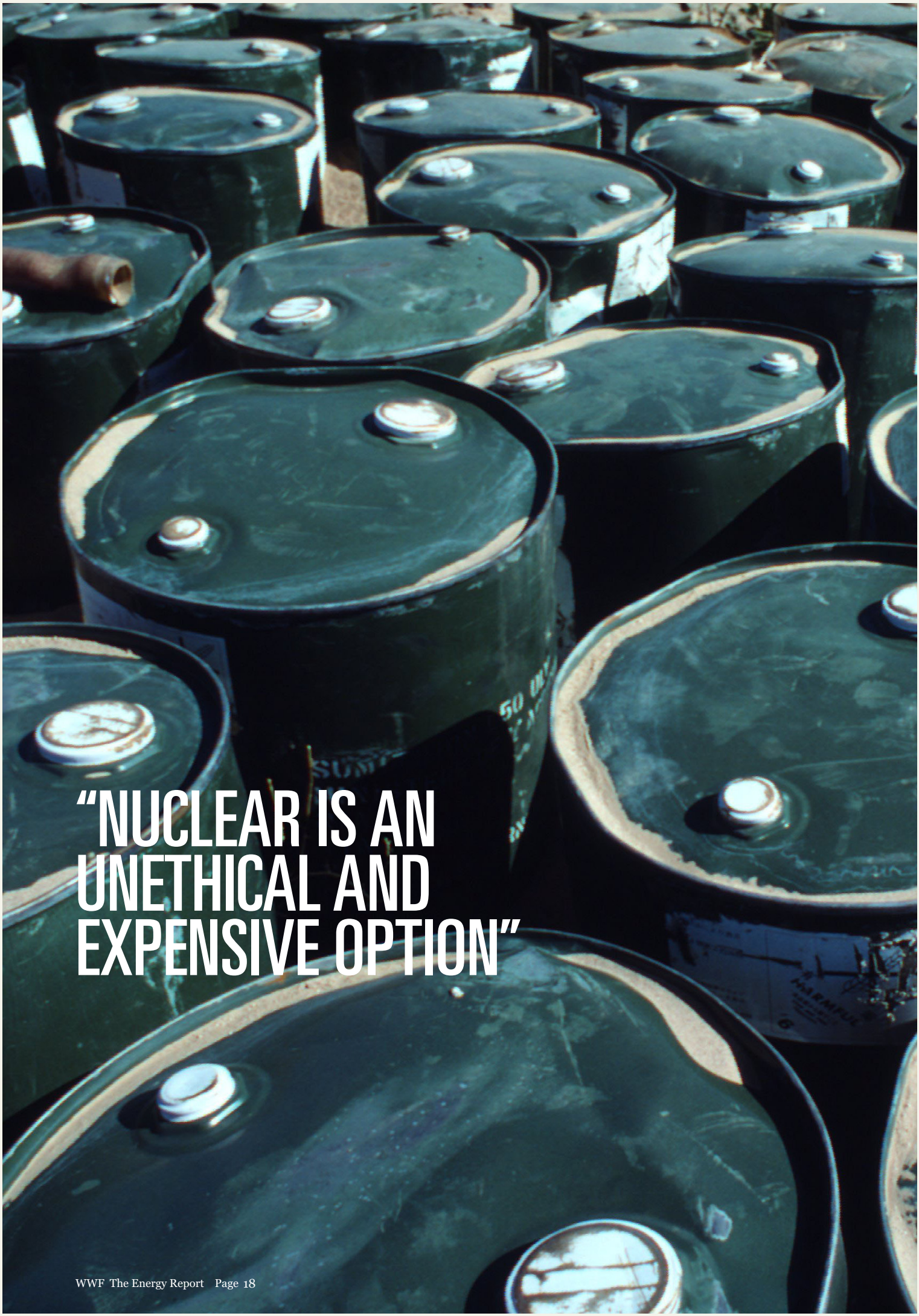

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"NUCLEAR IS AN UNETHICAL AND EXPENSIVE OPTION"

NUCLEAR WASTE WILL BE DANGEROUS FOR 10,000 YEARS

For some, nuclear power is seen to be a part of the solution to the energy crisis. It produces large-scale electricity with low carbon emissions – although mining and enriching uranium is very energy intensive.

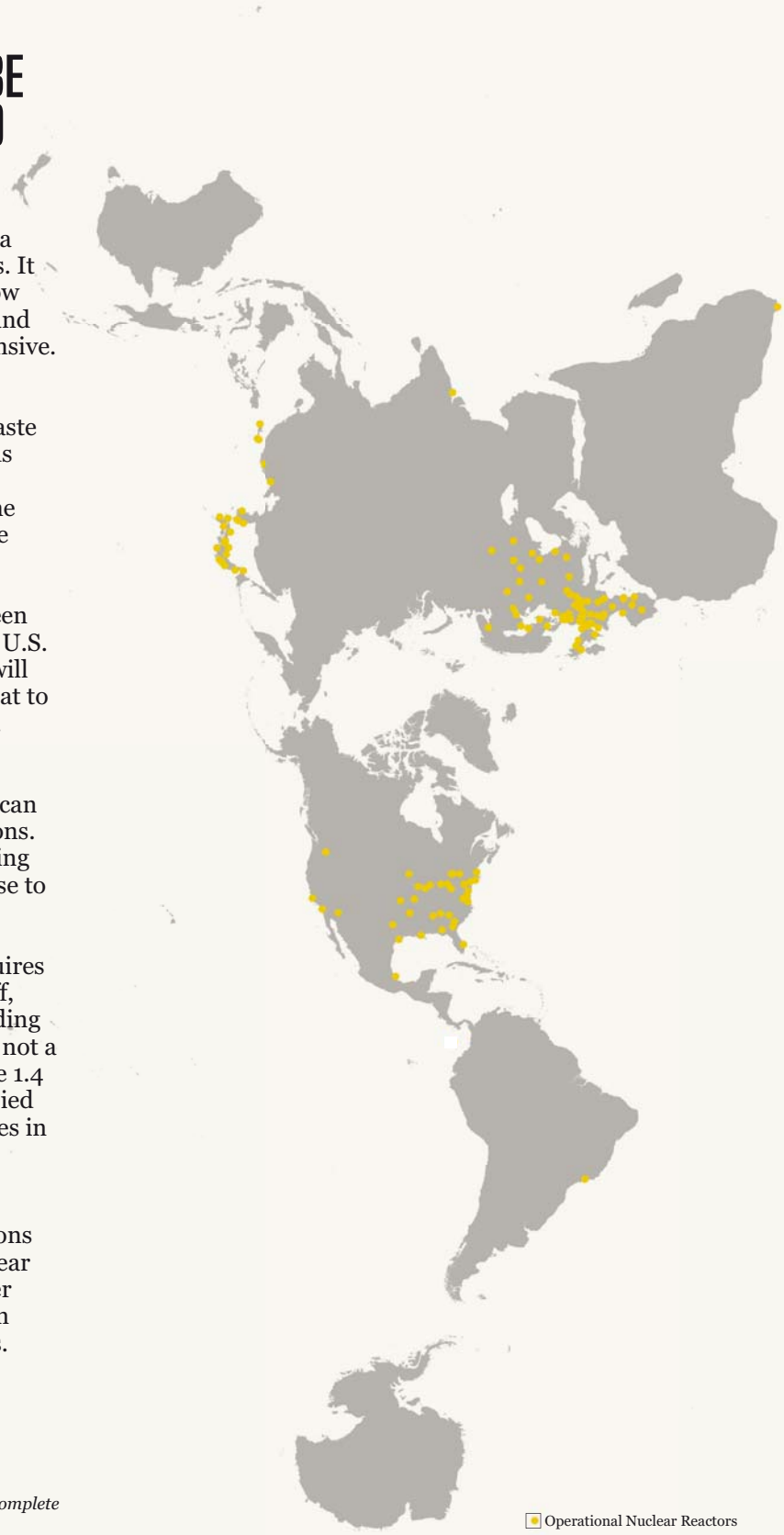
But we cannot escape the reality that nuclear fission produces dangerous waste that remains highly toxic for thousands of years – and there is nowhere in the world where it can be stored safely. The United States and Germany alone have accumulated more than 50,000 and 12,000 tonnes respectively, of highly radioactive waste which has not yet been disposed of securely. According to the U.S. Environmental Protection Agency, it will be at least 10,000 years before its threat to public health is substantively reduced.

Equally troubling, the materials and technology needed for nuclear energy can also be used to produce nuclear weapons. In a politically unstable world, spreading nuclear capability is a dangerous course to take.

Nuclear is no 'easy' technology. It requires a highly sophisticated and trained staff, and only works on a large scale, providing power around the clock. It is certainly not a viable way to provide electricity for the 1.4 billion people whom are currently denied it[10], many of whom live in remote places in fragile states.

Nuclear power is also an extremely expensive option. Before pouring billions into creating a new generation of nuclear power stations, we need to ask whether that money would be better invested in other, sustainable energy technologies.

10. IEA, World Energy Outlook (WEO), 2010, Paris



Map 3: Operational nuclear reactors
P. Hearn, Jr., T. Hare, et. al., Global GIS Database: Complete Global Set, 2002

WWF'S PERSPECTIVE

Climate change threatens to undo everything that conservation organizations like WWF have achieved over the last half-century. Polar bears may make the headlines, but in reality very few species will be unaffected by a changing climate. Many species could become extinct. Even entire ecosystems – such as coral reefs, mountain habitats, and large blocks of tropical rainforests such as the Amazon – could completely disappear.

Many plants and animals that have adapted to their environment over millions of years are vulnerable to even slight changes in temperature and rainfall. Warming and acidifying seas threaten coral reefs and krill – the basis of the marine food chain in many parts of the world. Large mammals like whales and elephants may be forced to travel further in search of food, leaving the safety of the protected areas that WWF and others have fought so hard to secure.

As part of the interwoven web of life, humans will not be immune to the consequences of a changing climate. WWF's mission is to protect the magnificent array of living things that inhabit our planet and to create a healthy and prosperous future in which humans live in harmony with nature. Solving the energy crisis is fundamental to this, whatever tough choices and challenges it brings.

"WE PREDICT, ON THE BASIS OF MID-RANGE CLIMATE-WARMING SCENARIOS FOR 2050, THAT 15–37% OF SPECIES IN OUR SAMPLE OF REGIONS AND TAXA WILL BE 'COMMITTED TO EXTINCTION'"*

** Thomas C.D. et al, 2004, Extinction risk from climate change. Nature, Vol 427, No. 8*

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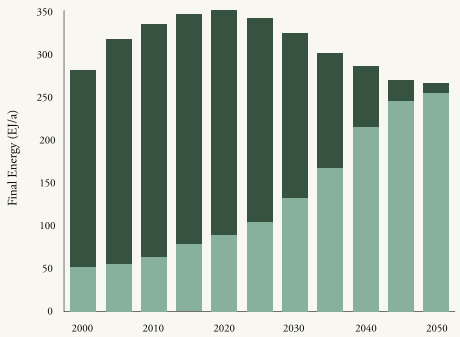


Figure 3: World Energy Supply
Source: The Ecofys Energy Scenario, December 2010

Fossil Fuel Supply

Renewable Energy Supply

Map 4: Fossil Fuel and Renewable Energy Potential

This OMA map is an artists' impression showing the abundance of Renewable Energy potentials. It is not intended to claim exact values for renewable energy potentials but represents a rough estimate based on landmass.

100% POSSIBLE

Switching to a fully renewable energy supply by 2050 is achievable, but there are challenges to overcome.

The global energy crisis is a daunting challenge. Yet we do not have to look far for the solutions. Energy derived from the sun, the wind, the Earth's heat, water and the sea has the potential to meet the world's electricity needs many times over, even allowing for fluctuations in supply and demand. We can greatly reduce the amount of energy we use through simple measures like insulating buildings, recycling materials and installing efficient biomass stoves. Biomass from waste, crops and forest resources has potential to provide a renewable source of energy – although this raises significant social and environmental issues, which we will discuss later in this report.

Around the world, people are taking steps in the right direction. In 2009, China added 37GW of renewable energy, bringing its total renewable capacity to 226GW – equivalent to four times the capacity required to satisfy the total peak electrical power consumption of Great Britain[11] or over twice the total electric capacity of Africa![12] In Europe and the U.S., more than half of all new power capacity installed in 2009 came from renewable sources. In the developing world, more than 30 million households have their own biogas generators for cooking and lighting. Over 160 million use "improved" biomass stoves, which are more efficient and produce less greenhouse gas and other pollutants. Solar water heating is used by 70 million households around the world. Wind power capacity has grown by 70 per cent, and solar power (PV) by a massive 190 per cent in the last two years (2008 and 2009). During the same period, total investment into all renewables has increased from about $US 100 billion in 2007 to more than $US 150 billion in 2009[13].

But the pace of change is far too slow. Non-hydro renewables still only comprise a mere 3 per cent of all electricity consumed. Huge quantities of fossil fuels continue to be extracted and used, and global carbon emissions are still rising. Government subsidies and private investments in fossil fuels and nuclear power ventures still vastly outweigh those into renewable energy and energy efficiency, even though the latter would give a far greater long-term return. While thousands of houses throughout the world, especially in Germany and Scandinavia, have been built to "passive house" standards that require almost no energy for heating and cooling, many more construction projects follow old-fashioned, energy-inefficient designs.

Moving to a fully renewable energy future by 2050 is a radical departure from humanity's current course. It is an ambitious goal. But WWF believes that it is a goal we can and must achieve. This conviction led us to establish a collaborative partnership with Ecofys, one of the world's leading climate and energy consultancies. We commissioned Ecofys to assess whether it would be possible to secure a fully renewable, sustainable energy supply for everyone on the planet by 2050.

The Ecofys scenario, which forms the second part of this report, is the most ambitious analysis of its kind to date. It demonstrates that it is technically feasible to supply everyone on the planet in 2050 with the energy they need, with 95 per cent of this energy coming from renewable sources. This would reduce greenhouse gas emissions from the energy sector by about 80 per cent while taking account of residual land-based emissions from bioenergy production.

The task ahead is, of course, a huge one, raising major challenges. However, the scenario Ecofys has mapped out is practically possible. It is based only on the technologies the world already has at its disposal, and is realistic about the rate at which these can be brought up to scale. Although significant investment will be required, the economic outlay is reasonable, with net costs never rising above 2 per cent of global GDP. The Ecofys scenario accounts for projected increases in population, long-distance travel and increased economic wealth – it does not demand radical changes to the way we live.

The scenario detailed by Ecofys for this report is not the only solution, nor is it intended to be a prescriptive plan. Indeed, it raises a number of major challenges and difficult questions – particularly for a conservation organization like WWF – which we will discuss in more detail on the following pages. To realize our vision of a 100 per cent renewable and sustainable energy supply, we need to further advance the Ecofys scenario; and we propose some of the social and technological changes that could help us do this.

In presenting the Ecofys scenario, WWF aims to show that a fully renewable energy future is not an unattainable utopia. It is technically and economically possible, and there are concrete steps we can take – starting right now – to achieve it.

11. Figures for UK energy demand come from the National Grid's website: http://www.nationalgrid.com/uk/Electricity/Data/Demand+Data/
12. EIA World Electric Data 2006 http://www.eia.doe.gov/iea/elec.html
13. Renewables 2010 Global Status Report, REN 21.

"WE CAN REDUCE OUR RELIANCE ON FOSSIL FUELS BY 70% BY 2040"*

** Source: The Ecofys Energy Scenario, December 2010*

THE ECOFYS SCENARIO IN A NUTSHELL[14]

In 2050, energy demand is 15 per cent lower than in 2005. Although population, industrial output, passenger travel and freight transport continue to rise as predicted, ambitious energy-saving measures allow us to do more with less. Industry uses more recycled and energy-efficient materials, buildings are constructed or upgraded to need minimal energy for heating and cooling, and there is a shift to more efficient forms of transport.

As far as possible, we use electrical energy rather than solid and liquid fuels. Wind, solar, biomass and hydropower are the main sources of electricity, with solar and geothermal sources, as well as heat pumps providing a large share of heat for buildings and industry. Because supplies of wind and solar power vary, "smart" electricity grids have been developed to store and deliver energy more efficiently.

Bioenergy (liquid biofuels and solid biomass) is used as a last resort where other renewable energy sources are not viable – primarily in providing fuels for aeroplanes, ships and trucks, and in industrial processes that require very high temperatures. We can meet part of this demand from waste products, but it would still be necessary to grow sustainable biofuel crops and take more wood from well-managed forests to meet demand. Careful land-use planning and better international cooperation and governance are essential to ensure we do this without threatening food and water supplies or biodiversity, or increasing atmospheric carbon.

By 2050, we save nearly €4 trillion per year through energy efficiency and reduced fuel costs compared to a "business-as-usual" scenario. But big increases in capital expenditure are needed first – to install renewable energy-generating capacity on a massive scale, modernize electricity grids, transform goods and public transport and improve the energy efficiency of our existing buildings. Our investments begin to pay off around 2040, when the savings start to outweigh the costs. If oil prices rise faster than predicted, and if we factor in the costs of climate change and the impact of fossil fuels on public health, the pay-off occurs much earlier.

14. A table summarising all energy data is provided on pages 231 and 232 of the Ecofys scenario.

"BY 2050, WE SAVE NEARLY €4 TRILLION PER YEAR THROUGH ENERGY EFFICIENCY AND REDUCED FUEL COSTS"

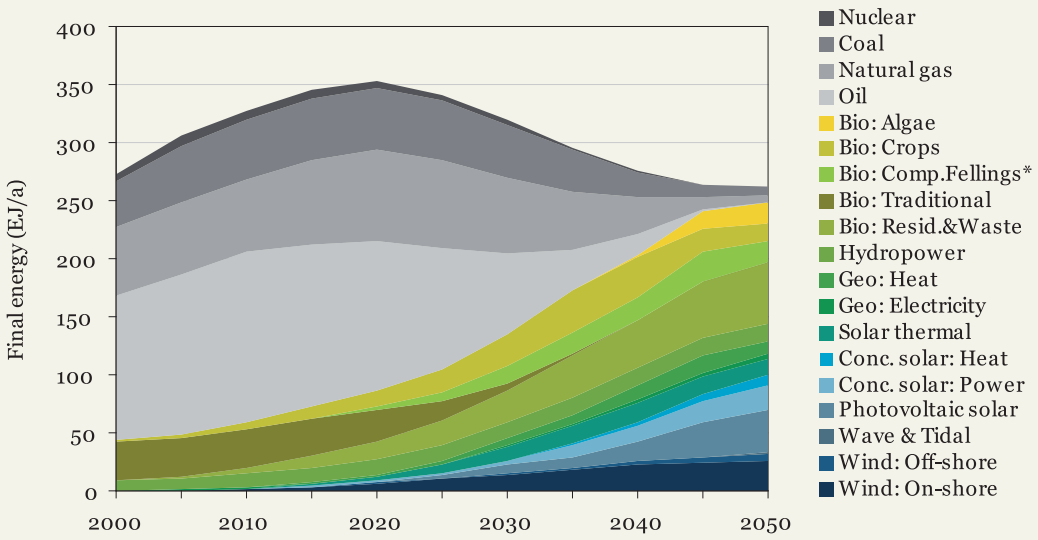
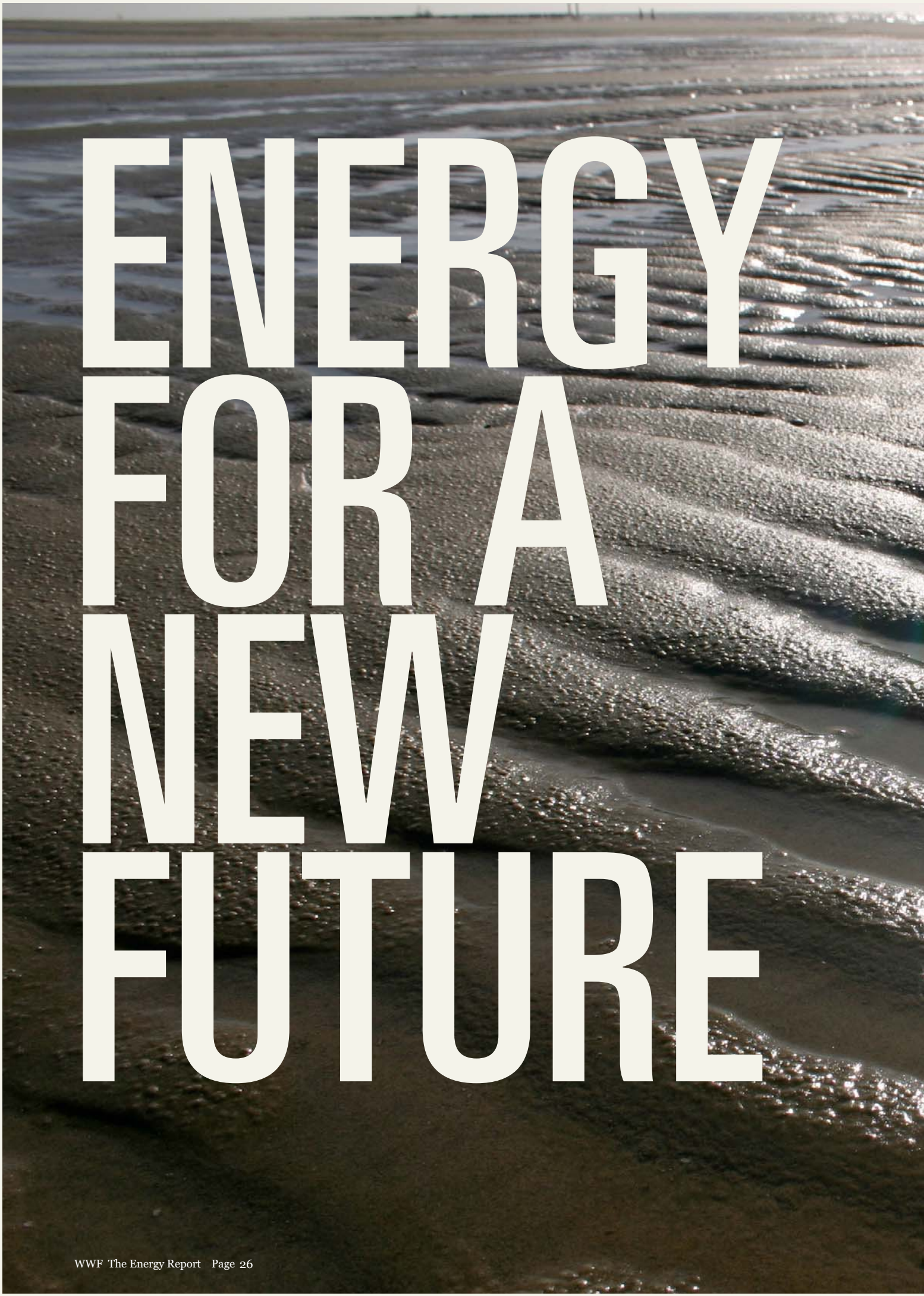


Figure 4: World Energy Supply by Source.
The Ecofys Energy Scenario, December 2010

Map 5: Global Population Density 2010

Gridded Population of the World, version 3 (GPWv3) and the Global Rural-Urban Mapping Project (GRUMP) produced by the Center for International Earth Science Information Network (CIESIN) of the Earth Institute at Columbia University.



ENERGY FOR A NEW FUTURE

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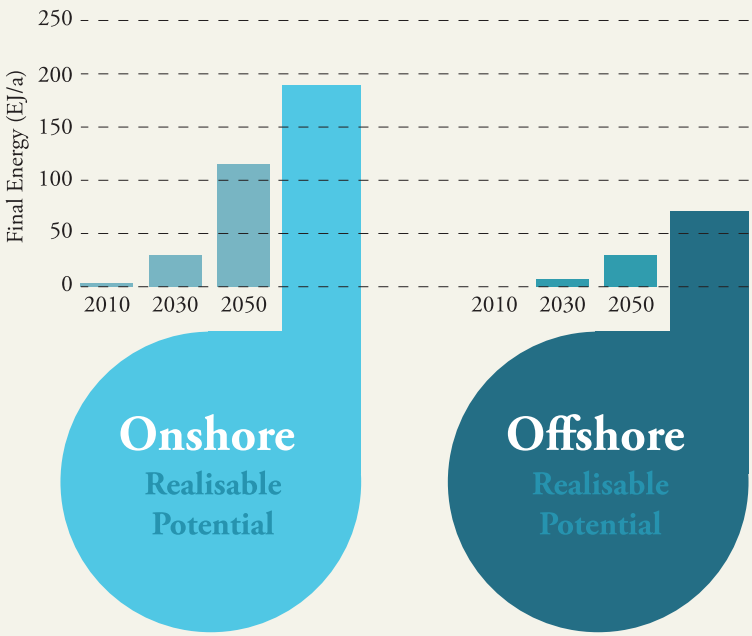
THE ENERGY MIX

Introducing the energy sources of the future

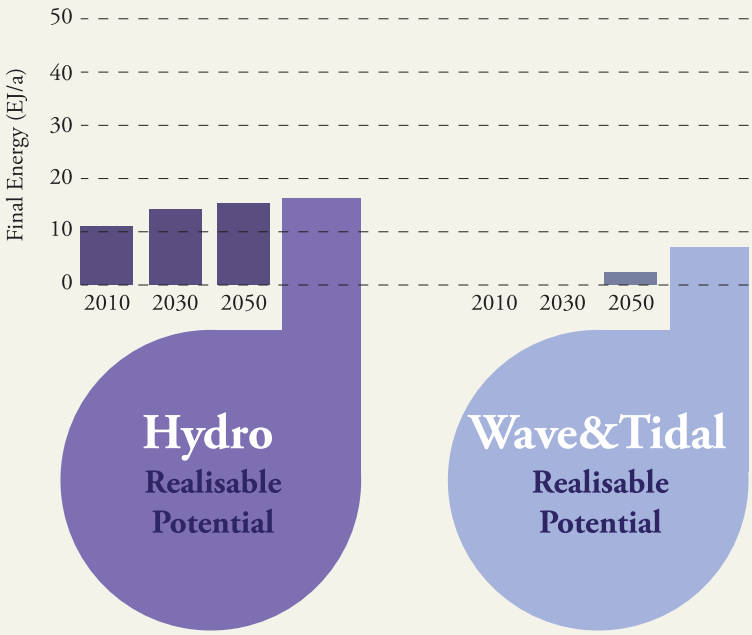
At the moment, more than 80 per cent of our global energy comes from fossil fuels (oil, gas and coal). The remainder comes from nuclear and renewable energy sources, mainly hydropower, and traditional biomass fuels such as charcoal, which are often used inefficiently and unsustainably. Under the Ecofys scenario, fossil fuels, nuclear power and traditional biomass are almost entirely phased-out by 2050, to be replaced with a more varied mixture of renewable energy sources.

The Ecofys scenario takes into account each resource's overall potential, current growth rates, selected sustainability criteria, and other constraints and opportunities such as variability of wind and solar sources. Technological breakthroughs, market forces and geographic location will all influence the ways in which renewable energies are developed and deployed, so the final energy breakdown could well look very different - while still based on 100 per cent sustainable renewables.

Global potential of wind power



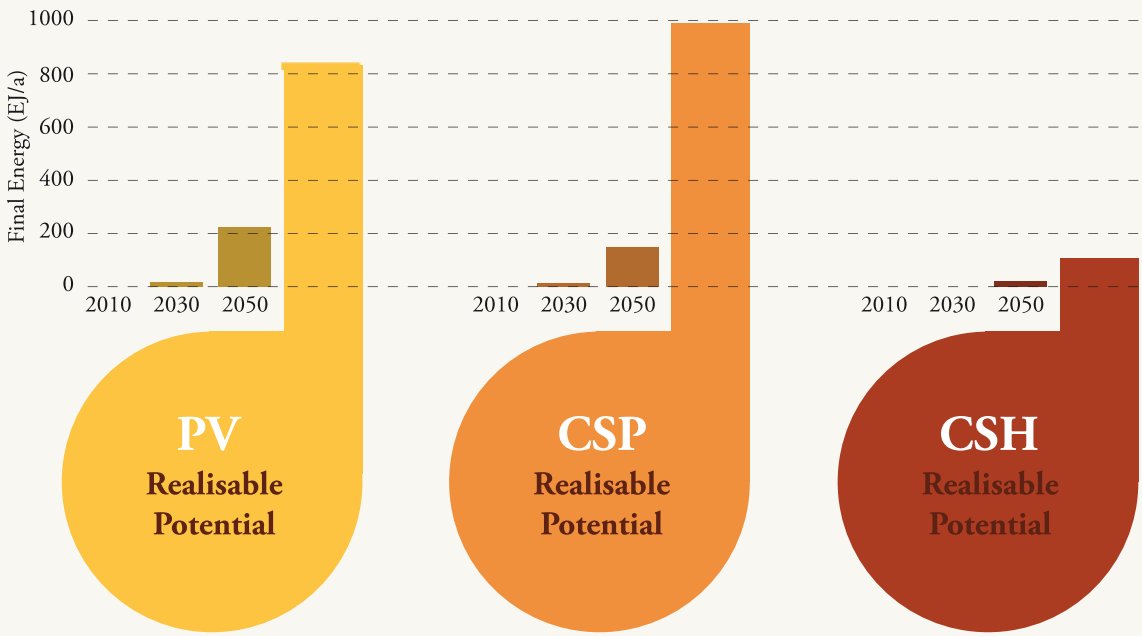
Global potential of water power



ENERGY OF THE FUTURE

"IN ORDER TO CUT GLOBAL GREENHOUSE GAS EMISSIONS BY AT LEAST 80% BY 2050, THE WORLD WILL NEED TO TRANSITION TO RENEWABLE ENERGY"

Global potential of solar power and heat



Global potential of geothermal energy

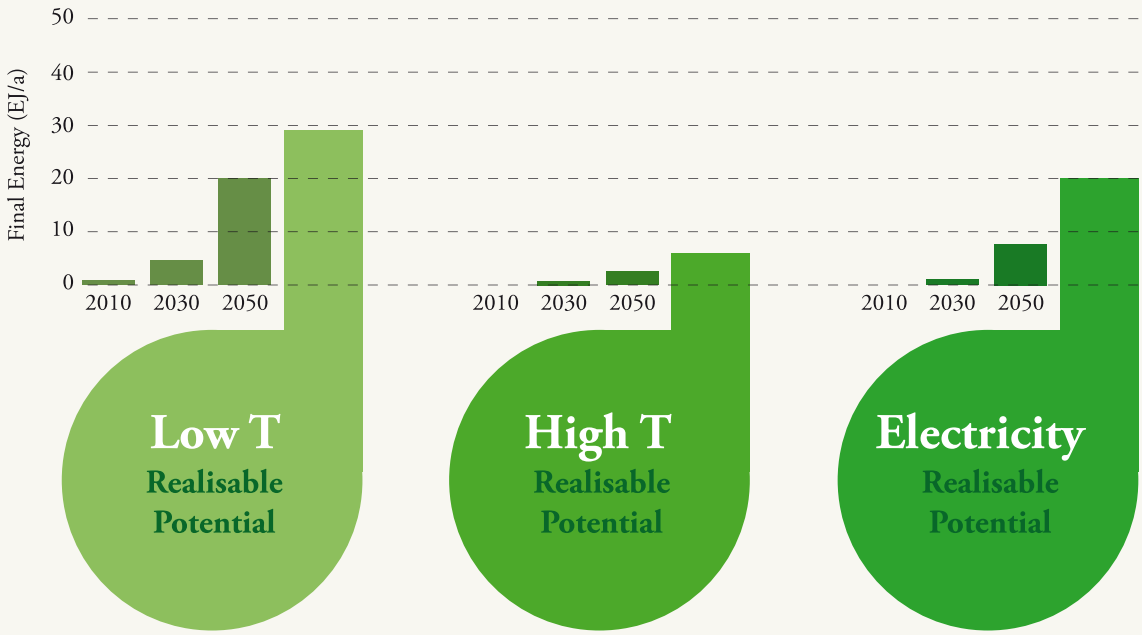
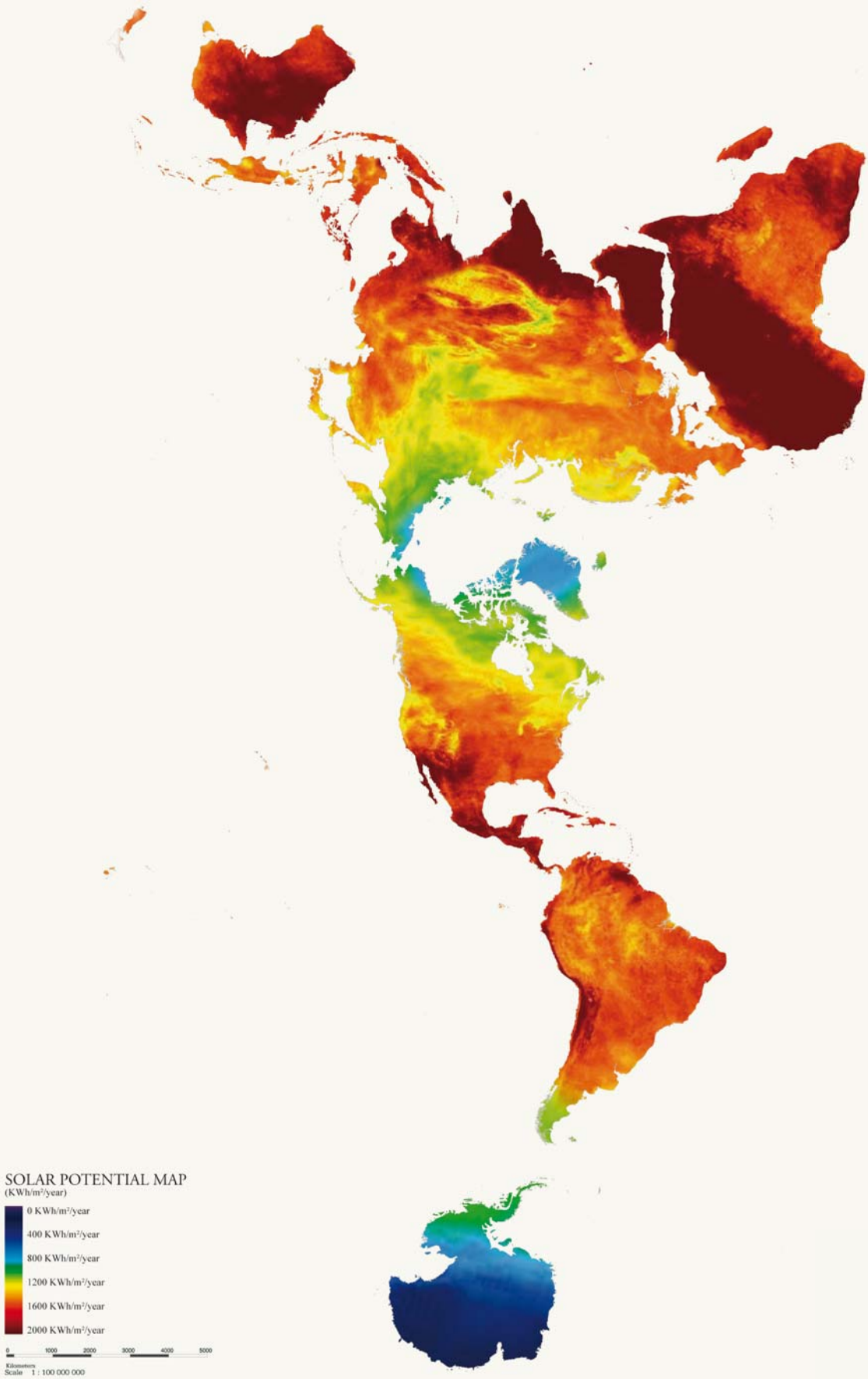


Figure 5: World Renewable Production Potential
The Ecofys Energy Scenario, December 2010
PV - Solar power from photovoltaics
CSP - Concentrating solar power
CSH - Concentrating solar high-temperature heat for industry
Low T - Low temperature heat
Hight T - High temperature heat



Map 6: Global Solar Potential
NASA Map of World Solar Energy Potential

© John E. Newby / WWF-Canon

Solar energy

The sun provides an effectively unlimited supply of energy that we can use to generate electricity and heat. At the moment, solar energy technology contributes only 0.02 per cent of our total energy supply, but this proportion is growing fast. In the Ecofys scenario, solar energy supplies around half of our total electricity, half of our building heating and 15 per cent of our industrial heat and fuel by 2050, requiring an average annual growth rate much lower than the one currently sustained year on year.

Solar energy provides light, heat and electricity. Photovoltaic (PV) cells, which convert sunlight directly into electricity, can be integrated into devices (solar-powered calculators have been around since the 1970s) or buildings, or installed on exposed areas such as roofs. Concentrating solar power (CSP) uses mirrors or lenses to focus the sun's rays onto a small area where the heat can be collected – for example to heat water, which can be used to generate electricity via a steam turbine or for direct heat. The same principle can be used on a small scale to cook food or boil water. Solar thermal collectors absorb heat from the sun and provide hot water. Combined with improved insulation and window architecture, direct sunshine can also be used to heat buildings.

For developing countries, many of which are in regions that receive the most sunlight, solar power is an especially important resource. Solar energy can generate power in rural areas, on islands, and other remote places "off-grid".

One obvious drawback of solar power is that the supply varies. Photovoltaic cells don't function after dark – although most electricity is consumed in daylight hours when sunshine also peaks – and are less effective on cloudy days. But energy storage is improving: CSP systems that can store energy in the form of heat - which can then be used to generate electricity - for up to 15 hours, are now at the design stage. This issue of variability can also be addressed by combining solar electricity with other renewable electricity sources.

"IF 0.3% OF THE SAHARA DESERT WAS A CONCENTRATED SOLAR PLANT, IT WOULD POWER ALL OF EUROPE"*

** Bridgette Meinhold, Desertec Foundation, 2009*

© National Geographic Stock / Sarah Leen / WWF

Wind energy

Wind power currently supplies around 2 per cent of global electricity demand, with capacity more than doubling in the last four years. In Denmark, wind already accounts for one-fifth of the country's electricity production. Wind could meet a quarter of the world's electricity needs by 2050 if current growth rates continue – requiring an additional 1,000,000 onshore and 100,000 offshore turbines. Electricity from offshore wind is less variable, and turbines can be bigger.

Although wind farms have a very visible effect on the landscape, their environmental impact is minimal if they are planned sensitively. When turbines are sited on farmland, almost all of the land can still be used for agriculture, such as grazing or crops. Unlike fossil fuel and nuclear power plants, wind farms don't need any water for cooling. Both on- and offshore wind developments need to be sensitively planned to minimise the impact on marine life and birds, and more research is needed in this area. Floating turbines, which would have less impact on the seabed and could be sited in deeper water, are being trialled.

"AN ADDITIONAL 1,000,000 ONSHORE AND 100,000 OFFSHORE WIND TURBINES WOULD MEET A QUARTER OF THE WORLD'S ELECTRICITY NEEDS BY 2050"*

** Source: The Ecofys Energy Scenario, December 2010*

Geothermal energy

The ancient Romans used the heat from beneath the Earth's crust to heat buildings and water, but only relatively recently have we begun to rediscover its potential. Under the Ecofys scenario, more than a third of building heat comes from geothermal sources by 2050. This is not restricted to volcanically active areas: direct geothermal heat can provide central heating for buildings in almost all parts of the world[15].

When temperatures are high enough, geothermal energy can be used to generate electricity and local heating, including high-temperature heat for industrial processes. Unlike wind or solar power, which vary with the weather, geothermal energy provides a constant supply of electricity. Iceland already gets a quarter of its electricity and almost all of its heating from its molten "basement". In the Philippines, geothermal plants generate almost a fifth of total electricity[16].

Geothermal electric capacity is growing at around 5 per cent each year; the Ecofys analysis suggests we could reasonably hope to at least double this growth rate to provide about 4 per cent of our total electricity in 2050. Geothermal would also provide 5 per cent of our industrial heat needs. Exploiting geothermal resources will undoubtedly affect the surrounding environment and the people who live there. Geothermal steam or hot water used for generating electricity contains toxic compounds, but "closed loop" systems can prevent these from escaping. If sites are well chosen and systems are in place to control emissions, they have little negative environmental impact. In fact, because geothermal plants need healthy water catchment areas, they may actually strengthen efforts to conserve surrounding ecosystems[17].

15.Direct geothermal heat should not be confused with heat pumps, which are included on the demand-side in the Ecofys scenario and provide heat in addition to geothermal energy.
16. http://www.geo-energy.org/pdf/reports/GEA_International_Market_Report_Final_May_2010.pdf
17. See: Geothermal Projects in National Parks in the Philippines: The Case of the Mt. Apo Geothermal Project,
Francis M. Dolor, PNOC Energy Development Corporation

© Michel Terrettaz / WWF-Canon

"BY 2050, MORE THAN A THIRD OF BUILDING HEAT COULD COME FROM GEOTHERMAL SOURCES"*

**Ecofys Energy Scenario, 2010*

"IF WE COULD HARNESS 0.1% OF THE ENERGY IN THE OCEAN, WE COULD SUPPORT THE ENERGY NEEDS OF 15 BILLION PEOPLE"*

© Wild Wonders of Europe /Inaki Relanzon / WWF

Ocean power

The motion of the ocean, through both waves and tides, provides a potentially vast and reliable source of energy – but there are significant challenges in converting it into electricity. Several pilot projects are underway to harness wave energy and to design sustainable tidal systems, but this is a relatively new technology. Recognising this constraint, the Ecofys scenario assumes that ocean power accounts for only 1 per cent of global electricity supply by 2050. However, it is likely to provide a significantly larger percentage in some particularly suitable areas, like America's Pacific Northwest and the British Isles.

Wave and tidal power installations could affect the local marine environment, coastal communities, as well as maritime industries such as shipping and fishing. It is critical that appropriate sites are selected and technologies developed that minimize any negative impacts.

** M.M. Bernitsas, et al., Vortex Induced Vibration Aquatic Clean Energy): A New Concept in Generation of Clean and Renewable Energy from Fluid Flow" OMAE '06*

Hydropower

Hydropower is currently the world's largest renewable power source, providing nearly one-fifth of all electricity worldwide. Large-scale hydropower plants store water in a reservoir behind a dam, and then regulate the flow according to electricity demand. Hydropower can provide a relatively reliable source of power on demand, helping to balance variable sources like wind and solar PV.

However, hydropower can have severe environmental and social impacts. By changing water flow downstream, dams threaten freshwater ecosystems and the livelihoods of millions of people who depend on fisheries, wetlands, and regular deposits of sediment for agriculture. They fragment habitats and cut-off fish access to traditional spawning grounds. Creating reservoirs means flooding large areas of land: 40-80 million people worldwide have been displaced as a result of hydroelectric schemes[18].

The Ecofys scenario reflects these concerns with a relatively small increase in hydropower. Hydropower would provide 12 per cent of our electricity in 2050 compared with 15 per cent today. New hydropower schemes would need to meet stringent environmental sustainability and human rights criteria, and minimize any negative impacts on river flows and freshwater habitats.

18. http://www.internationalrivers.org/en/way-forward/world-commission-dams/world-commission-dams-framework-brief-introduction

"NEW HYDROPOWER SCHEMES WOULD NEED TO MEET STRINGENT ENVIRONMENTAL SUSTAINABILITY AND HUMAN RIGHTS CRITERIA"

© Hartmut Jungius / WWF-Canon

© naturepl.com/ Tim Laman / WWF

Bio energy

Energy from biomass – materials derived from living or recently living organisms, such as plant materials or animal waste – is potentially the most challenging part of the Ecofys scenario. Bioenergy comes from a large variety of sources and is used in many different ways. Wood and charcoal have traditionally provided the main source of fuel for cooking and heating for hundreds of millions of people in the developing world. More recently, biofuels have begun to replace some petrol and diesel in vehicles.

In principle, biomass is a renewable resource – it is possible to grow new plants to replace the ones we use. Greenhouse gas emissions are lower than from fossil fuels, provided there is enough regrowth to absorb the carbon dioxide released, and good management practices are applied. Bioenergy also has potential to provide sustainable livelihoods for millions of people, particularly in Africa, Asia and Latin America. However, if produced unsustainably its environmental and social impacts can be devastating. We need comprehensive policies and mandatory certification to ensure bioenergy is produced to the highest standards.

Although the Ecofys scenario favours other renewable resources wherever possible, there are some applications where bioenergy is currently the only suitable replacement for fossil fuels. Aviation, shipping and long-haul trucking require liquid fuels with a high energy density; they cannot, with current technology and fuelling infrastructure, be electrified or powered by hydrogen. Some industrial processes, such as steel manufacturing, require fuels not only for their energy content, but as feedstocks with specific material properties. By 2050, 60 per cent of industrial fuels and heat will come from biomass. 13 per cent of building heat will come from biomass and some biomass will still be needed in the electricity mix (about 13 per cent), for balancing purposes with other renewable energy technologies.

We can derive a significant proportion of the bioenergy needs in the Ecofys scenario from products that would otherwise go to waste. These include some plant residues from agriculture and food processing; sawdust and residues from forestry and wood processing; manure; and municipal waste. Using these resources up to a sustainable level has other environmental benefits, such as cutting methane and nitrogen emissions and water pollution from animal slurry, and reducing the need for landfill. In developing countries, more than 30 million households have their own biogas digesters for cooking and lighting. Some residues and waste products are already used, for example as soil conditioners; the Ecofys scenario accounts for these.

The second major source of biomass comes from forests. According to the Ecofys scenario, we will need more than 4.5 billion cubic metres of wood products for energy purposes by 2050 coming from harvesting and processing residues, wood waste and "complementary fellings" – the difference between the amount of wood we use and the maximum amount that we could sustainably harvest in forests that are already used commercially. This is preferable to taking wood from virgin forests and disturbing important habitats, although more intensive forestry is bound to affect biodiversity. In addition, some of the biomass traditionally used for heating and cooking in the developing world, which will largely be replaced by renewable energy sources such as solar energy, can also be used for more efficient bioenergy uses. All the same, meeting demand sustainably will be a huge challenge.

Bioenergy crops provide a possible source of liquid fuel – either vegetable oils from plants such as rapeseed, or in the form of ethanol derived from crops high in sugar, starch or cellulose. The Ecofys scenario suggests we will need around 250 million hectares of bioenergy crops – equal to about one-sixth of total global cropland – to meet projected demand. This has the potential to cause deforestation, food and water shortages, and other social and environmental impacts, so must be considered with utmost care.

With an expected 2 billion more mouths to feed by 2050, it is vital that increased biofuel cultivation does not use land and water that is needed to grow food for people or to sustain biodiversity. This is no easy challenge. While Ecofys has applied a series of safeguards in its analysis, land and water implications of bioenergy feedstock production will need further research, especially at the landscape level.

A possible long-term alternative source of high-density fuel included in this scenario is algae. Algae can be grown in vats of saltwater or wastewater on land not suitable for agriculture. Large-scale cultivation of algae for biofuel is currently in development. In the Ecofys scenario, algae begins to appear as a viable energy source around 2030, and only a fraction of its potential is included by 2050.

The apparent need for large amounts of land for bioenergy is the aspect of the Ecofys scenario that produces the hardest challenges and raises the hardest questions. We will discuss these further on pages 60-61.

Map 7: World biomass potential
Artist's impression, OMA

THE CHAL-LENGES AHEAD

© Simon de TREY-WHITE / WWF-UK

THE CHALLENGES AHEAD

The Ecofys analysis shows that the world can technically meet its energy needs from renewable sources by 2050. But it throws up some difficult challenges – and not just technical ones. The social, environmental, economic and political issues this report raises are equally pressing.

On the technical side, two key factors will enable the world to meet its energy needs from renewable sources: (i) We need to reduce demand by improving energy efficiency and reducing wasteful use of energy; and (ii) because electricity and heat are the forms of energy most easily generated by renewables, we need to maximize the use of electricity and direct heat, with improvements to electricity grids to support this.

A sustainable energy future must be an equitable one. Its impact on people and nature will greatly depend on the way we use our land, seas and water resources. Changes in lifestyle also have a critical role to play.

Moving to a renewable future will mean rethinking our current finance systems. It will also require innovation.

Local, national and regional governance will need to be greatly strengthened to secure an equitable energy future. We need international cooperation and collaboration on an unprecedented level to bridge the gap between the energy-rich and energy-poor, both within and between countries.

These challenges are outlined on the following pages.

ENERGY CONSERVATION

How can we do more while using less energy?

Under the Ecofys scenario, global energy demand in 2050 is 15 per cent lower than in 2005. This is in striking contrast to "business-as-usual" projections, which predict energy demand will at least double. This difference is not based on any reduction in activity – industrial output, domestic energy use, passenger travel and freight transport continue to grow, particularly in developing countries. Instead, reductions come from using energy as efficiently as possible.

Energy conservation is one of the prerequisites of a future powered by renewables. We will not be able to meet the needs of our planet's expected nine billion inhabitants if we continue to use it as wastefully as we do today. It is the single most important element in the Ecofys scenario.

In every sector, solutions already exist that can deliver the massive energy savings we need. The challenge will be in rolling them out on a global scale as soon as possible.

In manufacturing, using recycled materials greatly reduces energy consumption. For example, making new products from recovered aluminium instead of primary aluminium cuts total energy use by more than two-thirds. Stocks of materials that take a lot of energy to produce, such as steel and aluminium, have grown over the past decades, making recycling and reusing materials increasingly viable. Finding alternatives to materials that take the most energy to produce, such as cement and steel, will mean further energy savings.

Product design also has considerable implications for energy use. Making cars with lighter (although not weaker) frames and with new materials, for example, and producing smaller cars reduces both the need for energy-intensive steel in manufacturing and their fuel consumption. Despite some very innovative models on markets already, there is still huge potential to tap into much higher efficiency levels for all energy-hungry appliances.

In the developing world, more than 160 million households now use improved biomass cooking stoves. Simply using a ceramic lining instead of an all-metal design can improve efficiency by up to a half. The stoves cost little, reduce carbon emissions and deforestation from charcoal production, and have immense health benefits. Even more efficient are solar cookers, which simply use and concentrate the heat from the sun. Distributed widely enough, these small-scale solutions add up to a significant reduction in energy demand.

The world already has the architectural and construction expertise to create buildings that require almost no conventional energy for heating or cooling, through airtight construction, heat pumps and sunlight. The Ecofys scenario foresees all new buildings achieving these standards by 2030.

At the same time, we need to radically improve the energy efficiency of our existing buildings. We could reduce heating needs by 60 per cent by insulating walls, roofs and ground floors, replacing old windows and installing ventilation systems that recover heat. Local solar thermal systems and heat pumps would fulfil the remaining heating and hot water needs. For all buildings to meet these energy efficiency standards by 2050, we will need to retrofit 2-3 per cent of floor area every year. This is ambitious, but not impossible – Germany has already achieved annual retrofit rates in this range.

The world will also need to use less energy for transport. That means making more fuel-efficient models of all forms of transport, and operating them more effectively. Improved air traffic management could reduce congestion and allow planes to follow more efficient routes and landing approaches, making a small but significant reduction in aviation fuel demands. Similarly, better port, route and weather planning, along with reduced speeds, can significantly reduce fuel use in cargo ships.

But we will also need to move to more efficient modes of transport; making greater use of buses, bikes, trams and trains, sending more freight by rail and sea, and swapping short-haul flights for high-speed trains. Indeed, WWF would argue that we need to go further than this, by reducing the number and length of journeys we need to take – by improving urban planning, logistics and communication technology, and reassessing our priorities.

The more energy we save, the easier the task of moving to a renewable energy future will become. It is one area where everyone can play a part.

© Michel Gunther / WWF-Canon

"THE GLOBAL COST OF LIGHTING IS $230 BILLION PER YEAR. MODERNIZING WASTEFUL TECHNOLOGY COULD SAVE 60%"*

** Mills, E. 2002, "The $230-billion Global Lighting Energy Bill.", International Association for Energy-Efficient Lighting, Stockholm*

DO MORE WITH LESS

© National Geographic Stock/ Jim Richardson / WWF

"ENERGY EFFICIENCY AND RENEWABLE ENERGY CAN REDUCE OUR DEPENDENCE ON FOSSIL FUELS BY 70% BY 2040"*

** The Ecofys Energy Scenario, December 2010*

WHAT NOW?

• We must introduce legally binding minimum efficiency standards worldwide for all products that consume energy, including buildings, along the lines of the Japanese "Top Runner" scheme and the European EcoDesign requirements. Governments, companies and experts will need to agree standards based on Best-Available-Technology (BAT) benchmarks, which should be monitored and strengthened regularly.

• Energy conservation should be built into every stage of product design. Wherever possible we should use energy-efficient, highly-durable and recyclable materials. Alternatives to materials like cement, steel and plastic that take a lot of energy to produce should be a focus for research and development. We should adopt a "cradle to cradle" design philosophy, where all of a product's components can be reused or recycled once it reaches the end of its life.

• We need strict energy-efficiency criteria for all new buildings, aiming toward near-zero energy use, equivalent to "Passive House" standards. Retrofitting rates must increase quickly to improve the energy efficiency of existing buildings. Governments must provide legislation and incentives to enable this.

• Energy taxation is a realistic option, particularly in wealthier countries. Taxes on petrol, electricity and fuels are already commonplace. Shifting taxes to products and cars that use more energy will help to steer demand toward more efficient alternatives.

• Developing countries must phase-out the inefficient use of traditional biomass, and pursue alternatives such as improved biomass cooking stoves, solar cookers and small-scale biogas digesters. Industrialized countries should facilitate this by providing financial assistance, as part of international development commitments and global efforts to reduce greenhouse gas emissions.

• Substantial investment is needed into public transport to provide convenient and affordable energy-efficient alternatives to private cars. We particularly need to improve rail infrastructure: high-speed trains, powered by electricity from renewable sources, should replace air travel as much as possible, and a maximum proportion of freight should be delivered by rail. Sustainable and public transport modes for all distances, particularly for rail-based transport, must be made cheaper than road- and air-borne traffic.

• Individuals, businesses, communities and nations all need to be more aware of the energy they use, and try to save energy wherever possible. Driving more slowly and smoothly, buying energy-efficient appliances and switching them off when not in use, turning down heating and air conditioning, and increased reusing and recycling are just some ways to make a contribution.

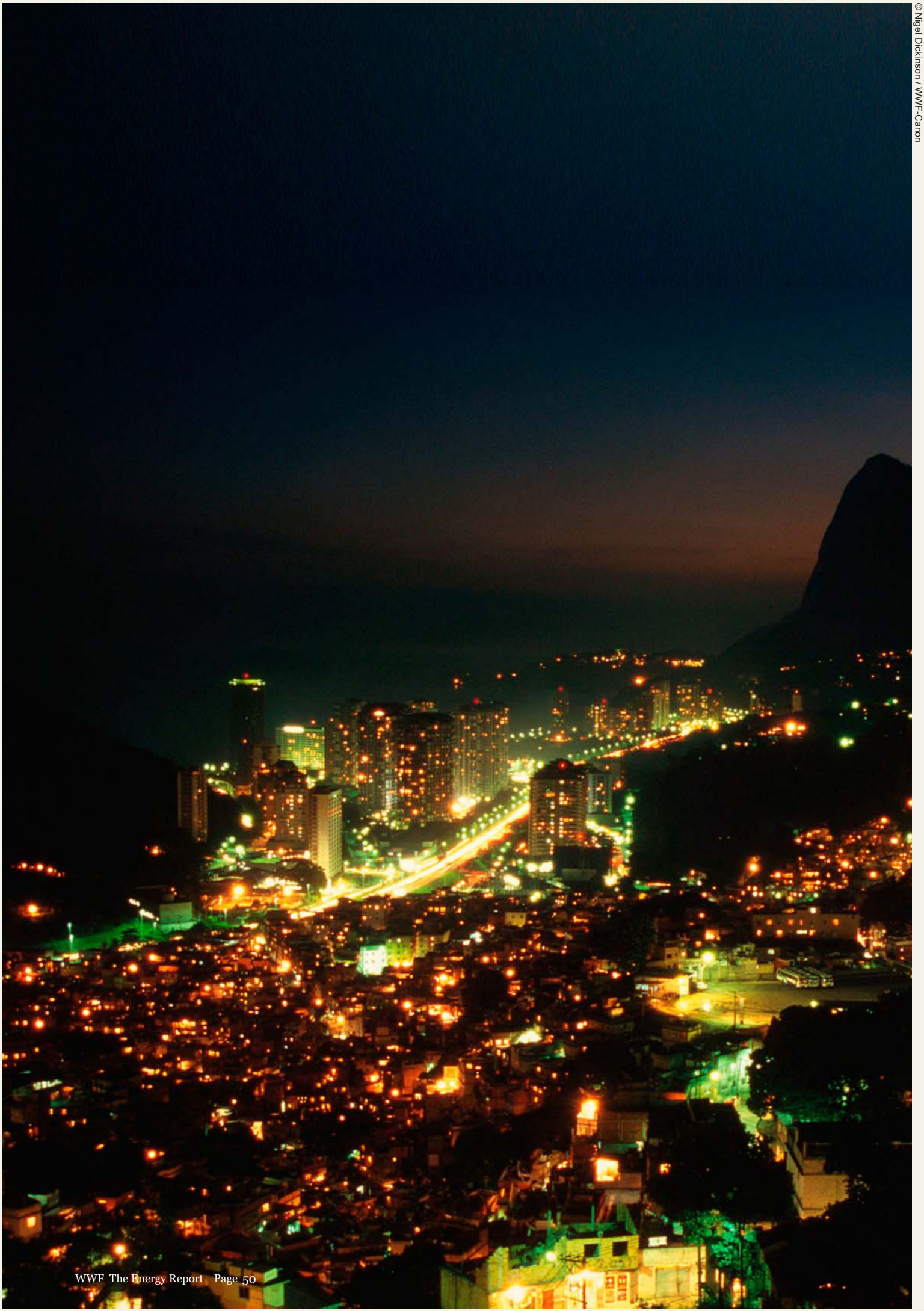
CASE STUDY

© National Geographic Stock / Tyrone Turner / WWF

"WWF HELPED DEVELOP TOPTEN, AN ONLINE SEARCH TOOL THAT IDENTIFIES THE MOST ENERGY-EFFICIENT APPLIANCES ON THE MARKET"

TopTen.info

Consumers and retailers can put pressure on manufacturers to be more energy efficient through their buying choices. WWF helped develop Topten (www.topten.info), an online search tool that identifies the most energy-efficient appliances on the market. Discerning buyers can compare energy-efficiency ratings for a growing number of items, including cars and vans, household appliances, office equipment, lighting, water heaters and air conditioners. Topten now operates in 17 countries across Europe and has recently been launched in the USA and China.



© Nigel Dickinson / WWF-Canon

ELECTRIFICATION

Renewable sources could provide effectively unlimited power, but how do we switch onto them?

The Ecofys scenario for a renewable energy future depends upon using electrical power from clean, renewable sources in place of fossil fuels and nuclear wherever possible. Currently, electricity makes up less than one-fifth of our total final energy demand; by 2050, under the Ecofys scenario, it accounts for almost half. Cars and trains, for example, will become fully electrified, while other energy uses (such as fuel to heat buildings) will be minimized.

Using more renewable electricity presents several challenges. First, of course, we need to generate it. That will mean massively increasing our capacity to produce power from the renewable resources with the least environmental impact – through wind, solar and geothermal power technologies in particular. While we will need many more large-scale renewable power plants, we will also generate more power at a local level, using solar PV roof tiles, water wheels and individual wind turbines, for example.

We are going to need massive investment to extend and modernize our electricity grids to cope with increased loads and different energy sources. We need to transmit power efficiently from offshore wind turbines, desert solar parks or remote geothermal plants to urban centres – while minimizing the impact of new power lines or subterranean cables. Efficient international networks will also help balance variable renewable sources from different regions. Within Europe, for example, wind and ocean power from the North Sea area could complement Alpine hydropower and solar power from the Mediterranean and even North Africa.

While solar and wind have the potential to supply an effectively unlimited amount of power, this is constrained by the capacity of electricity grids to deliver it. Our existing grid infrastructure can only manage a limited amount of these variable, supply-driven sources. Grids need to keep electrical voltage and frequency steady to avoid dangerous power surges, and need the capacity to meet peaks in demand. Today, we keep some power stations, notably coal and nuclear, working around the clock to provide a permanent supply of electricity (or "base load"). These power stations cannot simply be switched-off when renewable energy supplies are high, meaning some of this energy goes to waste.

The Ecofys analysis estimates that networks in industrialized countries could take about 20-30 per cent of total electricity from variable sources without further modernization. At a conservative estimate, this will rise to 60 per cent by 2050 through improvements in technology and grid management. The other 40 per cent would come from hydropower, biomass, geothermal electricity and CSP with storage.

The combination of large ("super") and "smart" grids holds the key. Power companies and consumers will get information on energy supply, and price, to help manage demand. Put simply, it will be cheaper to run your washing machine when the wind is blowing or the sun is shining. Households, offices or factories would programme smart meters to operate certain appliances or processes automatically when power supplies are plentiful. Utility companies would adjust electricity flow – for example, by tweaking thermostat temperatures – to cope with spikes in demand. We could also take advantage of times when supply outstrips demand to charge car batteries and to generate hydrogen fuel.

At the same time, we need to bring electricity to those who are not connected to the grid – particularly in rural areas in developing countries. We can do this by extending existing grids, or generating power at the household or community level through solar, micro-hydro, wind power or small-scale biomass plants. Providing the 1.4 billion who have no reliable electricity[19] with a basic supply of 50-100 kWh per year would require investments of about €25 billion per year between now and 2030[20] , or 0.05 per cent of global GDP.

The electricity networks that power our world are one of the great engineering feats of the 20th century. The work we need to do to modernize them over the coming decades will be one of the great feats of the 21st.

19. IEA, World Energy Outlook (WEO), 2010, Paris .
20. IEA, World Energy Outlook (WEO), 2009, Paris

© Adam Oswell / WWF-Canon

WHAT NOW?

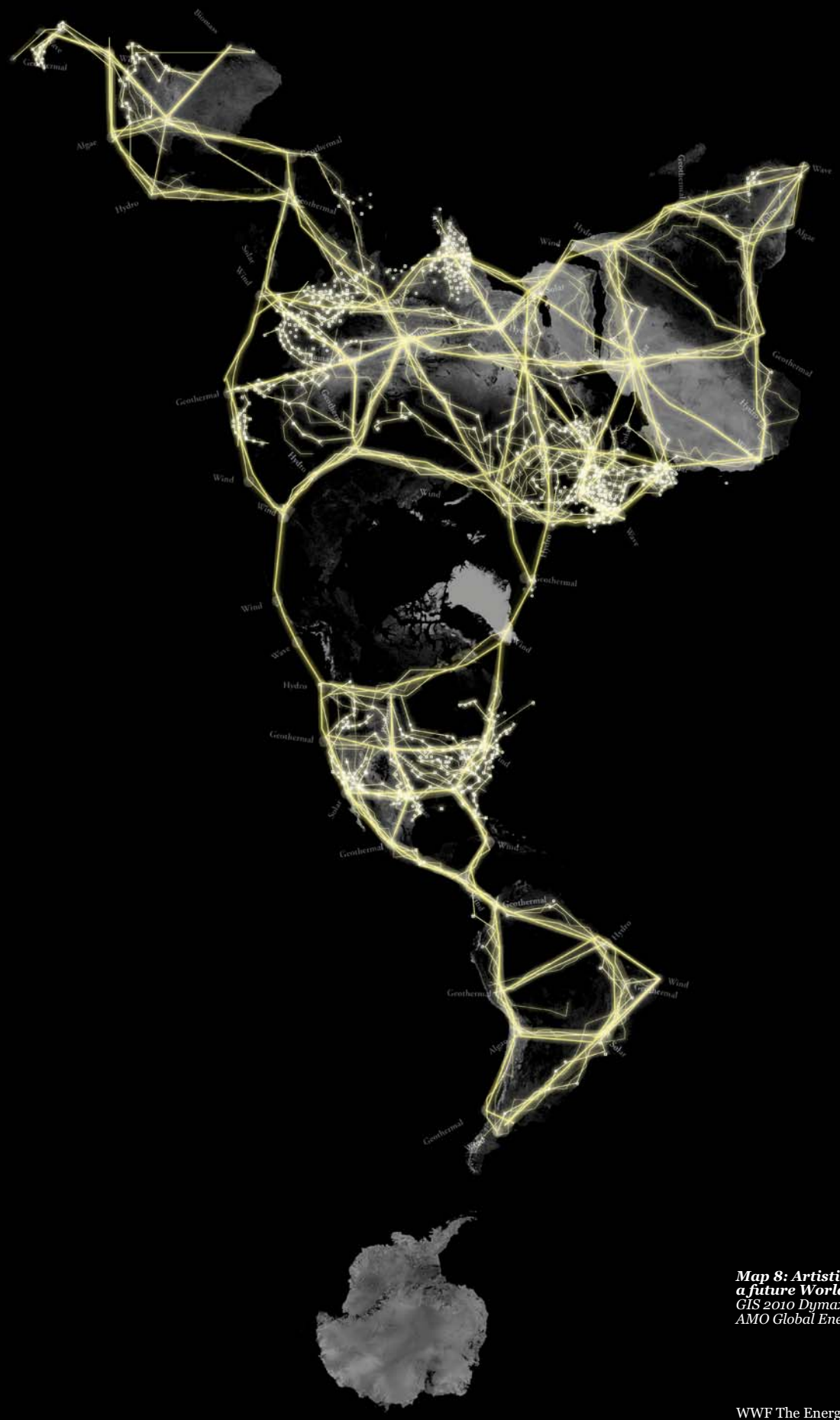
- We need to massively expand our capacity for generating electricity from renewable resources. Large-scale renewable power plants need to be built, before we divert investment into building a new generation of costly and unsustainable fossil fuel and nuclear power plants that could set us back decades. We also need to support local micro-generation, especially in areas where people have limited or no connection to electricity grids.

- Countries need to work together to extend electricity networks to bring power from centres of production to centres of consumption as efficiently as possible. International networks will help meet demand by balancing variable power sources (such as solar PV and wind), supported by constant sources (geothermal, stored CSP, hydro, biomass).

- We need urgent investment into smart grids to help manage energy demand and allow for a significantly higher proportion of electricity to come from variable and decentralized sources. This will help energy companies balance supply and demand more efficiently, and enable consumers to make more informed choices about their electricity use.

- More research is needed into efficient ways to store energy, including batteries, hydrogen and heat storage for solar power. We also need efficient grid management to release this energy when it is needed, and dispatch it over large distances.

- By 2050, all cars, vans and trains globally should run on electricity. We need legislation, investment and incentives to encourage manufacturers and consumers to switch to electric cars. Improvements in battery technology, and emergence of efficient fuel cells, could allow us to run electric trucks, and possibly even ships, reducing our dependence on biofuels. This is a long-term aim, but research and development is needed now.



Map 8: Artistic impression of a future World Energy Grid
GIS 2010 Dymaxion Projection-
AMO Global Energy Grid Anaylsis

CASE STUDY

© Simon de TREY-WHITE / WWF-UK

Micro-hydroelectricity

Near the village of Chaurikharka in Nepal, WWF installed a micro-hydroelectricity system as the demand for wood for cooking and heating was leading to deforestation in the area. Water is diverted from a stream to run a generator, then flows back into the stream, with minimal impact. More than 100 households in six villages now use electricity for cookstoves, microwaves, rice cookers, fridges and room heaters. Four more similar schemes are now operating in the area, saving hundreds of tonnes of fuel wood and improving daily life.

"WWF INSTALLED A MICRO-HYDROELECTRICITY SYSTEM AS THE DEMAND FOR WOOD FOR COOKING AND HEATING WAS LEADING TO DEFORESTATION IN THE AREA"

EQUITY

Everyone has the right to energy. So how are we going to provide it?

Historically, the world's energy consumption has not been fairly balanced. Rich countries have built their economies on cheap, plentiful fossil fuels, and continue to consume the vast majority of global energy supplies. With fossil fuel supplies dwindling, the rest of the world will not have this resource to fuel its own development. Adding to this inequity, poorer countries will suffer most from climate change, which is largely driven by the fossil fuel use of wealthier countries.

A sustainable energy future must be a fair one, in which the equal right of every person to benefit from the world's energy resources is recognized. The scale of the challenge is daunting. Around 1.4 billion people – a fifth of the world's population – have no access to reliable electricity[21]. And the population of developing countries continues to rise rapidly. Investments required for universal access to clean cooking for those 2.7 billion in developing countries who have no access to these services will be around €43 billion in total, or around €2 billion annually between 2010 and 2030, less than 0.005 per cent of global GDP[22].

In the absence of alternative sources of energy, hundreds of millions of people today use biomass as their primary source of fuel for cooking and heating. As a result, trees are cut down at unsustainable rates, leading to biodiversity loss, increasing carbon emissions, harming soil quality and leaving communities vulnerable to flooding. Biomass stoves are also a major health problem. Fumes from traditional cooking fires kill almost as many people in the developing world than malaria[23] – about two million women and children die prematurely each year from indoor pollution.

To move to a fully renewable future, in which people live in harmony with nature, we must end unsustainable biomass use. But we cannot do this without providing people with better alternatives. Efficient cookstoves are one simple, cost-effective way to significantly reduce the amount of biomass people use, and the carbon and "black soot" emissions and health impacts this causes. Planting fast-growing tree species for energy production also reduces the need to cut down or degrade primary forests – WWF's New Generation Plantation Initiative outlines sustainable management practices for doing this. These are, though, only part of the solution.

From solar power across Africa, to geothermal power in Indonesia, developing countries have great potential to power economic growth with renewable energy. Large-scale wind, solar and geothermal plants are beginning to appear. Renewables also offer hope to the hundreds of millions of people trapped in energy poverty. WWF is just one of many organizations helping to develop renewable energy projects across the developing world – particularly in rural areas, where approximately 85 per cent of people who have no access to reliable electricity live. As a result of these initiatives, thousands of communities now benefit from electricity from solar power, wind turbines, micro-hydro, and biogas plants fuelled by farming residues and manure.

Access to reliable energy can make a phenomenal difference. Electric pumps provide clean water. Refrigerators store food and medicines. Farms run more productively. Women who used to spend many hours every day collecting firewood and water have more time to devote to education, childcare or advancing their own livelihoods. Children get a better education through access to learning resources like the Internet, or simply by having electric lighting to read in the evenings. Historically, women's emancipation, better education and secure livelihoods have coincided with increased family incomes and hence falling birth rates, so access to sustainable renewable energy can also contribute to curbing population growth.

Biofuels can offer opportunities for developing countries – but they also pose a threat. Grown sustainably and traded fairly, they can provide a valuable cash crop for farmers and jobs for local communities. Without proper safeguards, however, they may displace food crops and drive deforestation, as well as compete for increasingly scarce water. We cannot abide a situation where developing countries grow large amounts of biofuel crops to support the lifestyles of the rich, while their own people do not have enough food to eat.

Renewable energy has tremendous potential to end poverty and transform lives for hundreds of millions of people. Ending energy poverty is at the heart of our energy vision.

© Brent Stirton / Getty Images / WWF-UK

WHAT NOW?

Developing countries need investment to develop their own renewable energy capacity. Countries with advanced renewable energy technology need to share their knowledge and expertise with developing countries. They should also support them to develop their own renewable industries and innovations.

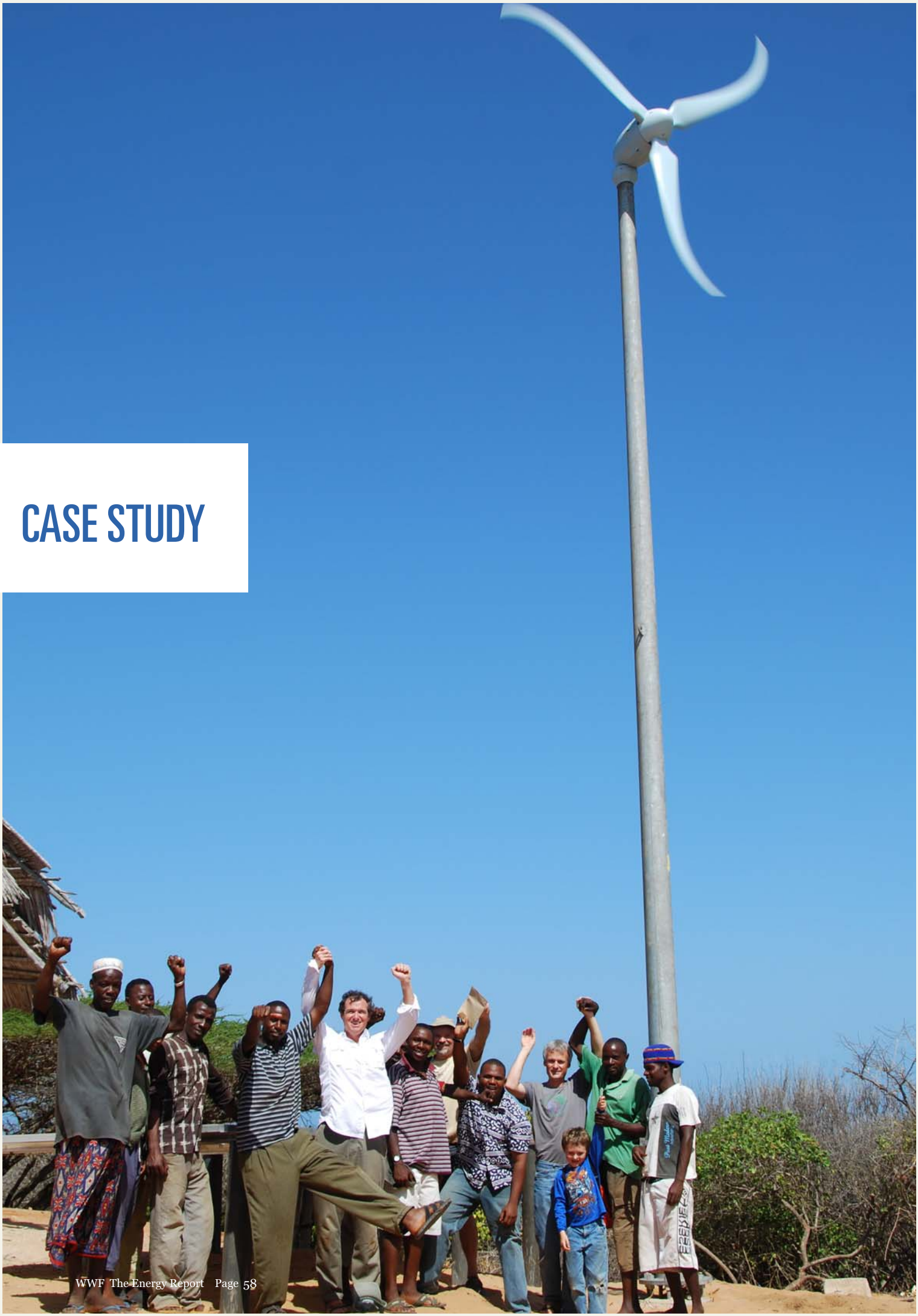
WWF and other NGOs have demonstrated ways in which communities can successfully generate their own electricity from renewable sources. Governments, aid agencies and investors should provide support to replicate projects like these on a much larger scale. Experience suggests that schemes are more successful when communities also pay some of the costs, as this increases their ownership of the project. Microfinance schemes and other financial innovations are needed to enable this.

The world needs to begin phasing-out the unsustainable use of biomass. Where communities still use traditional biomass inefficiently as a source of fuel, they need support to switch to modern clean energy solutions. These include solar cooking, more efficient cookstoves, biogas from digesters and improved charcoal-burning techniques. They should also use biomass sources with less environmental impact, such as crop residues or fast-growing tree species. This should form part of a wider programme to enable people to benefit from managing their own forests and natural resources in a sustainable way.

If land in developing countries is used to meet a growing demand for biofuels, we need to tackle the issues of food security, land-use planning, governance, water use, deforestation, loss of biodiversity, and the resulting loss of ecosystem services. We need a fair and sustainable system of trade and investment. Biofuels must not be grown where they threaten people's food and water supplies, or cause biodiversity loss.

Poorer countries need financing to move to a renewable energy future. Multi- and bilateral agreements must include support from richer countries to help poorer countries develop sustainable energy projects. Renewable energy must be at the heart of sustainable development policy and international aid programmes.

21. IEA, World Energy Outlook (WEO), 2010
22. IEA, World Energy Outlook (WEO), 2010
23. Global Alliance for Clean Cookstoves, UN Foundation, http://www.unfoundation.org/assets/pdf/global-alliance-for-clean-cookstoves-factsheet.pdf , retrieved 21 December 2010



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CASE STUDY

"WWF HELPED INSTALL SOLAR PV AND WIND POWER, WHICH HAS IMPROVED THE LIVELIHOODS AND HEALTH OF LOCAL PEOPLE"

SOLAR PV AND WIND POWER

There is no grid access in the remote coastal outpost of Kiunga, Kenya, where WWF supports a marine reserve protected area conservation programme. In 2009, WWF helped install solar PV and wind power, which has improved the livelihoods and health of local people. Benefits include a freezer for storing fish, electricity for health centres and charging points for cell phones.

LAND AND SEA USE

Our energy needs require land and sea surfaces. What can we do to limit the impact on people and nature?

Sustainability means living within the capacity of humanity's one and only planet, without jeopardising the ability of future generations to do the same. We need space for buildings and infrastructure, land to grow food and fibres and raise livestock, forests for timber and paper, and seas for food and leisure. More importantly, we need to leave space for nature – and not just because the millions of other species that inhabit our planet are important in themselves. We need healthy ecosystems to supply our natural resources, provide clean air and water, regulate our climate, pollinate our crops, keep our soils and seas productive, prevent flooding, and much more. The way we use our land and sea is key to securing a renewable energy future and perhaps the hardest challenge we face.

Over the coming decades, we will need to develop an extensive renewable energy infrastructure, and it will be essential that we put the right technologies in the right places. Solar farms, for example, can make use of unproductive desert areas, but it is important that no water is used merely for cooling solar power plants in arid areas. Geothermal fields are often found in unspoilt areas, so we need to choose sites carefully to minimize the environmental and social impact, and make sure surrounding areas are well protected. As discussed above, we need to assess all new hydropower plants especially rigorously, and should choose sites for offshore wind and ocean power carefully to minimize the impact on marine life. We also need to carefully plan the routes of the long-distance, high-voltage power lines and undersea cables we will need to transmit electricity from new production centres.

The thorniest issue, however, is the role of bioenergy[24]. The Ecofys scenario for a near-complete phase-out of fossil fuels relies on a substantial increase in the amount of bioenergy. In the absence of alternative technologies, this is based on organic waste, biomass from existing forests and biofuel crops on agricultural land.

© Edward Parker / WWF-Canon

The Ecofys analysis suggests that it is technically possible to do this in a sustainable way. According to the scenario, we can meet the increased need for solid biomass by taking more wood from forests than is already used commercially. If people in the developed world ate half as much meat as they do today, we would need less land for growing animal feed and grazing. That would free-up enough land to grow enough biofuel crops without threatening food security, clearing forests, increasing irrigation or losing biodiversity.

On a global level, there may be enough agriculture and forest land available to grow biofuels sustainably. Ecofys estimates that we would need around 250 million hectares of agriculture land, which is equivalent to about one-sixth of the total global cropland today, as well as 4.5 billion cubic metres of biomass from already disturbed forests. But what is possible on paper, even after the most rigorous analysis, is a different matter in practice. We have yet to identify where this land is, and how it is being used at the moment. We need to consider the rights of communities, including indigenous people, the movements of migratory species, the effect on water supplies, the type of infrastructure and governance systems in place, and a host of other constraints. In fact, the huge pressure we're placing on our planet means we need to take these considerations into account with all agriculture and forestry, and not only with bioenergy.

The land availability in the Ecofys scenario also rests on the assumption of a constrained growth in meat consumption. To achieve this equitably, people in richer countries would need to cut their meat consumption in half, with the rest of the world eating no more than 25 percent more meat than they do now. A diet that is high in animal protein requires far more land than a largely vegetarian diet – it is more efficient to eat plant protein directly than to feed it to animals first. Today, nearly a third of global land area (excluding Antarctica) is used for feeding livestock, either through grazing or growing animal fodder.

As the global population grows, the world is going to need to produce and consume food more efficiently and fairly: this will become even more urgent if our demand for biofuels grows too. Ecofys' calculations are based on crop yields rising by 1 per cent per year. This is less than the 1.5 per cent growth that the UN Food and Agriculture Organization predicts; however, climate change will increase the likelihood of crop failures.

Extracting more wood from forests will have an impact on biodiversity. Many of the world's commercial forests are already intensively used, so expansion will have to happen in areas with untapped sustainable potential. There is the potential to increase yields by using fertilizers and fast-growing species, although this too has implications on wildlife habitats, and water and soil quality. Some privately owned plots could sustainably provide more biomass, but there are economic and logistical hurdles. Any increase in forest biomass use must be coupled with efforts to reduce emissions from deforestation and degradation, and promote more forest growth. In other words, we must not release more forest carbon than we replace, even in the short term.

Because of the concerns bioenergy raises, WWF believes we need to take urgent action to reduce the demand for liquid fuels that the Ecofys scenario predicts, and to pursue alternatives. Further reductions in meat consumption, aviation and long-distance freight transport would help to reduce demand. Bioenergy from algae and hydrogen produced with renewable electricity are potential sustainable fuel technologies. In the meantime, better land-use planning, from the local to the global level, will be vital in securing a sustainable energy supply.

24. For more information on WWF's position on bioenergy, see www.panda.org/renewables

"THE WAY WE USE OUR LAND AND SEA IS KEY TO SECURING A RENEWABLE ENERGY FUTURE, AND PERHAPS THE HARDEST CHALLENGE WE FACE"

WHAT NOW?

- All large-scale energy infrastructure developments must satisfy independent, in-depth, social and environmental impact assessments. They should also meet – or exceed – the best social and environmental management practices and performance standards. The Gold Standard for best practice in projects delivering carbon credits provides a good example. For hydropower, WWF has participated in the development of the International Hydropower Association Sustainability Guidelines.

- To safeguard habitats and food supplies, water supplies and ecosystem services, world governments must stop the scramble for land for biofuels,. "Land-grabbing" – where rich countries buy or lease large tracts of land, especially in Africa, to grow biofuels or food – should be outlawed. Instead, we need to carefully analyze, country by country, what land and water is available for bioenergy, taking into account social, environmental and economic issues.

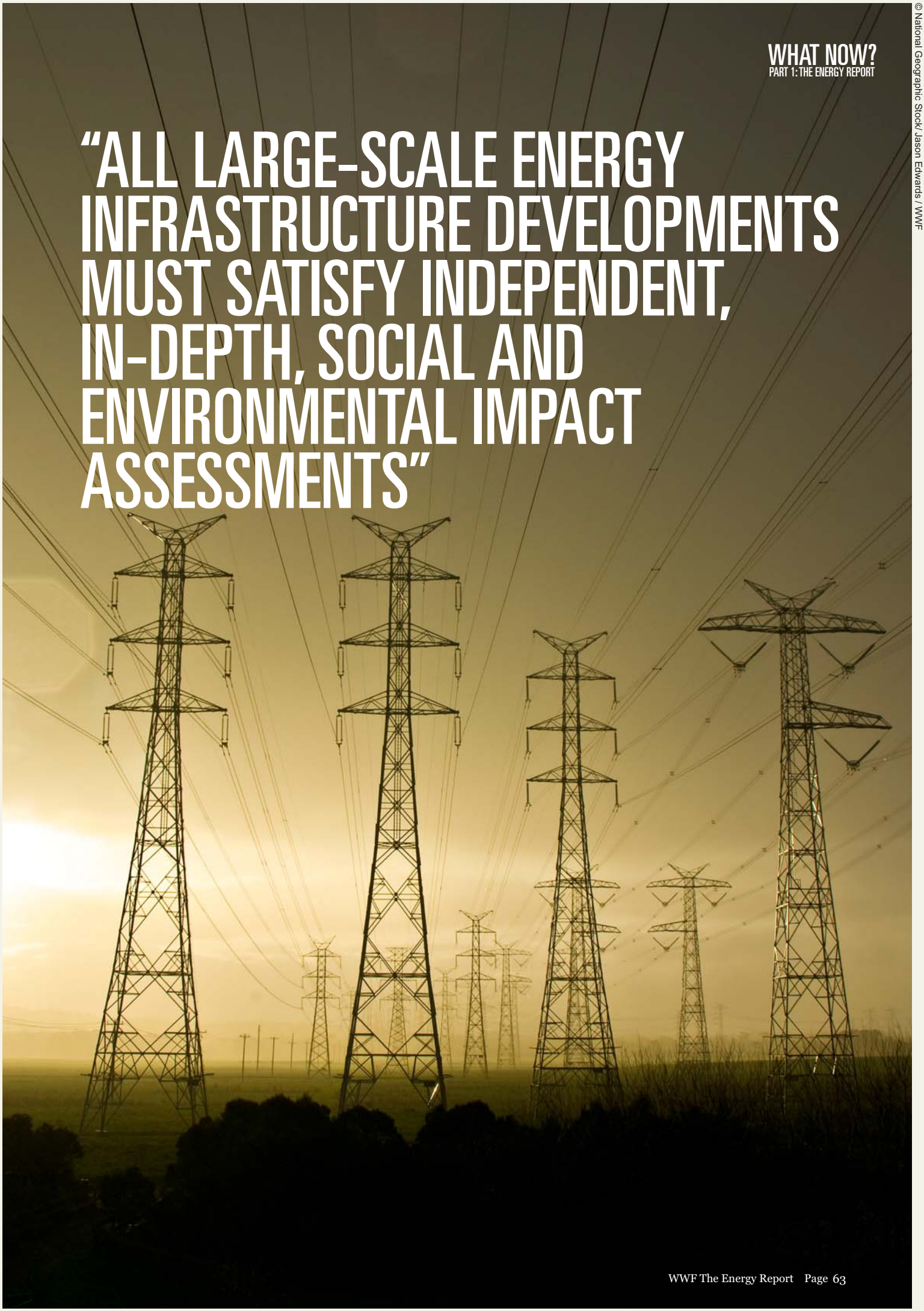
- Forestry companies, governments and conservationists need to identify areas of idle land (forests that have been cleared already but are no longer in use) where it may be possible to increase yields of biomass with the least impact on biodiversity. South East Asia, Russia and the Americas hold the most potential. WWF is supporting the Responsible Cultivation Area concept, which aims to identify land where production could expand without unacceptable biodiversity, carbon or social impacts. WWF is also helping to identify areas that should be maintained as natural ecosytems and primarily managed for conservation purposes through schemes such as the High Conservation Value Framework.

- We need to offset increased forest carbon emissions by stopping unsustainable fellings and deforestation. Schemes such as REDD (Reducing Emissions from Deforestation and Degradation), which offer developing countries incentives to conserve their forest carbon, will play an important role in this. We also need to promote and adopt community forest management and other sustainable forestry practices.

- Bioenergy production has to be based on sustainability criteria with strong legal controls – binding legislation and strict enforcement – at national and international levels. Voluntary standards and certification schemes, along the lines of the Forest Stewardship Council, the Roundtable on Sustainable Biofuels and the Better Sugarcane Initiative, also have a role to play. Because much bioenergy will be produced in developing countries, they will need support to develop and implement these standards effectively.

- As individuals, we need to make more considered choices about the food we eat, the transport we use, and other lifestyle factors that influence global land use. Public policy should help to guide these choices.

- We should limit growth in areas that depend on liquid fuels – notably aviation, shipping and heavy goods vehicles – at least until we have established a secure and sustainable supply of bioenergy. That means finding smarter ways to transport goods and people. These include using modes of transport that don't depend on liquid fuels, and reducing the length and number of journeys, for example by producing more goods locally or working remotely instead of commuting. We also urgently need to research and develop energy alternatives for sectors that rely on bioenergy as the only alternative to fossil fuels.



"ALL LARGE-SCALE ENERGY INFRASTRUCTURE DEVELOPMENTS MUST SATISFY INDEPENDENT, IN-DEPTH, SOCIAL AND ENVIRONMENTAL IMPACT ASSESSMENTS"

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“THE SUGARCANE IS USED TO PRODUCE BIOETHANOL. CANE RESIDUES ARE FED TO THE COWS, MAKING-UP FOR THE LOSS OF PASTURE”

BIOETHANOL

In the Brazilian region of Ribeirão Preto, cattle farmers grow sugarcane on some of their land that was previously used for grazing. The sugarcane is used to produce bioethanol. Cane residues are fed to the cows, making-up for the loss of pasture. As there are still only a few cattle per hectare, animal welfare doesn’t suffer, and farmers get an extra source of income.

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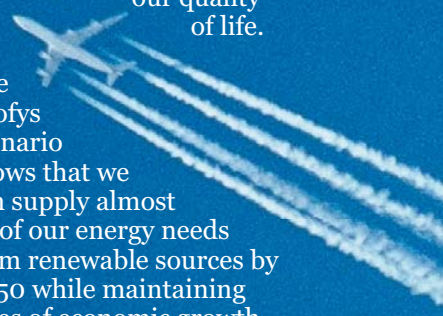
CASE STUDY

CRITICAL LIFE-STYLE CHOICES

LIFESTYLE

How do the choices we make in our own lives affect energy supplies?

Moving to a renewable energy future doesn't mean sacrificing our quality of life.



The Ecofys scenario shows that we can supply almost all of our energy needs from renewable sources by 2050 while maintaining rates of economic growth and leading prosperous, healthy lifestyles. Indeed, quality of life for many will improve immeasurably with access to electricity and clean energy.

We will, though, need to make wiser choices about the way we use energy. Lifestyle changes will allow us to reach a renewable energy future while reducing our impact on the planet. Since the anticipated need for bioenergy may push our forests, agricultural land and freshwater ecosystems to the limit, we particularly need to look at what we can do to limit bioenergy demand and land-use while aiming at 100 per cent renewables and make more land and water available to sustain people and nature.

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To grow enough food to nourish a growing global population, while also having enough land available to meet potential demand for biofuels, many of us will need to change our diets. As mentioned, the Ecofys scenario places limits on meat consumption growth. If future meat consumption is to be split more equitably, this would mean a halving of meat consumption per person by 2050 in OECD countries, and an increase by a quarter elsewhere. If we eat even less meat than this, then more land will be available to grow food or biofuel crops, or to return to nature.

Wasting less food will also save energy and free-up more land. According to Tristram Stuart[25], around half of our food is lost between field and fork... "Rich countries use up to four times more food than the minimum requirements of their populations (after adding/subtracting imports and exports); surplus is either fed inefficiently to livestock, causing a net loss in food calories, or it is wasted in the supply chain, or eaten in excess of dietary requirements. ... Poor countries have much smaller food supplies: fewer arable crops are fed to livestock, and less is wasted in the home".

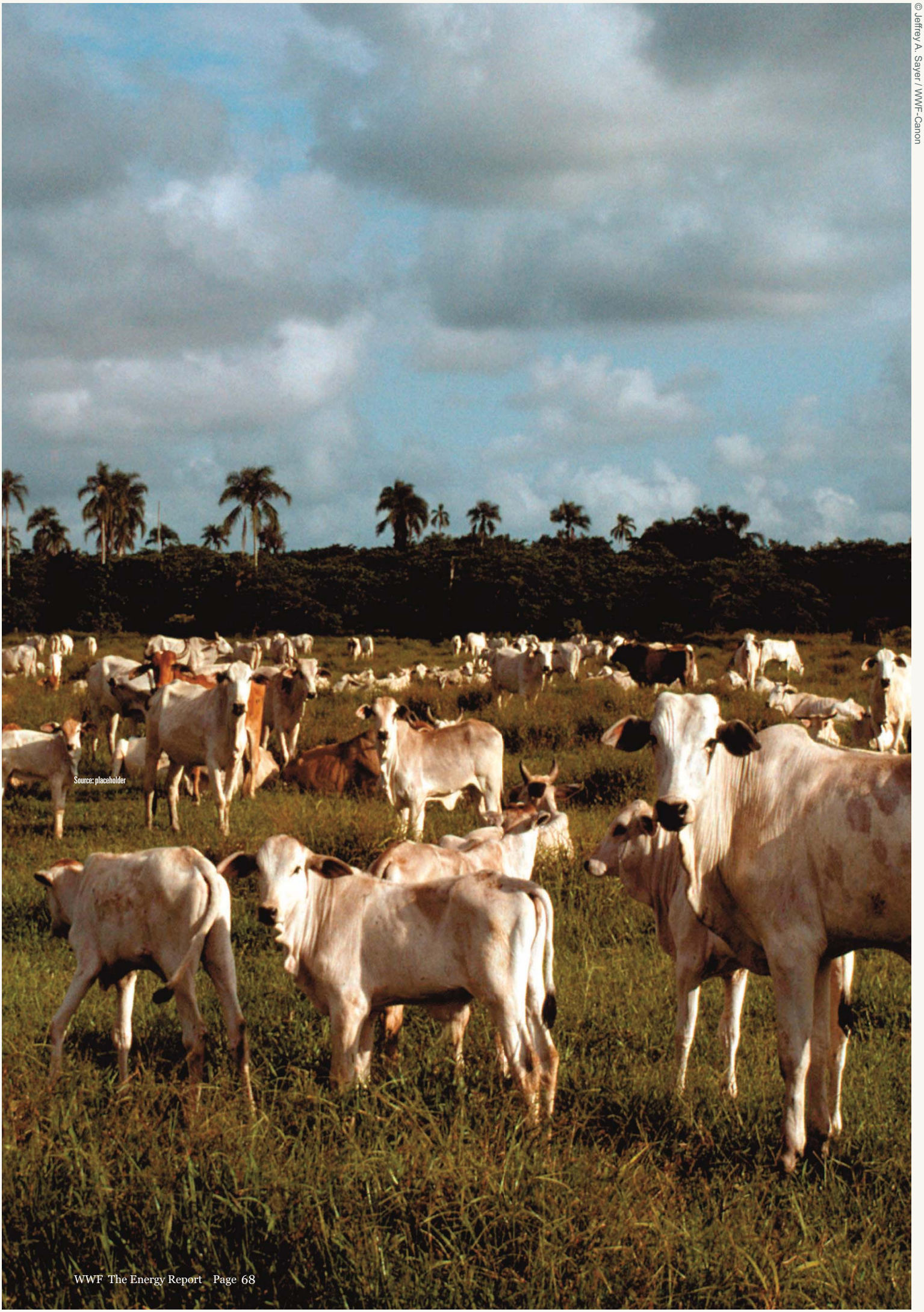
Reducing the distance that we transport food and other goods will also reduce the need for biofuels. The Ecofys scenario is based on established "business-as-usual" projections that predict steep rises in freight transport by 2050 – more than doubling in OECD countries and increasing fivefold elsewhere. If we cut rises in long-haul freight transport by a third compared to these projections, it would reduce the land needed for growing crops for transport by around 8 per cent, or 21 million hectares.

Personal mobility is also predicted to rise by 2050. Projections show the overall distance people travel will increase by half in OECD countries, and treble in the rest of the world. Ecofys suggests we can manage these increases if we move towards more efficient forms of transport – walking or cycling short distances, taking buses, and taking the train instead of flying. Improved communications technology will make work more flexible and home-working more viable in many jobs, reducing the need to commute. This would reduce congestion and improve the work-life balance for many. All the same, we will need massive investment in efficient public transport systems, along with fundamental changes in attitudes and behaviour.

Particularly sharp increases are expected in aviation transport, in rich and poor countries alike, and the Ecofys scenario includes these. Flying less would reduce the need for biofuels in the future, and substantially reduce carbon emissions today. A cut in passenger air travel by a third compared to Ecofys projections would reduce the land needed for growing crops for transport by an additional 19 million hectares. Videoconferencing and emerging innovative technologies could reduce the need for business travel. People may also choose to travel more slowly, or holiday closer to home.

Making lifestyle changes will take time. Communities that have collected firewood from forests for centuries will not switch to biogas cookers overnight. The attachment to large and fast cars runs deep in Western society. But history shows that people will change their behaviour when they understand the benefits and when policies steer them in the right direction: recycling is now second nature in many countries, while smoking rates have fallen with growing knowledge of the health risks. A better understanding of the impact of our own choices will help us move toward a fair and fully renewable future in which people live in harmony with nature.

25. Waste - Uncovering the Global Food Scandal. Tristram Stuart, 2009



Source: placeholder

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WHAT NOW?

- Every item we buy, all the food we eat, every journey we take uses energy. All people need to be more aware of the impact their lifestyle has, and what they can do about it. Public policy should help direct people to make wiser choices.

- Wealthier people everywhere should eat less meat, as part of a healthy, balanced diet. Governments, NGOs, individuals and the media need to raise awareness of the connection between our diets and energy needs, ecosystems and climate change. Regulations and pricing should reflect the true environmental and social costs of meat and animal products.

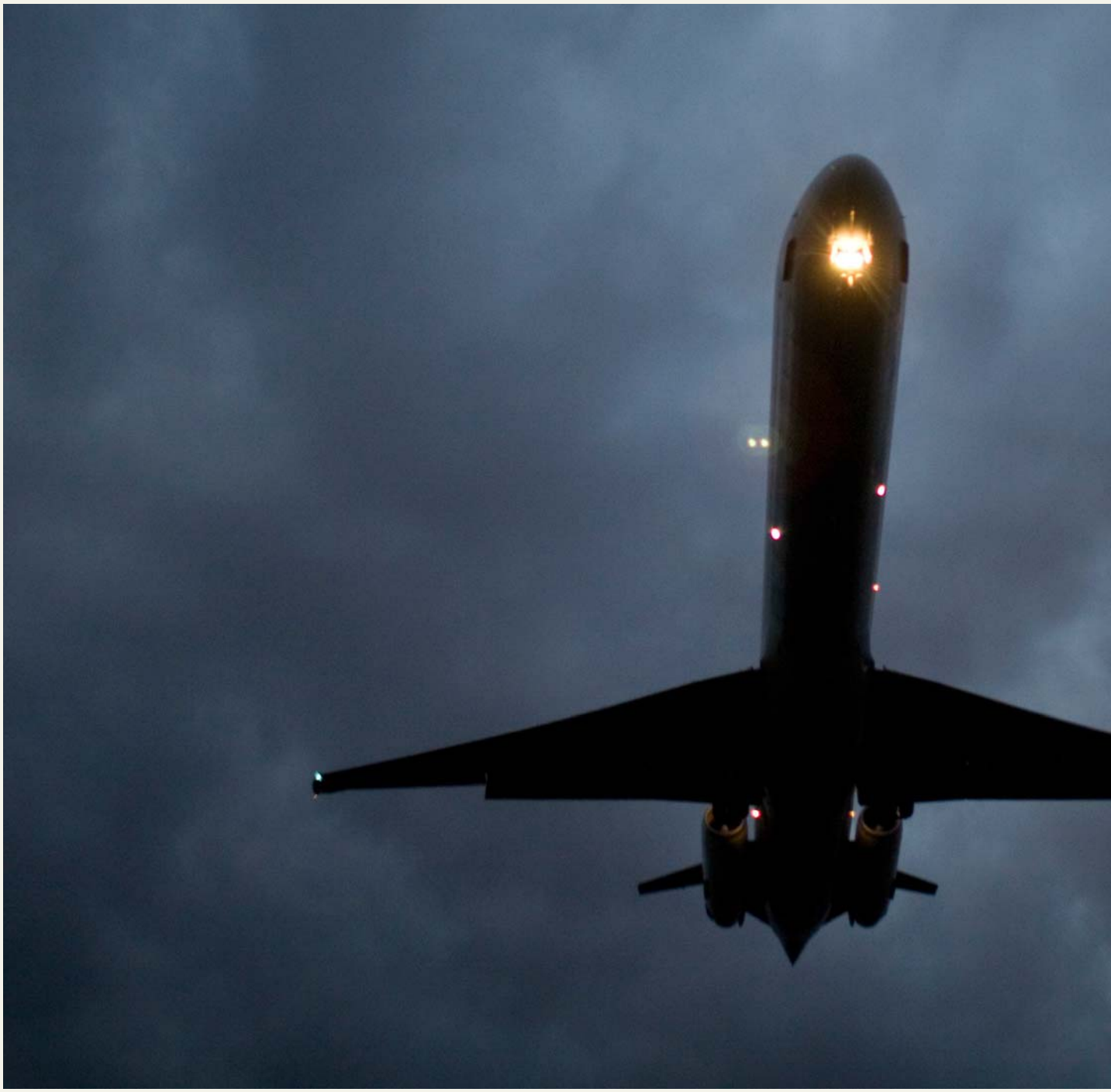
- Food waste by richer people needs to be minimized, and we need to raise awareness that about 50 per cent of all food is wasted and lost worldwide[26]. Consumers can help by only buying and cooking what they need, while food companies and retailers should reassess the way they package and promote perishable items. At a global level we need to re-examine the way we produce and distribute food to rebalance a system in which some regions have more food than they can use, while people in other places struggle.

- Big investments in public transport systems, particularly in emerging economies where personal mobility is growing fastest, are needed to provide an attractive alternative to private cars. Long-distance, high-speed trains powered by electricity from renewable sources need to be developed as an alternative to air travel.

- We need to explore other ways to optimize the distances that people and products travel to deliver the least GHG emissions over the life-cycle of a service or product. In part this means promoting regional economies and the use of local materials. Restaurants and retailers could equally source more regionally produced food that is in season - reducing the need for refrigerated storage. In many walks of life, Internet and mobile phone transactions can reduce the need for travel; employers should support home-working. International businesses should invest in videoconferencing and emerging communication technologies.

- Not everything should be grown or manufactured regionally, and trade between nations is essential to ensure the most effective (and energy efficient) use of resources and goods. Production and consumption of certified sustainable products, e.g. Rainforest Alliance, UTZ Certified, Organic or Fair-Trade, particularly from developing countries, needs to be encouraged. The social and environmental benefits for communities producing these products, and associated environmental benefits, are frequently greater than the environmental impact of the long-distance transport.

26. Lundqvist, J., C. de Fraiture and D. Molden. Saving Water: From Field to Fork - Curbing Losses and Wastage in the Food Chain. SIWI Policy Brief. SIWI, 2008.



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CASE STUDY

CUTTING AIR TRAVEL

Curbing the growth in air travel would mean less land is needed for growing biofuels. Under WWF-UK's One in Five Challenge, businesses and organizations are committing to cut 20 per cent of their business flights within five years. A dozen large employers have signed up to the programme, including the Scottish government. Audio, video and web conferencing provide alternatives to face-to-face meetings. It is no coincidence that a telecom firm, BT, became the first company to successfully meet the challenge.

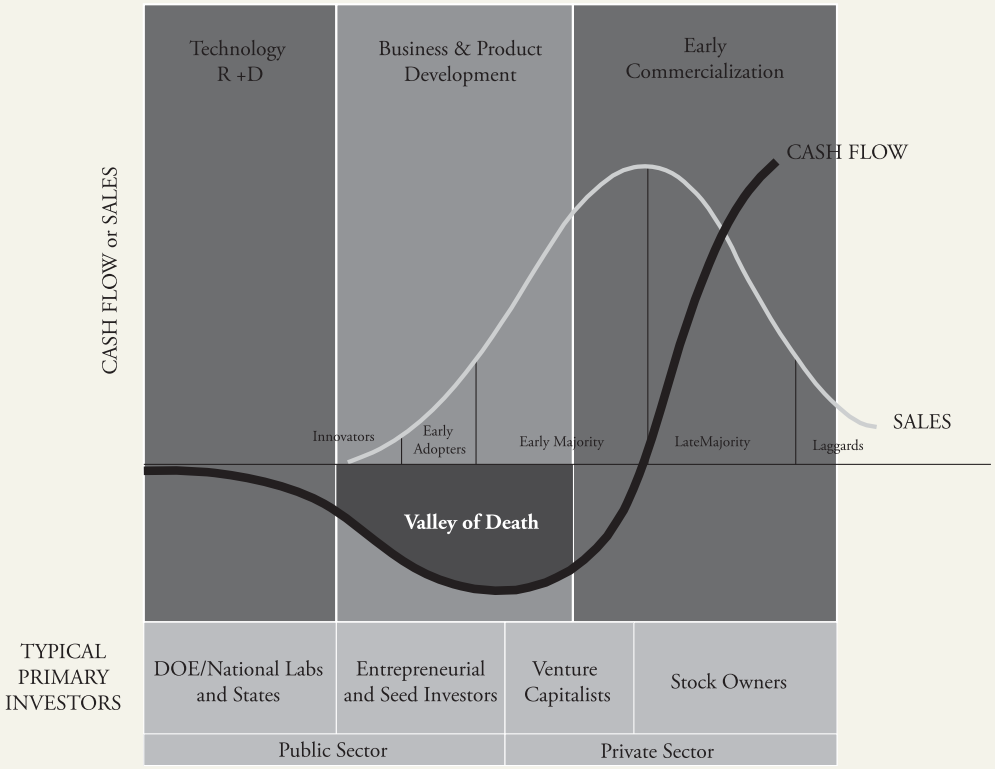


Figure 6: Pay back timeline of research and development in business
LM. Murphy and P.I Edwards, Bridging the Valley of Death: Transitioning from Public to Private Sector Financing, National Renewable Energy Laboratory May, 2003

LONG-TERM OPPORTUNITIES

FINANCE

Renewable energy makes long-term economic sense, but how do we raise the capital needed?

The world is emerging from the worst financial crisis for generations, and many nations are still feeling the effects. Governments are desperate to reduce budget deficits. Banks are reluctant to give credit. Financiers are looking for safe investments. Household budgets are already stretched.

It is not the best time to be looking for an extra €1 trillion a year. But that is what we need to find – now – if we're to move toward a fully renewable energy supply for everyone by 2050.

The investment will pay-off handsomely in the long run. By 2050, we will be saving nearly €4 trillion every year, according to the Ecofys analysis compared to a "business-as-usual" scenario. And that is purely the financial savings that come from reduced operating expenses – mainly fuel – costs. It doesn't take into account the costs we could incur from climate change – up to one-fifth of global GDP, according to the

Stern Review[27]– if we don't radically reduce our greenhouse gas emissions by moving to a renewable energy supply. Nor does it include the added value of the millions of jobs created, or the health and social benefits – such as better air quality and well-being.

But we will need to invest significant capital before we start seeing these returns. Large sums will be needed to install renewable energy-generating capacity on a massive scale, to modernize electricity grids, transform public transport infrastructure and improve the energy efficiency of our existing buildings. Global capital expenditure will need to continue to grow for the next 25 years to around €3.5 trillion a year, but will not rise above 2 per cent of global GDP. At the same time, energy savings and reduced fuel costs mean operating expenditure will soon start to fall. The savings will begin to outweigh the costs by 2040.

Unfortunately, our current financial system is not suited to taking the long view. Investors expect a return within a couple of years. New power developments cannot be left entirely to the free market as long as it is often cheaper to build a coal or gas power station than a wind farm or solar array. We need new financing models, such as public-private partnerships with shared risks, to encourage long-term investment in renewables and energy efficiency. Legislation and stable political frameworks will also help to stimulate investment: in Europe, for example, investors remain wary of supporting offshore wind projects as long as countries continue to squabble over who is responsible for the necessary grid upgrades.

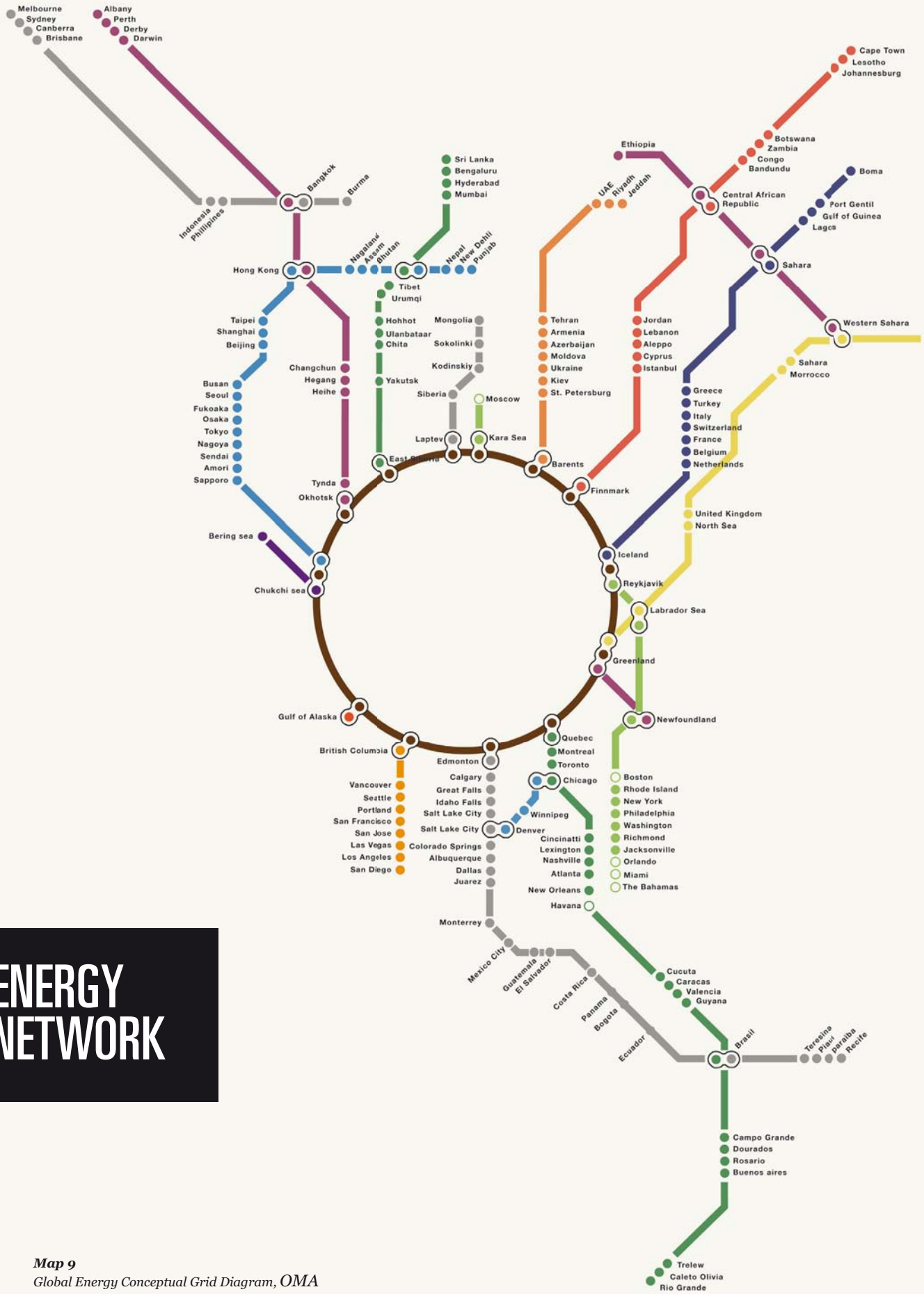
Feed-in tariffs are a key means of creating a more favourable climate for renewable energy. Under these schemes, payments are guaranteed to households, businesses, communities and other organizations that generate their own electricity from renewable sources, such as solar PV or wind power. By guaranteeing a return, feed-in tariffs have proved to be an effective way of encouraging people to invest in renewable energy, and are helping to bring down the price of generating electricity from renewable sources. They now operate in more than 50 countries, plus about 25 U.S. states and parts of China and India[28].

Growing support for renewable energy however, needs to be compared with the subsidies for conventional energy, which still dwarf clean power investment. A recent OECD report calculated the value of global fossil fuel subsidies at $US700 billion per year[29], with around two-thirds of this in developing countries. The aim of these subsidies is often to provide affordable fuel and electricity for poorer people, so they should not be cut outright; instead, the money could be reinvested into providing renewable energy and energy-efficiency measures.

While many governments are cutting public spending, investing in renewable energy could help stimulate economic growth, creating many "green collar" jobs. China recently announced plans to invest 5 trillion yuan (€580 billion) in a new 10-year alternative energy programme that will create 15 million jobs. Germany already employs about 300,000 people[30] in the renewable energy sector. Energy efficiency savings, especially in industry, can also help spur economic competitiveness and innovation.

The economic arguments in favour of moving toward a fully renewable energy supply are persuasive. When we also take into account the environmental and social costs and benefits, the case is undeniable. The challenge now is to overcome the clamour for short-term profits and recognize the long-term opportunities.

27. http://webarchive.nationalarchives.gov.uk/+/http://www.hm-treasury.gov.uk/stern_review_report.htm
28. Renewables 2010, Status Report; REN 21, Paris 2010
29. http://www.worldenergyoutlook.org/docs G20_Subsidy_Joint_Report.pdf
30. http://www.erneuerbare-energien.



ENERGY NETWORK

Map 9
Global Energy Conceptual Grid Diagram, OMA

WHAT NOW?

- We urgently need to create a level playing field for sustainable renewable energy.
Or, even better, one that is tilted in its favour – to reflect the potential long-term benefits. Feed-in tariffs should be extended, with similar schemes introduced for renewable heating. We need to end direct and hidden subsidies to the fossil fuel and nuclear sectors, but without increasing energy prices for the poorest.

- Financial support for renewable energies can only be truly effective if it allows open access to the market, to consumers. Unfortunately, monopolists of existing power supply often prevent exactly that. Thus, proactive, "preferred grid access" for renewables must be a part of any legislation - as currently enacted in the European Union. In most countries and regions that showed an increase in clean power in recent years, this legal provision was critically important.

- We need ambitious cap-and-trade regimes, nationally and internationally, that cover all large polluters, such as coal-fired power stations and energy-intensive industries. Setting a high price on carbon will help to encourage investment in renewable energy and energy efficiency, as well as reducing emissions.

- Global climate negotiations need a strong focus on providing finance and technology to help developing countries build their capacity for generating renewable energy and improving energy efficiency.

- People everywhere should install any effective micro-generation and energy-efficiency measures they can afford – in their own homes, businesses or communities – assuming these make environmental and economic sense. Governments, energy companies and entrepreneurs can encourage this.

- Policy-makers and financial institutions globally need to develop financial instruments that encourage investment in renewable energy.

- Investors should divest from fossil fuel and nuclear energy firms, and buy shares in renewable energy and efficiency-related companies. Anyone with savings can help to tip the balance by choosing banks, pension providers or trust funds that favour renewables.

- Politicians need to clearly support renewable energy and energy efficiency, and create supportive legislation to build investor confidence. Political parties need to reassure investors that broad energy policies will survive a change of government. Throughout the world, national legislation needs to overcome the bias toward the energy status quo, through measures such as legally binding energy-efficiency standards.

- More market incentives could encourage energy efficiency – such as reduced VAT on the most energy-efficient appliances, or varying rates of tax for cars and properties according to their efficiency.

"GEOTHERMAL ENERGY CAN PROVIDE UP TO TEN TIMES CURRENT GLOBAL ENERGY PRODUCTION"*

Green Geothermal

WWF's "Ring of Fire" programme is supporting Indonesia, the Philippines, Malaysia and Papua New Guinea to develop their geothermal potential in a sustainable way. The programme's vision is to increase the countries' geothermal capacity threefold by 2020, through green geothermal investment in the range of €18-40 billion. It may help to create 450,000 extra jobs compared to coal by 2015, and 900,000 by 2020.

*Source: IPCC, Working Group III, "Mitigation of Climate Change", 2007

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CASE STUDY

R&D INVESTMENT

INNOVATION

What advances will make our renewable energy vision a reality?

The energy scenario mapped-out by Ecofys in the second part of this report is ambitious and radical – but it is grounded firmly in what exists today. Only technologies and processes that are already proven have been included. These are sure to be refined and improved in the years ahead, but the report is cautious in estimating their growth potential. This means we have an opportunity to further advance on the Ecofys scenario – to increase the proportion of renewable energy from 95 per cent to 100 per cent by 2050, and to reduce the need for biofuels and the pressure this puts on food and water supplies and the natural world.

But to get there, we will need to substantially step-up our research and development (R&D) into renewable energy production and energy efficiency. At the moment, we spend around €65 billion a year globally on R&D in these areas, out of a total global expenditure of around €900 billion on R&D in all sectors[31]. We'll need to double this over the next decade. Under the Ecofys scenario, annual R&D expenditure rises to a high of €170 billion in 2040. Until 2025, the focus is on reducing energy demand – the most pressing requirement. This will come chiefly through developing more efficient materials, industrial processes and vehicle technology, particularly electric cars.

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The supply side – particularly renewable power and fuels – becomes increasingly important. As we have seen, smart energy grids that are capable of managing demand and accommodating a much larger proportion of variable electricity have a vital role to play, and will be an important area for R&D. Smart appliances that respond to varying electricity supplies will complement this.

We must also focus on improving storage of electricity generated by wind and solar. Several solutions are already in use. Solar power can be stored as heat. Wind power can be used to turn a flywheel, whose spinning motion then generates electricity when it is needed – a method of storing energy that goes back many centuries. Compressed air storage, which has been around since the 19th century, is another possibility: wind farms pump air underground, then release the compressed air to generate electricity on demand.

Electricity can also be stored in batteries, and battery technology will be a crucial area for development. We have yet to develop batteries that can store enough energy to power trucks over long distances.

Using renewable hydrogen, fuel cells, and electrifying trucking will slash the demand for biofuels – but this is a long way in the future. In the meantime, we need research into efficient biofuels, to find out which crops can produce the most energy for the least amount of land and water. Algae has the potential to provide a truly sustainable source of bioenergy – we need to research ways to produce fuels from algae with the least environmental impact. As a precaution, though, we should avoid locking ourselves into needlessly high levels of demand for liquid fuels.

Hydrogen could also have a major role to play in industry, aviation and shipping, although it provides only a small fraction of energy in 2050 under the Ecofys scenario. Hydrogen is the ultimate renewable fuel: the raw material is water, and water vapour is the only emission. It produces energy either through direct combustion or in fuel cells, and is easily produced through electrolysis, which can be powered by renewable electricity at times of high supply or low demand. However, major challenges remain in storing and transporting it. Intensive R&D into hydrogen could have a major impact on the future energy balance. The British Royal Mail is using hydrogen to fuel postal vans on the Scottish island of Lewis in a pilot project that is being watched with interest.

According to the Ecofys scenario, the world will still need to burn a small amount of coal in 2050 (less than 5 per cent of total energy supply). This is because some industrial processes, such as steel manufacturing, depend on specific chemical properties, as well as the very high temperature heat that it can produce. Research is needed into alternative production processes or materials that will allow us to phase-out fossil fuels altogether.

Technology moves fast. Just 50 years after the Wright Brothers made their first flight, jet planes were carrying passengers from London to Johannesburg. Tim Berners-Lee wrote the first World Wide Web page in 1991, and there are now two billion web users and an immeasurable number of web pages. Given the right political and economic support, human ingenuity will allow us to realize our vision of a 100 per cent renewable energy supply by 2050.

31. Estimated global spending on R&D for 2009 was US$1,140 billion – see http://www.battelle.org/news/pdfs/2009RDFundingfinalreport.pdf

"CURRENTLY, RENEWABLE SOURCES ACCOUNT FOR ONLY 13% OF THE WORLD'S ENERGY PROVISION"*

WHAT NOW?

We need to radically increase investments in researching, developing and commercializing technologies that will enable the world to move toward a 100 per cent renewable energy supply. These include energy-efficient materials, design and production processes, electric transport, renewable energy generation, smart grids and alternative fuels.

At the same time, we should stop pursuing ideas that will lock the world into an unsustainable energy supply, particularly techniques for extracting unconventional fossil fuels. We need to limit the damage from existing power stations, some of which will be with us for decades. One

Figure 7: Collage-image into what the future could be made of.
Everything changes but nothing changes. Invisible revolution.

** IPCC 2007: Working Group III: Mitigation of Climate Change*

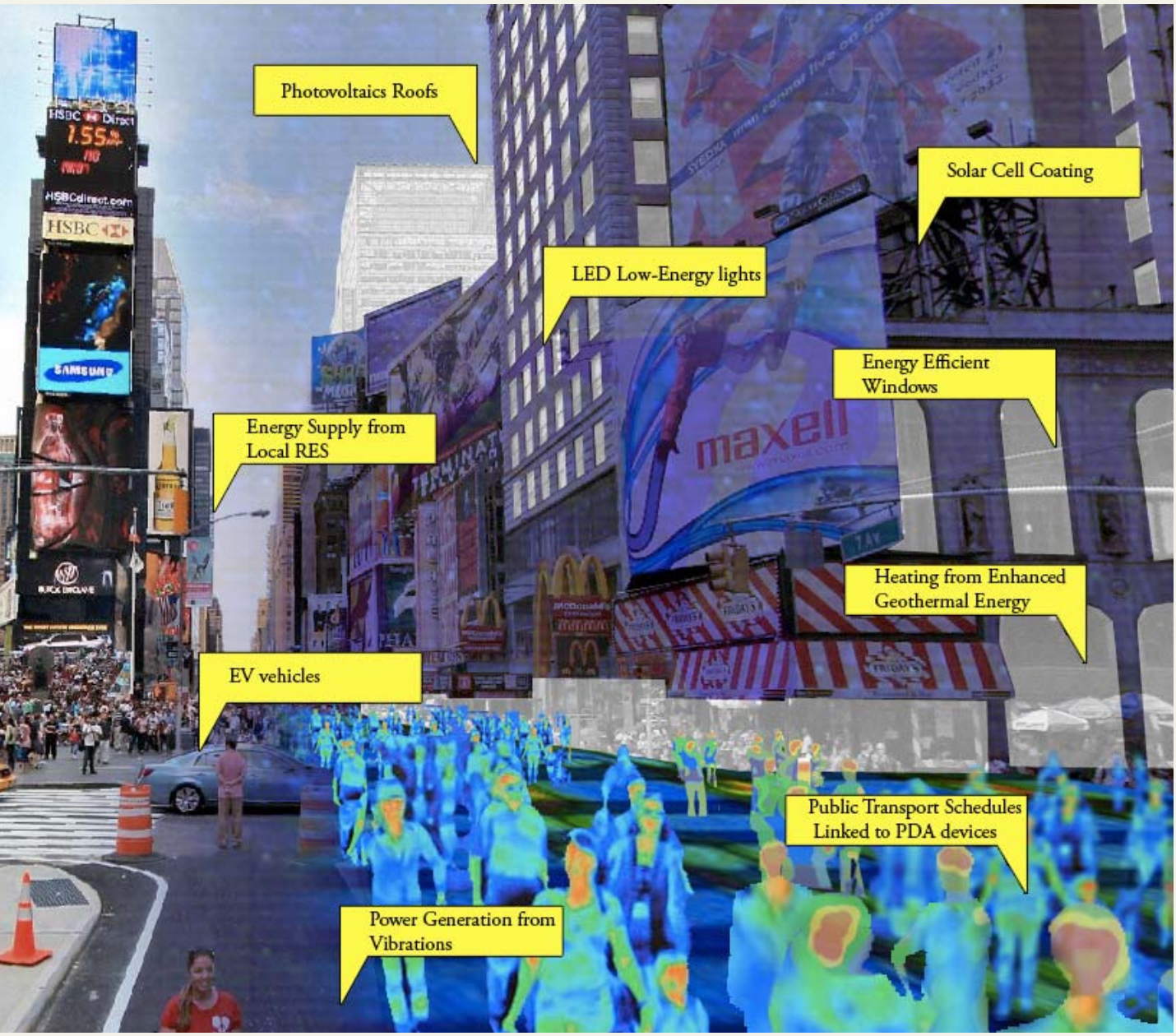
way to do this is through carbon capture and storage (CCS), which we should continue to develop for existing power stations, industrial processes with high carbon emissions (such as cement and steel manufacture), and biomass plants.

Global and national policies for renewable energy innovations are often fragmented or simply non-existent. Governments need to introduce supportive policies, in close collaboration with representatives from industry and finance.

We need to educate, train and support the scientists, engineers and other skilled workers who will dream-up, design, build and maintain our new energy infrastructure. We also need to support entrepreneurs and innovative companies with ideas to help us realize a renewable energy future.

Developing countries need support in building their own capacity for innovation. All of us will benefit from sharing knowledge within and across borders.

Because of the potential environmental and social impact of biofuels, research into alternative fuels – such as algae and hydrogen – should be a priority.



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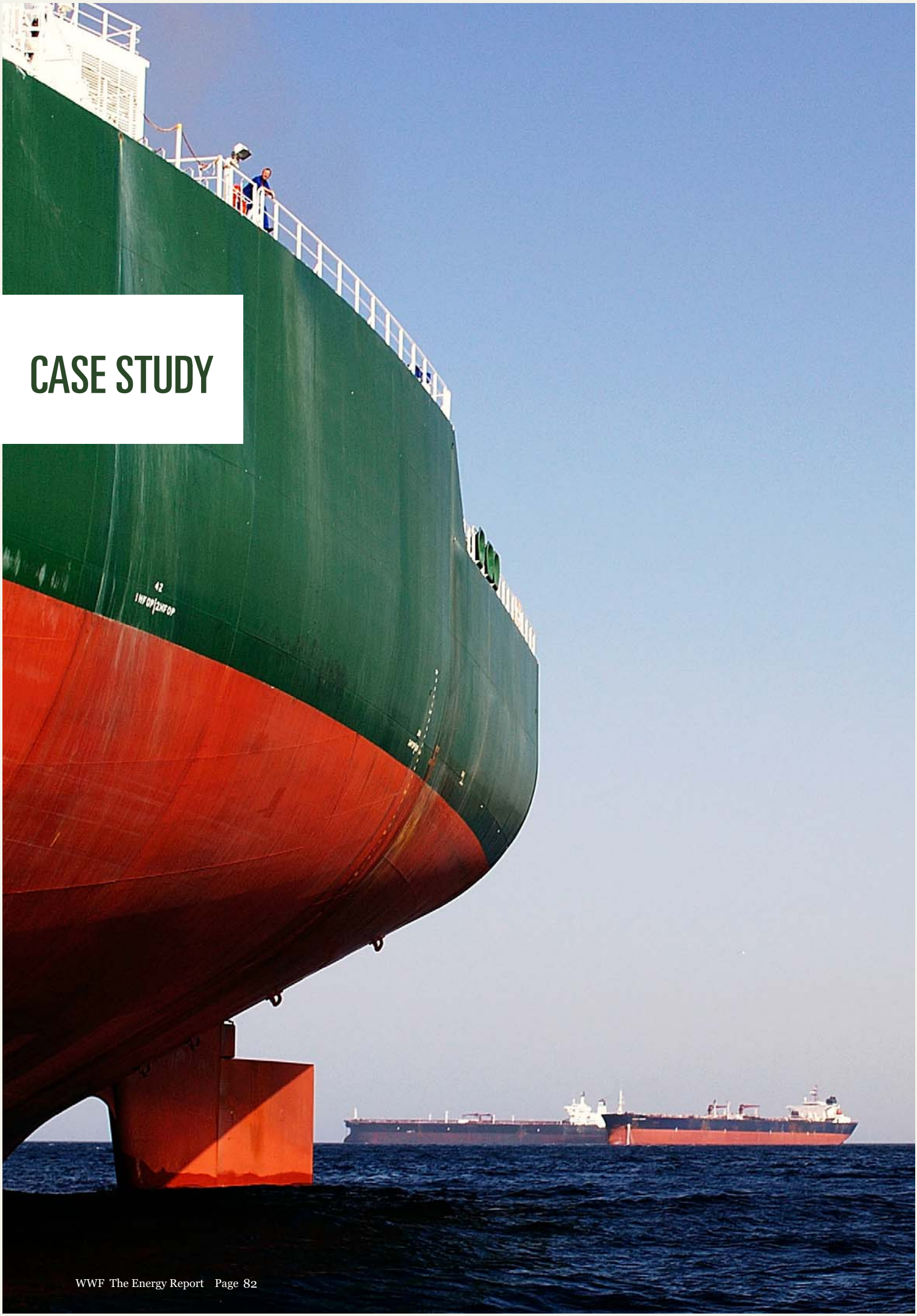


CASE STUDY

© Michel Gunther / WWF-Canon

"THE USE OF MODERN FUEL CELLS IN THE SHIPPING INDUSTRY CAN REDUCE TRANSPORT GHG EMISSION BY 20–40%"*

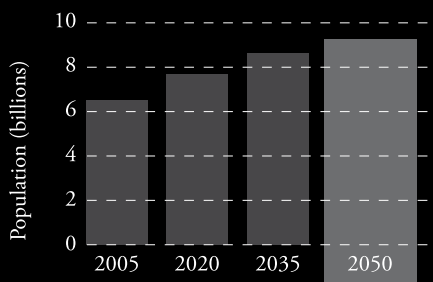
** IPCC 2007: Working Group III: Mitigation of Climate Change*

BACK TO THE FUTURE

Sometimes, innovation can mean going back to the past. Ships have always harnessed the power of the wind – and a new generation of sailing ships could help reduce the amount of fuel needed in the shipping sector. Hybrid cargo ships like the Ecoliner, made by Netherlands-based Fairtransport Shipbrokers, combine sails with back-up engines. German company Beluga SkySails has completed trans-Atlantic cargo voyages partly powered by a giant kite, which it claims can reduce fuel use by 10-35 per cent.[32]

32. http://www.skysails.info/english/information-center/background-information/skysails-performance-calculation/

Global Population
Growth Projections



Population

Growth Projections

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THE FUTURE IS IN YOUR HANDS

That the world faces an energy crisis is beyond doubt. There's a pressing need to secure a sustainable energy supply as demand for fossil fuels outstrips environmentally and economically sustainable supplies. A lack of access to energy is one of the main causes of poverty. On top of this, the world needs to start drastically reducing CO2 emissions within the next few years if we're to have the best chance of avoiding catastrophic climate change.

We – individuals, communities, businesses, investors, politicians – must act immediately, and boldly. Half-hearted solutions are not enough. We must aim for a fully renewable energy supply by the earliest possible date.

It is possible. The second part of this report lays out, in unprecedented detail, one way that we can do this. It isn't the definitive solution, and it isn't perfect. As we've seen, it raises many challenges and difficult questions. But it shows that solutions are at hand. We are putting it forward to catalyze debate and to spur action.

We now need to respond to the issues it raises. We need to take it further. But most of all, we need to act on it – each and every one of us. Starting today.

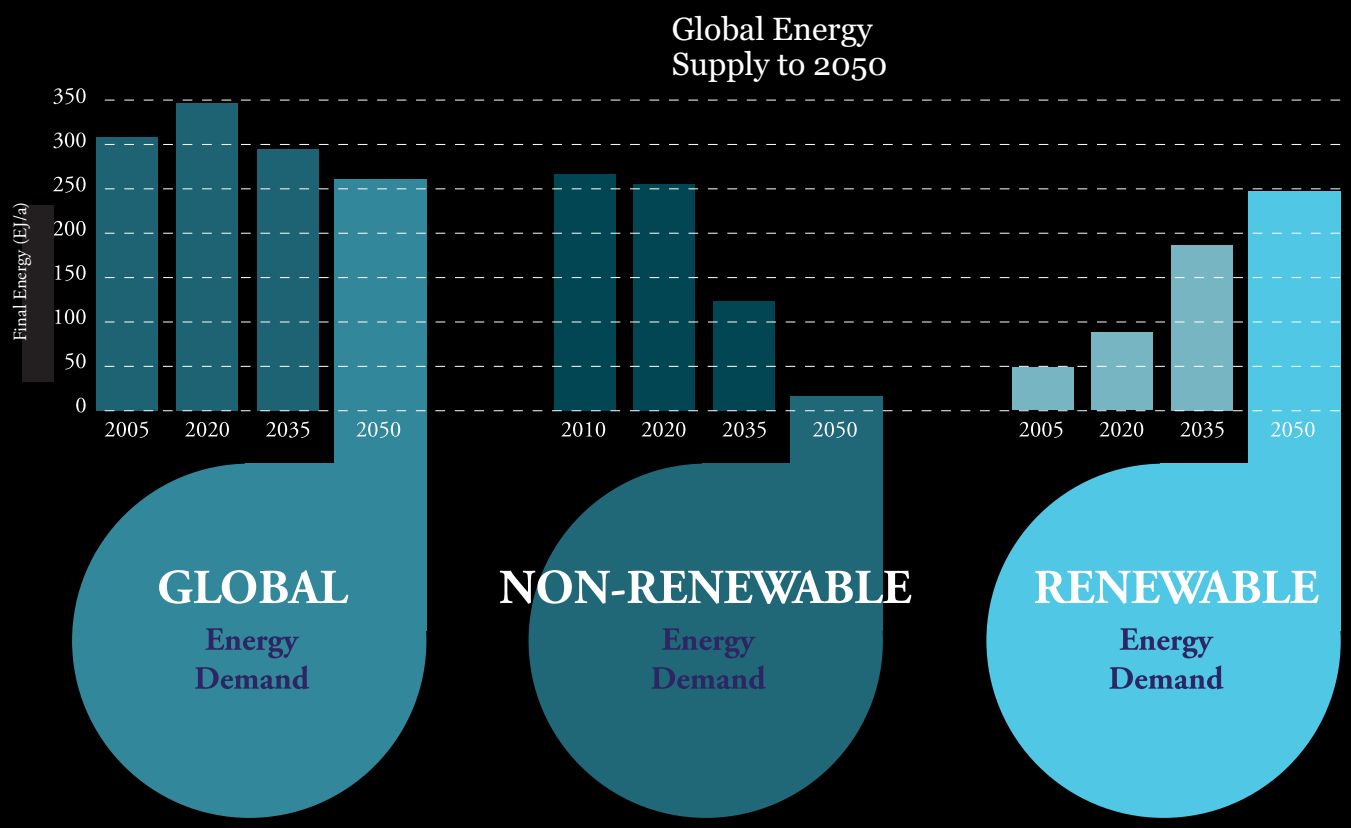
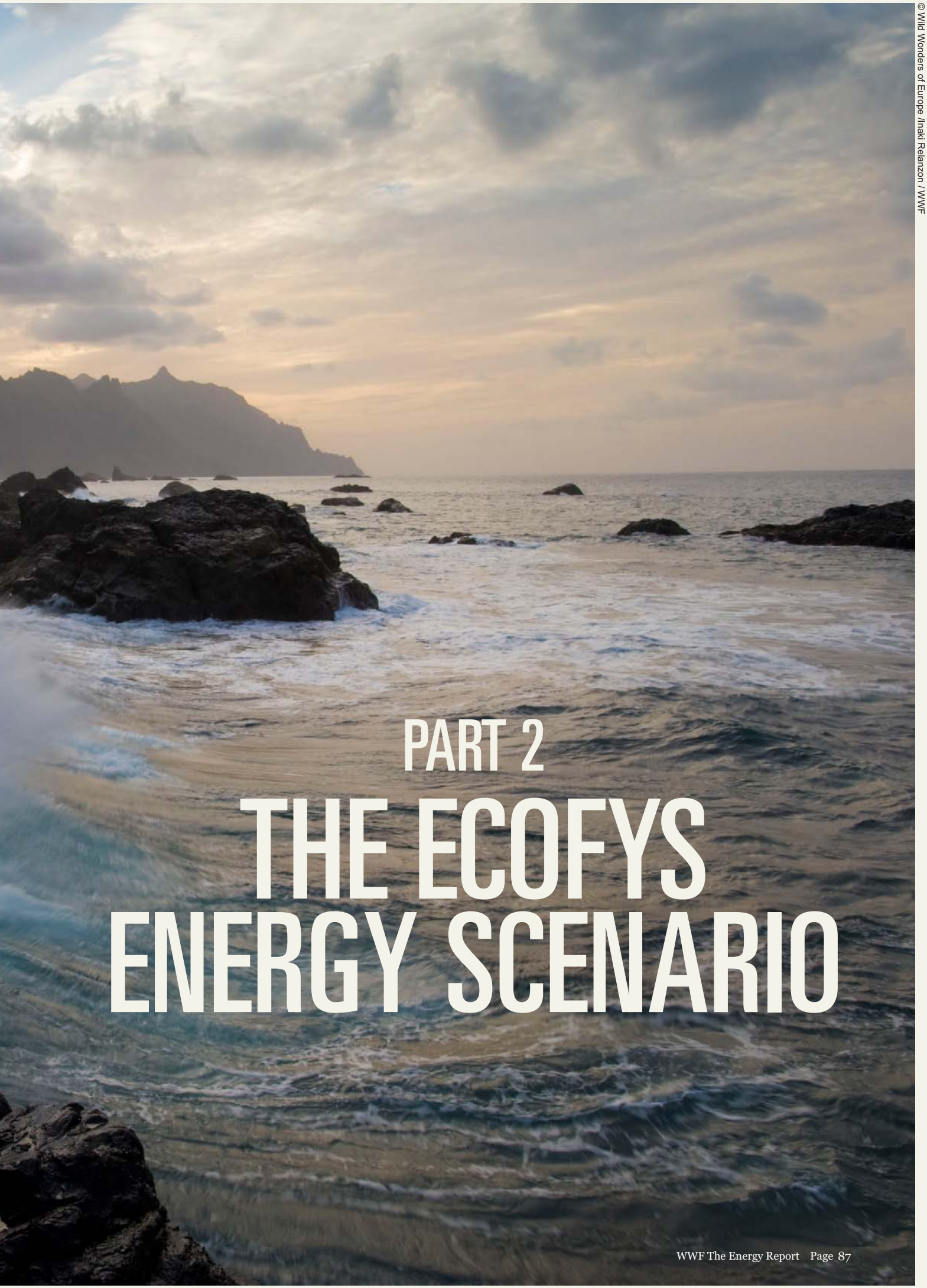


Figure 8: **World Renewable & Fossil Fuel Use Projection**



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PART 2
THE ECOFYS ENERGY SCENARIO

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The Ecofys Energy Scenario

By: Yvonne Deng, Stijn Cornelissen, Sebastian Klaus

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Preface

The Energy Scenario has been created by Ecofys, a leading consultancy in energy efficiency, renewable energy and climate change.
It began as an internal research project in 2008 and subsequently became a collaborative venture with WWF, who were also keen to investigate a possible road towards 100% renewable energy by 2050.

The main contributors are listed below, but the authors are indebted to many other advisors not on this list, who have contributed since the beginning of the project.

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Summary

The Energy Scenario is a possible pathway to a global, sustainable energy system. It takes a holistic approach to all aspects of energy use across the entire world and each possible means of supplying this energy from the sustainable sources we have available to us. It does so from the perspective of actual, physical activities that use energy: our industrial processes, our cars, our buildings.

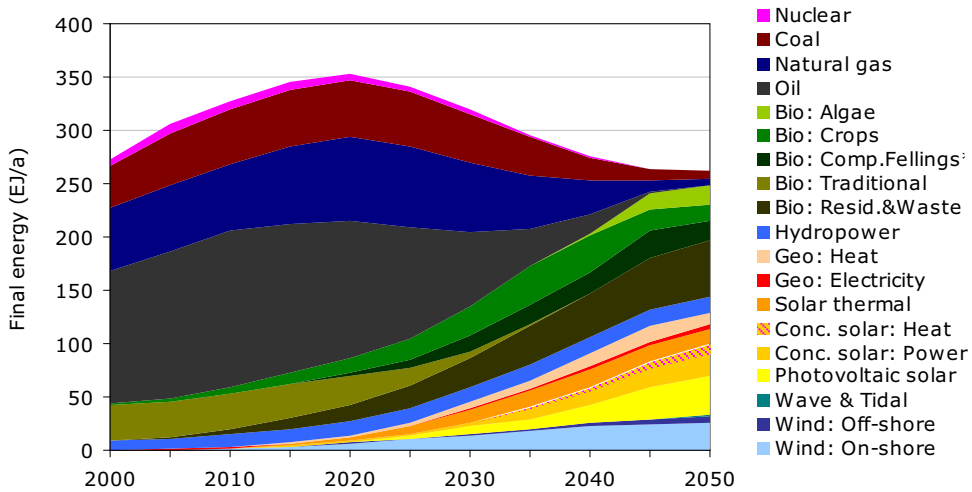
For each of these uses it asks the question:

- What is the **minimum** amount of energy required to deliver these functions?
- How can we supply this energy in a **sustainable** way?

The key aspects of this new, global Energy Scenario are:

- It takes an ambitious but feasible pathway in all sectors; we can build an energy system by 2050 which sources **95% of its energy from sustainable sources**.
- This energy system will use only a fraction of most of the sustainable energy sources, making this a robust scenario.
- We can move towards a world that can develop and sustain comfortable **lifestyles**, although our lives will look different.
- Energy **efficiency** is the key requisite to meeting our future energy needs from sustainable sources.
- Electricity is the energy carrier most readily available from sustainable energy sources and therefore, **electrification** is key.
- All **bioenergy** required, primarily for residual fuel and heat demands, can be sourced **sustainably**, provided the appropriate management practices and policies are in place.
- The Scenario's energy system will have large **cost advantages** over a business-as-usual system as initial investments will be more than offset by savings on energy costs in the later years.

The overall composition of global energy supply in the Scenario is shown below.



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1 Introduction

The last 200 years have witnessed an incredible increase in energy use by human societies worldwide. In recent decades it has become clear that the way this energy is supplied is unsustainable and both, short- and long-term energy security, are now at the top of the political and societal agenda.

The current public debate on the evolution of our energy system can be characterised as limited; it is constrained by our trust in existing systems and our mistrust of alternatives.
The mainstream consensus appears to be that the best we can hope for are incremental changes to the existing structure of our energy system. Typically, scenario studies show such incremental changes against a 'business-as-usual' reference.

This view of the future stands in stark contrast to the belief within the renewable energy world that, 'anything is possible'.
It is true that the pure, technical potential of many renewable energy sources far surpasses our current demand, and statements such as the following are often issued:

"The sun provides more energy to the earth in one hour than the entire world needs in one year".

Even when we assess renewable energy potentials more realistically, i.e. allowing for feasible deployment rates and taking regional differentiation into account, evidence suggests that we should be able to meet our energy demand from renewable sources, given their abundance (see Figure 1 - 1)[1,2]: Worldwide energy use in final energy terms (after conversion from primary fuels) was ~310 EJ[3] in 2007 (~500 EJ in primary energy terms). [IEA, 2009]

When we try to reconcile these figures, ~300 EJ/a of worldwide final energy demand, and 100s to 1000s of EJ/a of realisable, renewable energy potentials, we begin to understand that a more detailed view is needed. A view which considers energy, not

[1] NB: When referring to renewable energy 'potential' in this document, we mean the potential which can be deployed at any given point in time, as shown in this figure.
[2] Unless clearly labelled as primary energy, as done in Figure 1 - 1, all graphs showing energy in this document show final energy values. The reader is advised to bear in mind that in any chart showing final energy for both fuels and electricity, the share of electricity will look smaller than the actual share of energy functions delivered by that electricity. See also Section 3.4.4.
[3] Excluding non-energy use.

just in the right amount and in the right place, but in the right carrier form (e.g. electricity or fuel) and for the right purposes (heat in buildings vs. heat in industry).

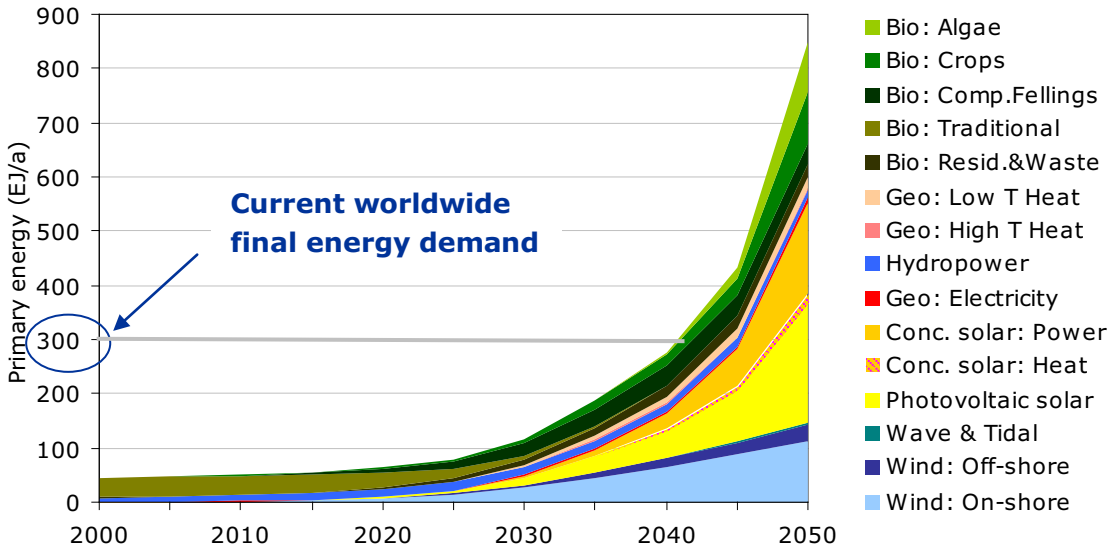

Figure 1 - 1 Global deployment potential of various renewable energy sources.

A holistic view on the energy system is required, and the Energy Scenario presented in this study provides exactly that: a holistic view on the energy system accounting for all sectors, all regions, all carrier forms.

The key question we pose is this:

"Is a fully sustainable global energy system possible by 2050?"

We have found that an (almost) fully sustainable energy supply is technically and economically feasible, given ambitious, but realistic growth rates of sustainable energy sources.
However, the path to this future world will deviate significantly from 'business as usual' and a few (difficult) choices will need to be made on the way; choices which we will discuss in this report.

This report is structured as follows:
In Section 2 (*Approach*) we will present the **conceptual framework** we created to represent the world's energy system. The framework is simple enough to be understood easily by an interested layman, but sufficiently detailed to depict the integral intricacies of the energy system being investigated.

In accordance with the presented approach, we first discuss our assumptions and subsequent findings for the **demand** of energy in Section 3 (*Demand*). We then move on to the **supply** of energy which we have split into two sections, due to the level of attention we have devoted to the supply from biomass: Section 4 (*Supply – Renewable energy (excl. bioenergy)*) discusses all sustainable energy options other than biomass; we prioritise the use of these sources. Section 5 (*Supply – Sustainable bioenergy*) then describes the use of biomass in the Scenario.

Finally, we also address the economic implications of our Scenario in Section 6 (*Investments and Savings*), before presenting a brief discussion on policy elements required to bring this Scenario to fruition in Section 7 (*Policy considerations).* We end with Section 8 (*Conclusions*).

2 Approach

The Energy Scenario forecasts future global demand and supply by inherently following the paradigm of Trias Energetica of:

1. Reducing energy demand to the minimum required to provide energy services
2. Providing energy by renewable, where possible, local, sources first
3. Providing remaining energy from 'traditional' energy sources as cleanly as possible

Figure 2 - 1 The Trias Energetica is a logical concept to inform our use of energy.

In detail, the following steps were established:

1. **Future energy demand is estimated**

   Energy demand is the product of the volume of the activity requiring energy (e.g. travel or industrial production) and the energy intensity per unit of activity (e.g. energy used per volume of travel).

   a. Future demand side activity is used from literature or estimated based on population and GDP growth.
   b. Future demand side energy intensity is forecast assuming fastest possible roll-out of most efficient technologies.
   c. Demand is summed up by carrier (electricity, fuel, heat).

2. **Future supply is estimated**

   a. The potential for supply of energy in the different carriers is estimated
   b. Demand and supply are balanced according to the following prioritisation:
      i. Renewables from sources other than biomass (electricity and local heat)
      ii. Biomass up to the sustainable potential
      iii. Traditional sources, such as fossil and nuclear which are used as 'last resort'.

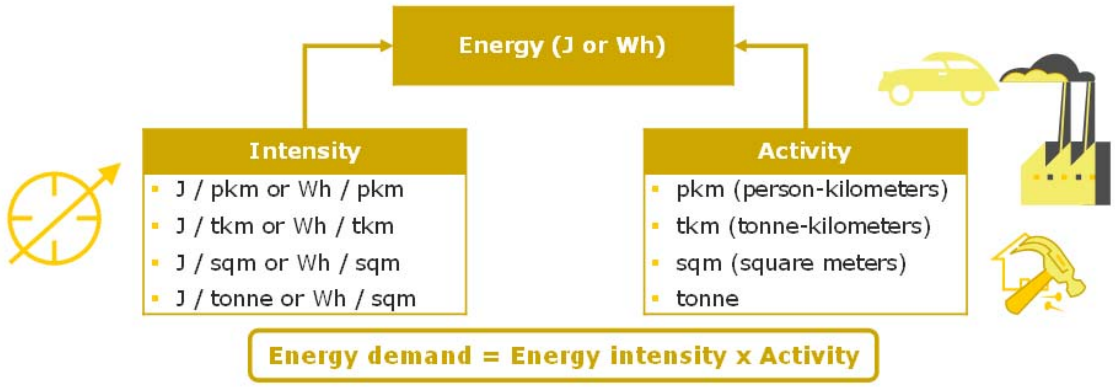

Figure 2 - 2 Conceptual approach to forecasting future energy demand.

As described in Section 1, it is imperative to compare demand and supply in some detail to arrive at meaningful conclusions. Energy flows have been characterised by carrier type, i.e. differentiated into electricity and fuels; in addition, heat demand is considered separately. We thus arrive at the three main carriers reported in the IEA energy balances, to which this work is calibrated. [IEA balances, 2008]

Figure 2 - 3 Energy use is examined in the three different carrier types: electricity, heat and fuel.

Taking this approach further, we examined energy demand in the various sectors of the energy system (see Figure 2 - 4).

Energy demand can be differentiated into the following sectors: Industry, Transport, Buildings & Services, Other[4]. For each of these sectors, energy demand needs to be characterised in detail, leading to an increasing differentiation of the energy carriers. To map out how energy demand will develop in the future, future activity levels have been assessed and future energy intensity has been based on strong efficiency assumptions.

Once energy demand has been established by carrier (sub)type (Step 1. in the Trias Energetica), the various supply options are used in priority order to fill this demand up to their realistic ***deployment potentials***[5] in a given year. It should be noted here

[4] 'Other' consists of Agriculture and Fishing and other non-specified uses as reported in the IEA Energy Statistics.

[5] Whenever we refer to the potential of an energy source in this report, we refer to this deployment potential. The deployment potential is the amount of energy a specific source could supply at a given moment in time given an ambitious, yet feasible deployment path from its current deployment state. Note that while the assumptions

that there is always a choice to be made of which technologies to include, depending on their stage of development. In this study we have tried to rely solely on existing technologies or technologies for which only incremental technological development is required. Where we have deviated from this assumption, this is clearly stated and explained.

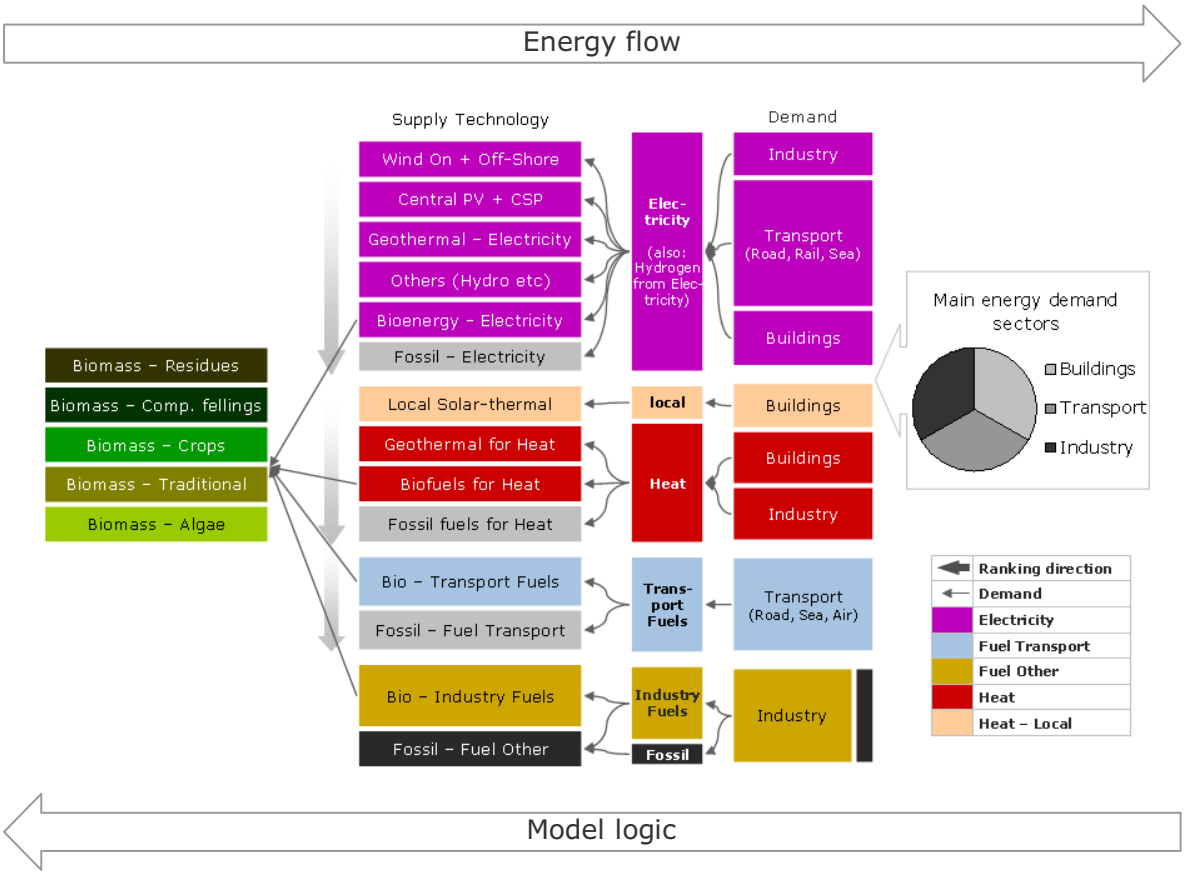

Figure 2 - 4 Overall approach used to calculate energy demand and supply from 2000 to 2050.

First, non-bioenergy supply options, such as wind, solar and geothermal, are exhausted. Most of these are single-energy-carrier options, e.g. solar PV or wind only supply electricity, local solar thermal provides only local building heat.
Secondly, the bio-energy options are deployed.

The full approach described above is shown in Figure 2 - 4. One important observation to make here is the number of different renewable sources available for electricity demand and the sparse number of options for heat and fuel carriers.

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on deployment rates are considered technically and economically feasible, they do not necessarily result in a least-cost scenario (see also Section 6) and usually require an alternative policy environment to 'business as usual' (see Section 7).

Although the Scenario is primarily global, it is fundamentally based on calculations at regional level within these 10 world regions, which differ greatly in their energy use and potential and their stages and speed of development:

- Europe
- North America
- Latin America
- Russia and other Eurasia
- Middle East
- OECD Pacific
- China
- India
- Rest of Asia
- Africa

2.1 Bioenergy approach

Bioenergy from biomass requires a more elaborate approach than most other renewable energy options for the following reasons:

- Bioenergy requires a more thorough analytical framework to analyse sustainability, as cultivation and processing of biomass and use of bioenergy have a large range of associated sustainability issues.
- Bioenergy encompasses energy supply for a multitude of energy carrier types using a multitude of different energy sources. Therefore a detailed framework of different possible conversion routes is needed.

We describe both elements of the Scenario's energy approach briefly in this section. More detail is given in Section 5.

Bioenergy sustainability

Bioenergy sustainability is a key aspect of the Energy Scenario. Firstly, the share of bioenergy in the overall renewable energy supply is reduced as much as possible by using other renewable energy options first. Secondly, the use of residues and waste is prioritised over the use of energy crops. For both of these categories, criteria are applied throughout the bioenergy chain to ensure sustainability. Figure 2 - 5 illustrates this approach. Section 5 describes the Scenario's bioenergy supply and its sustainability criteria in detail.

Bioenergy conversion routes

Because biomass can provide energy supply in a multitude of different energy carrier types, often in the same conversion route, the biomass use was channelled through all possible bio-energy routes, taking into consideration residues resulting from some of these routes. This approach is illustrated in a simplified diagram in Figure 2 - 6.

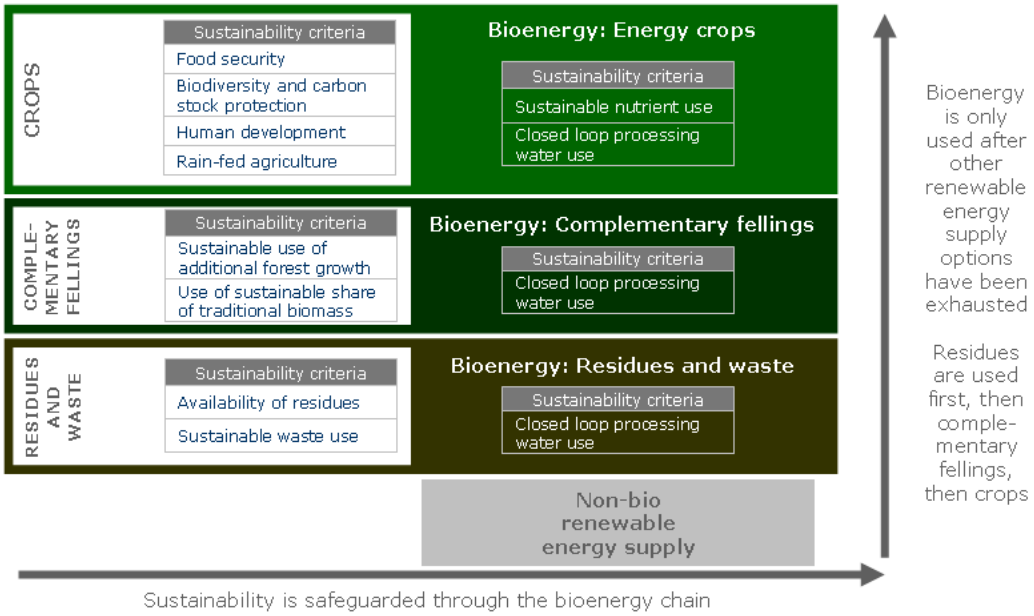

Figure 2 - 5 Framework applied in the Energy Scenario to ensure the sustainability of the Scenario's bioenergy supply. (The size of the shapes in the image is not indicative of the size of the categories in the Scenario.)

In order to keep the projection robust, the key principle in selecting the supply and technology options, was to only use options that are currently available or for which only incremental technological development is needed.
Two exceptions, where technological change of a more radical character is needed, are the inclusion of oil from algae as a supply option and fermentation of lignocellulose to ethanol fuel as a technology option. Both are not mature options in the current market, although both are approaching commercial viability. To allow for development still needed in algae growing and harvesting, we included the use of significant amounts of algae oil from 2030 onwards only.

Another important assumption is made on the traditional use of biomass. Currently, about 35 EJ of primary biomass is used in traditional applications. This consists primarily of woody biomass and agricultural residues harvested for home heating and cooking in developing countries. Toward 2050, the Scenario will supply energy for these demands through a route alternative to traditional biomass use. The traditional use of biomass is therefore phased out over time. A proportion of this phased out biomass is used within the Scenario in a sustainable manner, see also Section 5.6.

Within the Scenario, the different bioenergy routes displayed in Figure 2 - 6 are prioritised as follows:

1. Traditional biomass: As this biomass is currently in use, it is used first in the Scenario. Over time, the contribution of this category becomes less as it is phased out.

2. Sustainable residues and waste: Sustainable residues and waste, originating from agriculture, forestry and the food processing industry for example, are used to meet as much demand as possible[6].
3. Sustainable complementary fellings: This category consists of woody biomass gained from sustainable harvesting of additional forest growth and of the sustainable share of traditional biomass use. It is used to fill remaining demand in lignocellulosic routes, as much as possible.
4. Sustainable energy crops: Energy crops are used to fill as much of the remaining energy demand as possible while staying within their sustainable potential[7]. Energy crops include oil crops, starch and sugar crops and (ligno)cellulosic crops.
5. Sustainable algae: Algae are used to yield oil to fill the remaining demand in the oil routes. Algae are used last because their growing and harvesting is currently not a proven technology on a commercial scale.

The assumed conversion efficiencies of the routes presented in Figure 2 - 6 are given in Appendix C 3.

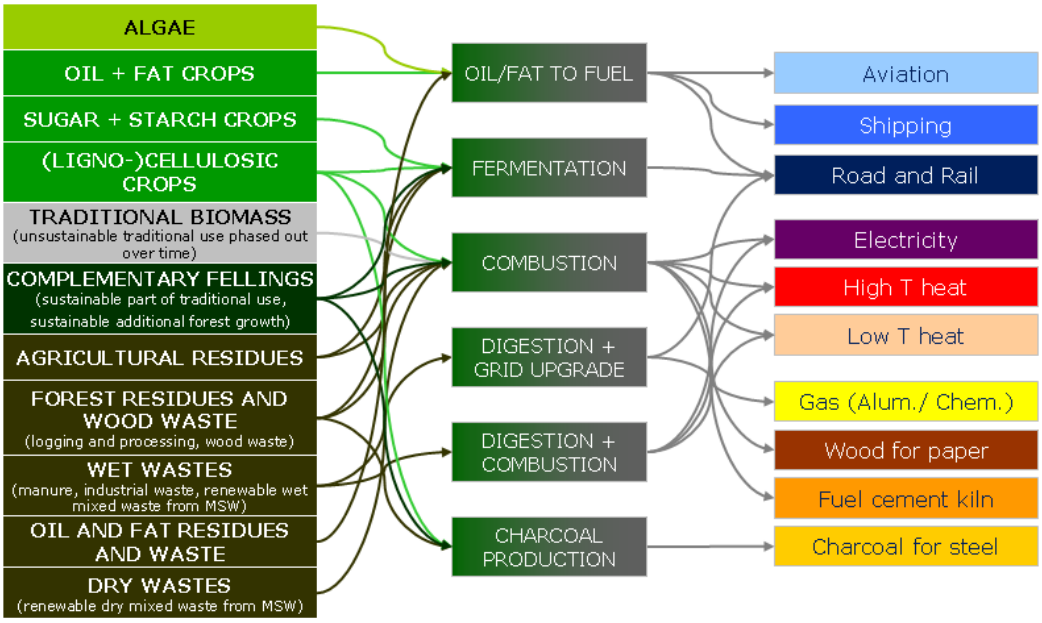

Figure 2 - 6 Bioenergy approach, showing the various biomass input types and conversion routes which result in various energy carrier types that meet demand.[8,9]

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[6] Competing uses are safeguarded, e.g. by keeping a suitable fraction of agricultural or forest residues on the field or in the forest, respectively.
[7] See Section 5 for the discussion on sustainable biomass.
[8] "Grid upgrade" refers to biogas being cleaned and compressed to allow it to be injected into gas grids.
[9] The size of the shapes in the image is not indicative of the size of the categories in the Scenario.

Box 2 - 1 Contingency: Technology choices on bioenergy conversion

CONTINGENCY	TECHNOLOGY CHOICES ON BIOENERGY CONVERSION

Section 2.1 describes the robust Scenario rationale for selecting technology options to include in the bioenergy conversion routes. These choices of course resonate in the final energy supply results and their contingencies.

The most notable effect occurs in the transport sector: the Scenario supplies the shipping and aviation fuel sectors through routes using only oils and fats as feedstock. Other potential future options such as thermochemical conversion of (lignocellulosic) biomass, for example gasification followed by Fischer-Tropsch synthesis, to shipping and aviation fuels are not included. This means that there is an increased need for oil supply from sustainable energy crops and algae compared to a situation where this thermochemical option is included. The large majority of this oil feedstock is used in the shipping and aviation sector.

In this Scenario we have chosen to exclude thermochemical conversion routes, because currently the development and implementation of other routes, such as the fermentation of lignocellulosic biomass, receive more attention than those of thermochemical conversion routes. It is possible that the development of these thermochemical conversion routes, or other fuel conversion routes, will progress faster than expected. In this case, additional routes would become available making the future bioenergy supply even more flexible than it is in the Scenario. Although we naturally welcome such renewable energy technology developments, we have chosen not to account for them quantitatively to keep the Scenario less dependent on unknown future developments.

3 Demand

3.1 Overall results

An understanding of our energy system begins with a detailed look at the demand of energy (see Section 2):

- Where is energy used?
- In what form and with which efficiency?
- Which functions does this energy deliver?
- Can this function be delivered differently?

A typical example to illustrate this approach is our energy use in buildings. A large fraction of our total energy demand, especially in cooler climates, comes from the residential built environment. The energy is used in the form of heat and often with very poor conversion efficiencies and large losses.
The desired function is a warm home, but does it need to be delivered in the current form? In fact, this function can be delivered with much less energy input if the building is insulated and heat loss is reduced.

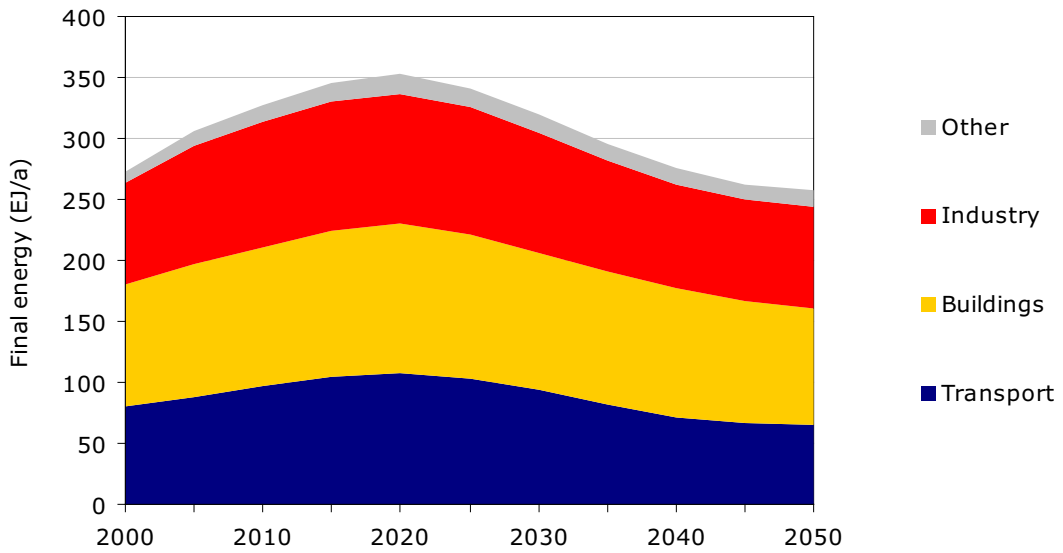

Figure 3 - 1 Global energy demand across all sectors, from 2000 to 2050.

Asking these questions in all three demand sectors[10], Industry, Buildings and Transport, leads to the Scenario for future energy demand as show in Figure 3 - 1.

[10] There are many different ways of looking at energy demand. The sectors we have chosen, Industry, Buildings and Transport, are congruent with the sectors for which the International Energy Agency (IEA) reports energy statistics, which form the basis

The overall result of the Energy Scenario is that energy demand can be reduced over the next four decades while providing more energy services to more people. The Scenario achieves this primarily, through the aggressive roll-out of the most efficient technologies. If this path is followed, energy demand can be stabilised and then **decreased** in comparison to current energy use worldwide.

This Scenario for future energy demand stands in stark contrast to the "business-as-usual" (BAU), or reference, scenarios which commonly assume a **doubling** of energy demand, even in the most optimistic cases (see Figure 3 - 2).
Even amongst other ambitious scenarios, the Energy Scenario is unique in its assumption of decreasing energy demand by 2050; most scenarios foresee, at best, a **stabilisation** of demand. [Climate Solutions; IPCC, 2000; Greenpeace, 2010; Shell, 2008; van Vuuren, 2007; WEO, 2009]

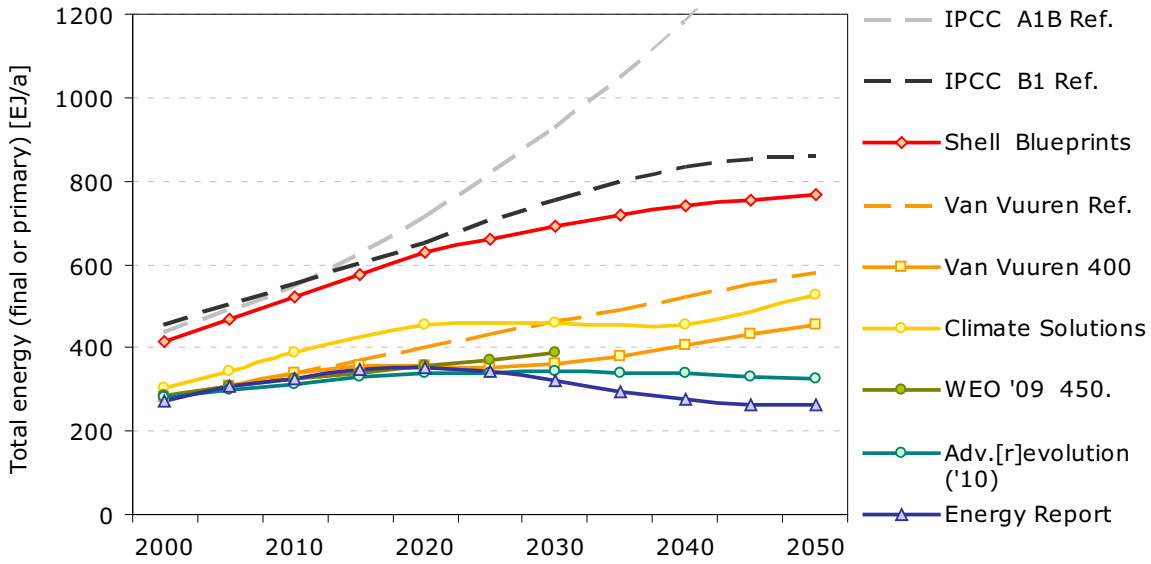

Figure 3 - 2 Comparison of global energy demand evolution in the Energy Scenario with other energy scenarios. Top three lines are in primary, lower six lines in final energy.

It is imperative to understand that the reduction of total energy demand in this Scenario is not derived from a reduction in activity. It depends primarily on the reduction of energy intensity, rather than a reduction of activity levels per capita (see Figure 2 - 2).
This means that the Energy Scenario presented here is founded on an assumption of increasing living standards and continuing economic development. Figure 3 - 3 shows

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of this work. These three sectors, which cover ~85% of total energy use, were studied in detail. The remaining sectors (including agriculture, fishing, mining etc) are included in this study, but were not examined separately. They are assumed to include energy functions that can be treated similarly as a mix of the buildings, transport and industrial energy functions. Non-energy use of energy carriers was excluded from this analysis.

the Scenario's underlying assumptions of population growth and GDP growth, which are used to project activity into the future. [UN, 2007; WBCSD, 2004]

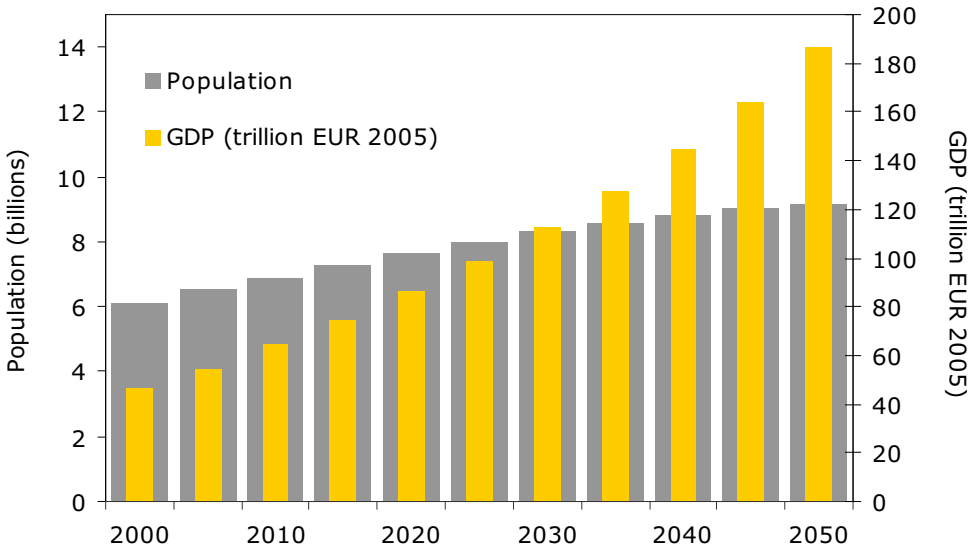


Figure 3 - 3 Global population and GDP used as the basis for the Scenario.

To illustrate this further, Figure 3 - 3 shows a summary of selected activity assumptions in the Scenario. The activities shown here are those activities which are most commonly associated with 'living standards' or 'comfort levels':

- The amount of residential living space
- The amount of industrial production[11], as an indicator of consumption
- The amount of passenger travel volume (person-km)

As Figure 3 - 4 shows, all of these activities increase over time, with the exception of industrial production in OECD regions, which is considered to have significant potential for activity savings by reducing waste, increasing re-use and improving material efficiency (see Section 3.2). As population stabilises in most industrialised countries and industrialising economies increasingly meet domestic demand for energy-intensive commodities, it is expected that per-capita production levels for some commodities will stabilise or even reduce without a reduction of end-user consumption.
This is discussed in more detail in the following sector-specific sections.

[11] 'A' sectors shown only here – see Section 3.2.1 for details.

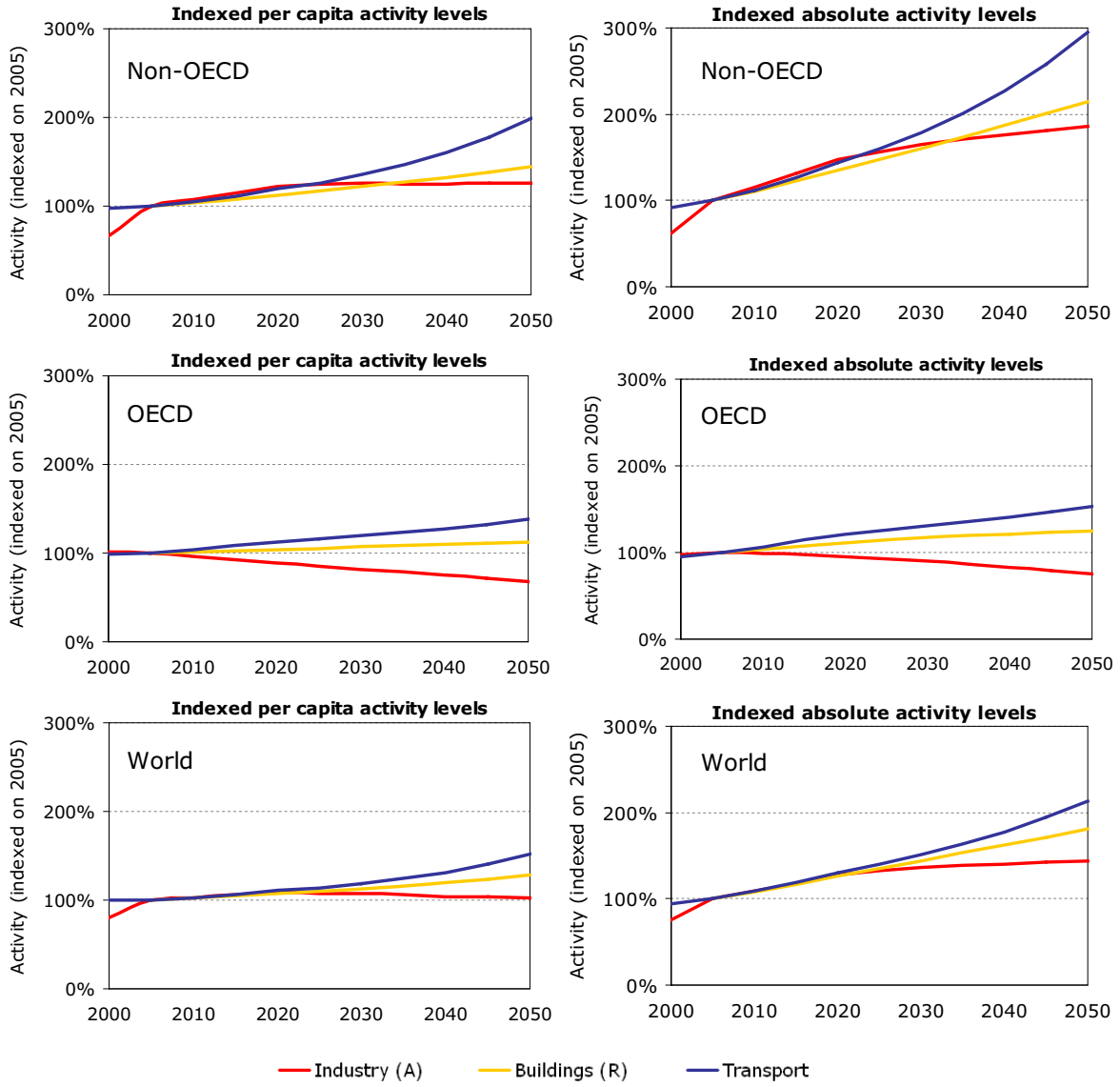


Figure 3 - 4 Activity levels indexed on 2005 in absolute terms (right) and per capita terms (left). Shown industrial production volumes in the 'A' sectors (Industry), residential floor space (Buildings), and passenger kilometers (Transport).

3.2 Industry

3.2.1 Industry – Definitions

The industry sector uses energy of all three carrier types in the definition used here: electricity, fuel and heat.

Industry comprises the following sectors (i.e. it excludes the power sector which is treated on the supply side of the Scenario – see Section 4):

Table 3 - 1 Industry sector definitions

Scenario Category	Industry sector (IEA definition)	Industry sector (Scenario marker sector)
"A"	Iron & steel	Steel
	Non-ferrous metals	Aluminium
	Non-metallic minerals	Cement
	Paper, pulp and print	Paper
"B"	Chemical & petrochemical	Chemicals
	Food & tobacco	Food
	[All others]	Other

The Scenario uses marker sectors to forecast evolution of activity and assess potential for efficiency improvements. This means, for example, that we assume efficiency improvements can be made in the entire non-ferrous metals sector which are analogous to the improvements we assume for the production of aluminium, etc.

For simplicity, we will refer to industry sectors by their Scenario names for the remainder of this report.

3.2.2 Industry – Future activity

Activity levels for the first four sectors (the 'A' sectors) are assessed in terms of tonnes produced, and linked to population growth. Activity levels for the last three sectors ('B' sectors) are assessed by GDP growth.

"A" sectors

For these sectors, an assumption is made on the future evolution of tonnes produced per capita, based on the logic of "intensity of use" curves (see Appendix B 1). This assumption is then multiplied by the future population to estimate total future production levels.

Figure 3 - 5 shows the resulting activity levels for the four industrial sectors steel, cement, aluminium, paper.

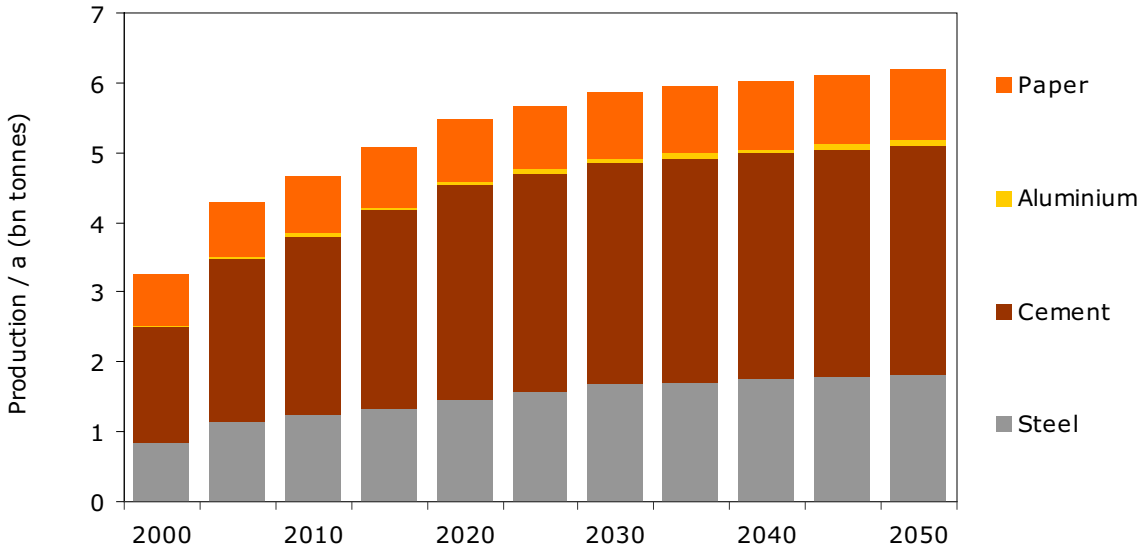


Figure 3 - 5 Global production levels of the 'A' industry sectors.

'B' sectors

For these industry sectors, data on current production is difficult to find and the aggregation of many different production processes makes this a very heterogeneous sector to treat at a technological level.
We therefore followed a similar approach to these sectors as that taken in many econometric models and assumed a future physical activity level linked to, but increasing less strongly than, GDP per capita.

Figure 3 - 6 shows the resulting activity evolution for both, A and B sectors, indexed on 2005 levels. Industrial production in the Scenario is assumed to increase for the coming decades in non-OECD regions and remain stable, with the beginning of a decrease, in OECD regions. These reductions do not require a compromise of living standards, but reflect an increased re-use of materials at the consumer end and advances in material efficiency at the producer's end, e.g. building cars with lighter frames, leading to lower steel demand per vehicle.

In addition to this reduced demand for materials, recycling is used during production to improve energy efficiency. Stocks of energy-intensive materials have grown over the past decades. As large parts of the stock reach the end of their life, it is expected that recycling will increase as the availability of recoverable materials increases. This might result in a situation where production from primary resources will be needed

only to offset losses due to dissipative use (e.g. hygienic papers, fertiliser), quality loss (e.g. paper fibre, plastics) or other losses.

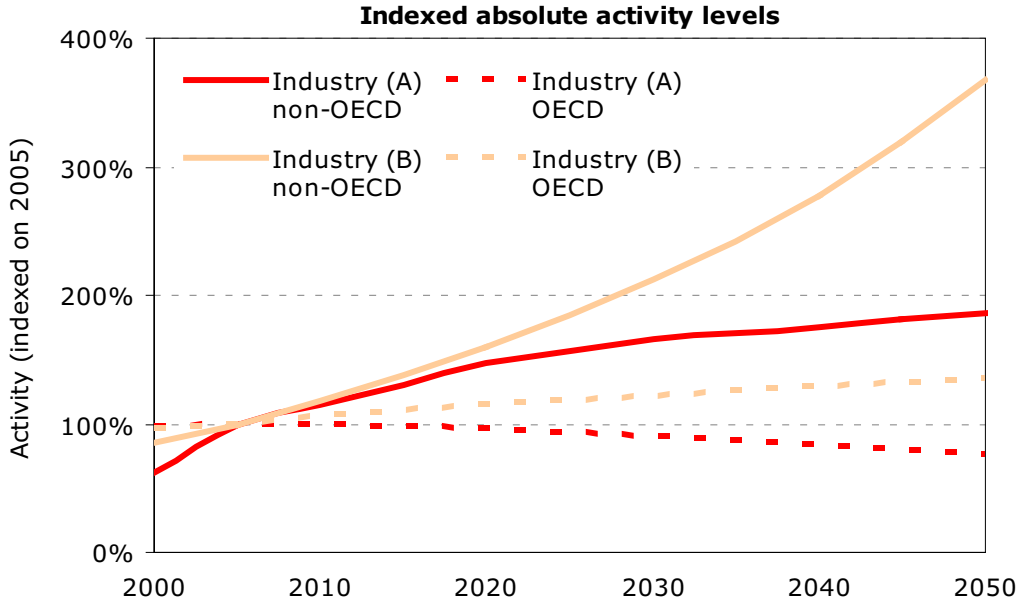


Figure 3 - 6 Indexed evolution of activity in the Industry sector.

3.2.3 Industry – Future energy intensity

Once the total production level has been determined for each sector, future energy intensity is estimated, based on key marker processes. The overall result is a decrease in energy intensity, measured in energy per tonne produced for 'A' sectors, and in energy per economic value for 'B' sectors.

The energy intensity evolution was examined in detail for the four 'A' sectors and the results are shown in Figure 3 - 7. Although the individual technologies vary by sector, all sectors follow these common assumptions:

- Increased use of recovered input materials or alternative routes
  - i.e. recycling of steel, paper and aluminium and alternative input materials into the clinker process in cement production
- Ambitious refurbishment of existing plants to meet performance benchmarks and stringent requirements for using best available technology (BAT) in all new plants.[12]
- Continuing improvements of BAT over time.

For the 'B' sectors, an annual efficiency improvement of 2% was assumed, which may be obtained through improved process optimisation, more efficient energy supply,

[12] No explicit assumptions are made on the early retirement of industrial plants, but the rapid move to BAT will likely require ambitious retrofitting or replacement of the least efficient plants.

improved efficiency in motor driven systems and lighting, as well as sector-specific measures.

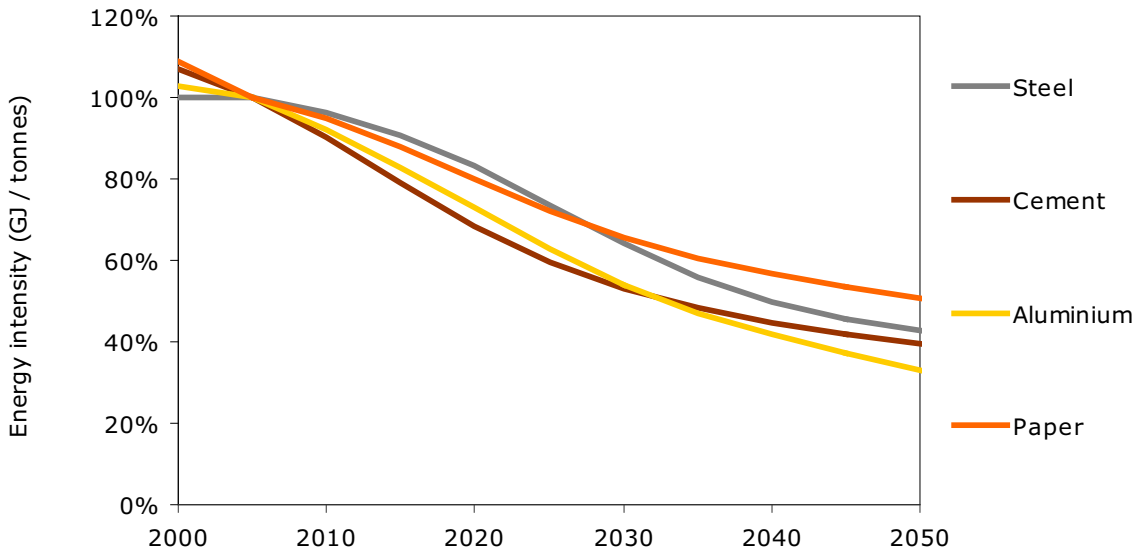


Figure 3 - 7 Evolution of energy intensity for the four 'A' industry sectors, including use of recycling/alternative routes.

Steel

In the steel sector, the standard production route uses blast furnaces which use coke from coal as an input. This route will see efficiency improvements over time as well as the increased use of the smelt reduction process. The current average energy need for this production process is around 20–25 GJ fuel and ~450 kWh per tonne produced; the Scenario assumes that this can be brought down to 12 GJ fuel and 100 kWh on average by 2050, (for example through widespread adoption of the smelt reduction process and assuming further improvements on current BAT). [Kim, 2002; Worrell, 2008]

Up to a third of the remaining fuel use will be provided by biomass in the form of biocoke to enable the move away from coal-based coke. The remaining fuel use is assumed to remain coke-based until 2050.
The recycled steel route is much more energy efficient, but rates of recycled material inputs are already high. The Scenario nevertheless assumes a small increase in the use of recycled materials to ~70% in OECD and ~45% in non-OECD regions by 2050. The recycled process is also assumed to increase its energy efficiency from around 5–6 GJ fuel and 600–800 kWh per tonne to 1.5 GJ fuel and 350 kWh per tonne in the electric arc furnace process. [Martin, 2000]

Cement

In the cement sector, which is used as a marker for the non-metallic minerals sector, efficiency improvements that are currently taking place should bring the average

energy intensity down from 5–6 GJ fuel per tonne to 3 GJ fuel per tonne. Also, a ~30% reduction on the electricity demand (to ~80 kWh per tonne) was assumed. Because of the high temperatures required, only half of the fuel needs can be provided by biomass, but where biomass is used, any combustible biomass is suitable. The Scenario also assumes a reduction in energy- and carbon-intensive clinker production. Clinker is replaced by industrial by-products such as blast furnace slags, fly ash or natural pozzolanes in up to 40% of cement production by 2050. This would result in cement that would set more slowly, but also be of higher strength. [Kim, 2002]

Box 3 - 1 Case study: State-of-the-art plants save energy in the cement industry.

CASE STUDY | STATE-OF-THE-ART PLANTS SAVE ENERGY IN THE CEMENT INDUSTRY

The cement industry is a large energy user and also an important global contributor to greenhouse gas emissions. The U.S. is the third largest cement producer in the world.

Salt River Materials Group operates a cement plant in Clarksdale, Arizona, U.S.A. The plant was built in the 1950's and over time, received various upgrades to increase kiln capacity and other operating systems.

In 1999, the company installed a set of new equipment that substantially improved energy performance. The plant upgrades included:

- A vertical roller mill for raw materials, fuels and, finished cement
- A new 5-stage, low NOx preheater/calciner kiln with state-of-the-art clinker cooler
- A modern kiln burner.

The new equipment improved energy performance substantially across the major energy intensive processes in the plant, reducing electricity consumption by 50% and fuel consumption by 37%. The upgrade made the Clarksdale plant one of the most efficient cement plants in North-America. It received recognition for this achievement from the ENERGY STAR program of the U.S. Environmental Protection Agency.

Aluminium

Aluminium, which is used as a marker for the non-ferrous metals sector, will include vastly increasing shares of secondary, recycled aluminium in the production process. Recycling of aluminium uses fuels which are not easily replaced by biofuels, but at 4–5 GJ per tonne, it is a much more efficient process than the production of primary aluminium which, in addition to 1–2 GJ per tonne for pre-baking of the anodes, uses 15–16 MWh (not kWh) of electricity per tonne of aluminium produced, equivalent to 55 GJ per tonne, i.e. it is an order of magnitude more energy intensive than recycling. The Scenario assumes that this can be reduced to around 12 MWh per tonne in the future, but prioritises the recycling of aluminium where possible. Shares of recycled

aluminium in total production are assumed to rise from 10–30% to 60% by 2050. [Worrell, 2008]

Paper

For the paper sector, the use of recycled pulp is economically and energetically wise, providing an 'instant' energy saving of 30–40%. The Scenario therefore assumes shares of recycled pulp in paper production to strongly increase in the future, especially in regions where current paper recovery rates are low, reaching an average of 70% by 2050. Where virgin pulp is still used (a minimum of 15–20% of input fibre), the Scenario assumes that energy intensity can decrease by around 40–50 % for both, fuel and electricity. [IEA, 2007]

3.2.4 Industry – Future energy demand

Figure 3 - 8 shows how the total industrial energy demand would develop, resulting from the evolution of activity and intensity. Demand will continue to increase initially in this Scenario, but will slow and peak around 2020, reverting back to 2000 levels by 2050.

As detailed above, this overall demand evolution requires a wholesale shift from current, often outdated technologies to current BAT levels, i.e. most efficient technologies as well as the use of alternative pathways and optimum recycling levels. It also assumes a modest reduction in production in OECD regions through increased material efficiency.

Note that a small share of the total heat demand shown in Figure 3 - 8 has been assumed to be provided by hydrogen fuel, see also Box 4 - 1.

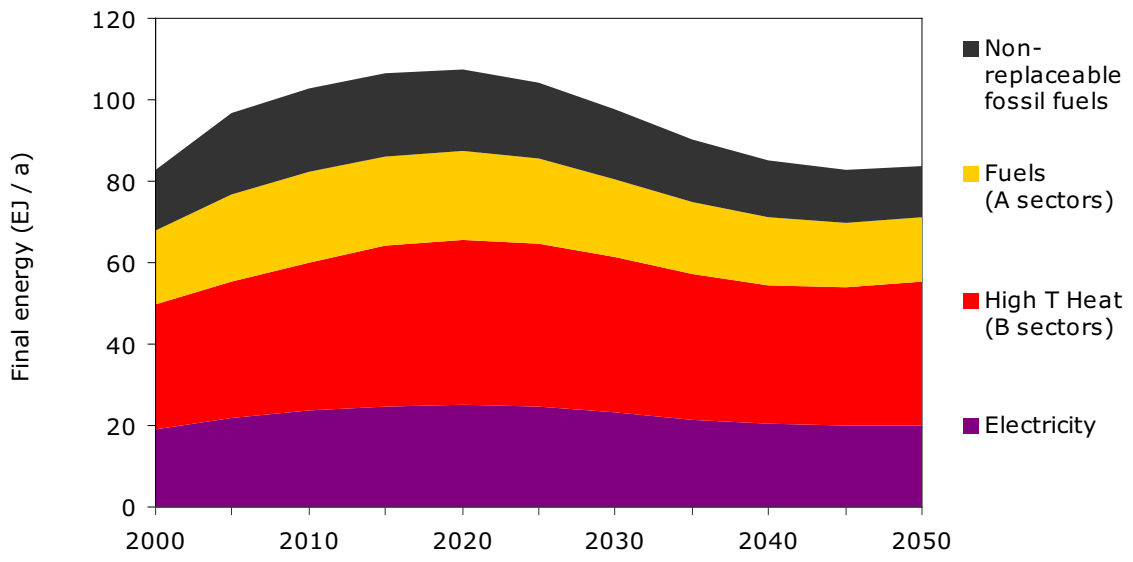


Figure 3 - 8 Global overall energy use in the Industry sector, by energy carrier type.

3.3 Buildings

The building sector provides great potential for energy savings and electrification. The sector is also marked by longevity: decisions on building design today influence building energy use for many decades, often up to a century, given the lifetimes of our building stock.

3.3.1 Buildings – Definitions

The built environment sector, which we will refer to simply as the 'Buildings' sector in this document, covers energy use in the residential and services sector, according to the definitions in the IEA Energy balances (see Table 3 - 2).[10]

Table 3 - 2 Building sector definitions.

Building sector (IEA definition)	Building sector (Scenario definition)
Residential	Residential
Commercial and public services	Commercial

3.3.2 Buildings – Future activity

The following steps are followed in this Energy Scenario to establish the future activity levels in the Building sector:

1. Total future floor area, which is the activity marker in the Building sector, is projected based on population growth and increased living space per capita[13]. Similarly to the industry sector, the future residential floor space per capita is informed by a relationship between living space and GDP per capita (see Appendix B 2).
2. Assumptions on typical, historical demolition rates are then used to split into floor area that exists today (pre-2005 stock) and floor area yet to be built (new stock). The results for the residential buildings sector are shown in Figure 3 - 9.

[13] This increase is not necessarily the same in all regions as starting points vary.

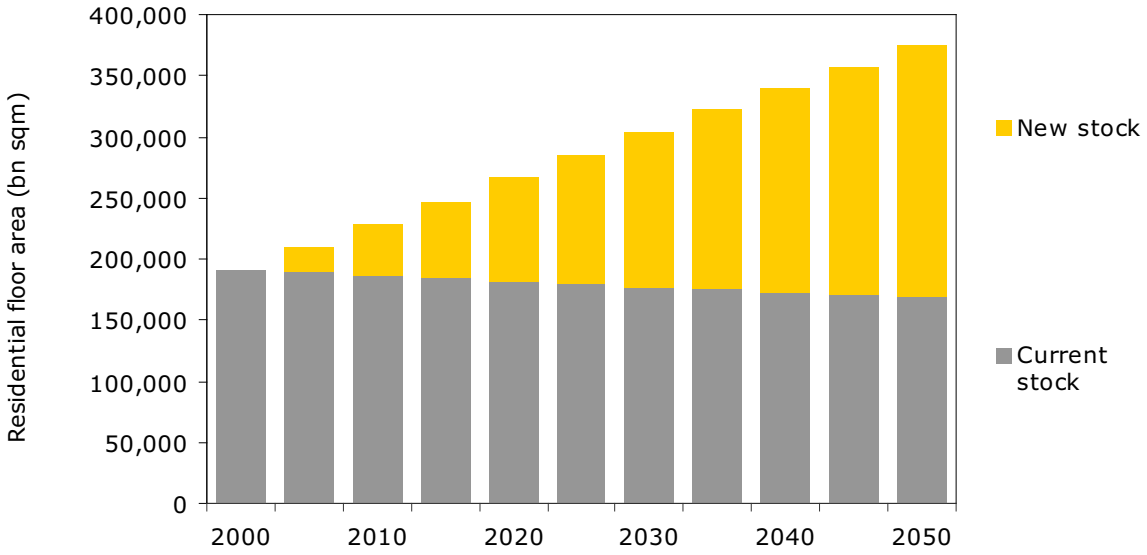


Figure 3 - 9 Global residential floor area evolution in the Buildings sector.

For commercial floor space, a similar approach is followed, but rather than using population growth as a marker, this evolution is pegged to GDP growth with a decoupling factor.

The overall evolution of residential and commercial floor space is shown in Figure 3 - 10.

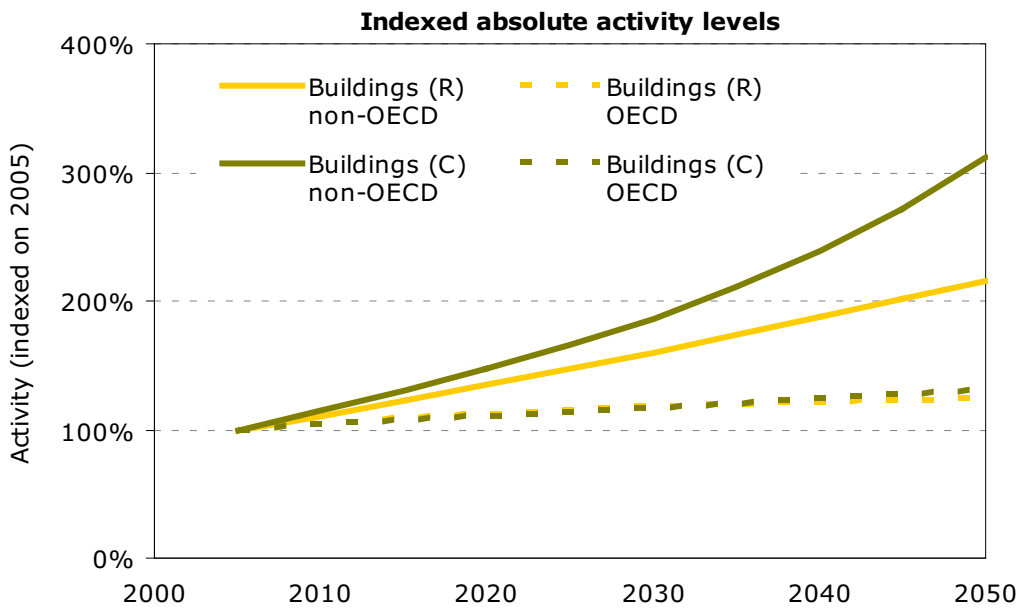


Figure 3 - 10 Indexed evolution of floor space (R=Residential, C=Commercial).

3.3.3 Buildings – Future energy intensity

The following steps are followed to discover the possible evolution of energy intensity for the Scenario, i.e. the possible future heat and electricity demand per square meter of living or commercial floor area.

For each type of floor area, future energy intensity was projected based on the following assumptions:

Existing pre-2005 stock:

1. All existing buildings would be retrofitted by 2050 to ambitious energy efficiency standards. This requires **retrofit rates of up to 2.5% of floor area per year**, which is high compared to current practice, yet feasible (see Figure 3 - 11.)
2. For a given retrofit, it is assumed that, on average, 60% of the heating needs could be abated by **insulating walls, roofs and ground floors,** replacing old windows with **highly energy efficient windows** and by installing **ventilation systems with heat recovery** mechanisms.
3. A quarter of the remaining heating and hot water need would be met by **local solar thermal systems**, the rest by **heat pumps**.[14]
4. **Cooling** will be provided by **local, renewable** solutions where possible (see Box 3 - 3).
5. Increased **electricity** needs per floor area due to increased cooling demand, increased appliances use (per area) and heat pump powering have also been estimated.

New stock:

1. The Scenario assumes that new buildings will increasingly be built to a **near zero energy use** standard[15]**,** reaching a penetration of 100% of new buildings by 2030. These are highly energy efficient buildings due to very low losses through the building envelope (insulation and improved windows) and almost no losses from air exchange (use of heat recovery systems).
2. The residual heat demand is covered by **passive solar,** (irradiation through windows) and internal, (people, appliances) **gains,** renewable energy systems in the form of **solar thermal** installations and **heat pumps.**
3. In comparison to a new building of today, this building type requires no fuel supply of any kind, i.e. it is an **all-electric** building.
4. The near zero-energy concept will also be applied to warm/hot climates, often reviving traditional building approaches. These include **external shading devices**

[14] Other technologies, such as wood pellet ovens, may have a role to play in niche markets or as a bridging technology, but have not been included in this Scenario which emphasises the use of heat pumps run on renewable electricity.

[15] By 'near-zero energy use' we mean buildings which have an energy use at levels comparable to the passive house standard developed in Germany.

and an optimal **ventilation strategy** (high exchange rates at night, less during the day) – see also Box 3 - 3.

5 There will be remaining cooling demand in these regions, especially in non-residential buildings with high internal loads from computers (offices) or lighting (retail). **Increased electricity needs** from increased cooling and appliances, as well as the use of heat pumps, has been estimated and included in this Scenario (see above).

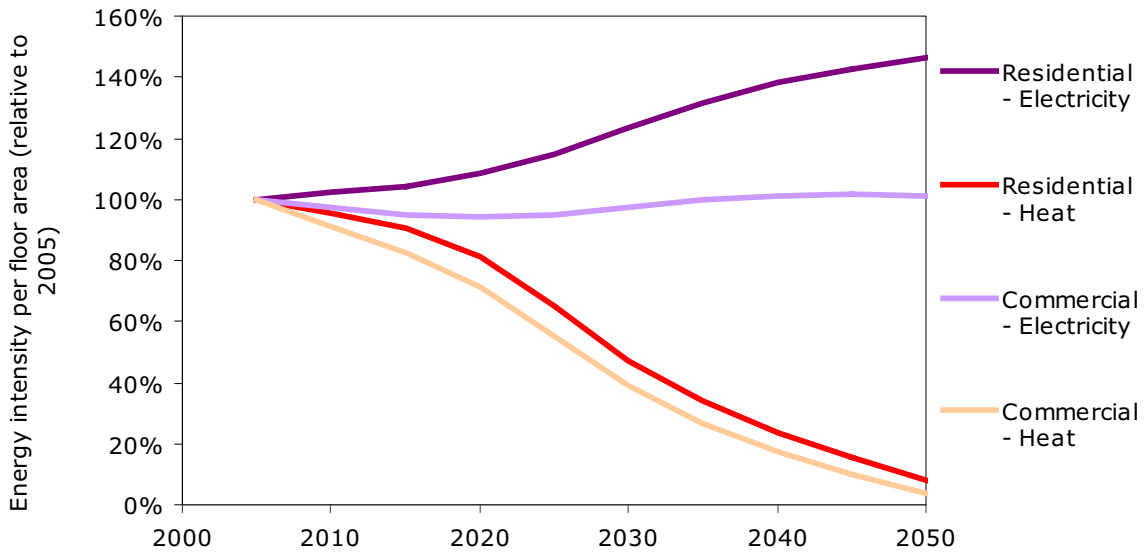


Figure 3 - 11 Evolution of energy intensity in the Buildings sector.[16]

The resulting overall evolution in energy intensity is shown in Figure 3 - 11. The drastically reduced heat demand can be observed as well as a ~50% increase in electricity demand per unit floor area, on average. This is due to increased electricity demand from heat pump operation, as well as an assumption on increased use of appliances, lighting and cooling which can only be partially offset by efficiency improvements.

[16] Note: Heat shown in this graph is all heat that is not supplied by heat pumps or solar thermal options. Electricity demand for heat pumps is included in the electricity line (as well as electricity for lighting and appliances).

Box 3 - 2 Story: Retrofit rates in Buildings.

STORY	BUILDING RETROFIT RATES

This Scenario assumes that retrofit rates will rise from their current levels to reach 2–3% by ~2020, to allow full retrofit of all existing building stock by or before 2050.

This may seem like a challenging ambition, given current retrofit levels in many parts of the world. However, this would not the first time such high retrofit levels have been achieved. According to the German CO_2 buildings report [DE Gov, 2006], the refurbishment rate in Germany in 2006 was approximately 2.2% and, according to the national energy efficiency action plan [DE Gov, 2007], the German government set a refurbishment rate target of 2.6% for 2016 in accordance with the current policy direction at European level.

3.3.4 Buildings – Future energy demand

Despite the strong increase in activity, i.e. floor space, the energy intensity reductions detailed above lead to a drastically reduced need for building heat in the form of fuels or heat delivered directly to buildings. At the same time, an increase in electricity use is expected. These results are shown in Figure 3 - 12.

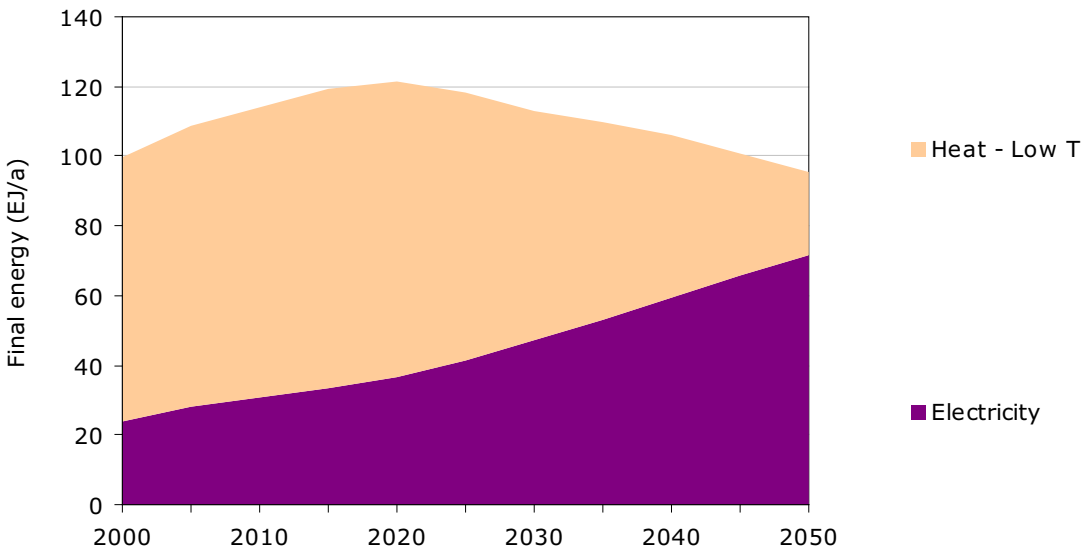


Figure 3 - 12 Global overall energy use in the Buildings sector, by energy carrier type.

Box 3 - 3 Case study: Building cooling demand in mediterranean countries.

CASE STUDY | BUILDING COOLING DEMAND IN MEDITERRANEAN COUNTRIES

MED-ENEC project, 2007/08. "Energy Efficiency in the Construction Sector in the Mediterranean" (www.med-enec.com).

The MED-ENEC Project is considered to be a major element in designing and implementing cooperation efforts between the EU and MEDA Countries and between MEDA countries themselves as part of the Euro-Mediterranean Partnership.

Most of the MEDA countries are characterised by a strong contrast between high-energy demanding urban and industrialised centres and rural areas where access to energy is often low. The expected growth in population and economy as well as the urbanisation put pressure on the existing energy infrastructure. The building stock is one of the principal consumers, responsible for about 25-45% of the final energy consumption with ascending tendency.

The largest potential for improvement exists in urban areas and the reduction of the cooling demand requires a holistic approach to integrate demand side management and energy efficiency in the planning process of buildings.

The MED-ENEC project follows a sustainable business approach, which incorporates demonstration projects and capacity building into one integrated effort. The project focuses on strengthening business services and supporting markets, improving institutional capacities and establishing favourable institutional structures, as well as fiscal and economic instruments.

The project includes 10 pilot building projects in ten countries: These were realised under local conditions with local entrepreneurs and achieved outstanding results:

- Three national Energy Globe Awards
- Follow-up activities in the countries
- Overall savings of 900 t/a or 45,000 t over lifetime
- High potential for large scale implementation

3.4 Transport

3.4.1 Transport – Definitions

Activity in the transport sector is commonly given in person-km (pkm) for passenger transport and tonne-km (tkm) for freight transport.
The transport sector is thus differentiated into passenger and freight modes in the Scenario. The detailed definitions are given in Table 3 - 3.

Table 3 - 3 Transport sector definitions

Transport mode (IEA definition)	Transport mode (Scenario definition)
Road	PSNGR - PTWs[17]
Road	PSNGR - Car, City
Road	PSNGR - Car, non-City
Road	PSNGR - Bus+Coach
Rail	PSNGR - Rail
Aviation	PSNGR - Plane
Road	FRGHT - Truck
Rail	FRGHT - Rail
Aviation	FRGHT - Plane
Domestic navigation + World Marine Bunkers	FRGHT - Ship

3.4.2 Transport – Future activity

The Energy Scenario is using a detailed, established BAU transport activity forecast for future traffic volumes [WBCSD, 2004]. This BAU scenario foresees a marked increase in worldwide travel volumes, in accordance with GDP projections (see Figure 3 - 13).

Modal shifts are then applied to this BAU forecast to arrive at volumes by mode in the Energy Scenario. The results are shown in Figure 3 - 14 for passenger and in Figure 3 - 15 for freight transport.

In the BAU case, transport volumes are expected to increase substantially, especially in developing economies, with a clear emphasis on individual road transport. Although an overall increase in transport can be expected as GDP rises, it is clear that the modal split implied in the BAU case will not result in the most efficient transport system and would likely lead to considerable infrastructure challenges.

[17] PTW = Personal two and three wheelers

The Scenario therefore assumes substantial modal shifts away from inefficient individual road and aviation modes and towards the more efficient rail and shared road modes.

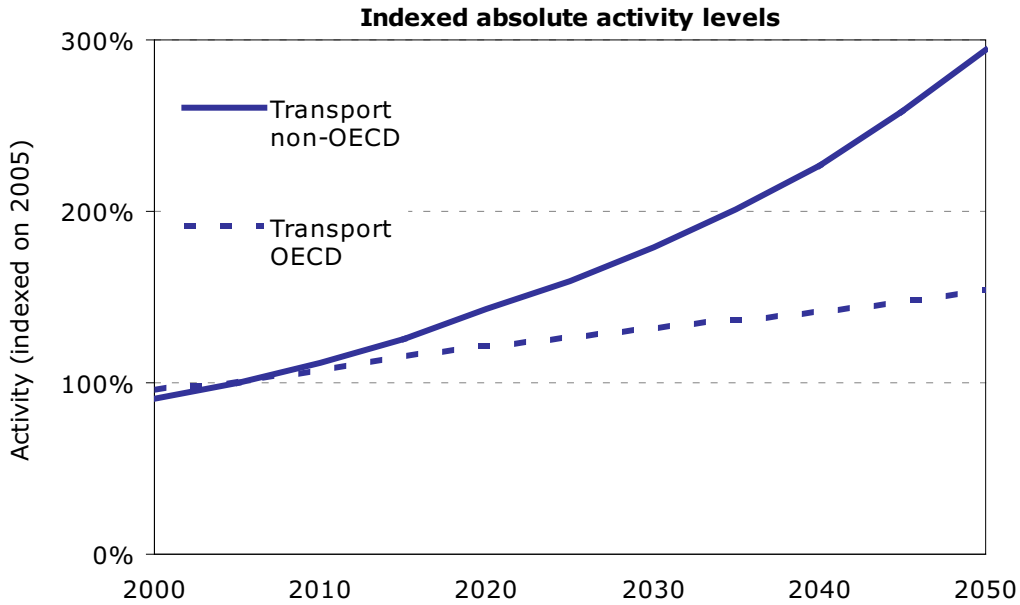


Figure 3 - 13 Indexed evolution of activity in the Transport sector.

The resulting, much decreased growth of worldwide car traffic (resulting from an increase in non-OECD regions and a stabilisation or decrease in OECD regions) is coupled with a large increase in shared travel modes, especially rail travel.

The modal shift even results in a modest overall reduction in externally powered passenger travel volumes forecast for 2050, primarily through:

- a shift from car travel to human-powered travel such as walking and cycling[18] and
- a shift from (business) aviation travel to alternatives such as videoconferencing[19].

It should be noted that this change of travel pattern away from individual car transport and towards more efficient modes requires an approach to land use planning which makes high-coverage mass-transit systems possible and ecologically and economically sustainable.
Although the modal shift assumptions may be considered ambitious, they could in theory be pushed even further.

[18] Note that the distances involved in the modal shift to walking and cycling are short, so the overall person-km volume shifted is small.
[19] Videoconferencing will mainly displace a share of business travel which represents the minority of passenger air travel. [CCC, 2009]

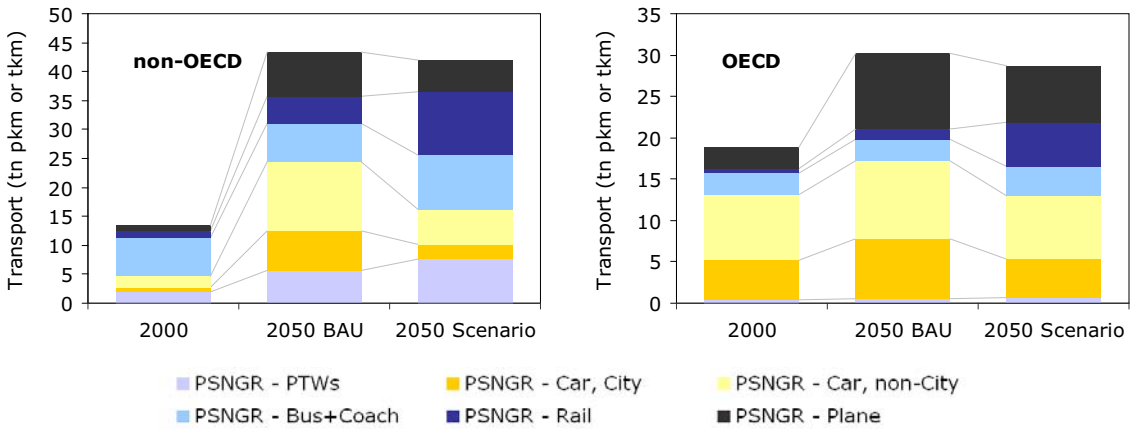


Figure 3 - 14 Modal shift for passenger transport.

For freight, volume was shifted from aviation and truck modes towards rail[20]. Although a reduction of overall freight volumes may be desirable in a more localised economy model, this option was not considered here for lack of a quantitative basis for such assumptions.

Note that the increase in rail capacity needed to sustain the increase in both passenger travel and freight traffic is very large. It can be argued that in the BAU, a similar increase in road traffic would have been required, but the challenge of assuring a high-capacity and well-managed rail network should not be underestimated.

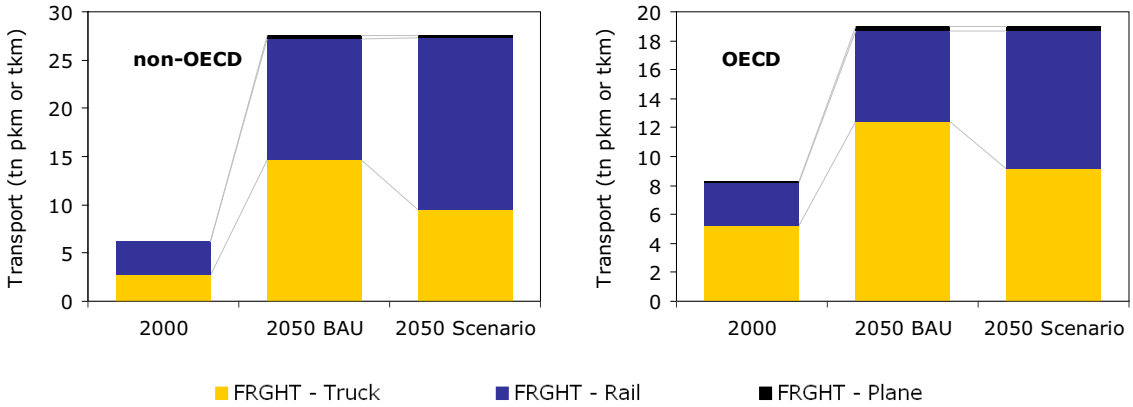


Figure 3 - 15 Modal shift for freight transport.

[20] Note that due to data availability, long-term energy use for freight by ship was not modelled based on activity but based on GDP forecasts, akin to the 'A' and 'B' sector approach in Industry.

3.4.3 Transport – Future energy intensity

The steps below are followed to ensure that the Scenario employs the most efficient transport modes with the highest likelihood of a renewable energy supply:

1. Moving to efficient technologies and modes of employment, e.g. trucks with reduced drag, improved air traffic management or reduced fuel needs in hybrid buses.
2. Electrifying the mode as far as possible, e.g. electric cars in urban environments and electric rail systems.
3. As a last step, providing the fuel from sustainable biomass, where possible (see Section 5).

Table 3 - 4 summarises the fuel shift assumptions that calculations within the Scenario are based upon. The most noteworthy assumptions are:

- A complete shift to plug-in hybrids and/or electric vehicles becoming the main technology choice for light duty vehicles.
- Long-distance trucks undergoing large efficiency improvements due to improved material choice, engine technology and aerodynamics rather than moving to electric transport (due to the prohibitive size and weight of batteries required with current technology). The 30% electric share for trucks represents fully electrified delivery vans covering 'the last mile'.
- A (small) share of shipping fuel being gradually replaced by hydrogen, won from renewable electricity. This has been deemed a feasible option due to the centralised refuelling of ships (see also Box 4 - 1).

Box 3 - 4 Story: Material needs for batteries.

STORY	MATERIAL NEEDS FOR BATTERIES

The electrification of the transport sector foresees a wholesale shift to electric vehicles and plug-in hybrids for all cars, buses and ~30% of trucks/delivery vehicles. This large volume of electrically enabled vehicles will require a concomitant production of batteries; a typical electrical vehicle with a 150 km range would require a battery weighing up to a quarter tonne.

The enabling technology for electric vehicles in recent years has been the Lithium-Ion battery, which achieves energy densities sufficiently high to produce vehicles with 150 km range. Assessing the required lithium volume for the Scenario under the assumption that all vehicles would use this material is out of the scope of the study. However, the worldwide supply of lithium is clearly of concern given the large volumes needed for electric vehicles. In parallel with recycling and re-use in other sectors, lithium-ion batteries would need to be refurbished for renewed use. In addition, further research and development into alternative materials and different charge storage technologies will also need to be undertaken.

Table 3 - 4 Efficiency and fuel shift assumptions for all transport modes.

Mode	Efficiency gains 2050 vs 2000	Electri-fication[21]	Comments
PSNGR - PTWs	50%	40% – 90%[22]	e.g. scooters
PSNGR - Car, City	75% (2000: 8–11 l/100 km 2050: 2–3 l/100 km)	90%	90%, i.e. most transport done by electric vehicles or on electric portion of plug-in hybrid vehicles
PSNGR - Car, non-City		70%	
PSNGR - Bus+Coach	50% – 65%	50% – 70%	Hybrids / electric, especially in cities
PSNGR - Rail	30%	95% – 100%	Shift to fully electrified rail, resistance reduction, space optimisation
PSNGR - Plane	~50%	n/a	Improvements in airframe and engine design, gains from air traffic management optimisation [CCC, 2009]
FRGHT - Truck	65%	30%	'last-mile' delivery vans electric
FRGHT - Rail	30%	95% – 100%	Shift to fully electrified rail
FRGHT - Plane	~50%	n/a	[see passenger plane travel above]
FRGHT - Ship	~50%	None [but ~5% (H_2) from electricity]	Propeller and hull maintenance and upgrades, retrofits including towing kite, operational improvements including speed reduction; small share of hydrogen fuel in ships [IMO, 2009]

The resulting overall evolution of energy intensity in the transport sector, differentiated by fuel and electricity use, is shown in Figure 3 - 16. Note that the share of electricity looks relatively small in comparison to the fuels, because these still need to undergo conversion at a comparatively lower efficiency to generate mechanical energy for the wheels.

[21] Where a shift takes place from fuel to electricity it is assumed that the electrically powered vehicle will need 1.5–2.5 times less final energy on average, since the energy is delivered to the vehicle in an already converted form.

[22] Lower end of range used for OECD regions, where motorcycles are the norm, higher end of range for non-OECD where PTW are assumed to include a much higher fraction of electric scooters.

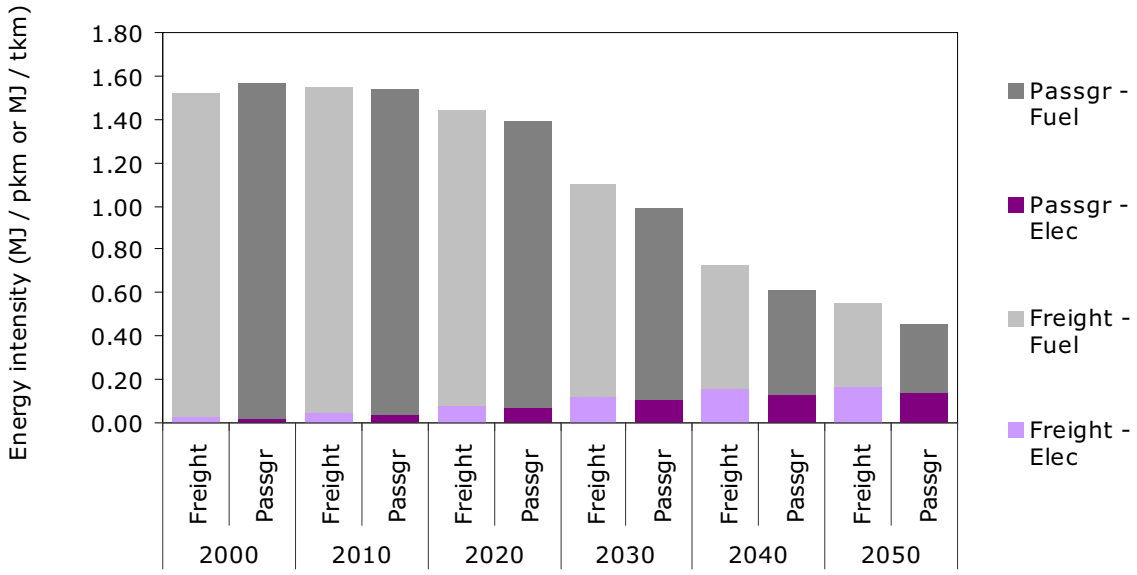


Figure 3 - 16 Evolution of energy intensity in the Transport sector.

3.4.4 Transport – Future energy demand

The assumptions on activity evolution with modal shift and on energy intensity evolution with fuel shift, lead to the overall energy demand evolution in the transport sector shown in Figure 3 - 17.

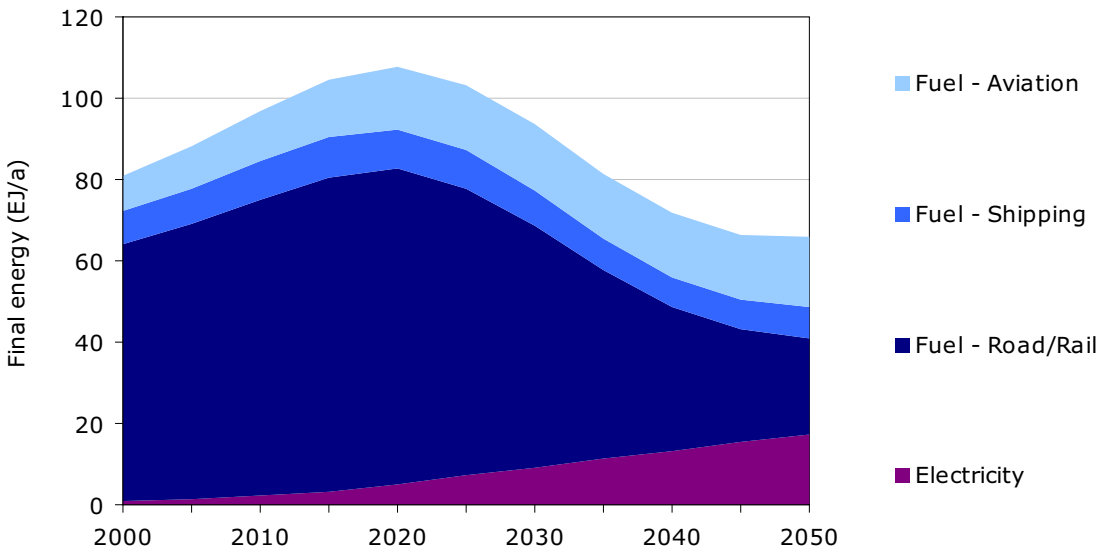


Figure 3 - 17 Global overall energy use in the Transport sector, by energy carrier type.

The ambitious assumptions on energy efficiency and electrification lead to a contraction of energy demand in the transport sector, despite a strong increase in underlying activity. When interpreting Figure 3 - 17 it is important to remember that

as demand is shown in final energy *as defined in the IEA energy balances*, the share of electricity in transport looks small, even though for many modes it delivers the vast majority of mechanical energy to the wheels. This is because the fuels still undergo conversion in the vehicle's combustion engine and therefore represent a higher energy content (see also footnote 2).

Note that a small share of the shipping fuel demand shown in Figure 3 - 17 has been assumed to be provided by hydrogen fuel, see also Box 4 - 1.

Box 3 - 5 Contingency: Freight transport.

CONTINGENCY | **FREIGHT TRANSPORT**

Freight transport, as well as aviation and shipping, is one of the transport sectors which represents the greatest demand for fuel. Although the Scenario contains strong electrification for short distance freight, e.g. electric delivery vans for all 'last mile' journeys, as well as a significant amount of modal shift from trucks to rail freight, there is a residual amount of long-distance trucking which is not thought to be amenable to electric vehicles in the short term future.

Other options exist for this demand, which have not been modelled in this study:

- Move to a more localised economy

A proportion of today's freight transport is used to move goods between locations which could be both producers and consumers of that product, rendering the freight questionable from an energy point of view. An example of this is the shipping of agricultural commodities from one region of the world to another which could produce the same commodity locally. Quantifying this effect is out of scope of this study, but it should be noted that reduction of these freight volumes represents a contingency opportunity for reducing energy demand for road, air and sea freight.

- Use of hydrogen in long-distance trucking

As explained in Box 4 - 1, hydrogen fuel was assumed to be unavailable for long-distance trucking within the time frame of this study. However, another pathway could be conceived to a sustainable transport sector where special attention would be given to the establishment of a suitable hydrogen fuel charging network that would allow its use in long-distance freight. In such a scenario, fuel demand from fossil fuels or biofuels for road freight could theoretically be significantly reduced.

4 Supply – Renewable energy (excl. bioenergy)

4.1 Overall results

The assumptions detailed in Section 3 for the demand side lead to:

- A much reduced demand overall compared to 'business-as-usual' (BAU)
- A higher electrification rate

The resulting overall demand split is presented in Figure 4 - 1. Note in particular that the demand for power rises steadily from just below 60 EJ/a to over 120 EJ/a. In contrast, heat and fuel demand grow at first, before reducing drastically in later years[23].

In the next step, this demand must be matched with energy supply. In accordance with the approach (see Section 2), this is done in the following order:

1. Where available, non-bioenergy renewable options are used first
2. If demand cannot be fully satisfied, bioenergy is used up to the sustainably available potential in that year (see Section 5)
3. All residual demand is supplied by conventional source, such as fossil and nuclear energy.

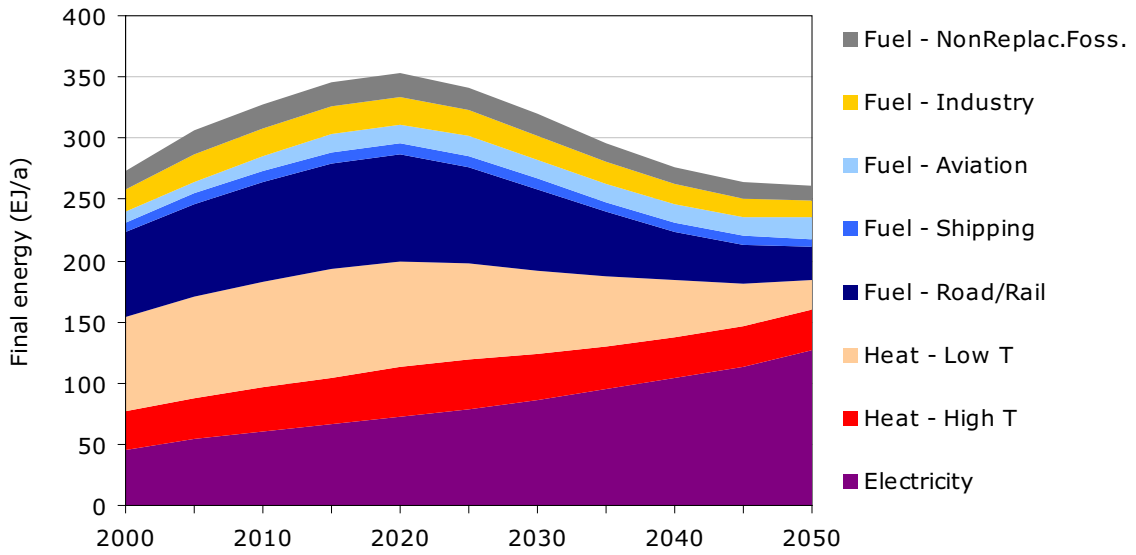


Figure 4 - 1 Global energy demand in all sectors, split by energy carrier.

[23] Note that the share of electricity looks small in comparison to, e.g. transport fuels, since these still have to undergo conversion at a comparatively lower efficiency to generate mechanical energy for the wheels.

Following this strict prioritisation of options, the overall evolution of energy supply is found as shown in Figure 4 - 2[24].

Stabilising energy demand driven by strong energy efficiency coincides with fast renewable energy supply growth in the later years, resulting in an energy system that is 95% sustainably sourced.

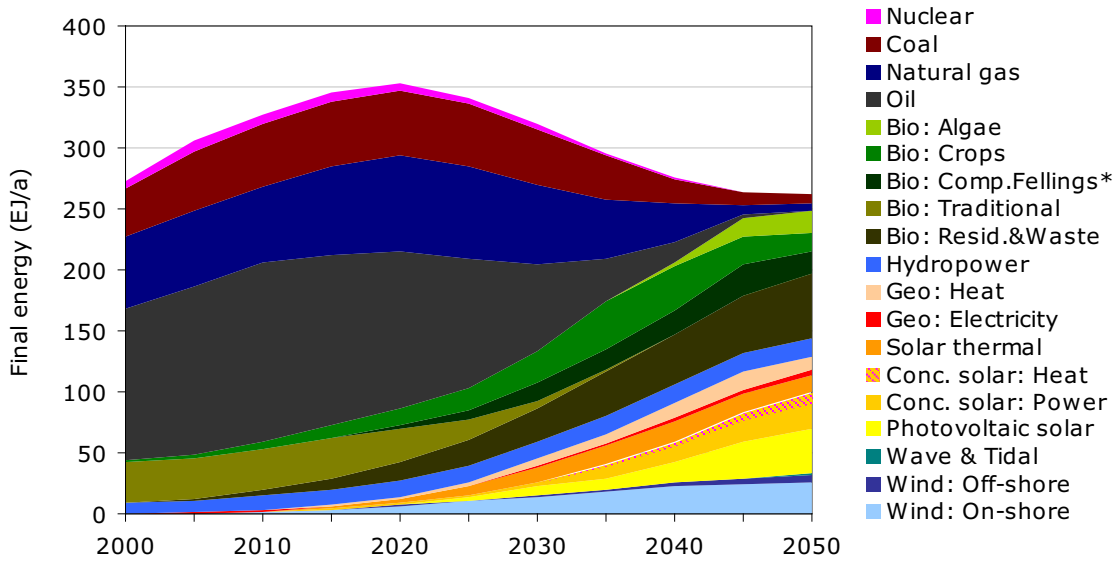


Figure 4 - 2 Global energy supply in the Scenario, split by source. (*Complementary fellings include the sustainable share of traditional biomass use.[25])

In the following sections, these results will be discussed in greater detail for each of the demand sectors, preceded by a presentation of the detailed, assumed, renewable potentials. Special attention will be given to the complex subject of bioenergy in Section 5.

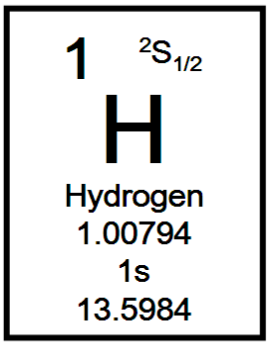
[24] The reader is reminded that because this graph presents final energy, the share of fuels, e.g. from fossil or bioenergy, looks large in comparison to the electricity and heat options.

[25] Original sources are not explicit on the composition of the traditional use of biomass. It has been grouped with complementary fellings here as we expect a large share of it to be forest-sourced, especially in later years.

Box 4 - 1 Story: The role of hydrogen fuel in the Energy Scenario.

STORY	THE ROLE OF HYDROGEN FUEL IN THE ENERGY SCENARIO

Hydrogen fuel presents a number of **benefits** which allow it to play a bridging role in this Scenario:



- It is a fuel, and could therefore lighten the demand for renewable fuels and/or high temperature heat for which only very few sustainable options exist.
- It can be fully sustainable, e.g. if generated via electrolysis from renewable power sources.
- If generated from renewable sources in this way, it can also function as a storage medium for renewable power, i.e. storing electricity generated by the supply-driven power sources in times of overproduction.

In addition to these benefits however, a few **challenges** do exist:

- There is no existing transport network for hydrogen fuel. This would mean that wholesale installation of a new type of charging infrastructure would be required to make hydrogen fuel available to distributed transport users, such as passenger cars
- Hydrogen has a lower energy density than conventional fuels, and a lower mass density even at high pressures, making it bulky to store and transport
- Converting electricity to hydrogen and then back to electricity is considerably less efficient than using the original electricity directly.

For the reasons above, the Scenario uses hydrogen primarily in applications where:

- Journeys are between load centres or use is directly near production sites so that the demand could easily be integrated with a new renewable power network (i.e. not used in passenger transport, but suitable for central industrial installations)
- The time / distance between charging stations is small (e.g. only used in a fraction of short distance shipping and not assumed to be suitable for road transport)

In addition to displacing fuel and heat demand, some hydrogen is required in the production of N fertiliser to obtain sustainable nutrients for the production of biomass for sustainable bioenergy.

In total, 9 EJ of additional electricity demand is used in 2050 to

- Displace ~5 EJ of **industrial fuels and heat**, primarily in chemical, aluminium and cement production
- Displace ~0.5 EJ of **shipping fuel**
- Supply 3.5 EJ of electricity to produce **fertiliser** through hydrogen

4.2 Potentials for renewable power and heat (excl. bioenergy)

The **deployment potential** shown in the graphs in this section is the potential on which this study is based. It is the potential which can be realised at any given point in time, given technical barriers and ambitious, yet feasible market growth developments.
The deployment potential does not necessarily represent the most cost-effective development, i.e. it does not account for market barriers or competition with other sources. The **realisable potential** is the fully realisable potential of the resource with a long-term development horizon.

4.2.1 Wind

The Scenario includes power generation from both on-shore and off-shore wind. The growth of on-shore wind power has been remarkable in the last decade, with annual growth rates exceeding 25% in most years. Given the scarcity of land in some regions of the world, increasing attention is given to off-shore wind generation. Several off-shore wind parks are already in operation worldwide and many more are currently in operation and planning phases. [GWEC, 2007; Hoogwijk, 2008; Leutz, 2001; REN21, 2010; WWF, 2008]
The Scenario is based on the assumption that there is potential for a continuing steady growth in wind power over the next two decades with growth levels slowing significantly thereafter.
For off-shore wind, potential annual growth rates of ~30%, for on-shore wind rates nearer 20%, are used.

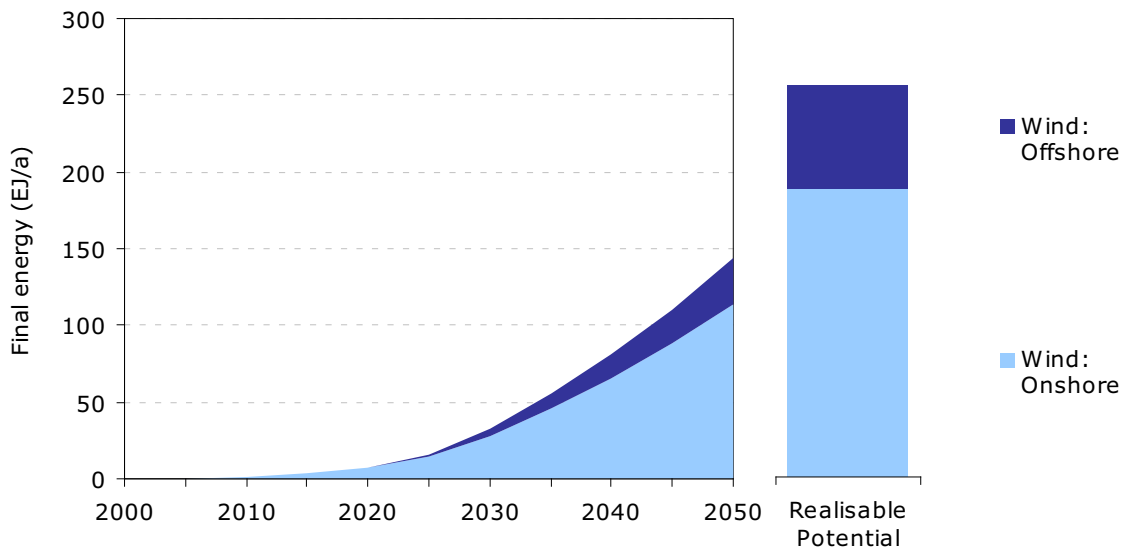


Figure 4 - 3 Global deployment potential of wind power. (Left: Evolution of deployment potential over time, right: Maximum feasible potential)

4.2.2 Water

We group two types of power production under the heading of 'water' power for the purpose of this report: Hydro power and wave and tidal power.
Hydro power is the biggest renewable power source to date, providing almost 15% of worldwide power; over 980 GW installed capacity in 2009. [REN21, 2010]
Although hydro power can be produced sustainably, past projects have suffered from ecological and societal side effects. We have therefore severely restricted future growth of hydro power to reflect the need for an evolution that respects existing ecosystems and human rights. [WWF, 2006; Hoogwijk 2008].

Potentials for wave and tidal power, also called 'ocean power', are less dense than other forms of power, such as wind or solar, but can be heavily concentrated, on windy coastlines such as Great Britain, for example. There are several on-going pilot projects to harness wave energy and to design sustainable tidal systems. The Scenario includes wave and tidal energy, the potential being estimated at around 5% of the potential of off-shore wind, which reflects regional estimates where available. [EOEA, 2010; OES-IA, 2010]

The potential for both, hydro and wave/tidal power sources, is depicted in Figure 4 - 4.

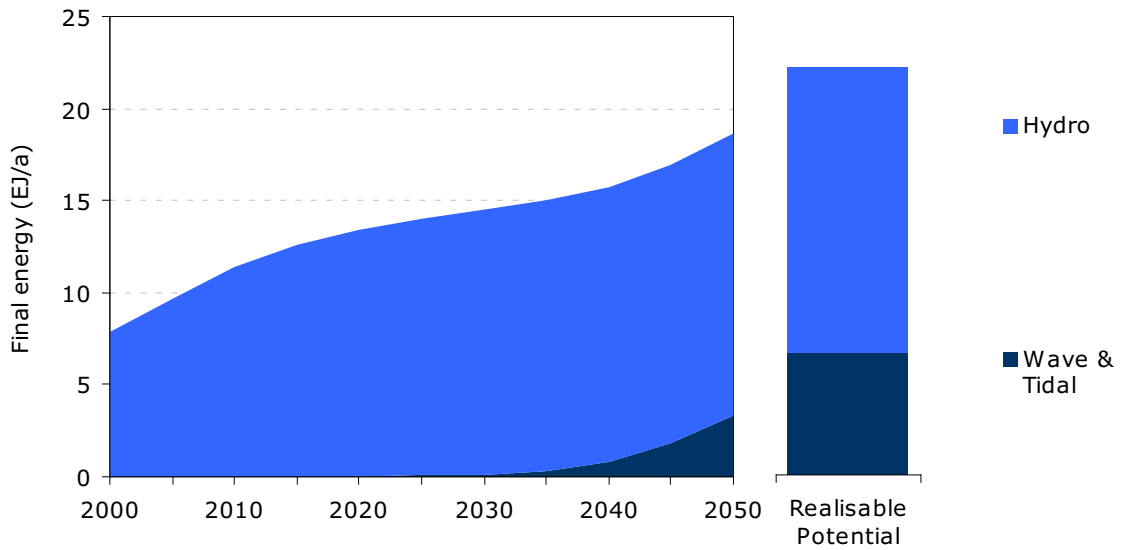


Figure 4 - 4 Global deployment potential of hydro and ocean power. (Left: Evolution of deployment potential over time, right: Maximum feasible potential)

4.2.3 Sun

The largest technical potential and *realisable* technical potential for sustainable power and heat generation is from direct solar energy, particularly in regions with a large amount of direct irradiation.

The Energy Scenario includes four different sources of solar energy:

- Solar power from photovoltaics (PV)
- Concentrating solar power (CSP)
- Concentrating solar high-temperature heat for industry (CSH)
- [Solar thermal low-temperature heat for buildings[26]]

The potential adopted for the first three sources is shown in Figure 4 - 5.

PV is a well-established source of electric energy; around 21 GW of capacity installed worldwide at the end of 2009 [REN21, 2010]. The Scenario contains a potential for PV based on continuing annual growth rates of 25-30%, including outputs from both building-integrated and large area PV installations, for the next two decades. [EPIA, 2009; Hoogwijk, 2008]

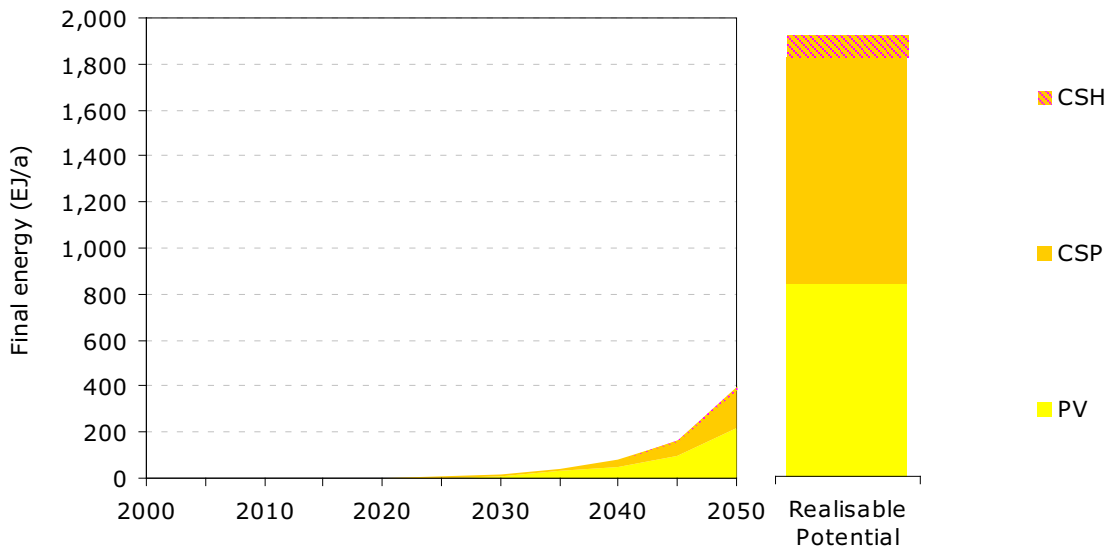


Figure 4 - 5 Global deployment potential of solar power and heat (excl. building solar thermal). (Left: Evolution of deployment potential over time, right: Maximum feasible potential)

[26] Solar thermal heating for buildings is a well-established technology, already in widespread use. In this Scenario however, it is treated on the demand side, with a potential equal to around 10% of current heat demand in buildings. An independent potential graph is therefore not reproduced here.

With increasing storage times, CSP is attracting attention for its potential to provide power on demand, even after dark. Systems with up to 15 hours of storage are now at the design stage. Although still in infancy, the expectations for CSP are large and the Scenario is therefore based upon the assumption that the coming decades will witness a strong penetration of this technology into the market, with possible growth rates of approximately 20%.

CSH, concentrating solar heat, would enable industrial installations to directly utilise the high temperatures generated by concentrated solar farms. This technology is not yet on the market and is therefore only included at a very small potential in this study, at around a tenth of the potential of CSP[27].

4.2.4 Earth

Geothermal energy from the high temperatures found below the earth's surface can be used directly ('direct use') to produce building heat. At sufficiently high temperatures, it can also be used for power generation and/or process heat.
Geothermal energy has been exploited for many years, with around 10GW of power production capacity installed worldwide at the end of 2007. Given the lack of attention given to this option in the past and its enormous potential to supply demand-driven renewable power, the Scenario is based on the premise that the current 5% annual growth rate could potentially be doubled to reach the levels of other renewable power options.
The potential for geothermal energy in the Scenario is shown in Figure 4 - 6.

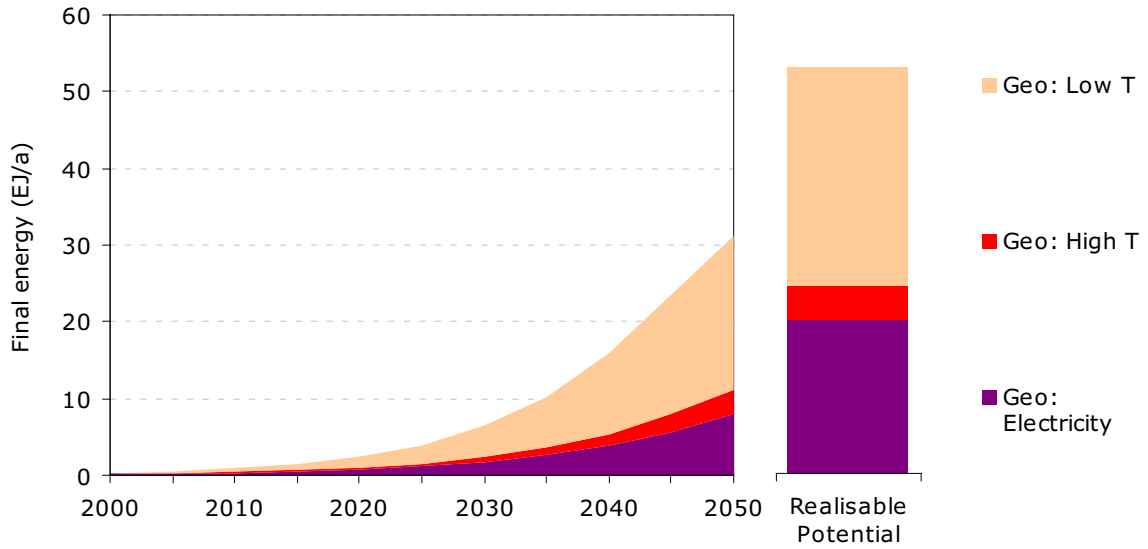


Figure 4 - 6 Global deployment potential of geothermal energy. (Left: Evolution of deployment potential over time, right: Maximum feasible potential)

[27]This is a conservative assumption. Further study on the distribution of the industrial heat demand and the availability of near-by CSH sources is recommended.

Box 4 - 2 Story: The sustainability of renewable energy.

STORY	THE SUSTAINABILITY OF RENEWABLE ENERGY

The Energy Scenario classifies energy from the sun, wind, water and earth as renewable, including biomass. It aims to use these energy sources to displace energy from conventional sources such as coal, oil, gas and nuclear power as these are reliant on fuels which are replenished on a vastly different timescale than that of their use.

However, even renewable energy sources must be carefully assessed regarding sustainability and impact on the local environment. Section 5 is entirely dedicated to the sustainability of bioenergy, but other options also raise concerns that need to be addressed. The key objective is sustainable landscape and infrastructure development planning. If carefully planned within the local context, renewable energy can be beneficial without unacceptable 'side effects'.

4.3 Results – Electricity

One of the key topics on the supply "side" is the evolution of the future power supply system.

As we saw in Section 4.2, there are many different renewable electricity options available, the potential far outstripping even future demand; a renewable energy 'paradise'. The diversity and abundance of different sustainable power supply options is one of the reasons why an effort has already been made on the demand side to electrify demand, through the use of heat pumps in buildings and through ambitious electrification in the transport sector, for example.

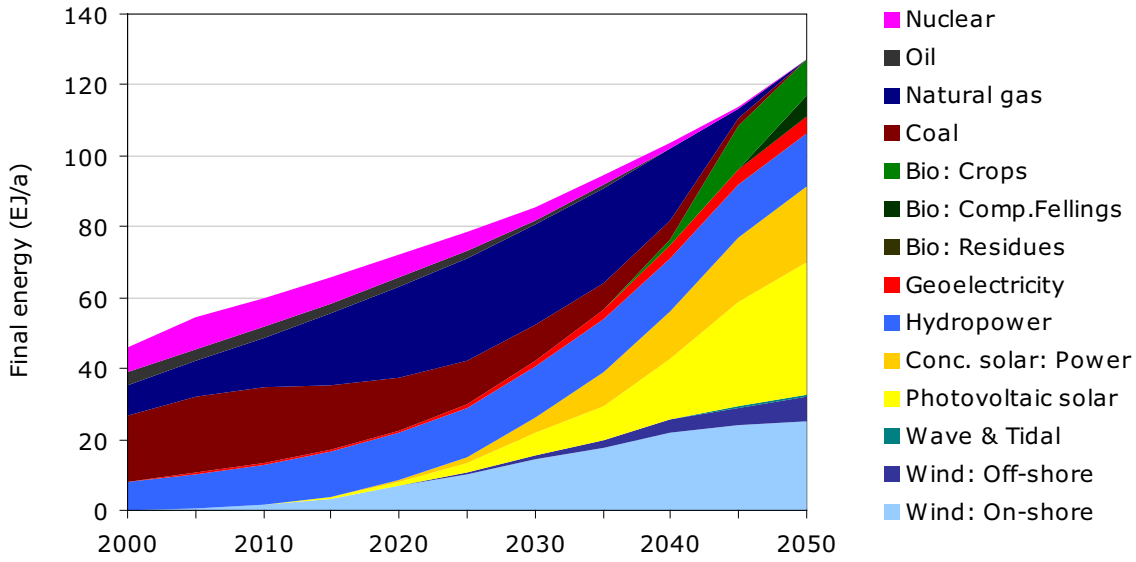


Figure 4 - 7 Global power supply in the Energy Scenario.

Figure 4 - 7 shows how much of the available renewable power is actually used in the Scenario, given the evolution of power demand.

Box 4 - 3 Story: Supply- versus demand-driven electricity sources.

STORY	SUPPLY- VERSUS DEMAND-DRIVEN ELECTRICITY SOURCES

The electricity supply system is rapidly changing. Only a few decades ago, it consisted of large, centrally dispatched fossil or nuclear power plants. Capital-intensive nuclear or coal-fired power plants with low operational costs were employed to cover the 'base load', the level of power always required, even at night. This guaranteed long operating hours, enabling the high investments for these plants to be recovered. Natural gas-fired "peak load" plants, with lower capital investments but higher running costs, were employed to cover the additional load during daytime.

The electricity supply system is becoming an increasingly dynamic marketplace to which many different suppliers can supply varying amounts of energy, and where parts of the demand can even be controlled to arrive at an optimal balance of supply and demand. Most power plants will have a variable output; there is no longer a 'base load'. For instance, a growing amount of wind power is available at practically zero marginal cost during hours of high wind speed, which may sometimes coincide with (night-time) hours of low demand. Even if a former, "base load" power plant finds a customer for its power during such periods, it will not earn back its investment during those hours, due to low power prices (close to marginal cost).

For the Scenario, we discern between 'supply-driven' sources, which deliver power at zero marginal cost when the natural resource (sun, wind, water) is present and 'demand-driven' sources, which can be operated independently at variable levels. With the correct combination of sources, and adequate grid coupling over large geographical areas, it will be possible to reliably provide the required amount of electricity at all times. Increasing the fraction of supply-driven sources, and the electrical 'balancing' provided by the demand-driven sources, create substantial technical challenges and will require a strong R&D effort.

In addition to the careful balancing of demand and supply, there is a further constraint on the power system in this Scenario: The amount of supply-driven[28] power sources is constrained to a ceiling, given in a percentage of total electricity demand, to reflect the fact that a certain amount of balancing, or demand-driven sources are required to ensure continuous supply. See Table 4 - 1 for the classification of sources.

[28] Supply-driven power options are those sources whose generation at any given hour depends on the availability of the energy source, e.g. wind power, photovoltaic power or ocean power. Demand-driven power options are those options which can be more easily tailored to demand, such as geothermal electricity, hydro power, CSP with storage and electricity from biomass.

To equilibrate load patterns, and therefore allow an increasing share of supply-driven power into the grid, electricity grids should be well-connected within a region. Given the current state of electricity grids in most parts of the world, this means a large investment into the construction or expansion of regional grid capacity.
Bottlenecks must be removed to allow unhindered transmission of electricity by

- increasing capacity and
- increasing the range of transmission lines

Beyond 2020 there may also be an additional demand for technologies that can provide greater grid stability. The Scenario works on the premise that R&D expenditure will be focussed on developing such technologies (see also Section 6).

Table 4 - 1 Classification of RES power into supply-driven and demand-driven (balancing) options.

Source	Type[28]
Wind Onshore	Supply-driven
Wind Offshore	Supply-driven
Tidal & Wave	Supply-driven
PV	Supply-driven
CSP	Demand-driven
Geo	Demand-driven
Hydro	Demand-driven[29]
Bioelectricity	Demand-driven

Even assuming that action on preparing power systems is taken immediately, the Scenario accounts for the long lead times (15–25 years) typical for such large infrastructure projects by constraining the solar and wind power share initially and gradually lifting this constraint over time.[30]

Figure 4 - 8 shows the limits the Scenario places on the share of supply-driven electricity that is allowed to be fed into the electricity grid. The premise is that current power systems would be able to take 20–30% of supply-driven electricity without major changes in infrastructure or management systems, see e.g. [Ecofys, 2010].

[29] Hydropower is classed as demand-driven here. However, good environmental practices should include attention to minimum water flows.
[30] Note that no explicit assumptions are made on early retirement of existing coal-fired power plants at the global scale. However, for most regions the additional construction of coal-fired power plants is clearly not compatible with the development pathway set out in this Scenario.

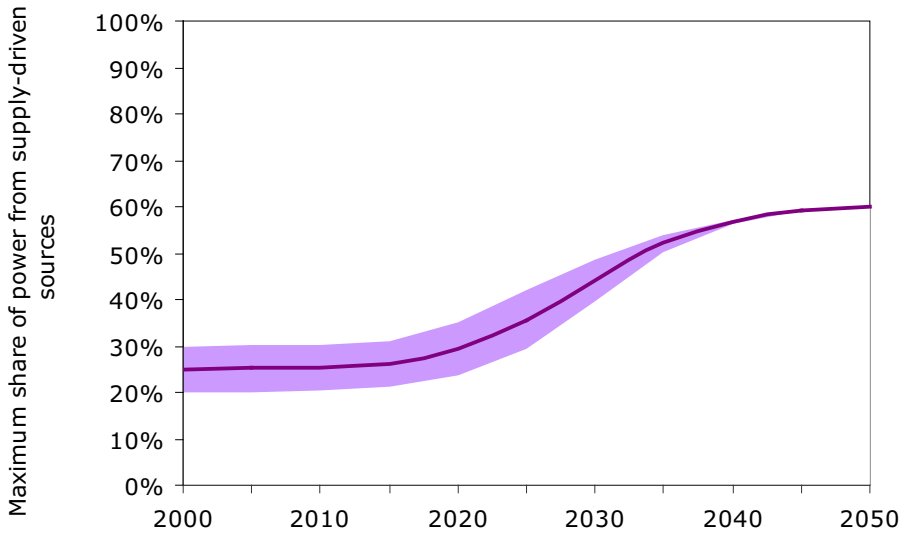


Figure 4 - 8 Constraint placed on PV and wind power due to grid limits. Range represents differences across regions.

For greater penetrations of renewable energy, only limited analysis is available. Based on a number of studies [Blok, 1984; Sørensen, 2004; ECF Roadmap, 2010] we expect that the limiting share could rise to 60% by 2050 for all regions, provided that electricity systems are re-designed to offer much more flexibility than they do today. This requires that full use is being made of **all** the following levers:

- Grid capacity improvements to remove bottlenecks and increase transmission capacities.
- Demand side management, particularly for wholesale customers, but also at individual consumer level
- Storage, in the form of pumped hydro[31], centralised hydrogen storage, and heat storage
- Remaining excesses of renewable electricity can be converted to hydrogen for use as a fuel in specific applications (see Box 4 - 1).

It must be noted here that the Scenario merely places the limits mentioned above, on the energy system, in essence postulating that power systems will be able to evolve in such a way as to allow these assumptions to be valid. To assess exactly how this could

[31] Energy may be stored in hydropower reservoirs, either through balancing of natural inflows with generation-determined outflows, or through pumps that use electricity in off-peak hours to refill the reservoir. All hydropower infrastructure has potentially significant environmental and social impacts. Attention must be paid to downstream flows, as peaking operations can impact on natural habitats and human use of rivers. Through smart choices for locations, designs and operating regimes, such impacts can be avoided, minimised, mitigated or compensated, in accordance with existing internationally agreed sustainability criteria.

be achieved, and which role storage and smart grid systems would play was beyond the scope of this study.

The grid constraint explains why renewable power options are not fully utilised, even though the deployment potential outstrips demand. Figure 4 - 9 shows that large contingencies in the supply-driven power supply sources appear as early as 2030. The reason these potentials are not fully utilised is the grid constraint[32], i.e. the fact that our grids will need time to prepare for the large share of supply-driven electricity sources.

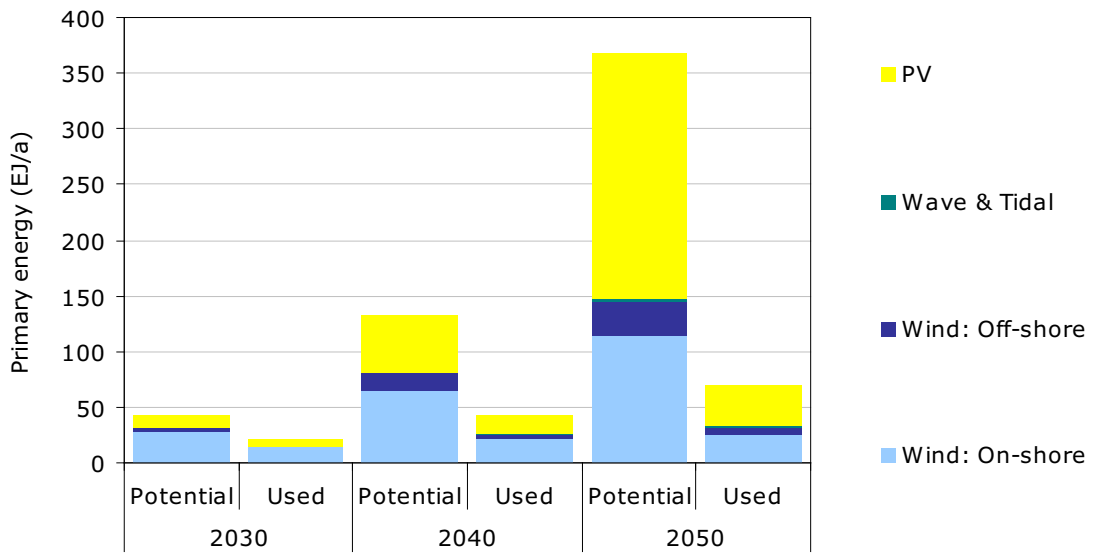


Figure 4 - 9 Global deployment potential vs actual usage of supply-driven power.

Even for demand-driven power supply options, the full potential is not utilised. This may be surprising, since there remains a gap in demand, which is filled by bioenergy. The reason for this is regional differentiation. Figure 4 - 10, for example, shows a large potential for CSP in later years. However, as most of this potential lies in regions with a low electricity demand, it cannot be fully utilised[32].

[32] Note: The Energy Scenario allows sharing of electricity within each of the world's ten regions. Sharing between regions has not been taken into account; in reality, this should be used to further optimise world power supply.

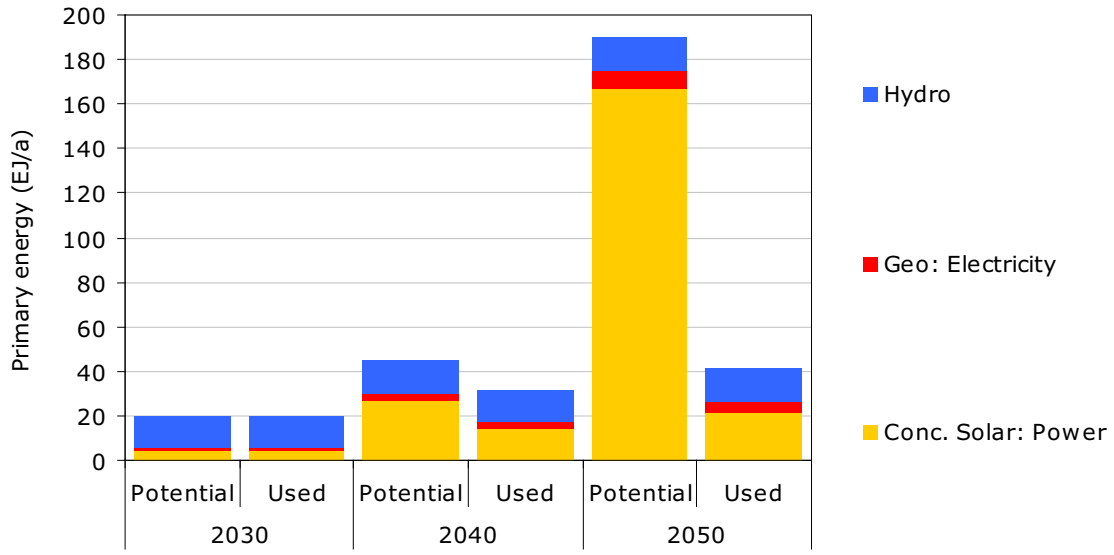


Figure 4 - 10 Global deployment potential vs actual usage of demand-driven (non-bio) power.

4.4 Results – Heat and Fuels for Industry

Given the renewable energy potentials in Section 4.2 (and bioenergy – see Section 5), the following supply picture emerges for heat and fuel demand in the Industry sector (see Figure 3 - 8).

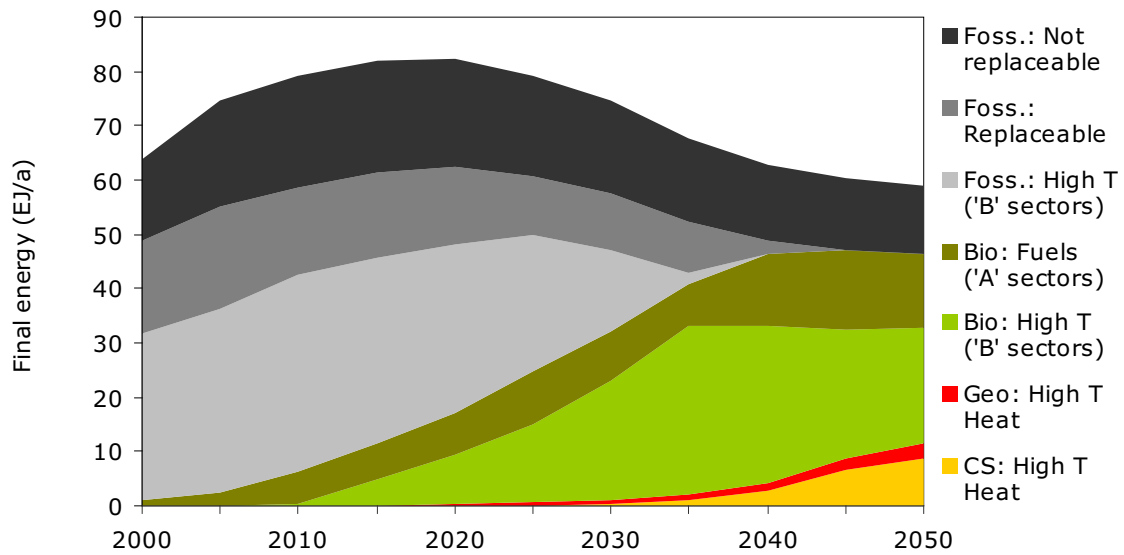


Figure 4 - 11 Split of supply options in the global Industry sector (excluding electricity).

Supply from fossil fuels dominates in the early years. As sustainable bioenergy becomes available, it begins to displace these fuels, thereby expanding beyond its 'traditional' domain of the paper sector. By 2050, bioenergy supplies almost two thirds

of industrial fuel and heat demand after ambitious efficiency measures have been taken.
Direct industrial process heat is partially supplied by geothermal heat and after 2030, by direct concentrating solar heat. A residual fossil fuel demand remains, for industrial processes which rely not only on the energy and carbon content, but also mechanical properties of current fossil fuels, for example.

4.5 Results – Heat for Buildings

Given the renewable energy potentials in Section 4.2 (and bioenergy – see Section 5), the following supply picture emerges for the heat demand in the Buildings sector (see Figure 3 - 8).

Efficiency measures from both, ambitious retrofitting and higher standards for new buildings, result in a rapidly contracting heat demand in the built environment from 2015 onwards. Where heat is still required, for space heating, water heating and cooking, for example, it will be increasingly supplied by geothermal and solar options. The current use of traditional biomass will be phased out and only a small share deemed sustainable, up to 30% of the current amount, will be used in latter decades. In the final years of the Scenario, even this small amount of biomass should no longer be required due to other renewable options and a diminishing demand.[33]

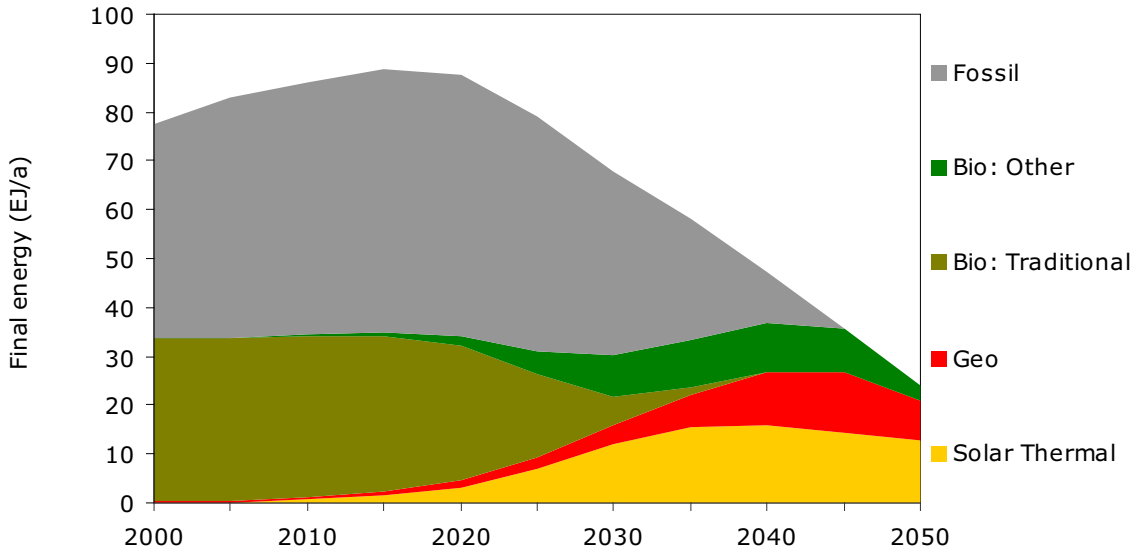


Figure 4 - 12 Split of supply options in the global Buildings sector (excluding electricity).

[33] Note that there may be a share of the ~11 EJ of sustainable, traditional biomass that could be used to supply other bioenergy needs in the final years to 2050. However, as the composition of this traditional biomass use is not exactly known, we have chosen here not to divert it into other bioenergy streams.

4.6 Results – Fuels for Transport

Given the renewable energy potentials in Section 4.2 (and bioenergy – see Section 5), the following supply picture emerges for the fuel demand in the Transport sector (see Figure 3 - 8).

Energy demand will continue to rise for several decades, but growth of this demand will slow due to modal shifts and electrification. Around 2020, overall demand will begin to decrease, falling far below 2000 levels by 2050. The uptake of biofuels for vehicle transport will be accelerated from its current growth with the maturity of many new conversion technologies that provide biofuels for a range of end uses, including aviation fuel. By 2050, all remaining transport fuels will be fully supplied by bioenergy and fossil energy sources will be phased out entirely.

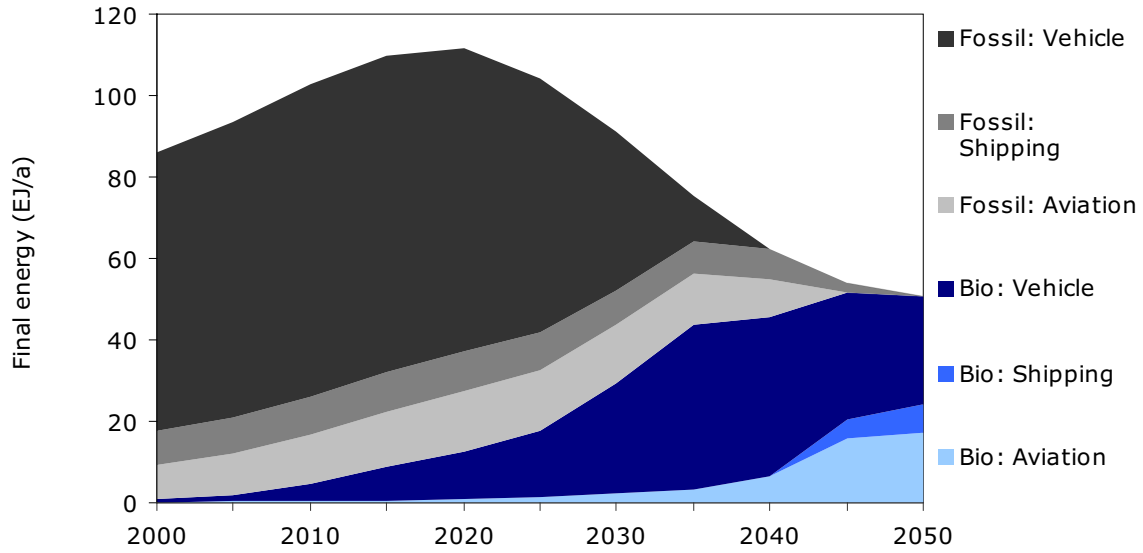


Figure 4 - 13 Split of supply options in the global Transport sector (excluding electricity).

4.7 GHG Emissions

Although the Energy Scenario is focused primarily on the achievement of a sustainable energy system, it may also be of interest to examine the resulting emissions profile for that new energy system. We include below a basic analysis of the emissions that would result from the energy system in the Scenario using standard emission factors for fossil energy carriers and LCA factors from literature and our own analysis for all bioenergy sources. [IPCC, 2006]

Wind, solar, water and earth energy sources are expected to have zero emissions with the exception of hydro power which is attributed an emission factor of ~10 tonnes CO_2 / GWh; a high estimate. [Gagnon, 1997].

Figure 4 - 14 demonstrates the total evolution of energy-related emissions from the Energy Scenario in CO_2-equivalents[34] given the assumptions above. This graph includes lifecycle emissions from the production of bioenergy (see Section 5.9) and hydropower (labelled 'CO_2 Renewables').

In the earlier years, the emissions clearly follow the evolution of energy demand and supply (see Figure 4 - 2). In the later years however, the displacement of emission-intensive supply options by low-and zero-emission options leads to a rapid contraction of overall emissions.

In total, the Energy Scenario would witness approximately ~900 billion tonnes of CO_2–equivalent emissions emitted between 2000 and 2050.

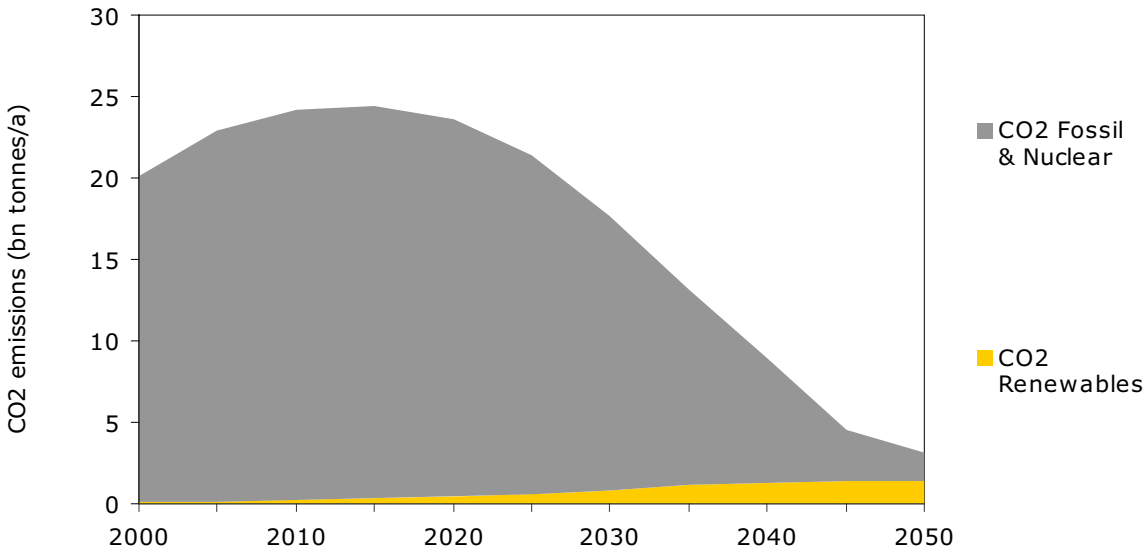


Figure 4 - 14 Global CO2-eq GHG emissions from the energy system in the Scenario.

Overall, the Energy Scenario would lead to a ~80% decrease in energy-related CO_2-equivalent emissions versus 1990 levels by 2050[35,36].

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[34] The emissions shown here are CO_2-equivalent emissions. However, since this concerns emissions from the energy system only, the vast majority of emissions are CO_2. A very small fraction of the emissions come from NO_x and CH_4 which have been converted to CO_2-equivalents for aggregate use here.

[35] These are 'raw' emissions. When correcting for the fact that a larger share of the remaining emissions are emitted by aviation, this reduces to ~70% due to the impact of aviation at higher altitudes.

[36] Emission reductions may be even larger, if the emissions from hydropower could be reduced. The emission factor for hydropower was chosen according to historically observed rates here, however, smaller hydropower options, e.g. run-of-the-river installations, would be expected to have lower emissions.

Carbon capture and storage

The application of carbon capture and storage (CCS) may lead to a further decrease of emissions from industrial and electricity-generating use of fossil fuels and biomass in later years.

However, employing CCS to the majority of emissions in this Scenario is not very attractive, primarily because it is expected to mature too late, by 2025–2030. By the time CCS could then be deployed on a large scale, the use of fossil fuels will have declined so heavily that investments would not be likely to yield the required returns.

In the context of the Scenario, it would therefore be more logical to focus on:

- options to reduce or replace the 5% fossil energy use that remains until and after 2050
- options to reduce the CO_2 emissions from the combustion of biomass
- options to reduce the CO_2 emissions from the industrial use of biomass
- options to reduce the lifecycle CO_2 emissions from the production of biofuels
- CCS systems that start on fossil fuels, but that are suitable for later conversion into BECCS (Bioenergy with CCS).

5 Supply – Sustainable bioenergy

5.1 Summary: Meeting demand with sustainable bioenergy

The Scenario incorporates a significant share of sustainable bioenergy supply to meet the remaining demand after using other renewable energy options. The Scenario only includes bioenergy supply that is sustainable and leads to high greenhouse gas emission savings when compared to fossil references.[37]

Figure 5 - 1 shows that the Scenario is capable of meeting demand with bioenergy within the sustainable potential and simultaneously accomplishing high greenhouse gas emission savings.

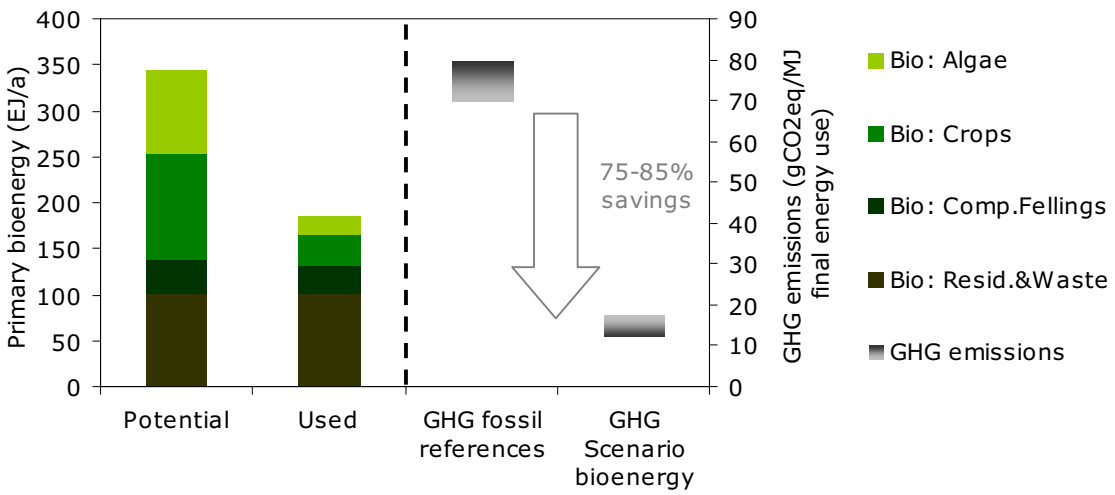


Figure 5 - 1 Overview of the Energy Scenario's sustainable bioenergy use versus sustainable potential and sustainable bioenergy greenhouse gas (GHG) emissions versus fossil references for 2050.

It is important to understand that, compared to other studies [Greenpeace, 2010; Shell, 2008; OECD/IEA, 2009] the Energy Scenario uses a relatively large amount of bioenergy, shown in Figure 5 - 2.

[37] The Scenario's approach to bioenergy sustainability is described in Section 5.2 and detailed further in Sections 5.3 through 5.7. The resulting greenhouse gas emission savings are presented in Section 5.9.

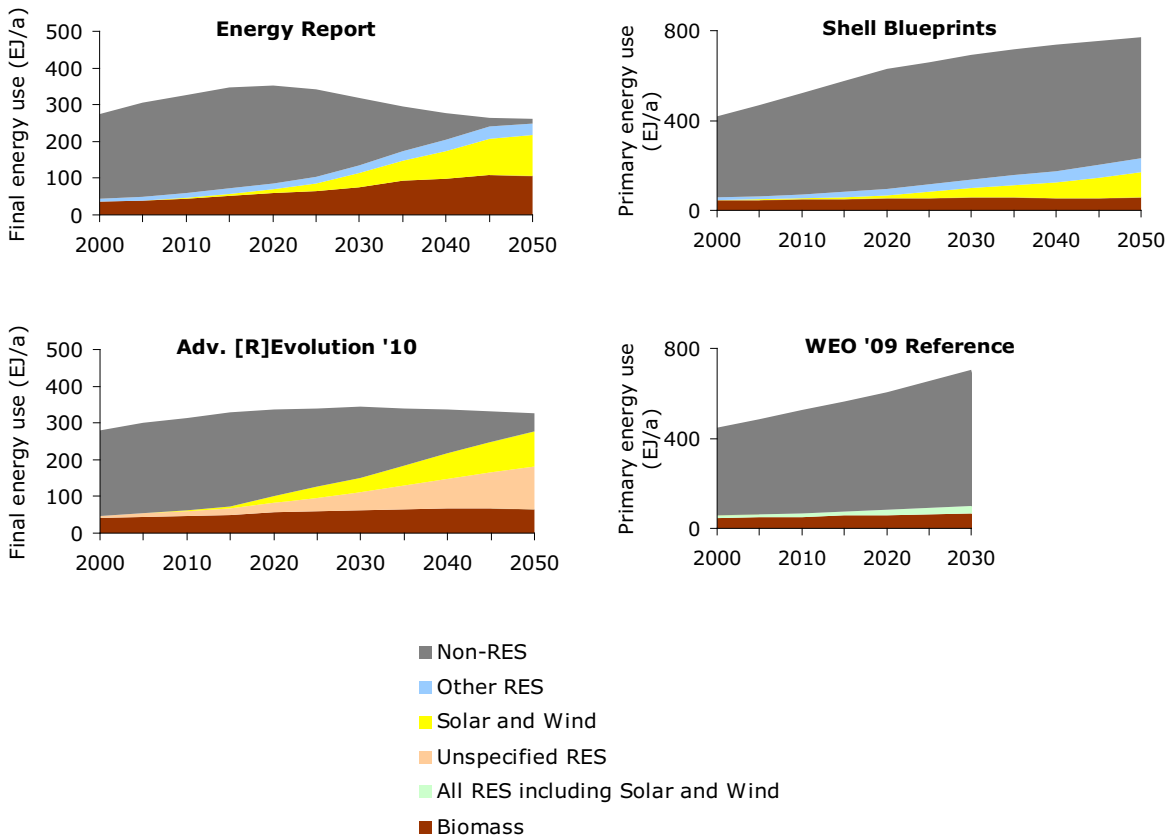


Figure 5 - 2 Overview of shares of renewable energy in the Energy Scenario and other studies. The absolute numbers can not be compared between the two graphs on the left and the two on the right as they are in final and primary energy use, respectively.

The predominant reason for this large bioenergy share is that the Scenario has a significantly higher total renewable energy share in its energy supply than the other studies, reaching 95% in 2050. When trying to achieve such high renewable energy shares, finding a renewable fuel and heat supply is the biggest challenge.

The Scenario's bioenergy is therefore mostly used mainly to provide transport fuel and industrial fuel and heat, i.e. to meet energy demands that can not be met through renewable electricity or other renewable heat applications. Only very small amounts of bioenergy are used for electricity production, where not enough demand-driven capacity exists from other sources (see Figure 5 - 3). As overall demand stabilises during the last ten years of the time horizon, bioenergy use will also stabilise.

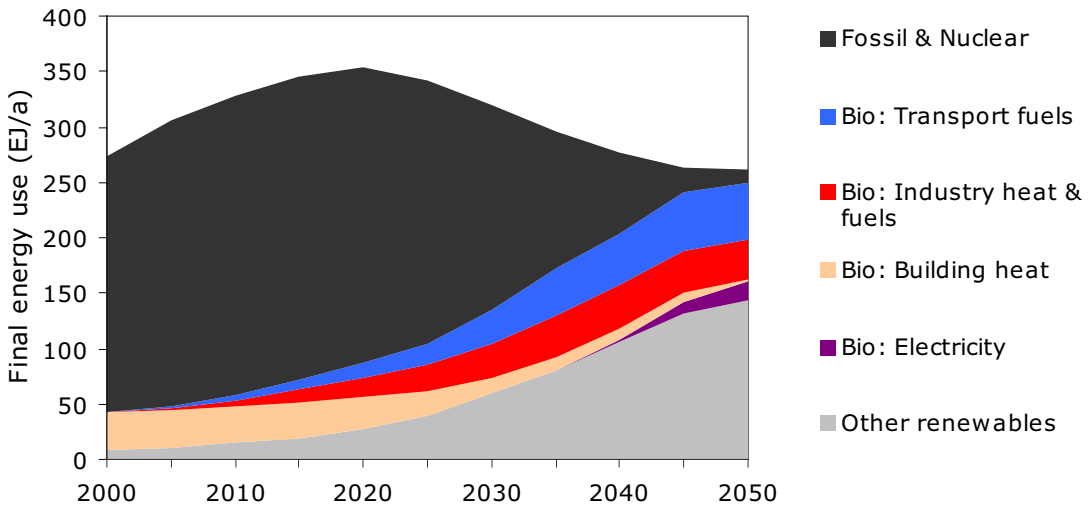


Figure 5 - 3 Global use of bioenergy versus other renewable and non-renewable energy sources.

The main energy demand types covered by bioenergy include:

- ***Transport fuels where energy storage density is often a crucial factor; especially***:
  - Long distance road transport
  - Aviation
  - Shipping

- ***Industrial fuels where electric or solar heating is insufficient; especially***:
  - Applications that require very high temperature
  - Applications that require a specific energy carrier, e.g. a gaseous fuel or solid fuel. One example would be the steel industry where the structural strength of a solid fuel is required.

As these demands can typically only be met through a bioenergy supply option, the amount of bioenergy supply needed in the Scenario is large. This means that in the earlier years of the Scenario's time horizon the full sustainable bioenergy potential is used. However, towards 2050, as with the other renewable energy options in the Scenario, this full bioenergy potential is no longer required and contingency supplies become available, shown in Figure 5 - 1. The contingencies in the crop category mean that not all hectares of the identified sustainable land potential need to be used for energy cropping.

Box 5 - 1 Contingency: Materials from biomass.

CONTINGENCY	MATERIALS FROM BIOMASS

Currently, fossil fuels such as oil (products), natural gas and coal are not used solely to supply energy: these sources are also used as feedstock to produce materials such as plastics. These materials could also be produced using biomass based feedstocks such as wood, biogas and vegetable oils. There could therefore be a competition for biomass between the materials and energy sector.

As the use of material feedstocks occurs outside the energy system, it is beyond of the scope of the Scenario. An exception would be the assessment of the potential for sustainable forestry for bioenergy purposes in Section 5.5. In this assessment, the current and future demand for industrial roundwood, used in the construction sector and the pulp and paper industry, was taken into consideration.

Even though material feedstock use is beyond the scope of the Scenario, we have made an assessment of the extent to which this can influence the energy system. IEA data [IEA balances, 2008] show that in 2006, a total of 490 Mtoe or 21 primary EJ of oil (products), natural gas and coal were used as petrochemical feedstock. This corresponds to 9% of the total use of these fossil fuels. Extrapolating this to 2050 using the Scenario's population growth and GDP growth, results in a 2050 estimate of 66 EJ of material feedstock use. As this estimate does not include potential future gains in material efficiency and recycling, it may be an overestimation.

From Figure 5 - 1, it can be seen that this 66 EJ demand for material feedstocks could be supplied by the sustainable biomass potential in 2050, in addition to the biomass needed for bioenergy purposes. In addition, materials based on biomass can be used in a cascading approach; after the product lifetime they can be used as an energy source, by combustion for example. This approach integrates the use of biomass resources for materials and for energy instead of these uses competing.

5.2 Sustainability of bioenergy: Approach to ensure sustainability

The bioenergy supply must be sourced sustainably and create high greenhouse gas emission savings in order for the Energy Scenario to be sustainable. The Scenario ensures this by its comprehensive conceptual approach to bioenergy sustainability, shown in Figure 5 - 4.
A more detailed description is provided in Sections 5.3 through 5.9.

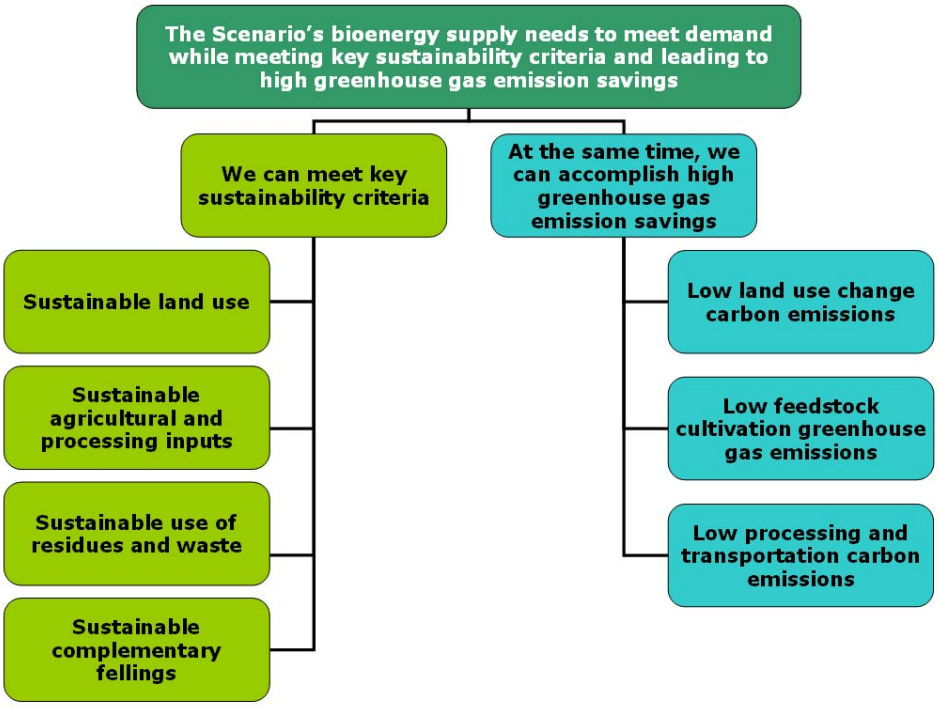


Figure 5 - 4 Conceptual approach to bioenergy sustainability in the Energy Scenario.

From the conceptual view in Figure 5 - 4, we have derived a set of sustainability criteria to assess the sustainable bioenergy potentials from residues, wastes, complementary fellings and energy crops and algae. These criteria are presented in Table 5 - 1.

Table 5 - 1 Sustainability criteria used for bioenergy.

Topic	Subtopic	Criteria applied to ensure sustainability topic is addressed
Land use and food security	Current land use	• Exclusion of conversion of current forested, protected and agricultural cropland
	Agricultural water use	• Exclusion of areas not suitable for rain-fed agriculture
	Biodiversity protection	• Partially contained in current land use criterion • Additional exclusion of land with high biodiversity value
	Human development	• Partially contained in current land use criterion • Additional exclusion of land for human development
	Food security	• Partially contained in current land use criterion • Additional exclusion of land for meeting food demand
Agricultural and processing inputs	Processing water use	• Closed loop for processing water in biofuel production
	Agricultural nutrient use	• N fertiliser production from sustainable energy and feedstock • P and K fertiliser use: closed loop approach
Complementary fellings	Sustainable use of additional forest growth	• Exclusion of protected, inaccessible and undisturbed forest areas • Exclusion of non-commercial species • Exclusion of wood needed for industrial purposes
	Use of sustainable share of traditional biomass	• Exclusion of 70% of the current traditionally used biomass
Residues and waste	Availability of residues	• Exclusion of residues that are not available
	Sustainable waste use	• Additional recycling • Exclusion of waste from non-renewable sources

Box 5 - 2 Case study: Sustainable land use by sugar cane and cattle integration.

CASE STUDY | SUSTAINABLE LAND USE BY SUGAR CANE AND CATTLE INTEGRATION

We need land for different uses: for providing food, fibre, housing and energy and for conserving nature and its biodiversity. As the available amount of land is limited, it is important to accommodate these growing demands in a sustainable way.

One way to sustainably increase the productivity of land is the introduction of mixed crop-livestock agricultural systems. An example of such a system is the integration of sugar cane and cattle [Sparovek, 2007]. This concept is used in the Brazilian region Ribeirão Preto.

Land that was previously only used for extensive cattle farming is now also partially used for growing of sugarcane. This sugarcane is processed into ethanol fuel. The residues originating from this processing are used as supplementary feed for the cattle. Because there is now a source of cattle feed, less pasture land is required to feed the same stock of cattle, freeing up the land for the sugarcane cultivation.

Results show that, using this method, the same land that once supported a certain number of cattle now supports the same number of cattle while also producing ethanol from sugarcane. In addition, the income of local farmers is improved. Animal welfare is not jeopardised because the cattle intensity is still very low.

Together they cover the following sustainability topics reflecting those found on the left hand side of Figure 5 - 4:

- ***Land use and food security (Section 5.3)***: we have excluded land to ensure that biodiversity protection, forest carbon stock protection, human development and food demand are not impaired by bioenergy cropping. In addition, we have included only land suitable for rain-fed agriculture in our bioenergy crop land potential.
- ***Agricultural and processing inputs (Section 5.4)***: we have already restricted bioenergy cropping to land suitable for rain-fed agriculture. This is a significant agricultural input sustainability criterion, as water is one of the main agricultural inputs. In addition, we use a closed water loop approach for the processing of biomass in biofuel plants to ensure sustainable processing water use. Agricultural nutrient inputs are also required to be as low as possible through using precision farming and a closed loop approach where possible. Finally, all nitrogen fertiliser is produced from sustainable energy and feedstocks.
- ***Complementary fellings (Section 5.5)***: we have included only complementary fellings originating from sustainable harvesting of wood. The first source is additional forest growth. To ensure this harvesting is sustainable, only commercial

species in forests that are accessible, unprotected and already disturbed are included. The second source is a share of the current traditional biomass use. To ensure its sustainability, the majority of this traditional biomass is phased out and is not used in the Scenario.

- ***Residues and waste (Section 5.6)***: we have included only residues and wastes that originate from a renewable source. Any residues that are not available, due to competing uses for example, are also not taken into consideration.

All these criteria and their applications in the Scenario are discussed in further detail in Sections 5.3 through 5.6. Section 5.9 discusses how this affects the greenhouse gas emission savings achieved by using bioenergy in the Scenario.

5.3 Sustainability of bioenergy: Land use and food security

The Scenario explicitly prioritises a number of land uses over land use for bioenergy cropping. In addition, the Scenario restricts bioenergy cropping to land suitable for rain-fed cultivation of energy crops in order not to require irrigation[38] as an agricultural input.

Therefore the following land is not used for bioenergy cropping in the Energy Scenario:

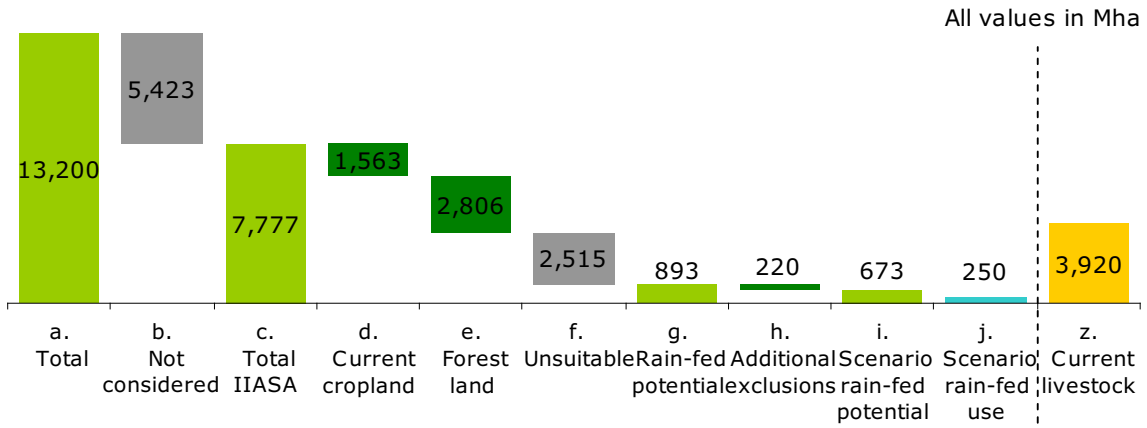
- Land used for supplying food, feed and fibre; taking into account future population growth and a diet change scenario
- Land used for protection of biodiversity and high carbon stock forest ecosystems
- Land used for human development by expanding the built environment
- Land not or marginally suitable for rain-fed cultivation of energy crops

We performed an assessment of land potential for rain-fed cultivation of energy crops based on this land use prioritisation. Figure 5 - 5 shows the results of this assessment. We acknowledge that substantial land use planning (policy) is required to direct land use in the correct manner. This is discussed further in Section 7.2.3.

The assessment was based on data from a recent IIASA study [Fischer, 2009]. Section 2.7 in that that report provides an assessment of production potential for different bioenergy crops. We used the source data of this study and additional Ecofys

[38] We recognise that agricultural water use is a complex issue. On the one hand intensive use of irrigation can lead to (local and regional) fresh water shortage. On the other hand, irrigation is a means to reach the full production potential of the land thereby reducing the need for additional agricultural land. Therefore we have chosen to plan energy cropping on land suitable for rain-fed agriculture. This leads to a satisfactory yield without requiring additional water use. Related practices that increase production, such as temporarily storing rain water to apply it to the land later, can be used in cases where they do not lead to detrimental effects on the (local and regional) ecosystem and water supply.

analyses to perform the assessment for the Energy Scenario using the stepwise approach reflected in Figure 5 - 5 and described in detail in the accompanying text.



a. Total global land mass (excluding Antarctica)
b. Excluded: protected land, barren land, urban areas, water bodies
c. Total land considered in the IIASA study
d. Excluded: current agricultural cropland
e. Excluded: unprotected forested land
f. Excluded: not suitable for rain-fed agriculture
g. Potential for rain-fed agriculture
h. Excluded: additional land for biodiversity protection, human development, food demand
i. Energy Scenario potential for energy crops
j. Energy Scenario: land use for energy crops
z. Current land used to support livestock (for reference only; overlaps with other categories)

Figure 5 - 5 Results of the Energy Scenario assessment of land potential for rain-fed cultivation of energy crops.

1. Starting point: the total global land mass except Antarctica of 13,200 Mha.
2. Exclusion of all current protected land, barren land, urban land and inland water bodies as they cannot be used for agriculture. According to the IIASA data, this totals 5,423 Mha.
3. Exclusion of current agricultural cropland to safeguard current food production. According to the IIASA data, this totals 1,563 Mha. See also Figure 5 - 8.
4. Exclusion of conversion of all current unprotected forested land to protect forest biodiversity and forest carbon stocks. According to the IIASA data, this totals 2,806 Mha. See also Figure 5 - 8.
5. Exclusion of all land that is not or marginally suitable for rain-fed agriculture to ensure only rain-fed bioenergy cropping. According to the IIASA data, this totals 2,515 Mha. See also Figure 5 - 9.
6. Exclusion of additional land for future requirements for biodiversity protection, human development and food demand. This was done based on Ecofys literature analyses discussed in more detail in Figure 5 - 10 through Figure 5 - 13. This totals 220 Mha.

Based on this assessment, we calculated a total sustainable land potential of 673 Mha for the Energy Scenario's rain-fed cultivation of energy crops. The details of this assessment are explained further in Sections 5.3.1 through 5.3.5.

The assessed potential is located on grassland and non-densely vegetated woodland. Most land of these types is currently used as low-intensity grazing lands for livestock. It can be made available for other purposes through a combination of limiting future demand for livestock products and intensifying livestock systems with a very low current intensity. This is described in greater detail in section 5.3.5 and Box 5 - 4. In addition, Box 5 - 4 provides background on the total amount of land currently used to support livestock of about 3,920 Mha[39].

The 673 Mha potential was used as a potential for the Energy Scenario. However, the Scenario does not use this full land potential. The maximum land use for bioenergy cropping in the Scenario is 250 Mha in 2050 as shown in Figure 5 - 5.

Both values, the 673 Mha of available land and the 250 Mha actually used for bioenergy cropping, are heavily influenced by the assumptions made in the construction of this Scenario. For example, the available land depends on the evolution of food demand and agricultural productivity (see Section 5.3). The actual land used for bioenergy cropping depends on many assumptions, most notably so in the Transport sector (see also Appendix D).

[39] Number is given for comparison only.

Box 5 - 3 Story: Land use in the Energy Scenario.

STORY	LAND USE IN THE ENERGY SCENARIO

Full land mass worldwide, excluding Antarctica, encompasses about 13,200 Mha (132 million km^2). The status or function of this land is commonly referred to as the "land use". There are many types of land use. Some of them describe active land use by humans, such as land used for agriculture, and land used for human development such as urban areas and transport infrastructure. Other land uses reflect the natural state of the land, such as forested area or grass- and woodland.

The Scenario incorporates a land use analysis based on seven different land uses. In this analysis, presented in this Section 5.3 and its subsections, we calculate the effects of population growth, diet changes, bioenergy use and biodiversity protection on global land use, among others. Figure 5 - 6 shows the land use in the current situation and the Scenario in 2050.

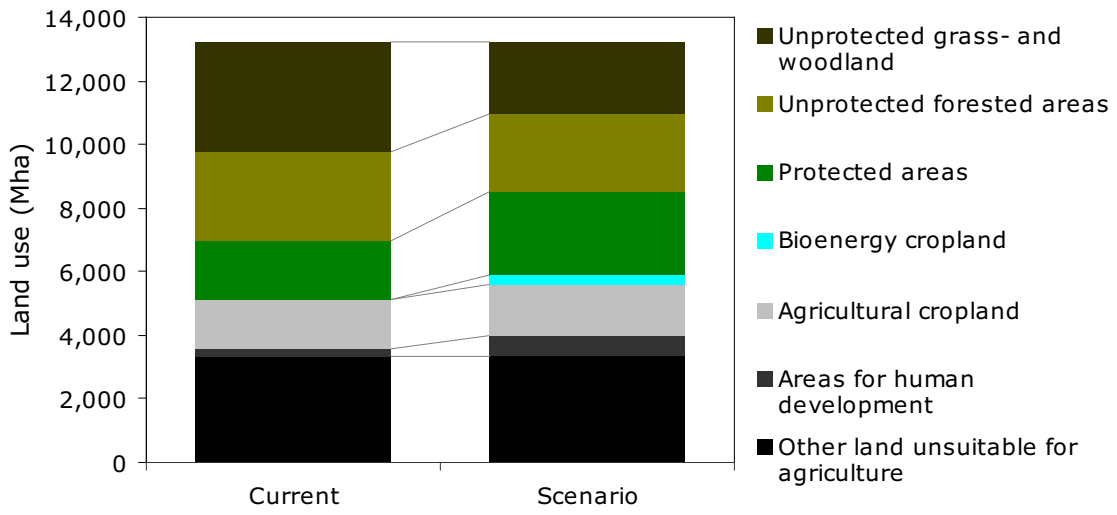


Figure 5 - 6 Land use of the global land mass excluding Antarctica (total: 13,200 Mha) in the current situation and in the Energy Scenario in 2050. The bioenergy cropland value of 250 Mha is the maximum land use for bioenergy crops in the Scenario.

From Figure 5 - 6, it is apparent that there is an increase in bioenergy cropland that is relatively large compared to the current situation but small in comparison to the total land use. A significant amount of currently unprotected area, both forest and grass- and woodland, is also placed under protection. More details on all land use types are provided in this section and subsections. We acknowledge that substantial land use planning (policy) is required to direct land use in the correct manner. This is discussed further in Section 7.2.3.

5.3.1 Current land uses

We excluded land from the Energy Scenario that currently has a land use making agriculture of energy crops not possible or not acceptable. These were the following land uses:

Not possible

1. Barren land
2. Urban areas
3. Inland water bodies

Not acceptable

4. Protected land
5. Forested land
6. Agricultural cropland

The first four land uses in the above list were pre-excluded in the IIASA source study, reducing the assessed land as shown in Figure 5 - 7.

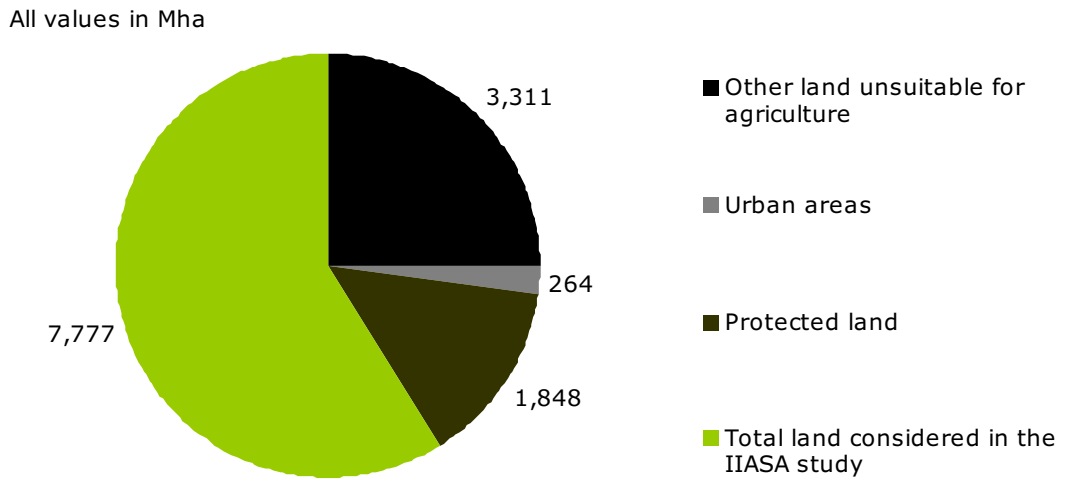


Figure 5 - 7 Pre-excluded land uses in the IIASA study. Other land unsuitable for agriculture includes barren land and inland water bodies.

We then further excluded the conversion of current forested land and agricultural cropland to safeguard current forest biodiversity and carbon stocks and current food production[40]. Figure 5 - 8 shows the results of these exclusions.

[40] Additional biodiversity and food security safeguarding were done in a later step, see Sections 5.3.3 and 5.3.5.

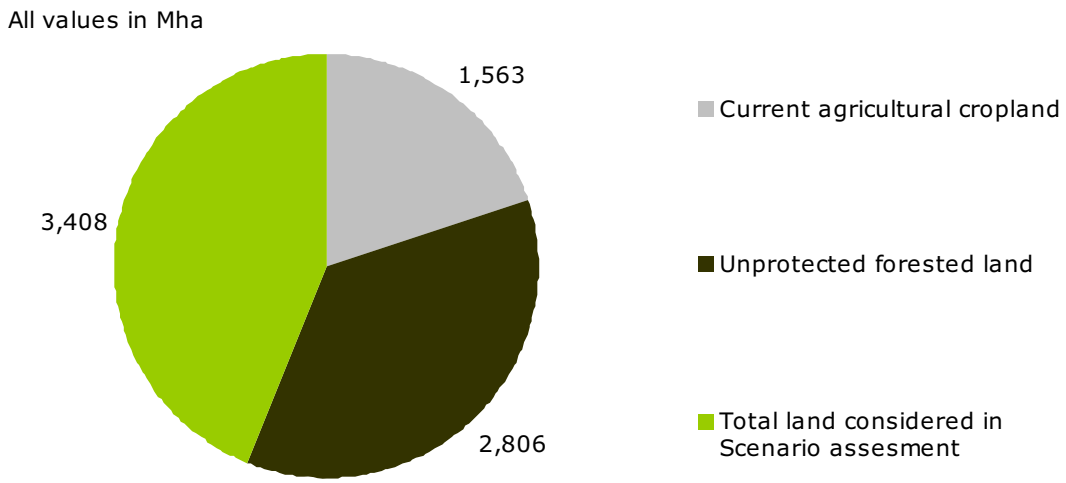


Figure 5 - 8 Land exclusions in the Scenario based on current land use for agricultural cropland or as unprotected forested land.

In total, 3,408 Mha of the initial 13,200 Mha remained after these exclusions of current land uses.

5.3.2 Suitability of land for rain-fed agriculture

We also ensured that no unsustainable water input would be necessary for energy crop cultivation. Therefore, we excluded all land that was found to be either not suitable or only marginally suitable for rain-fed agriculture in the IIASA study. Figure 5 - 9 shows the results of this step.

In total, 893 Mha of the initial 3,408 Mha remained after these exclusions.

5.3.3 Biodiversity protection

The German Advisory Council on Global Change (WBGU) performed a study on the conservation of the biosphere [WBGU, 1999]. One of the conclusions of this work was that between 10–20% of the world land mass should be protected to preserve the different functions of the biosphere, such as climate regulation, and its biodiversity.

The most recent statistics provided by the World Database on Protected Areas state that 14% of the land mass is currently protected. [WDPA, 2009]

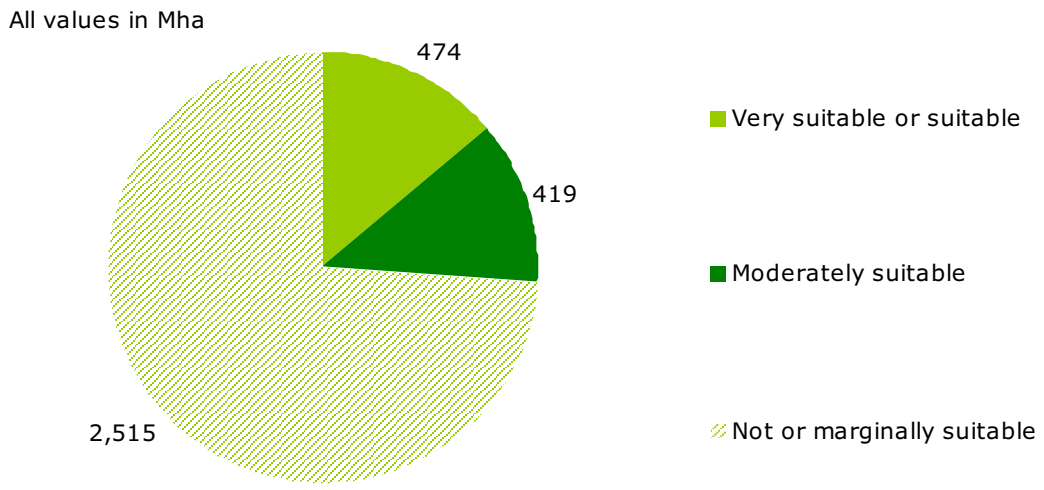


Figure 5 - 9 Land exclusions in the Scenario based on suitability for rain-fed agriculture.

Therefore, to be at the upper limit of the range put forward by the WBGU, an additional 6% of the global land mass should be protected. Although it is not known where this 6% is located, we assume in our calculations that meeting this requirement will also reduce the land potential for rain-fed cultivation of energy crops by 6%. This reduction is additional to the exclusion of protected land based on IIASA data as presented in Section 5.3.1. The reduction totals 54 Mha and is shown in Figure 5 - 10.

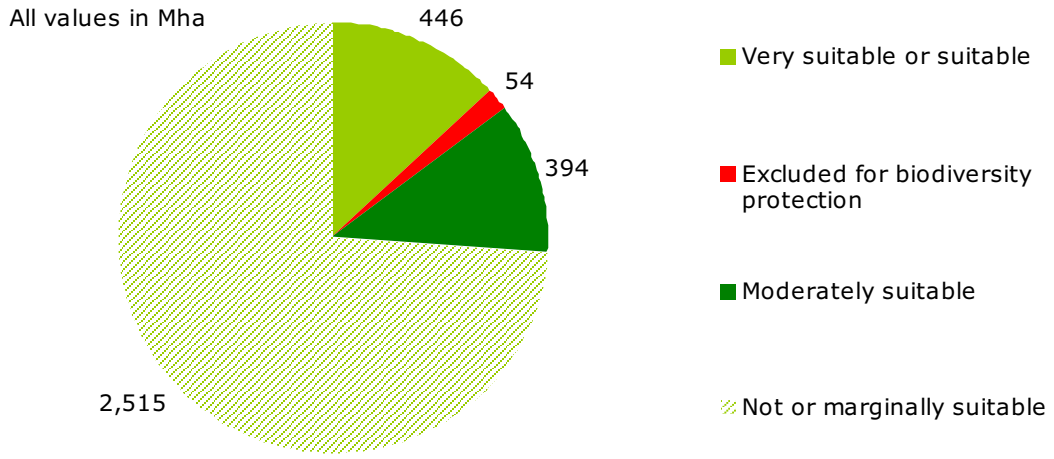


Figure 5 - 10 Land exclusions in the Scenario based on biodiversity protection.

5.3.4 Human development

Hoogwijk performed a study on potentials of renewable energy sources, including an assessment of the increase in land use for the built environment [Hoogwijk, 2004]. Current land use for the built environment was estimated to be 2% of the total global land mass excluding Antarctica. United Nations projections estimate this land use to be 4% in 2030 [UNEP, 2002].

We therefore assume that land use for the built environment will increase from the current 2% to 4% in 2030. We extrapolated this figure, using the population growth numbers used throughout the Energy Scenario, to a 5% land use in 2050. The growth from current to 2050 land use for the built environment therefore requires excluding 3% of global land mass, excluding Antarctica, for this purpose.
Next, we have assumed that all of this expansion will take place on unprotected grass- and woodland because expansion into other land types is either not possible, not acceptable or much less likely. 3% of the global land mass, excluding Antarctica, amounts to 12% of the unprotected grass and woodland. We have therefore reduced the land potential for rain-fed cultivation of energy crops by 12% for human development.

This reduction is additional to the exclusion of urban areas based on IIASA data presented in Section 5.3.1. The reduction totals 104 Mha, shown in Figure 5 - 11.

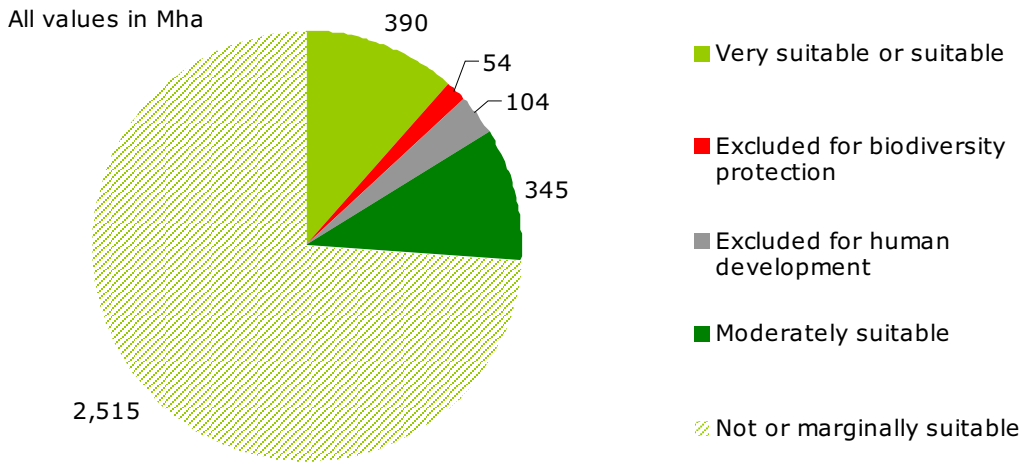


Figure 5 - 11 Land exclusions in the Scenario based on human development.

5.3.5 Food demand

The need for agricultural cropland to meet future food demand is a highly debated issue. We took a pragmatic approach to assess whether or not the current agricultural cropland is able to sustain future food demand growth. The premise of our approach

was the assumption that, in 2005, food supply equalled food demand[41]; both were indexed at 100%. We then forecast their evolution to 2050 as follows:

We extrapolated the ***growth in food demand*** using the following stepwise approach:

1. We started with current per capita calorie values [FAOSTAT, 2010b] of ~2,400 plant kilocalories per capita and 350 and 950 animal product kilocalories in non-OECD and OECD regions, respectively[42]. Animal product calories were converted into crop equivalents with conversion factors based on the crop feed intake necessary to produce them. The basis for these factors[43] were feed intakes of ~17 (meat) , ~2.4 (eggs) and ~1.7 (dairy) kg of feed per kg of produced animal product.
2. We calculated a "business-as-usual" (BAU) per capita diet in the period 2005–2050 differentiated between OECD and non-OECD countries. This was done based on existing diet projections [FAO, 2006].
3. We then assumed that total animal product consumption worldwide will be constrained to a growth of no more than ~65% between 2005 and 2050, which means that the average animal product consumption per capita (in crop equivalents) increases by about 10% over the same timeframe, given population projections.[44]

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[41] This means that we do not make assumptions on changes of food distribution patterns when forecasting future demand and supply. It does not mean that current food distribution patterns should be maintained. There clearly is an imbalance in food distribution globally currently, but this topic was not part of this study.

[42] Of which ~210 (non-OECD) and ~480 (OECD) calories are meat products, and the rest are dairy, eggs, fish etc.

[43] For meat, this factor was derived from literature values for feed efficiencies per animal type [Smeets, 2008] and current distribution of consumption of meat per animal type [FAO, 2006], which is a mixed diet of bovine, ovine, pig and poultry products. For eggs, literature values from [Blonk, 2008] were used. For dairy, literature values from [Smeets, 2008; Pimentel, 2003; Linn, 2006] were used. The feed is assumed to have an energy content of 19 MJ/kg of dry matter. [Smeets, 2008]

[44] This can be achieved in the following diet scenario, which should only be considered as an example:

- The diet has the same meat (and egg) intensity in both OECD and non-OECD countries by 2050.
- This diet means a ~50% reduction in meat consumption (constant in egg consumption) in 2050 compared to 2005 in OECD countries and an ~25% growth in meat consumption (60% in egg consumption) in non-OECD countries.
- Dairy product consumption is held constant in OECD regions and more than doubled in non-OECD regions to reach ~50% of the OECD per-capita intensity in 2050.
- The overall daily per capita food intake in this meat-constrained diet is about 2,800 kilocalories per capita per day in non-OECD regions and 3,000 in OECD

4 We then multiplied the constrained per capita diets with Scenario population growth numbers to get a total growth in food demand in crop equivalents. This was indexed against 2005 and is presented in the yellow line in the graph in Figure 5 - 12.

We extrapolated the growth in ***food supplied by the current agricultural cropland*** by using a yield increase of 1% per year. This value is an intermediate value in a range of yield increase projections of 0.4 to 1.5% found in literature [FAO, 2009; FAO, 2006; PBL, 2009; IIASTD, 2009; Erb, 2009]. The impact of climate change on yield projections was not explicitly considered in this analysis. However, by choosing the intermediate value of yield increase projections we have tried to be moderate in our assumptions.

This yield increase was applied to the indexed value in 2005 of 100% and is represented by the blue line of the graph in Figure 5 - 12. For reference, Figure 5 - 12 also contains the indexed yield development of coarse grains over the last 50 years, which has been higher than the 1% assumed in the Energy Scenario.

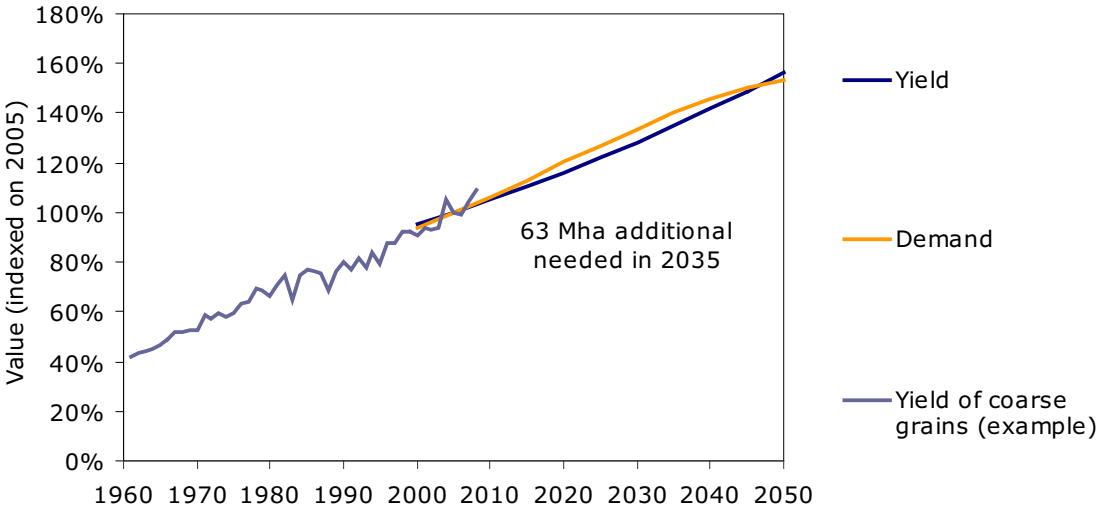

Figure 5 - 12 Calculation of land exclusions in the Scenario based on global food security.

From the graph in Figure 5 - 12 it can be observed that, under our Scenario's assumptions the current agricultural cropland is projected to be able to supply the entire food demand for 2050. However, in intermediate years this is not always the case. We have calculated that the maximum shortage of food from current agricultural cropland occurs in 2035 and amounts to about 4% of current agricultural cropland. This totals 63 Mha.

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regions. This means an ~10% decrease in 2050 compared to 2005 in OECD countries and a ~10% growth in non-OECD countries.

Box 5 - 4 Story: The role of livestock feeding in global land use

STORY	THE ROLE OF LIVESTOCK FEEDING IN GLOBAL LAND USE

Land use for the feeding of livestock is a large contributor to total global land use. Because exact numbers are difficult to obtain, we have made an estimation using literature data on:

1. Agricultural cropland used for growing animal feed crops. [IIASA, 2009] estimates that 33% of the current 1,563 Mha of agricultural cropland are used for growing animal feed crops. This equates to 520 Mha.
2. Land used as permanent meadow or pasture. According to [FAOSTAT, 2010a] data this land use was around 3,400 Mha in recent years.

This means that about 3,920 Mha of the 13,200 Mha or 30% of the global land mass, excluding Antarctica, is used for supporting livestock.

This shows that there is a large potential for additional land availability for other purposes when the claim of livestock feeding on land use is reduced. The Scenario includes two routes for reducing this claim:

1. ***Reducing the demand for livestock products, most importantly, meat.*** This is done by constraining meat consumption, creating a more sustainable diet. This could be achieved through a ~50% reduction in per-capita meat consumption in 2050, compared to 2005 in OECD countries. Stipulating a diet with the same meat intensity for non-OECD countries, this implies a ~25% growth in meat consumption in 2050 compared to 2005 in non-OECD countries. More details on these diet assumption can be found in Section 5.3.5.
2. ***Intensifying very low intensity livestock systems.*** As estimated above, about 3,400 Mha of land is in use as permanent meadow or pasture. These livestock systems often have a very low intensity; less than one to a few heads of cattle per hectare. These systems can be intensified sustainably, e.g. by integrating them with crop cultivation, without jeopardising animal welfare. In this way, the same amount of land can not only yield the original amount of livestock products, but also additional products such as food crops or bioenergy crops. The example of sugar cane and cattle integration is given in Box 5 - 2.

By using these two levers, the Scenario has a sustainable view on production and consumption of livestock products, leading to a sustainable land use presented in Box 5 - 3.

Box 5 - 5 Contingency: Modelling the future demand for, and supply of, food.

CONTINGENCY	MODELLING THE FUTURE DEMAND FOR AND SUPPLY OF FOOD

Food is the most important agricultural product in the world. This is reflected by the fact that practically all agricultural production is directed at feeding the world's population directly, or indirectly by feeding livestock that supplies animal products. Other agricultural products, such as fibres for clothing, biomass for energy generation and tobacco production, make up a very small share of the total current agricultural production.

This means that modelling the food demand and supply and the balance between them, is important for all agricultural and land use analyses, including the Scenario's bioenergy potential analysis. This is a complex task for the following reasons:

- Demand: future food demand depends on the size of the world's population and the composition of its diet. This diet, in turn, depends on parameters such as wealth and cultural choice. Particularly important is the intensity of animal products in that diet, as these require a large amount of animal feed.
- Supply: future food supply depends on the area available for food cultivation and the food yield per area unit. The development of this yield is hard to predict over longer timescales because it depends on numerous factors such as R&D results, technology adoption, education and sustainability requirements.
- Balance of demand and supply: the balance between food supply and demand is poorly understood. It is often argued that the current food supply is adequate for the entire global demand, but that distribution problems lead to food shortages in parts of the world[45].

The land available for bioenergy cropping in the Energy Scenario is strongly dependent on the assumptions made in the food analysis. Where possible, we have used conservative assumptions, with one notable exception, that we have included a constraint on the consumption of meat, creating a more sustainable diet, see Section 5.3.5.

[45] The Energy Report does not make explicit assumptions on changes in the food distribution system. This means that in terms of the calculations here, we assume that food supply and demand are in balance now and will remain in balance in the future. Balance means that there is no shortage of food production at the global level for which we would need to 'set aside' additional land and that there is no overuse of cropland at the global level which could be taken out of food production without affecting supply. This does not mean that local shortages or oversupplies do not exist, but merely that the Scenario makes no assumption on these patterns changing in one way or another in the future. Reducing waste in the food and agricultural sector may improve the situation; this was not in the scope of this study but additional research into this issue would be valuable.

CONTINGENCY	MODELLING THE FUTURE DEMAND FOR AND SUPPLY OF FOOD

Table 5 - 2 shows that any changes in these factors can have large effects on the need for additional cropland for food. The examples in the table show how the changes can result in a slight or sharp increase or a sharp decrease of the current agricultural cropland.

Similarly, the effect of demand on the actual land **used** in the Scenario (rather than the land potential shown here) can be affected by changes on the demand side. This is briefly discussed in Appendix D.

Table 5 - 2 Additional need for cropland for food: Effect of different assumptions for food supply and demand and their balance.

Parameter	Example change compared to value used in the Energy Scenario	Cropland for bioenergy	
		Available	Used
Scenario results	**-**	***673***	***250***
Supply: Annual yield increase	0.4–1.5% instead of 1%[46]	300–1,080	-
Demand: Meat consumption	25–75% instead of ~50% reduction in meat consumption[47]	350–1,270	-
Balance of demand and supply	Supply is 90–110% of demand in 2005 instead of being equal	500–800	-

Although the identified 63 Mha is the largest amount of additional land needed for meeting food demand in any given year to 2050, we choose to exclude it from the potential over the entire period in the Scenario. This reduction is additional to the exclusion of current agricultural cropland based on IIASA data as presented in Section 5.3.1. The reduction is visualised in Figure 5 - 13.

[46] See Section 5.3.5 for more information on Scenario assumptions on this topic.

[47] See Section 5.3.5 and Box 5 - 4 for more information on Scenario assumptions on this topic.

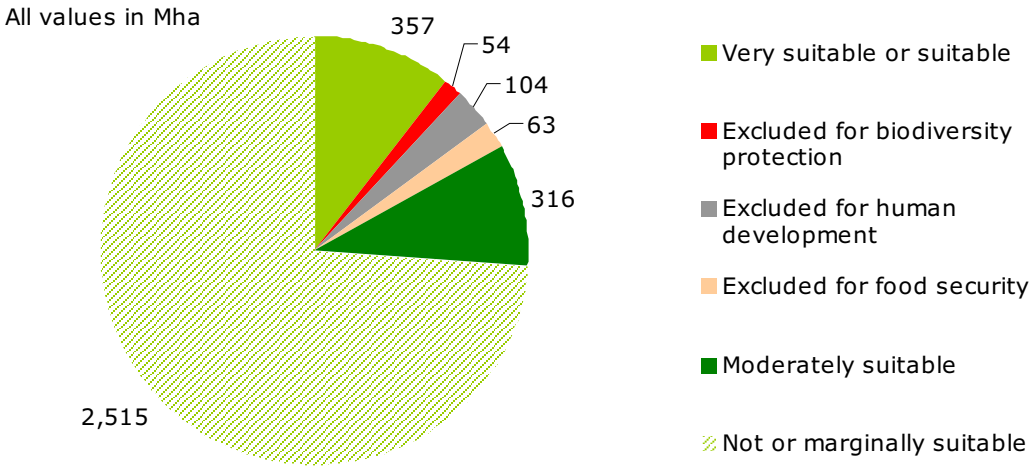


Figure 5 - 13 Land exclusions in the Scenario based on food security.

5.4 Sustainability of bioenergy: Agricultural and processing inputs

To guarantee sustainable agriculture and processing of energy crops, we included a sustainable framework for the inputs required for them.

Processing water use

We assessed, from literature, expert opinions and our previous experience, that a closed loop approach for biofuel processing water is currently commercially available. This means that biofuel plants can discharge as much clean water as their total water intake and therefore do not need to be detrimental to the normal water supply. Technology supplier Dedini [Dedini, 2008] claims that the plants that it builds intake non-potable river water and discharge potable water. If this is confirmed, these plants could serve as water purification plants.

Agricultural water use

The yield projections for energy crops in the Scenario are based on rain-fed agricultural systems where nutrients are added to the land.

Regarding agricultural water use, this means that no irrigation[38] is used for the Scenario's energy crops. Energy crop yields are scaled in accordance with the land's suitability for rain-fed agriculture (see also Appendix C 2) to reflect this. This means that most of the Scenario's yields are at around 50–70% of the maximum yield currently obtained in high input agricultural systems. These yield numbers are presented in Appendix C 2.

Box 5 - 6 Story: Water use for bioenergy in the Energy Scenario.

STORY	WATER USE FOR BIOENERGY IN THE ENERGY SCENARIO

Water, particularly freshwater, is an important resource for the human population. We use it for nutritional purposes, as drinking water, as an agricultural resource and for other purposes such as cleaning, recreation and transport. Water is also an essential factor in the preservation of nature and its biodiversity. Water should therefore be used sustainably throughout the Energy Scenario. The Scenario accomplishes this sustainable water use by incorporating:

- ***Closed loops in processing water for bioenergy***: bioenergy processing plants discharge water at the same or a higher purity level as they take it in. See Section 5.4 for more information.
- ***Rain-fed cultivation of bioenergy crops***: bioenergy crops are not irrigated in the Energy Scenario. They take the necessary water from natural rainfall. See Section 5.4 for more information.
- ***Seawater or brackish water cultivation of algae***: algae oil used for producing biofuels for transport is obtained from algae cultivated in seawater or brackish water instead of freshwater. See Section 5.7 for more information.

Agricultural nutrient use

Regarding agricultural nutrient use, the Energy Scenario includes a framework for the most commonly used nutrients, based on nitrogen, phosphorus, and potassium. This framework aims to minimise the need for the addition of nutrients and produces nitrogen based nutrients from sustainable sources.

- All fertilisers: nitrogen (N), phosphorus (P), potassium (K): closed loop approach can be adopted as far as possible to minimise need for fertiliser.
  - Precision farming minimising need for N, P and K inputs
  - Minimising N, P and K losses to the environment
  - Recycling N, P and K from residue and waste streams, by returning digestate to the land, for example.
- Nitrogen (N) fertiliser
  - N fertiliser is produced with sustainable heat in the Scenario
  - N fertiliser hydrogen feedstock is produced from renewable electricity in the Scenario

Therefore, to ensure the most sustainable nutrient use possible, we included in the demand side of the Scenario model:

- All heat energy input required to produce N fertiliser for bioenergy cropping
- All electricity required to produce hydrogen for N fertiliser for bioenergy cropping. This mechanism can also be used as storage for supply-driven renewable electricity sources

As nitrogen from air is the only other necessary component for the current method of N fertiliser production[48], N fertiliser production for bioenergy cropping is fully sustainable as long as the required electricity is extracted from sustainable sources as it is in the Energy Scenario.

In addition, we advise a closed loop approach for nutrients as much as possible by using precision farming techniques, minimising nutrient losses and recycling nutrients from residue and waste streams. The trend in this direction has already begun in agriculture in developed countries due to economic or policy considerations on nutrient application, for example.

Precision farming aims to adjust nutrient application to the exact need of the crop. Nutrient losses can be minimised by improved application methods where nutrients are applied in such a way that they are less susceptible to runoff. Nutrient recycling can be achieved by returning nutrient-rich residues and waste to agricultural land. This can include nutrient recovery from returning digestate from wet waste (e.g. manure) digestion to the land as a fertiliser, as the nutrients are preserved during the digesting step, see Section 5.6. Another example would be nutrient recovery from human sewage streams. We acknowledge that the necessary technologies and practices for such a closed approach need to be further refined and more widely adopted before it can be optimised.

5.5 Sustainability of bioenergy: Complementary fellings

Wood from forests is harvested for different purposes, such as construction, paper production or energy production. We have analysed the sustainable potential for the harvesting of woody biomass from forests for energy purposes in the Energy Scenario, taking into consideration the demand for wood for other purposes. These sustainable complementary fellings consist of two components which are discussed here.

[48] In current N fertiliser production, natural gas reacts gas with air at high temperatures and pressures to produce ammonia which is further processed into N fertilizer. As the natural gas is both a source for heat as for hydrogen, we have replaced this with sustainable heat and hydrogen in our Scenario.

Box 5 - 7 Story: Forests in the Energy Scenario.

STORY	FORESTS IN THE ENERGY SCENARIO

Forests are important in a sustainable global ecosystem. They take up CO_2 and store it in the form of biomass and release oxygen. In addition, forests host an integral part of the world's biodiversity. Therefore, we do not allow any expansion of cropland into currently forested area in the Scenario, for neither food nor bioenergy. In fact, we increase the world's protected land areas by about 50%. For more details, please refer to Box 5 - 3.

Vegetation in the forests grows by taking up CO_2 and the energy from sunlight. A share of this growth can be harvested to provide woody biomass for purposes such as construction and energy. This should be implemented in a sustainable way. The biomass potential from forestry that is included in the Scenario comes from sustainable sources, namely:

- Sustainable complementary fellings consisting of two subcategories:
  - Complementary fellings from areas where there is remaining sustainable forestry potential after satisfying other demand for industrial roundwood, for construction and the production of paper for example.
  - Sustainable use of traditional biomass: there is currently a traditional biomass use for primary energy supply in many areas, especially rural areas in developing countries. The Scenario phases out this traditional use of biomass towards 2050 as it becomes increasingly replaced by other supply options such as solar thermal options. We estimate that, as a global average, a 30% share[49] of the freed potential currently used as traditional biomass can be harvested in a sustainable manner. This 30% share therefore remains included as sustainable biomass in the Scenario supply to meet demand for low temperature building heat, as it does today. The other 70% of the current traditional biomass is not considered sustainable use and is phased out in the Scenario.
- Sustainable wood processing and logging residues and wood waste: residues from sustainable forestry and wood processing for non-bioenergy applications, e.g. sawdust from timber mills, and waste wood material.

Sections 5.5 and 5.6 provide further detail on sustainable complementary fellings and on wood residues and waste, respectively. A schematic overview is provided in Appendix E.

[49] We recognise that the size of this share is an estimation and that it may vary due to local conditions. Therefore the sustainable use of biomass previously used as traditional biomass should be adapted to the local situation. In addition, least sustainable uses should be phased out first.

5.5.1 Additional forest growth

Sustainable additional forest growth is defined here as growth that is currently not harvested and that:

- is not needed for future growth in demand for industrial roundwood, (e.g. for construction or paper production)
- can be harvested in an ecologically sound way.

The Scenario's potential for sustainable additional forest growth was primarily based on a study by Smeets [Smeets, 2008], with some modifications as described below.

According to the study, the world's **technical potential** for additional forest growth would be ~64 EJ of woody biomass in 2050. However, the **ecologically constrained potential** is found to be ~8 EJ. The reason for this discrepancy is the exclusion of all protected, inaccessible and undisturbed areas[50] from the ecological potential. This means that only areas of forest classified as 'disturbed and currently available for wood supply' are included.
A further sustainability safeguard is the use of only commercial species in the gross annual increment, rather than all available species[51].

Because the calculations by Smeets are partially based on an older source [FAO, 1998], an additional calculation was done for a selection of six countries (Brazil, Russia, Latvia, Poland, Argentina and Canada). This was considered necessary because in some of these countries, the area of 'disturbed' forest could have considerably changed in the time period from 1998 until today.
In the additional calculation, the amount of sustainable complementary fellings resulting from the additional disturbed forest area available for wood supply, compared to the original base data, was determined, based on more recent country reports for the Global Forest Assessment 2010 (with data ranging from 2004–2008) [FAO, 2010]. This resulted in additional potential, particularly for Russia and Canada. The main differences were caused by the updated statistics on disturbed forest available for wood supply. The additional potential for the six countries was included in the ecological potential by Smeets, resulting in a total global potential for sustainable additional forest growth of ~27 EJ.

[50] Safeguarding also those areas used for conservation of soil, slopes and watershed.
[51] The potential is determined by the gross annual increment (i.e. forest growth in a year per area), the forest area considered and the demand for wood products. Since the value for the gross annual increment for commercial species is based on the country average, whereas in the forest areas under consideration the share of commercial species will be relatively high, the potential is likely to be underestimated here, providing a 'buffer' for safeguarding sustainable harvesting practices.

Several factors have contributed to this relatively large additional potential:
The most significant of these factors are :

- the updated statistics on the use of forests compared to data from period 1986–1995 (also with increased reliability)
- the relatively large changes in forest sectors in countries like Russia and Brazil (development of forestry sectors, better overview of functions of forest areas and improved accessibility)
- the more detailed set of categories and definitions in the statistics as currently indicated by FAO.

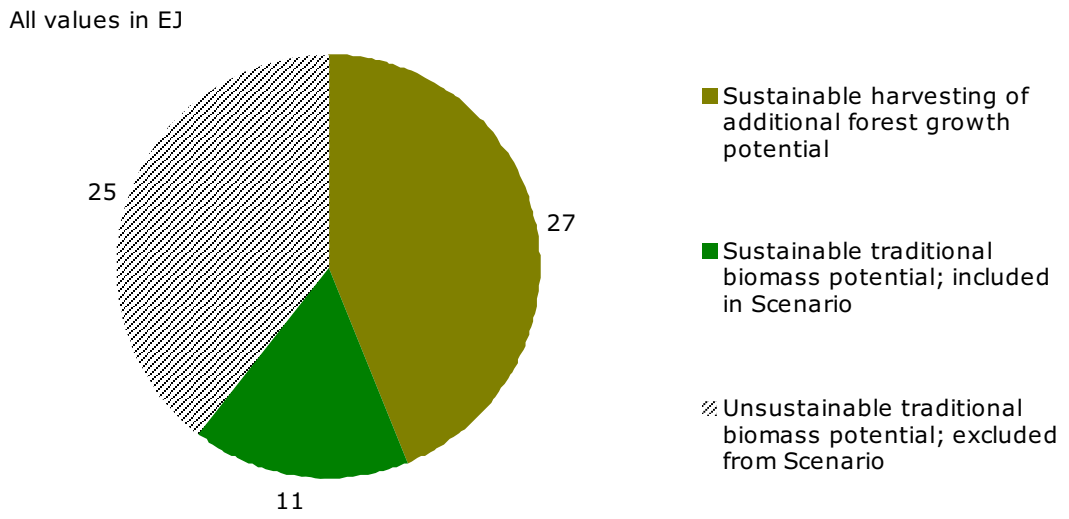


Figure 5 - 14 In- and exclusions for the complementary fellings category based on sustainable harvesting of additional forest growth and sustainable use of traditional biomass.

5.5.2 Sustainable share of traditional biomass use

Grouped in the category of 'Complementary fellings (incl. traditional use)' the sustainable share of current use of biomass for traditional uses also appears, primarily for domestic heat production. We work upon the assumption that the majority of this use is woody biomass[52], though other sources clearly contribute.
The Energy Scenario works on the assumption that any traditional use of biomass that is considered unsustainable today will be gradually phased out and replaced with more sustainable approaches such as solar thermal options.

[52] No detailed data on the composition of traditional biomass use was available. We have therefore opted not to allow it to feed into any other supply routes than heat use in the residential building sector. However, in reality, a share of it may be suitable for lignocellulosic conversion routes.

No literature data was available on the sustainable share of current traditional biomass use. Therefore, as the Scenario gradually phases out traditional biomass use, we have estimated that 30% of the phased out biomass can be harvested sustainably. This amounts to approximately 11 EJ worldwide potential for this category. Note that in the later years of the Scenario, this potential is not completely used, as heat demand in buildings decreases substantially and other renewable options take over.

In total we have included 38 EJ of woody biomass in the complementary fellings category as shown in Figure 5 - 14.

5.6 Sustainability of bioenergy: Use of residues and waste

We performed a literature study on residues and waste for the categories[53] shown in Figure 5 - 15. The full list of sources used can be found in Appendix G 5.

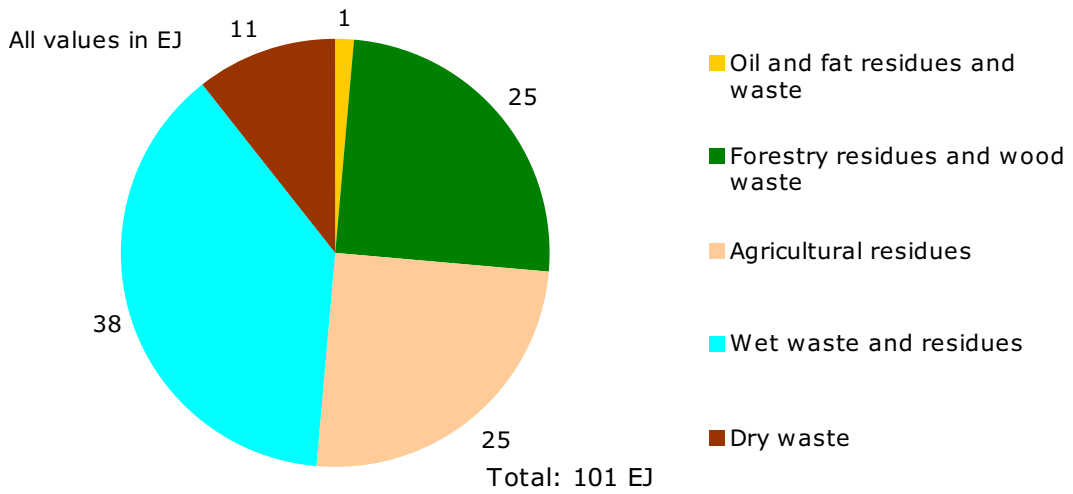


Figure 5 - 15 Sustainable residues and waste potential found in the Energy Scenario for 2050 in five categories. [54]

After obtaining the literature values for the potential of each residue and waste class, we performed three additional analyses to arrive at the final residue and waste potential figures:

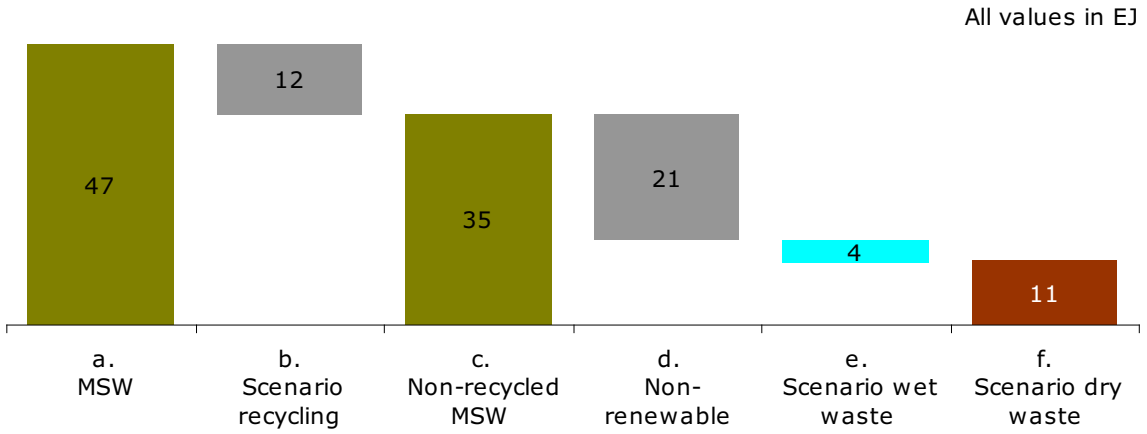
[53] Human sewage is not included as an energy source in the Energy Report as literature on this potential is very limited, so no conclusive data could be gathered. In any case, it is very likely that human sewage would only be a very minor contributor to the overall residue and waste potential [EEA, 2006]. Of course, the Scenario still supports the concept of energy generation from human sewage both in developed and less developed countries. However, for the above reasons, it is not quantitatively included in the Scenario's energy supply.

[54] Individual values can sum to a different total due to rounding differences.

1. We adapted literature projections for 2050 for manure and waste animal fat potential to reflect the meat consumption level in the Scenario in Section 5.3.5.
2. We altered the dry waste potential from municipal solid waste (MSW) to reflect the fact that not all MSW is renewable and that some MSW is wet and some is dry, see Figure 5 - 16:
    a. From the global potential of 47 EJ we estimated, based on literature, that 25% could be recycled, (e.g. paper). This is in addition to the recycling that takes place after pre-sorting at the source, such as recycling of paper collected in separate bins in households or at packaging companies.
    b. From the remaining potential of 35 EJ we estimated, based on literature, that 60% is non-renewable, e.g. plastics.
    c. From the remaining potential of 15 EJ we estimated, based on literature, that 75% is dry waste and 25% is wet waste.
3. We changed the availability share (also referred to as recoverable fraction, RF) of some of the categories because they were inconsistent with other Scenario principles[55]. As an example, the RF used for straw in OECD countries is presented and explained in Figure 5 - 17. The recoverable fractions we used in our analyses are detailed in the table in Appendix C 1.

Wood processing residues and wood waste were based directly on [Smeets, 2008], which already considers the competing uses for these residues and wastes from other industries (for example paper & panel board industries). The study initially calculates the ecologically sound potential of these residues and then subtracts all demand, including the competing uses, within a trade-based model[56].

[55] An example would be the return of digestate to the land as fertiliser, which we included for the digestate of residues of e.g. sugar beet and cassava. Because of this, residues that are normally left on the land for nutrient recycling, can instead be taken off the land, digested and returned to the land providing the same nutrient recycling.
[56] It may be considered preferable to substract demand for specific streams from the potential and thus keep close links between streams and their specific uses. [Smeets, 2008] takes a slightly different approach in order to investigate geographical splits and trade impacts. This is consistent with a long-term view on trade flows of intermediate products.



a. Global mixed MSW after pre-sorting recycling options
b. Excluded: additional recycling in Scenario
c. Non-recycled mixed MSW
d. Excluded: non-renewable waste
e. Energy Scenario wet waste from mixed MSW
f. Energy Scenario dry waste from mixed MSW

Figure 5 - 16 Additional analysis for renewable municipal solid waste potential.

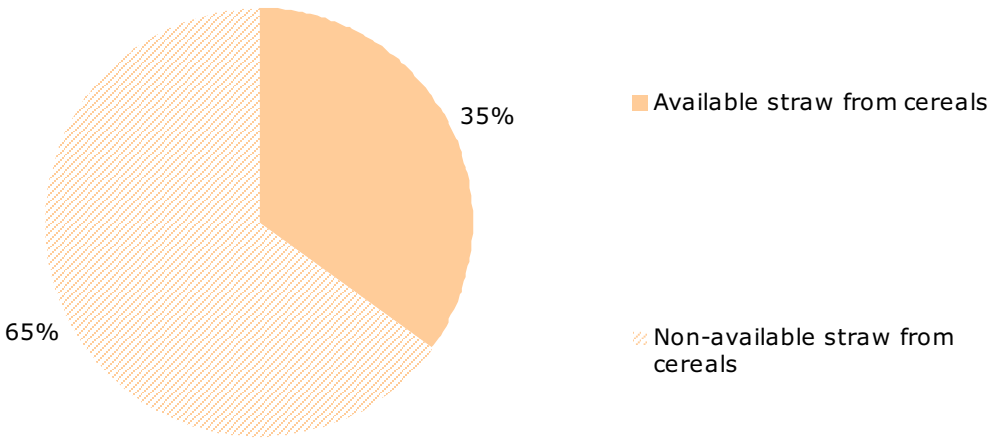


Figure 5 - 17 Recoverable fraction of straw from cereals in OECD countries. Only 35% of the straw is available for energy purposes due to competing use as soil fertiliser, animal feed or animal bedding and because of collection barriers.

The resulting residues and waste categories are listed below. Their origin[57] in the biomass chain is denoted with a letter between brackets: primary (P), secondary (S) and/or tertiary (T):

- Oils and fats – 1 EJ (S, T):
  - Animal fat
  - Used cooking oil
- Forestry residues and wood waste – 25 EJ (P, S, T):
  - Logging residues – ~5 EJ
  - Wood processing residues ~10 EJ
  - Wood waste – ~10 EJ
- Agricultural residues – 25 EJ (P, S):
  - Cereals
  - Rapeseed
  - Coffee
  - Soy
- Wet waste and residues – 38 EJ (S, T):
  - Sugar beet processing residues
  - Potato processing residues
  - Manure
  - Oil palm empty fruit bunches
  - Palm oil mill effluent
  - Sugar cane
  - Cassava
  - Wet municipal solid waste
- Dry waste – 11 EJ (T):
  - Dry municipal solid waste

5.7 Sustainable algae

The Energy Scenario uses algae oil to supply remaining demands in oil routes after the use of residues, waste and bioenergy crops[58]. Because commercial-scale algae growing and harvesting is currently still in development, the Scenario only includes significant algae use from 2030 onwards. The approach to using algae in the Scenario is based on a recent Ecofys study [Ecofys, 2008] on the worldwide potential of aquatic biomass. This study identified a number of different long-term feasible potentials for aquatic biomass. The total long-term energy potential in this study, including macroalgae cultivation at open sea that requires substantial technology development,

[57] Primary residues are related to biomass production (e.g. straw), secondary residues to biomass processing (e.g. sawdust) and tertiary residues to product use (e.g. manure). Tertiary residues, especially when they no longer have an economic value, are often called waste. See also Appendix F.

[58] As not all land identified in the sustainable bioenergy cropland potential is suitable for growing oil crops, algae are needed even though the cropland potential is not fully used.

is approximately 6,000 EJ. The most conservative scenario only contains algae oil from microalgae grown in open ponds on non-arable land filled with salt water. The total potential for algae oil from this technology was estimated at 90 EJ of oil.

The cultivation of algae in the Energy Scenario takes place in a framework that optimises the beneficial properties of microalgae, while remaining within the boundaries set by the land-based algae cultivation scenario from the study. In this framework the bioenergy sustainability criteria set forward by the Scenario are respected. The framework consists of the following elements:

- Microalgae are cultivated on non-arable land that does not accommodate significant carbon stocks
    - Agricultural fertilisation consists primarily of nitrogen and CO_2 fertiliser
    - The cultivation takes place in salt water
- Oil is extracted from the algae and fed to a biofuel processing plant
- Cultivation energy inputs consist of electricity for pumping and oil extraction etc…
- Optional: The remaining algae biomass can be refined to collect high value components, e.g. proteins. It may be possible to produce animal feed products from the protein fracture, potentially reducing the need for growing animal feed crops.
- The biomass residues of oil extraction can be digested, either directly or after the optional refining step. The produced biogas is combusted to produce electricity and heat. The electricity production covers the cultivation energy inputs.
- The digestate of the digestion step and the CO_2 obtained from the biogas combustion are fed back to algae to close the nutrient cycle. For nitrogen nutrients we aim to close 75% of the cycle.
- The cycle of algae cultivation recommences.

This cycle is shown schematically in Figure 5 - 18.

The maximum amount of algae oil used in the Scenario is 21 EJ of oil in 2050. Based on the yields calculated in the Ecofys study, this amounts to approximately 30 Mha use of non-arable land. The 21 EJ oil use is about 25% of the 90 EJ algae oil potential identified in the most conservative scenario containing only algae oil from microalgae grown in open ponds on non-arable land filled with salt water. Therefore, the algae oil use in the Scenario fits comfortably within the potential identified in the Ecofys study, especially as further potential from algae cultivation in open water may be tapped due to future technological progress.

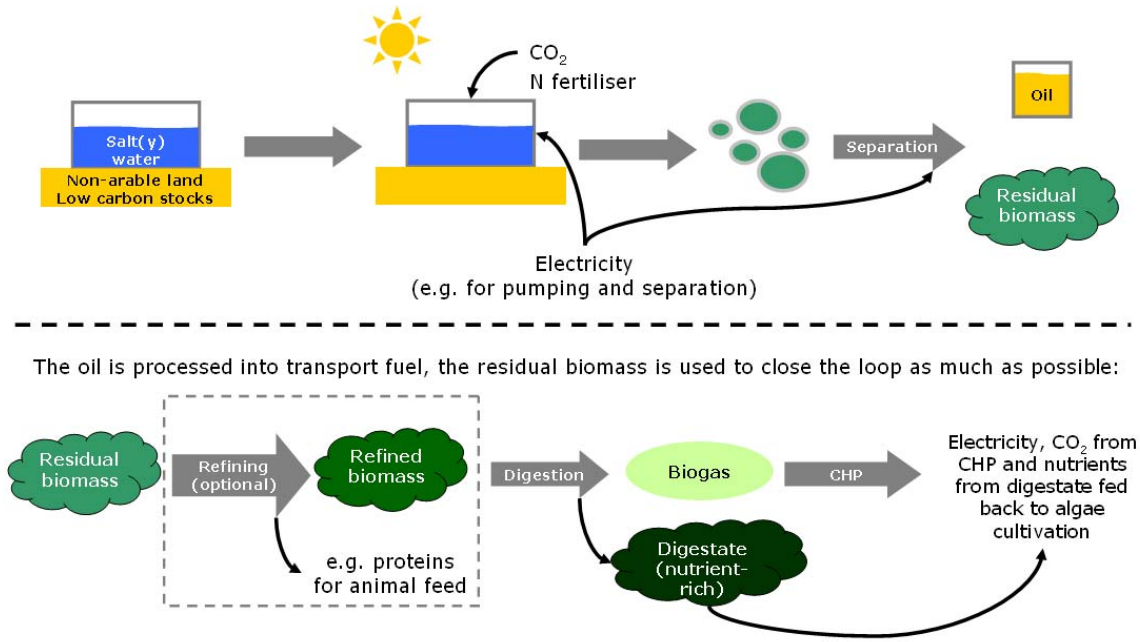


Figure 5 - 18 Schematic representation of algae cultivation cycle.

Box 5 - 8 Case study: Microalgae as an energy source

CASE STUDY	MICROALGAE AS AN ENERGY SOURCE

Microalgae are small organisms, typically with a size in the micrometer range, that live in aqueous environments. Like plants, they capture CO_2 and sunlight through photosynthesis. This makes them an important food source for other aquatic species. Microalgae are part of the large family of algae which also include macroalgae such as seaweeds.

Microalgae grow quickly and can synthesise valuable components such as proteins, fats and oils, and antioxidants. Therefore algae are commercially cultivated for high added value nutritional additives such as omega-3 fatty acids. One example is the company Earthrise that has grown microalgae in pond systems in the United States for the natural foods market since 1982.

The oil produced by algae can also be used for energy purposes. Large scale cultivation of microalgae for these purposes is currently under development worldwide. Examples of players include Sapphire and PetroAlgae in the USA, Cellana in Hawaii and Seambiotic in Israel. Major energy companies such as Shell, a partner in Cellana, and ExxonMobil [ExxonMobil, 2009] have also started investing in algae technology for energy purposes.

5.8 Comparison with other studies

We compared the land used for energy crops and the primary bioenergy use of bioenergy crops and algae in the Energy Scenario with literature values on potentials [Smeets, 2008; IEA, 2009; Dornburg, 2008; IAASTD, 2009; Hoogwijk, 2004; Erb, 2009; Van Vuuren, 2009; WBGU, 2008; Campbell, 2008; Field, 2008]

In our comparison we differentiated between studies that applied no or few sustainability criteria and those that applied a set of sustainability criteria in the same range as the Energy Scenario[59].

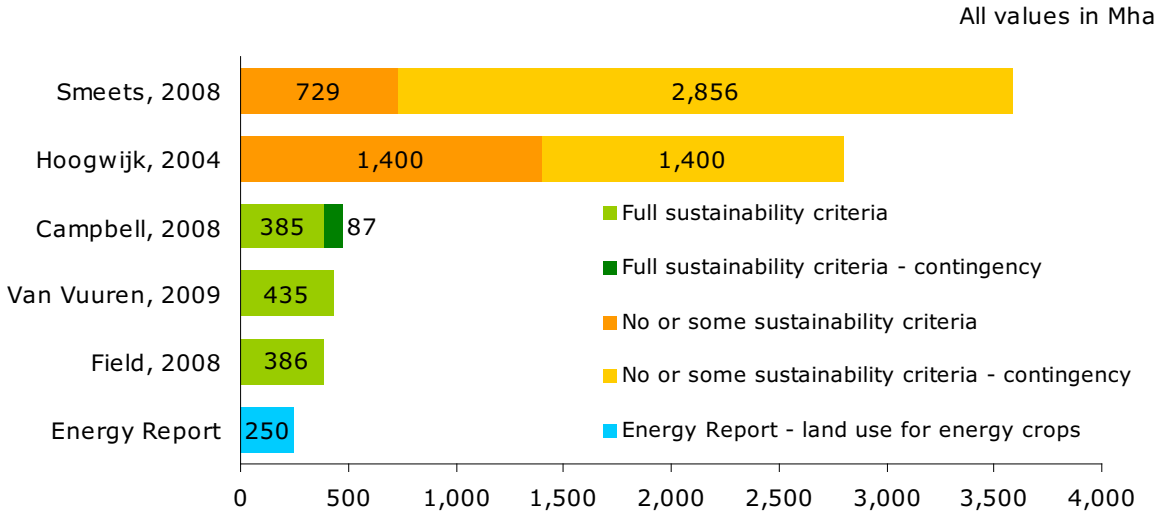


Figure 5 - 19 Comparison of global land use in the Energy Scenario with bioenergy area potentials from literature. Contingency indicates the author gave the potential as a range rather than a definitive number.

Figure 5 - 19 shows that the land used for bioenergy cropping in the Energy Scenario is at the lower end of the range of potentials found in literature. It is important to note

[59] Studies labelled "No or some sustainability criteria" generally take into account food security and biodiversity criteria. Studies labelled "Full sustainability criteria" generally added criteria on water use, soil protection, degradation of land and deforestation and forest carbon stocks. This leads to a similar range of criteria types as that of the Energy Report. However, the method and degree of applying these criteria and the assumptions made during the analysis vary strongly, which leads to the difference in results between the studies. An example of the effect of different assumptions on food security in the Scenario on the outcome of the analysis is given in Box 5 - 5.

that the given land use for energy crops in the Energy Scenario is the maximum amount used during the 2005–2050 timeframe.

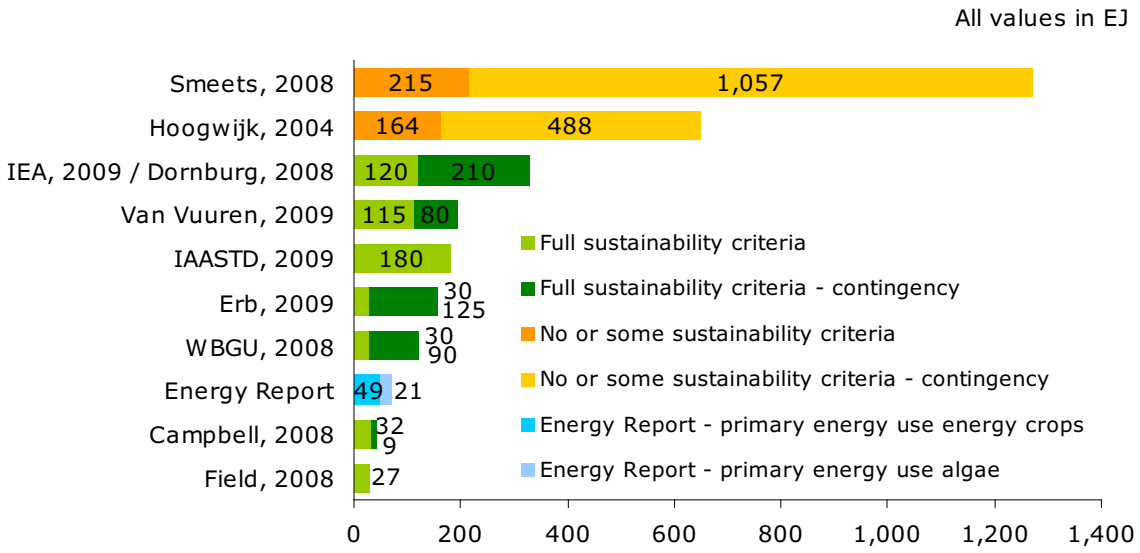


Figure 5 - 20 Comparison of global primary energy use from energy crops in the Energy Scenario with primary bioenergy potentials from literature. Contingency indicates the author gave the potential as a range, e.g. due to uncertainty in future yields. As [IEA, 2009] and [Dornburg, 2008] give the same numbers and partially have the same authors, they are grouped together.

Figure 5 - 20 demonstrates that the primary bioenergy use from energy crops in the Energy Scenario is at the lower end of the range of potentials found in literature. It is important to note that the primary bioenergy use from energy crops in the Energy Scenario in Figure 5 - 20 is the maximum amount used during the 2005–2050 timeframe. This maximum use occurs in 2035 and use is lower in all other years.

5.9 Sustainability of bioenergy: Greenhouse gas emission savings

The sustainability framework for bioenergy presented in Section 5.2 incorporates the fact that bioenergy use should achieve high greenhouse gas (GHG) emission savings compared to fossil alternatives. Therefore, we have performed a life cycle analysis of the GHG emissions associated with bioenergy use in the Scenario.

We have included GHG emissions from six different contributors in the bioenergy life cycle:

- Emissions from land use change when land is converted to bioenergy cropland. Emission factors for these conversions were obtained from [IPCC, 2006]
- Emissions from the production and application of nitrogen fertiliser for bioenergy crops and algae [IFA, 2009; IPCC, 2006; Ecofys, 2008]
- Emissions from agricultural fuel inputs for cultivation of bioenergy crops, forestry and collection of agricultural residues [JEC, 2008]

- Emissions from transport of biomass to the processing site [JEC, 2007]
- Emissions from energy inputs during bioenergy conversion [Ecofys, 2008b]
- Emissions from transport of the bioenergy carrier to the end use location [JEC, 2007]

Most of these contributors include emissions associated with energy use. As the Energy Scenario drastically increases the share of renewable energy technologies that have low or no GHG emissions, we have made two separate calculations: in one the emission factors for the energy inputs were extracted from the IPCC fossil fuel references [IPCC, 2006b] and in the other, they were taken from Energy Scenario data. Therefore, we present results as a range.

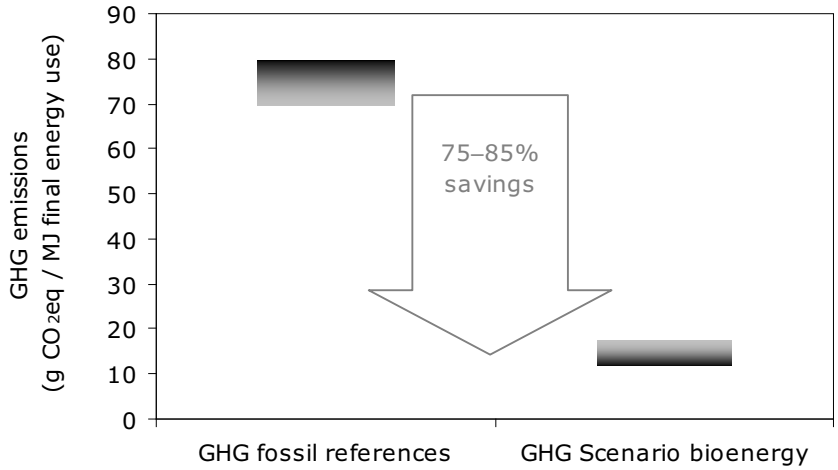


Figure 5 - 21 Energy Scenario bioenergy greenhouse gas (GHG) emissions versus fossil references for 2050.[60]

Figure 5 - 21 shows the results of the life cycle analysis. For 2050, we have calculated that the GHG emissions associated with bioenergy are 12–18 gCO_2eq/MJ final energy use. The values for the corresponding fossil references are 70–80 gCO_2eq/MJ[60]. This means that even for the most conservative calculation, (with fossil reference for energy inputs) average GHG emission savings are ~75%. When the corresponding Energy Scenario values are used, average GHG emission savings are ~85%.

[60] For consistency, fossil references are based on current IPCC direct emission values used throughout the Scenario. This means that they do not include life cycle emissions associated with fossil fuel production, such as drilling and transport emissions. In addition, they are not corrected for the likely future development of increased fossil emission factors due to increasing difficulty of fossil fuel production from e.g. tar sands.

6 Investments and Savings

6.1 Introduction

The Energy Scenario examines the feasibility of a fully renewable energy future by taking a bottom-up, physical approach to the energy system. It does not necessarily present the most cost-efficient way of achieving this goal. It is however, insightful to estimate the associated investment and savings of this energy system in comparison to a BAU energy system.

The following sections will

- describe approaches and assumptions used to derive investments and savings resulting from the Energy Scenario
- indicate the functionality and limitations of the underlying calculations

The generic approach for all sectors, as well as basic data and parameters used in all or most of the sectors, is presented in Section 6.2.
Following Section 6.2, specific methods, assumptions and results are presented in separate sections for each of the sectors:

- industry
- buildings
- transport-infrastructure
- transport–vehicle technology
- power
- electricity grids
- renewable heat and fuels
- research and development (R&D)

Considerations for the uncertainty of key parameters and the distribution of investments and revenues form the conclusion.

6.2 General

The two **key questions** that the cost model for the Energy Scenario attempts to answer are:

- What will be the net costs of the Energy Scenario?
- What will be the upfront investments?

To answer these two questions, the cost calculations per sector differentiate between capital expenditures (**CapEx**) and operational expenditures (**OpEx**), which include savings due to lower or no fuel costs.

Costs and savings until 2050 are calculated and fully accounted for in the year in which they occur, meaning that investment is not levelised, which is sometimes practised to inform long-term strategy,[61] therefore, the results shown, present "real" investment needs, or "cash flow" for any given time period. This approach is more appropriate for the global and macroeconomic view of the Energy Scenario and to answer the two key questions. To assess the profitability of the investments, a levelised cost approach would need to be added.

Although energy-related CapEx and OpEx have been quantified as well as possible, indirect investments and savings are not taken into account. Therefore, all external benefits, such as reduced risk of environmental degradation, insured and non-insured costs from decreased climate damages, reduced adaptation costs, reduced health costs, are not calculated.
[Stern 2006] estimated the costs of climate change in a business-as-usual scenario to be between 5–20% of annual GDP, depending on the scope of social costs taken into consideration, compared to 1% of GDP for keeping global emissions between 500 and 550ppm CO_2-eq.[62]

All calculated costs and savings are additional to the reference case mentioned above. This means that total investments would usually be much higher than CapEx, but the major share of investments would have to be made in the reference scenario anyway. By focusing on the economic differences between the Energy Scenario and business as usual, the results for investment and savings highlight the net financial impact of the Scenario.

All cost values are given in EUR_{2005}.

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[61] The US Energy Information Administration defines levelised costs as representing *"the present value of the total cost of building and operating a generating plant over its financial life, converted to equal annual payments and amortized over expected annual generation from an assumed duty cycle."* Because of the Scenario's cash-flow approach, the total up-front investments (CapEx) are only compared with that same year's fuel cost savings (OpEx). A levelised cost approach, which is more common for private investments, would spread the CapEx over the total lifetime and include also savings after 2050, leading to a higher profitability of investments in renewable energies than conventional power plants.

[62] [Stern, 2006], Summary of Conclusions

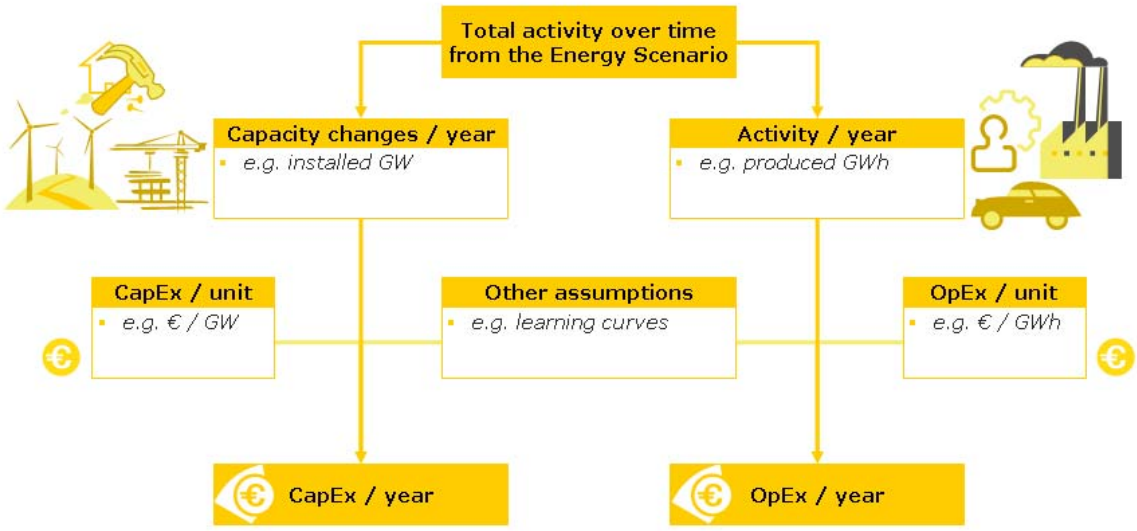

Figure 6 - 1 Generic approach for cost calculations.

In **general**, the **approach** for each sector uses the same set of sector-specific activity data as the Energy Scenario to calculate:

- additional capacity requirements per period (e.g. production capacity in tonne/a or generation capacity in MW) for the CapEx calculations and
- more efficient or renewably fuelled activity per period (e.g. produced tonnes or generated MWh) for OpEx calculations.

The capacity data are then multiplied with unit costs per capacity (e.g. EUR/tonne/year or EUR/MW), or similar, to calculate the CapEx costs per period. The activity data are multiplied with unit costs per activity (e.g. EUR/GJ for fuel savings), or similar, to calculate the OpEx costs per period.

For all sectors except electricity grids, a basic set of **energy prices** is applied to calculate fuel expenditures and savings. These energy prices are derived from a comprehensive price set for 2010 and forecasted using annual growth rates of 2% on average, with a range of 1–4% depending on fuel, sector and customer [EIA, 2009]. However, for the projected biomass market in the Scenario, we applied a demand-driven logic to the prices of different biomass sources, with a ceiling of 5% for annual price increases. This leads to a larger relative price increase for bioenergy which was deemed a suitable assumption given the sparse historical data and lack of certainty over future developments of this market.
The results for some key energy prices, including average biomass prices, are shown in Figure 6 - 2. A sensitivity analysis on the energy prices is presented in Section 6.10.

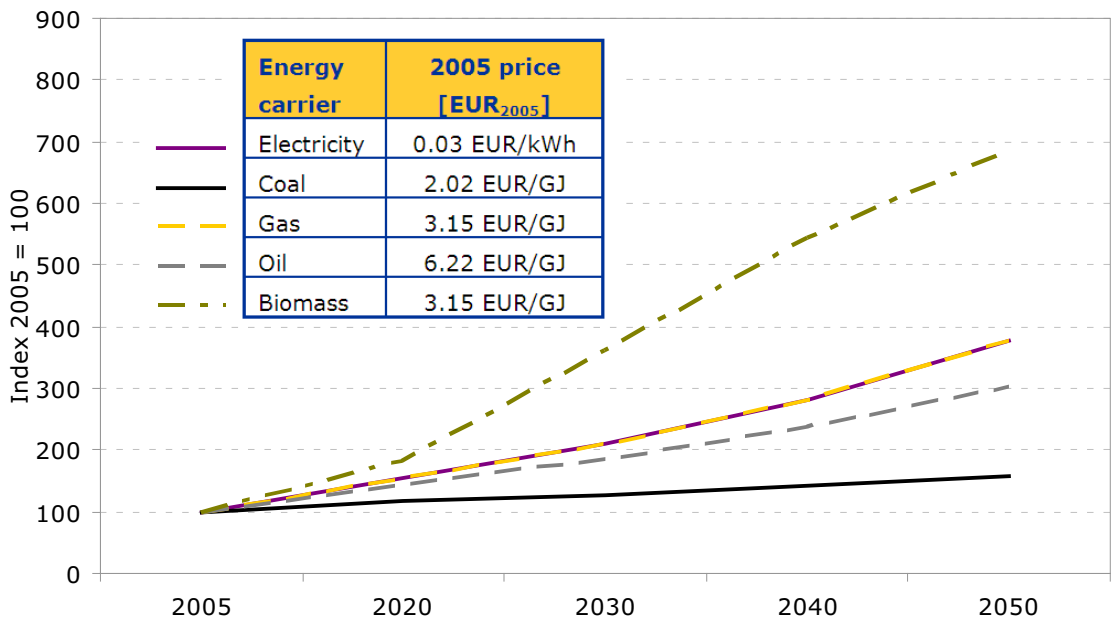

Figure 6 - 2 Indexed development of energy prices. A (weighted) average (w.a.) is shown for the biomass index, which carries a large uncertainty.

Sector and technology specific **lifetime years and progress ratios** were used for several sectors.

Table 6 - 1 shows for which sectors lifetime years or progress ratios have been used in calculations. Progress ratios indicate the learning potential for a certain technology or production process. The learning potential is expressed as a reduction in costs in relation to cumulative production. For example, a progress ratio of 0.8 means that costs will reduce by 20% each time cumulative production is doubled. Therefore, young technologies with less cumulative production will generally have stronger cost decreases than older technologies with higher cumulative production and the same progress ratio.

Table 6 - 1 Lifetime years and progress ratios used by sector.

Sector	Lifetime years used?	Progress ratios used?
Industry	X	Implicit
Buildings	X	X
Transport-Infrastructure	X	-
Transport–Vehicle Technology	X	X
Power	X	X
Grids	X	-
Renewable heat and fuels	X	X
R&D	-	-

Key findings

The overall results on investment and savings for the Energy Scenario shown in Figure 6 - 3 present two findings that will be echoed in sector-specific results:

1. Annual CapEx costs are positive (= investments) and at around 1 trillion EUR per year initially higher than negative OpEx costs (= savings). CapEx grow until 2035 to almost 3.5 trillion EUR per year, but the growth of OpEx savings is much higher.
2. Net results turn from costs to savings by 2040. At their maximum, net costs are below 2 trillion EUR per year, but turn to net savings of almost 4 trillion per year in 2050, with OpEx savings reaching more than 6.5 trillion EUR per year.

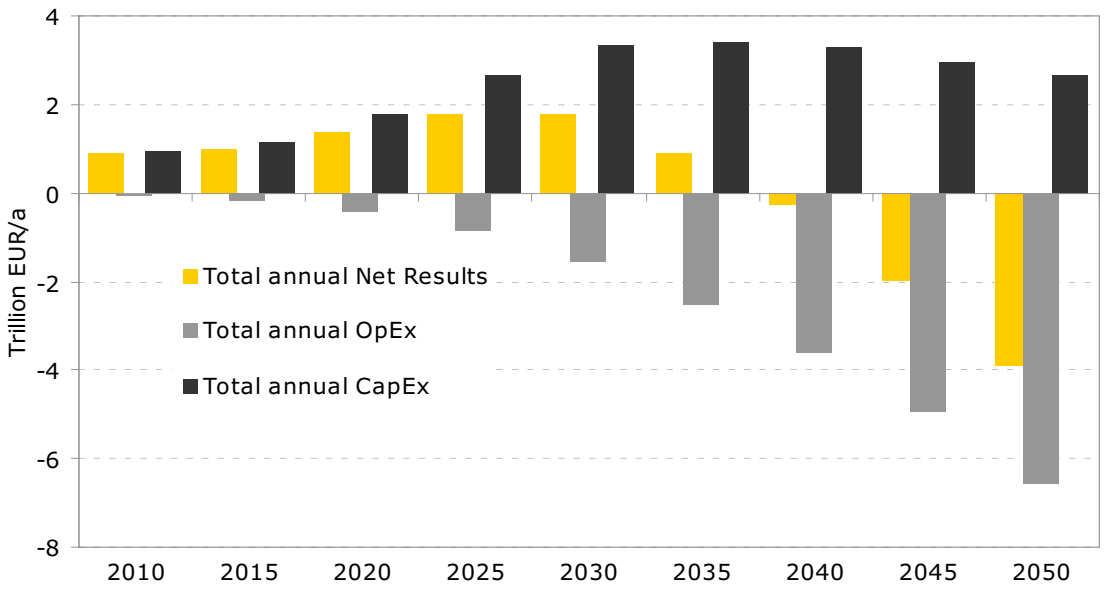

Figure 6 - 3 Total global annual cost results for Energy Scenario.

If net costs for all sectors are compared as shown in Figure 6 - 4, it is clear that investment in buildings will dominate total costs until 2030. In 2040, total net costs are turned to net savings led by savings in the transport sector (infrastructure and vehicle technology). These savings outweigh the steadily increasing costs for renewable heat and fuels, primarily from biomass, in the later years. Note, however, that these costs bear high uncertainty and price developments have been estimated conservatively here (=strong increase). This potentially leads to a considerable overestimation of costs for the renewable heat and fuels sector.

In general, upfront CapEx investments are higher than OpEx savings in the first half of the modelled time period. Therefore, almost all sectors incur net annual costs until 2030. Continuously growing fuel savings due to higher efficiencies and rising fuel prices lead to net annual savings after 2040, primarily driven by savings in the transport sector.[63]

[63] Transport is divided into "Infrastructure" and "Vehicle Technology". The infrastructure part includes all investments and savings due to changes in the

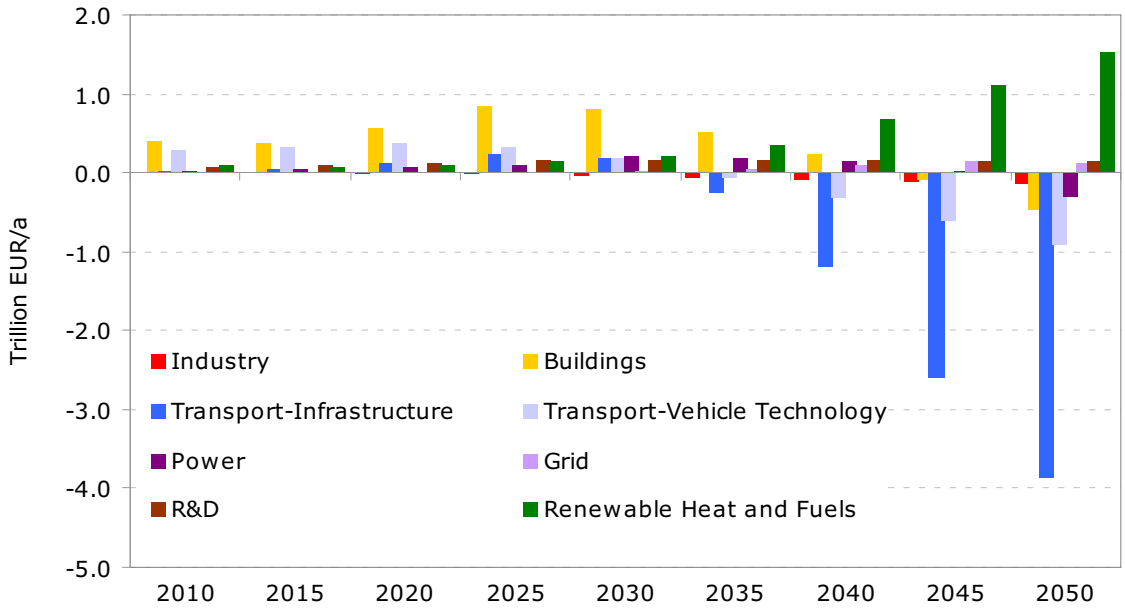

Figure 6 - 4 Net cost results per sector.

A comparison between GDP and CapEx, OpEx and net costs for the Energy Scenario is shown in Figure 6 - 5. Given the projected growth of global GDP, net costs will peak in 2025 in relative terms, staying below 2% of GDP. OpEx savings will continuously rise and reach 3.5% of global GDP in 2050, leading to net savings of about 2%.

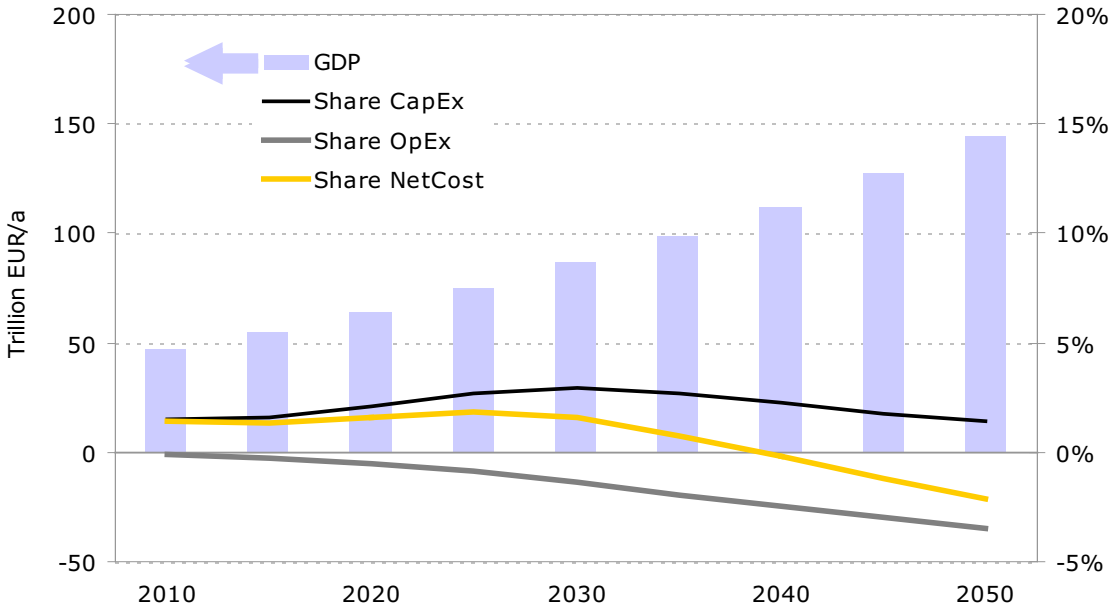

Figure 6 - 5 Comparison of cost results with global GDP.

transport activity (modal shift). Additional costs for more trains, buses, railroads and railroad power are overcompensated by lower costs for saved cars, trucks, road construction and maintenance, as well as the associated saving on transport fuels. More detail is given in Section 6.5.

6.3 Industry

The industry sector is divided into the following seven subsectors (see also Table 3 - 1):

- Iron and steel
- Cement
- Aluminium
- Paper
- Chemicals
- Food
- Others

For the first four sectors ('A' sectors), the CapEx costs are derived from sub-sector specific payback years for the required energy efficiency improvements determined in the Scenario. These efficiency improvements are assumed to be regularly applied improvement measures[64] with definite and fixed payback years shown in Table 6 - 2, assuming technological advancements and rising marginal improvement costs balance out on average, for all regions and the total timescale.

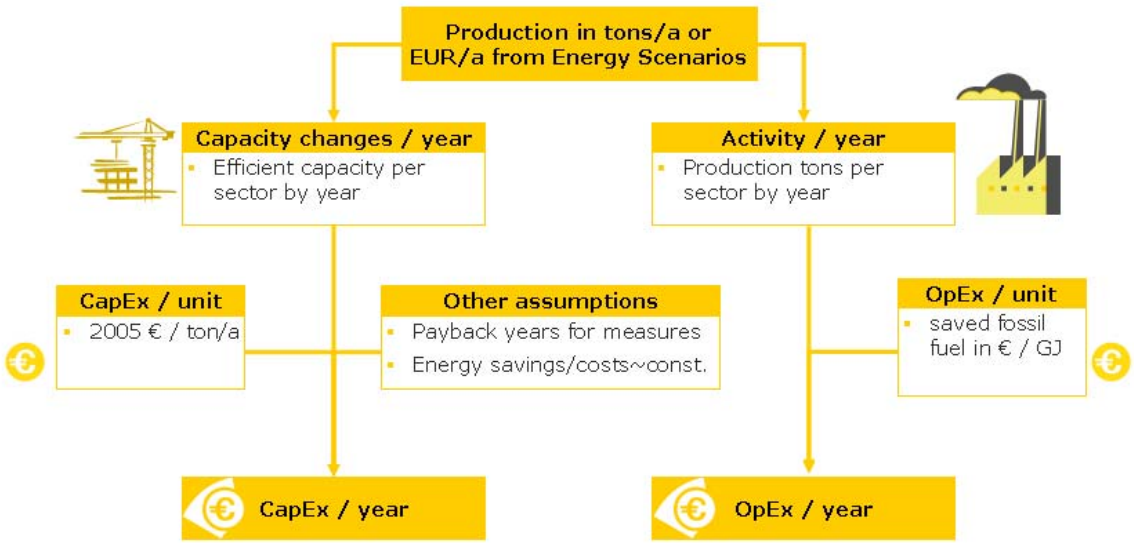

Figure 6 - 6 Approach for industry.

These (higher) energy efficiency measures have not been carried out so far. This may be due to:

- companies demanding shorter payback times
- a lack of information on these measures and their benefits
- other reasons that hinder the implementation of cost-efficient energy-savings measures

[64] Not including CCS

The payback years for the measures required to achieve the Energy Scenario's additional efficiency improvement are estimated with all implications of the Scenario in mind. This means that the same measures may have longer payback periods in the baseline, as the Scenario contains stronger developments in energy efficiency technologies across all sectors and regions than the baseline. Because of economies of scope and scale, the costs for energy efficiency measures in the industry sector are lower in the Energy Scenario than in the baseline. Parts of the costs are "paid back" by higher demand (and prices) for more energy efficient products and production processes.

Table 6 - 2 Payback years per industry sub-sector

Sector	Payback years
Steel	4
Cement	3.5
Aluminium	4
Paper	5.5

The payback years are multiplied by fuel costs to calculate investment per annual production unit. CapEx costs are then calculated based on capacity data derived from activity data used in the Scenario, including the costs for end-of-lifetime replacements.
OpEx costs are derived from a fixed OpEx cost share of 2% in relation to CapEx to account for higher operational costs for energy efficiency equipment, as well as fuel cost savings derived from the basic set of energy prices and efficiency improvements, including a shift from fossil fuels to electricity for several processes.

The results for the four 'A' sectors were then extrapolated to the entire industry sector using their relative size in energy terms.

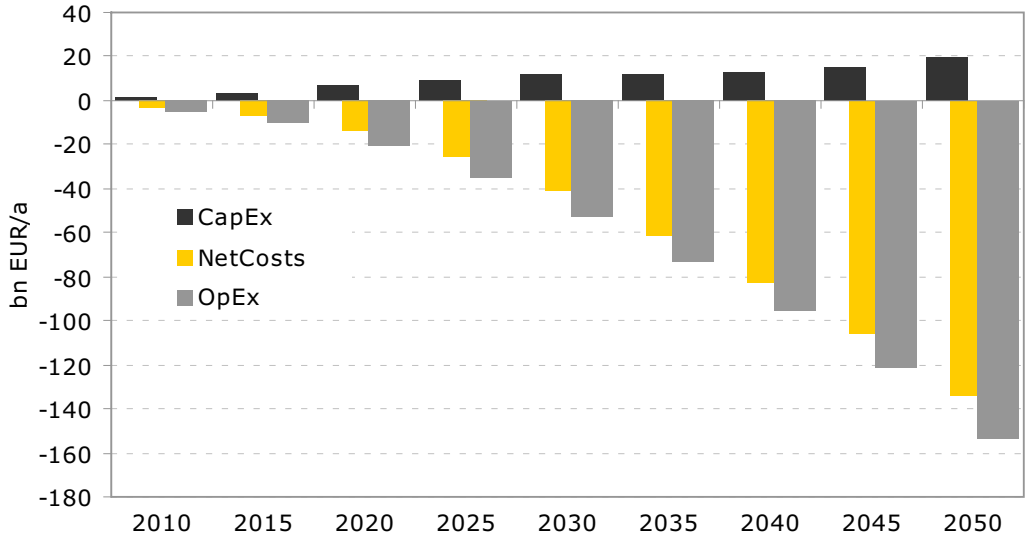

Figure 6 - 7 Results for industry (all sectors).

Key findings

The investment in the industry sector will peak at 20 billion EUR annually in 2050, shown in Figure 6 - 7. This is a lower peak investment compared to other sectors. As payback rates are estimated to be below five years, fuel savings exceed investments after the first period. Annual CapEx will grow slowly and steadily until 2050. Continuous efficiency improvements aggregate fuel savings over time however. Therefore, the respective savings continue to increase until 2050, when net savings increase to 134 bn EUR annually.

6.4 Buildings

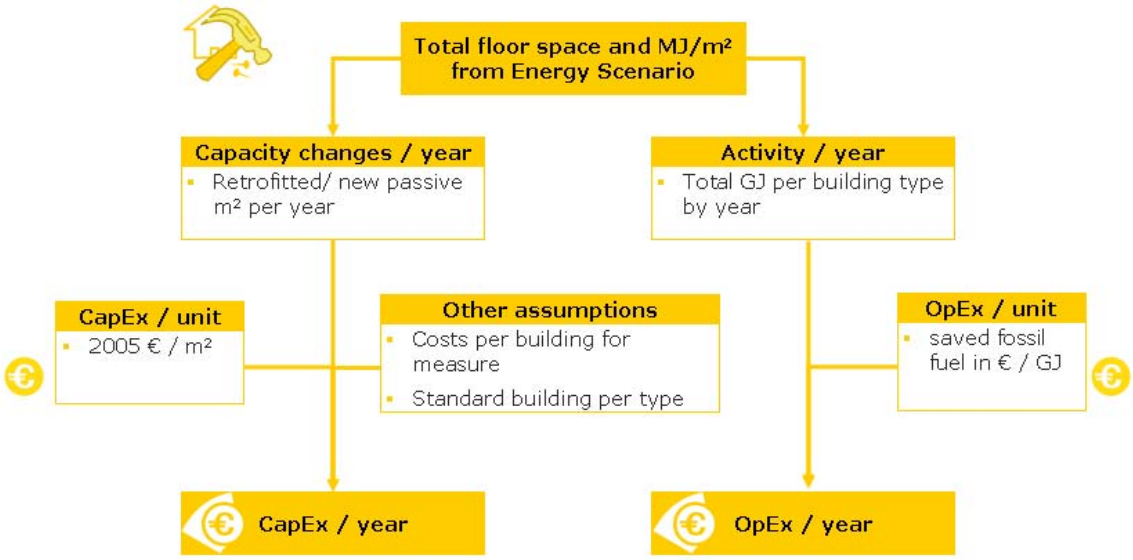

Figure 6 - 8 Approach for buildings.

The cost calculations for the building sector differentiate between residential and commercial buildings. Commercial buildings are assumed to have 2.5 times the floor area of residential buildings, creating economies of scale when energy efficiency measures are applied. These measures and respective costs per square meter of floor area are defined in Table 6 - 3 for both categories. The investment per measure is based on current prices and expected progress ratios until 2050. The progress ratios allow for a reduction of specific costs over time.

Table 6 - 3 Investments and progress ratios per measures and sector (in EUR/m2 floor area).

Sector	Process	Technology	Progress ratio	Invest. in 2010
Residential	Retrofit	Solar thermal	0.8	20
		Heat pump	0.75	100
		Insulation	0.9	109
		Ventilation w/ heat recovery	0.9	60
	New	Passive	0.8	100
		Solar thermal	0.8	20
Commercial	Retrofit	Solar thermal	0.8	13
		Heat pump	0.75	67
		Insulation	0.9	86
		Ventilation w/ heat recovery	0.9	40
	New	Passive	0.8	67
		Solar thermal	0.8	13

Based on the evolution of retrofitted and newly built floor area in the Scenario, CapEx costs are calculated per period, including the costs for end-of-lifetime replacements of new build or retrofitted energy efficient buildings. Lifetimes for new, as well as retrofitted building measures are estimated to be 25 years.
OpEx costs are calculated using the efficiency improvements and related energy savings per square meter from the Scenario and energy prices for end-use electricity and heat.

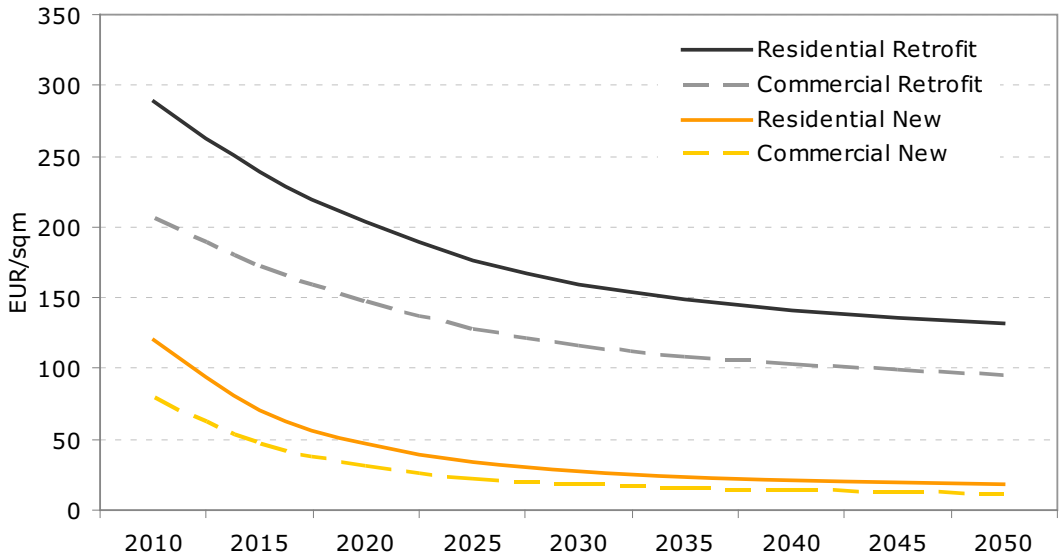

Figure 6 - 9 Unit costs development for buildings.

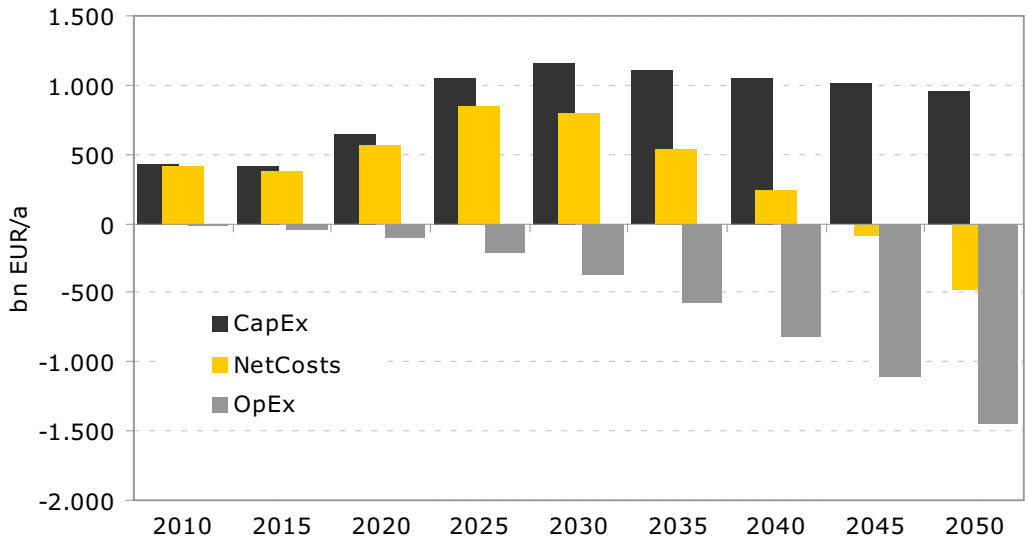

Figure 6 - 10 Results for buildings.

Key findings

As shown in Figure 6 - 10, annual CapEx costs in the built environment peak at almost 1,200 billion EUR annually worldwide in 2030. Net costs peak in 2025 at ~850 billion EUR annually, as increasingly, energy savings are higher than investments, also due to decreasing unit costs. The trend of increasing annual savings and slightly decreasing investment continues and leads to net annual savings in 2045 and a maximum of over 450 billion EUR saved in 2050.

6.5 Transport

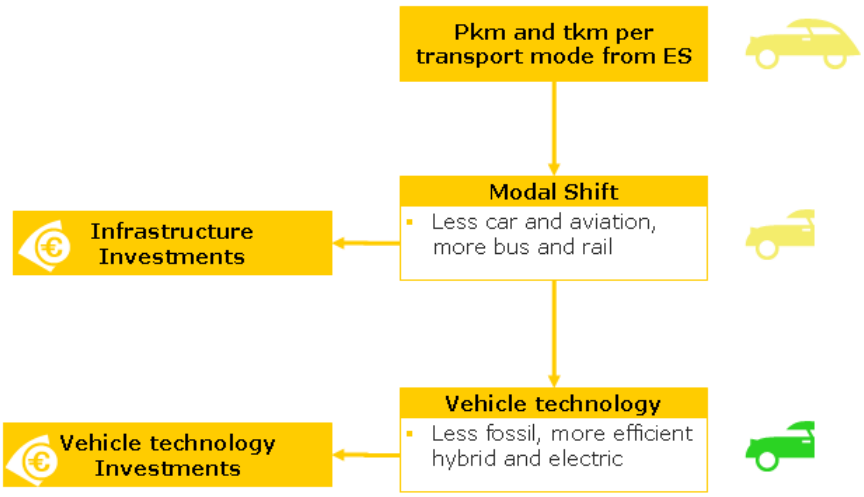

Figure 6 - 11 Approach for total transport.

Transport costs are calculated by differentiating between two aspects of shifts in the transport system:

- Investment and savings related to a shift of passenger and transport volumes between transport modes (**transport-infrastructure**), and
- Investment and savings related to a shift between fuels and efficiency improvements (**transport-vehicle technology**).

Investments and savings are calculated for infrastructure first, then for vehicle technology. The fuel shifting costs are thus based on the modal split determined by the Scenario. This ensures that expenditures or savings are not double-counted. It must be noted however, that results for infrastructure and fuel shifting would change if the order of calculation were reversed.

For **infrastructure**, based on activity data for the baseline as well as the Energy Scenario, required capacities per transport mode (in number of vehicles) as well as required road and rail track kilometres (due to car transport and rail passengers, respectively) are calculated. Together with unit prices for standard vehicles per transport mode, CapEx investment can be calculated for both scenarios. The CapEx difference between these scenarios is then the CapEx for infrastructure.

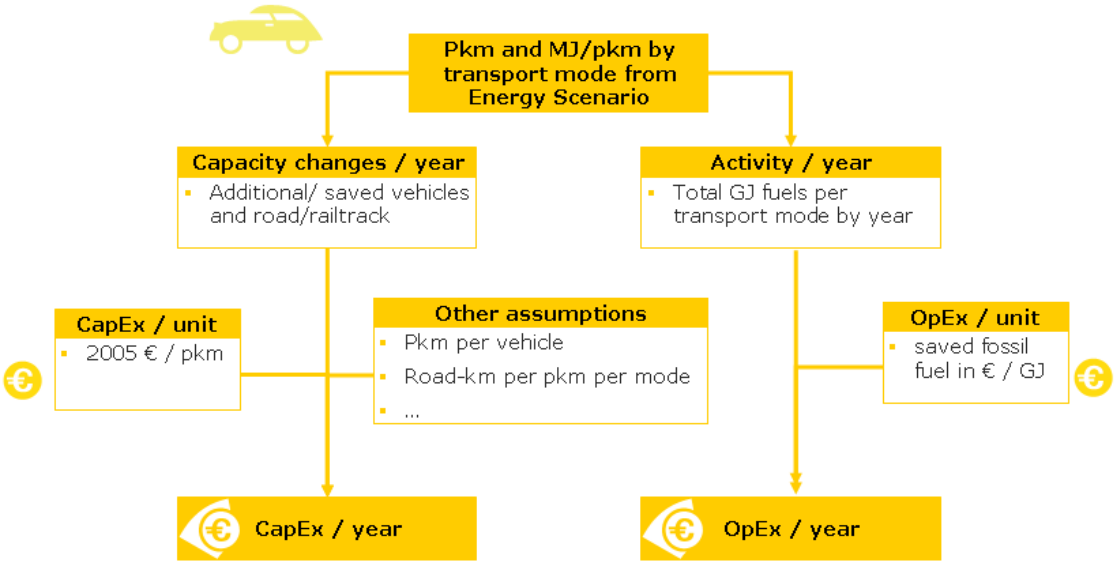

Figure 6 - 12 Approach for transport - infrastructure.

OpEx costs for infrastructure consist of fuel savings due to the choices of more efficient transport modes. These fuel savings are calculated using activity data per transport mode for the baseline as well as the Energy Scenario, which are then multiplied by respective fuel efficiencies for each transport mode and fuel price.

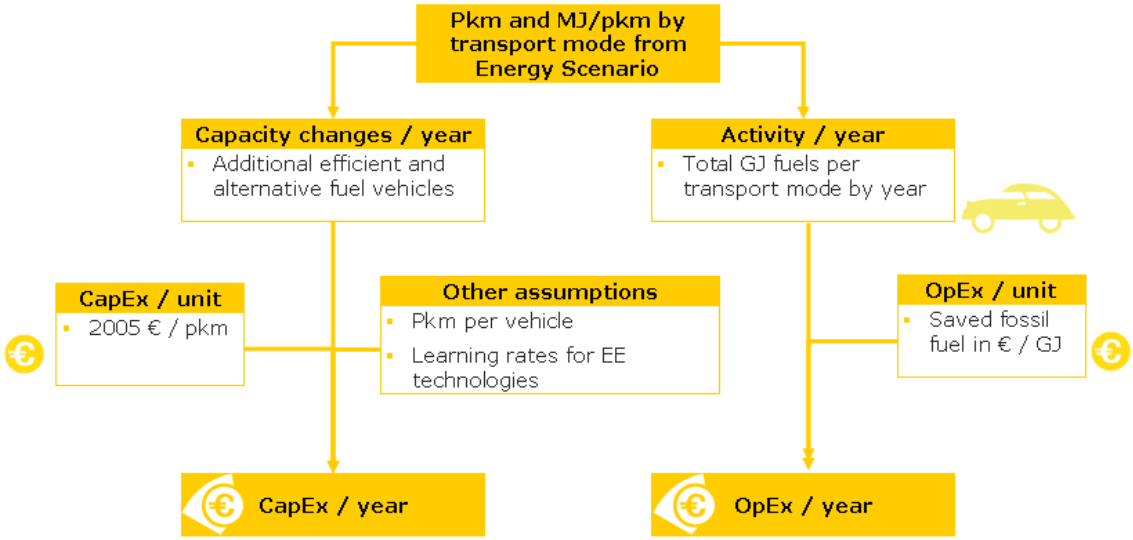

Figure 6 - 13 Approach for transport - vehicle technology.

The CapEx investment for **vehicle technology** is calculated based on additional capacities for more efficient and alternatively fuelled vehicles (e.g. plug-in hybrid cars and busses). The respective capacities are derived from the "modal-shifted" activity

data of the Energy Scenario, to avoid double-counting. The capacity numbers are multiplied by additional vehicle costs. These are derived by using current extra costs (e.g. hybrid vs. standard car) and progress ratios to allow for a reduction of these additional costs. The results give the additional annual CapEx per transport mode.

OpEx costs for vehicle technology are based on the annual efficiency improvement as well as annual activity data per transport mode. The efficiency improvements include a replacement of fossil fuels by electricity. Although electricity is generally more expensive than fossil fuels,[65] the efficiency improvements lead to net OpEx savings.

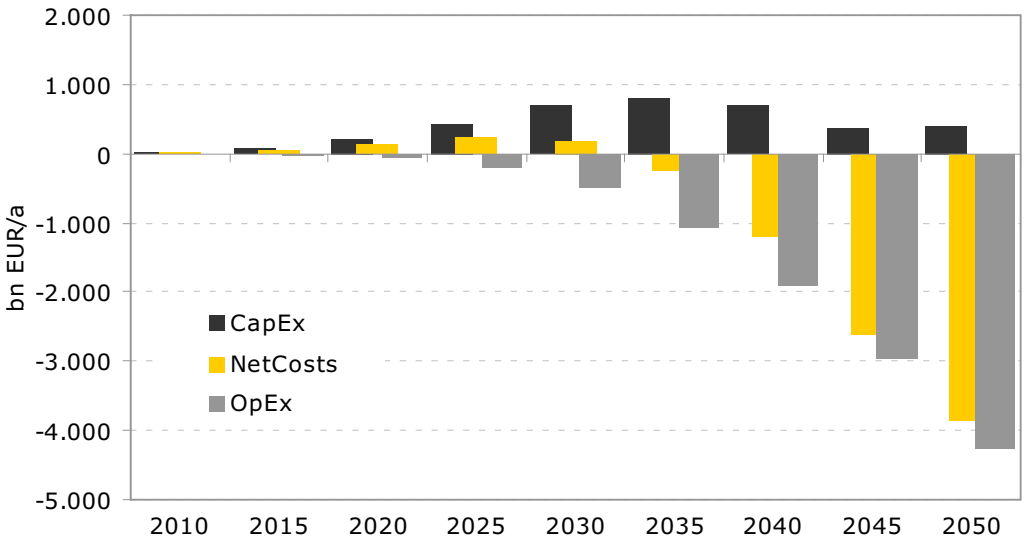

Figure 6 - 14 Results for transport - infrastructure.

Key findings

Results for transport–infrastructure shown in Figure 6 - 14, present growing CapEx that peak at ~800 billion EUR annually in 2035. Simultaneously, fuel savings increase throughout the period and peak at around 4,300 billion EUR in 2050, leading to net savings of almost 3,900 billion EUR that year. Due to the combination of the CapEx peak in 2035 and constantly increasing savings, net costs peak at ~230 billion EUR annually in 2025.

[65] This regards the real costs of production. End-user prices may differ due to subsidies or taxes for generation, infrastructure and consumption.

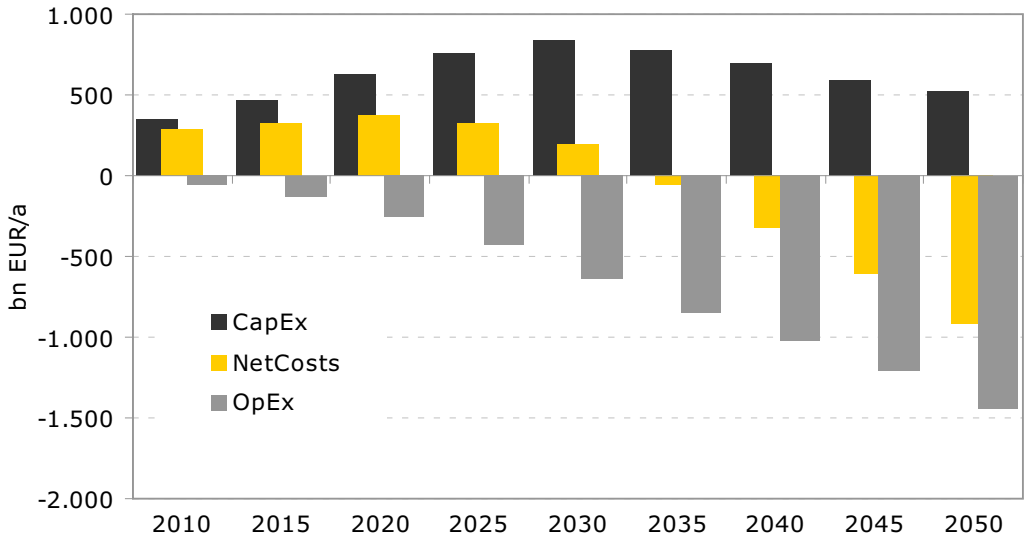

Figure 6 - 15 Results for transport - vehicle technology.

Key findings

As Figure 6 - 15 shows, investments for vehicle technology peak at 835 billion EUR annually in 2030. As for other sectors, savings from efficiency improvements grow stronger than investment, leading to annual fuel savings of ~1,400 billion EUR by 2050. While net costs peak at 370 billion EUR in 2020, net savings increase to over 900 billion EUR in 2050.

It should be noted that fuel savings in the transport – vehicle technology sector do not account for baseline efficiency improvements of vehicles. Based on the modest fuel efficiency improvements of the last 30 years for road transport, it is not unreasonable to assume that possible fuel savings through technical advancements would have been offset by demand for higher engine power, increased weight and more electrical equipment.

6.6 Power

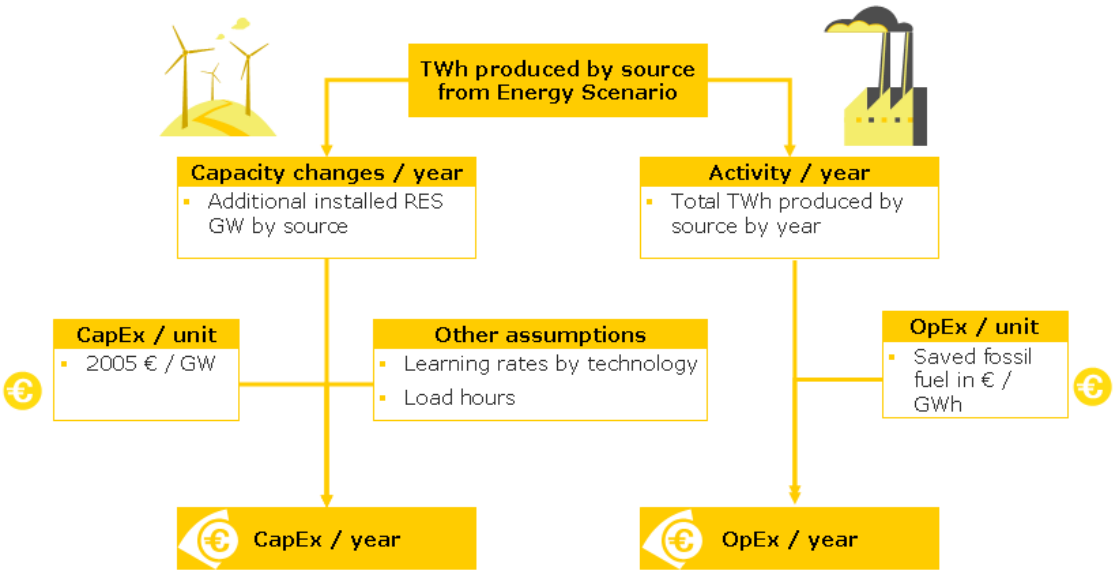

Figure 6 - 16 Approach for power.

The CapEx costs for power are calculated from additional capacity and unit costs. Additional capacity (in MW) per source is calculated based on activity data per renewable energy source. Capacity unit costs for the different sources are taken from literature sources, mostly [Ecofys, 2009a], as well as expert knowledge. Only CapEx investments for demand-driven power sources have been offset against CapEx investments for conventional plants that would have been built or replaced in the reference scenario. All supply-driven power source investments have been treated as fully additional, e.g. wind and PV. They therefore represent a high estimate.
The calculated CapEx costs per RES source are shown in Table 6 - 4.

Table 6 - 4 Capacity costs of RES electricity (000s EUR/ MW).

Source	Load Hrs	Progress ratio	2010	2020	2030	2040	2050
Wind onshore	2000	0.85	1,200	1,000	800	800	700
Wind offshore	3500	0.9	3,000	2,100	1,800	1,700	1,500
Wave	2500	0.9	3,600	3,100	2,800	2,500	2,300
PV	1000	0.8	3,300	2,100	1,400	1,000	700
CSP	4000	0.9	4,400	3,800	3,300	2,900	2,500
Geothermal	7000	0.8	3,500	3,100	2,700	2,300	2,000
Hydro	5000	1	2,500	2,500	2,500	2,500	2,500

The capacity unit costs until 2050 are derived by using current investment per MW as a basis and applying progress ratios for future periods.

OpEx costs are calculated using generated power (in GWh) from renewable sources and fossil fuel costs for the current power mix. Operational costs for RES power are assumed to balance out with saved operational costs for conventional power. Therefore, OpEx costs are fuel costs savings.

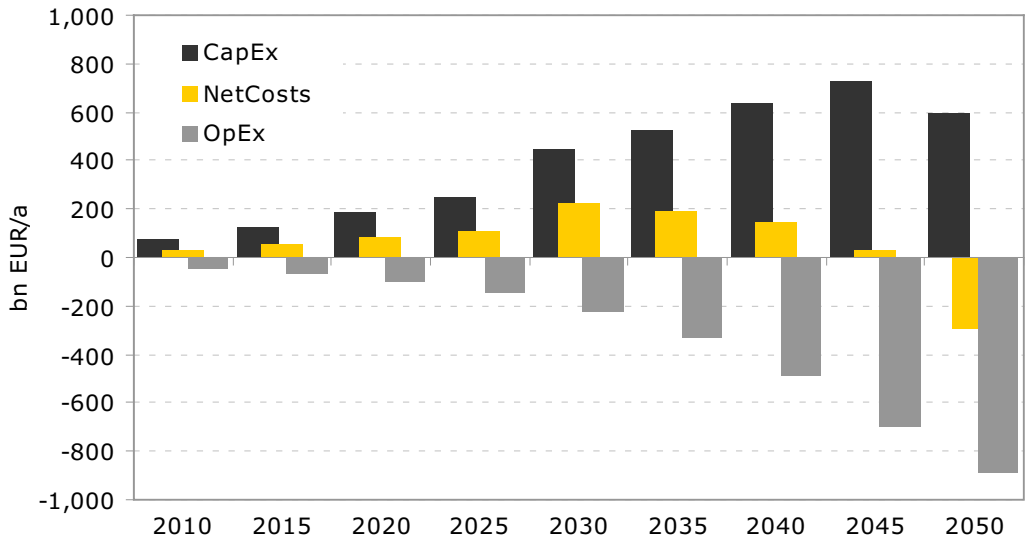

Figure 6 - 17 Results for power.

Key findings

CapEx costs follow the growth of renewable power in the Scenario and peak at ~730 billion EUR in 2045. Only by 2050, do fuel savings (OpEx) begin to outweigh the investment costs and net costs become savings of ~300 billion EUR (see Figure 6 - 17). It must be stressed again that we present 'cash-flow' calculations here, leading to net savings only in the final years of the time frame. On a levelised[61] cost basis, renewable electricity sources become cheaper than conventional sources much sooner than 2050.

6.7 Electricity Grids

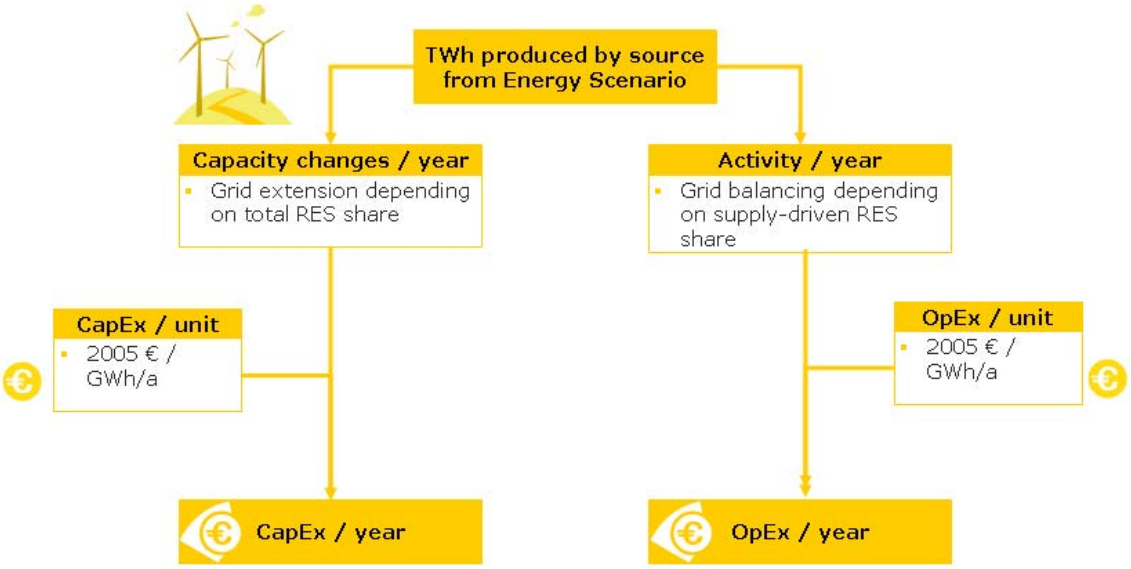

Figure 6 - 18 Approach for electricity grids.

In general, it should be noted that very few studies on investments and savings for large-scale power systems with RES shares above 30% exist [DCEN 2008, GreenNet EU-27, 2005, DCEN 2009]. This makes it difficult to provide good estimates of the associated costs and savings. In the following we attempt to quantify the potential economic impacts of the power system upgrades assumed in the Energy Scenario.

The costs for electricity grids consist of costs for grid extension & reinforcement (CapEx) and grid balancing (OpEx). Requirements for grid extension and reinforcement capacity are calculated from renewable energy power production data from the Scenario. Grid capacity in a given period is related to additional annual renewable power generation of the following period. CapEx costs are calculated by multiplying the capacity data with unit costs for grid extension & reinforcement. The unit costs are extrapolated from [GreenNet EU-27, 2005]. These literature values depend on the share of renewable energy sources (RES) from total power generation, indicating that higher RES shares lead to increasingly higher unit costs.

Grid balancing costs are calculated based on annual power generation of supply-driven sources (wind on-shore, wind off-shore and PV) and respective unit costs. The unit costs are also based on [GreenNet EU-27, 2005]. They depend on the share of supply-driven renewable electricity, leading to higher balancing unit costs at higher shares.

Based on the approach mentioned above, both CapEx and OpEx costs for electricity grids are positive, contrary to other sectors where savings offset investments.

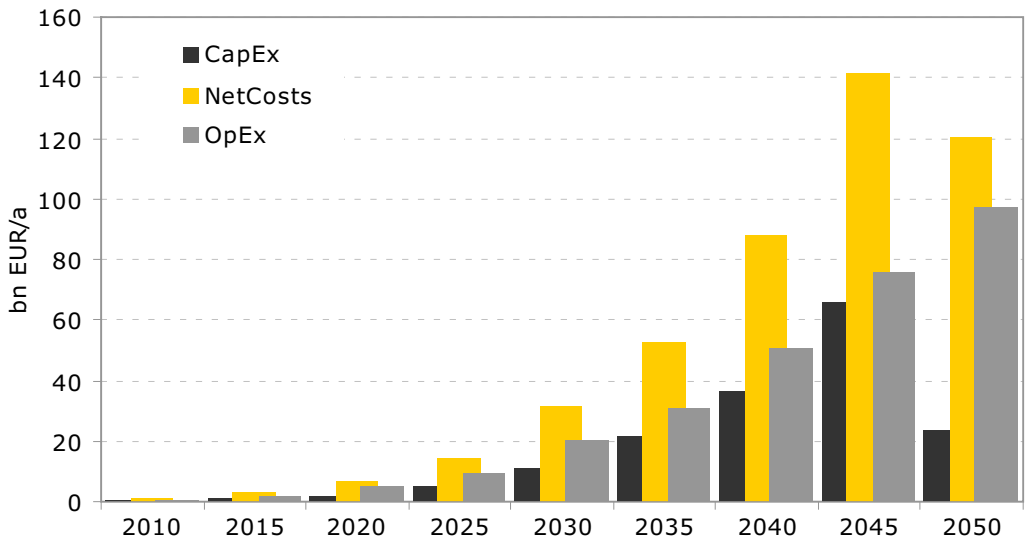

Figure 6 - 19 Results for electricity grids.

Key findings

As Figure 6 - 19 shows, grid balancing costs rise to almost 100 billion EUR annually worldwide in 2050. They are always higher than CapEx (grid extensions) costs, which peak at ~70 bn EUR. Together, they lead to maximum net costs of ca. 140 bn EUR.
As both CapEx and OpEx costs increase steadily until 2045, so do net costs. Due to a sharp decrease of CapEx costs in 2050, net costs also decrease to 120 bn EUR annually in 2050. This sharp decrease is a result of the supposition that most of the grid extension and reinforcement has been carried out by 2045, as RES shares are already close to 100%.

6.8 Renewable heat and fuels

The net costs for renewable heat and fuels are calculated from:

- the costs for geothermal, concentrated solar heat and the costs for biomass converted to fuels,
- the savings from saved conventional (heating) fuels.

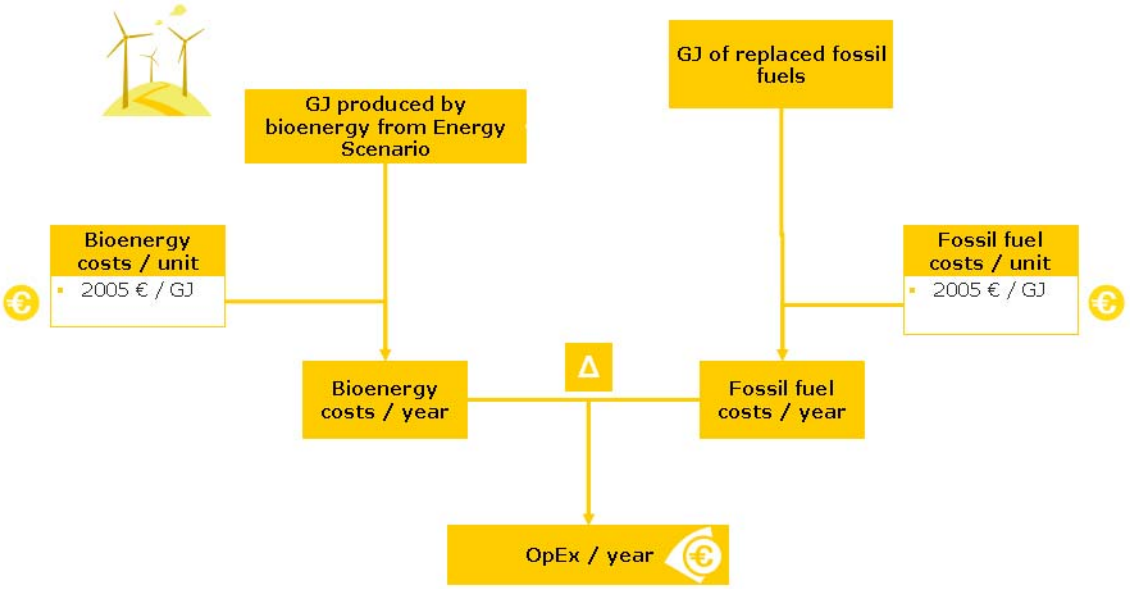

Figure 6 - 20 Approach for bioenergy.

Costs for renewable heat are taken from literature sources. OpEx costs for fuels are based on annual bioenergy supply used in the Energy Scenario, as well as bioenergy and conventional fuel prices per fuel. Biofuel prices are calculated using current average prices per fuel as a starting point, and using a growth function that relates to technological improvement due to learning, as well as lower marginal and average crop yields due to increased use of less fertile land. Bioenergy costs do not include CapEx costs for plants such as bio-refineries, as these may be balanced by reduced costs for conventional plants/refineries. Prices of saved conventional fuels for heating and fuels are taken from the main set of prices used throughout the cost calculations.

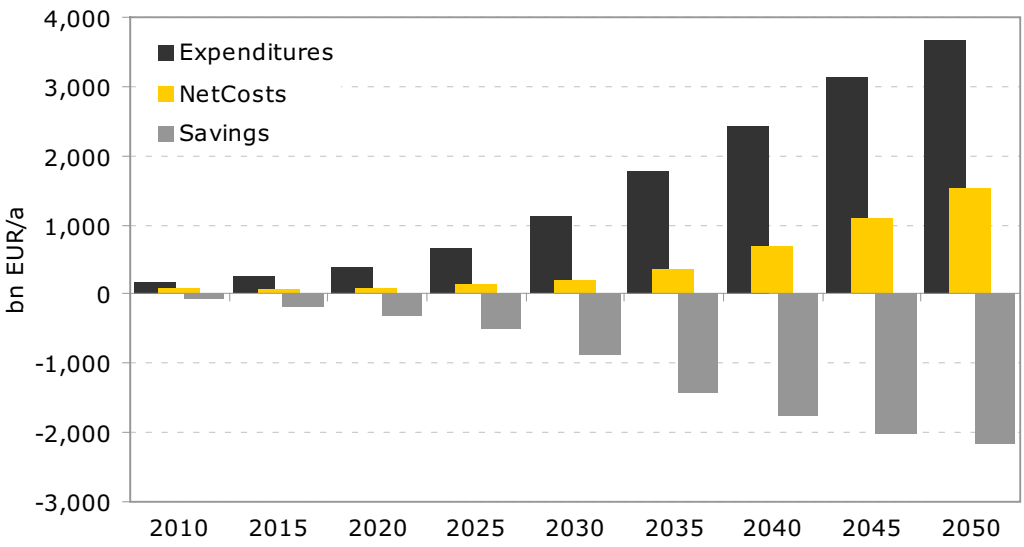

Figure 6 - 21 Results for renewable heat & fuels.

Key findings

Figure 6 - 21 shows that steadily increasing expenditures for renewable heat and fuel lead to increased net costs of 1.5 trillion EUR per year in 2050, despite increased savings. This is due primarily to the fact that bioenergy prices are modelled to increase with demand, increasing costs of marginal yield outweighing the economies of scale of a growing market. Regarding the fundamental change of bioenergy use between 2010 and 2050, these assumptions contain high uncertainties and were therefore constructed from a conservative standpoint (=high cost increases). A more optimistic view that assumes higher economies of scale and lower price increases can be expected to change the outcomes considerably.

6.9 Research & Development

Costs for research and development (R&D) include CapEx costs only. They are calculated from CapEx investment per sector and sector-specific R&D intensities. R&D investment for a given 5-year-period is based on the CapEx investment for that sector for the following period.

The specific R&D intensities by sector are assumed to be around 7% on average, depending on the sector. In accordance with necessary technological development for the Energy Scenario, we assume higher shares for

- industry
- transport (Transport – vehicle technology) and
- electricity grids sectors,

and lower intensities for

- buildings,
- infrastructure (Transport – infrastructure).
- power
- renewable heat and fuels

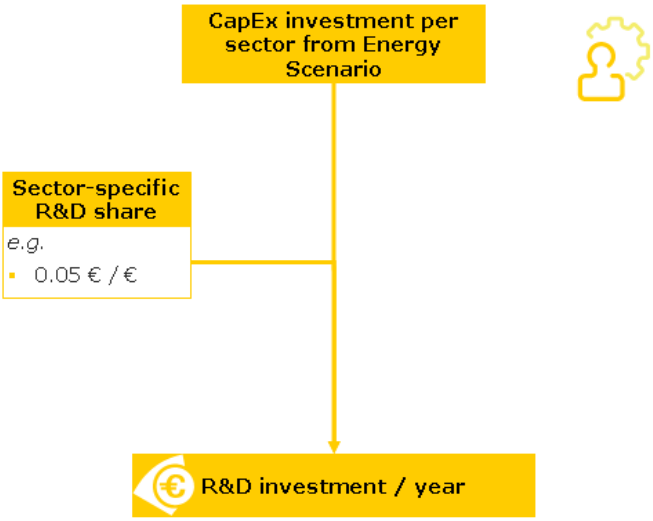

Figure 6 - 22 Approach for R&D.

Key findings

Figure 6 - 22 shows that R&D investments rise to ~170 billion EUR in 2040 and decrease slightly afterwards. They reach 155 bn EUR in 2050. Until 2025, R&D spending is largely directed to energy demand sectors, especially the transport sector. Although this sector continues to be the top recipient, R&D spending is partially shifted to energy supply sectors after 2030, particularly the power and renewable fuels.

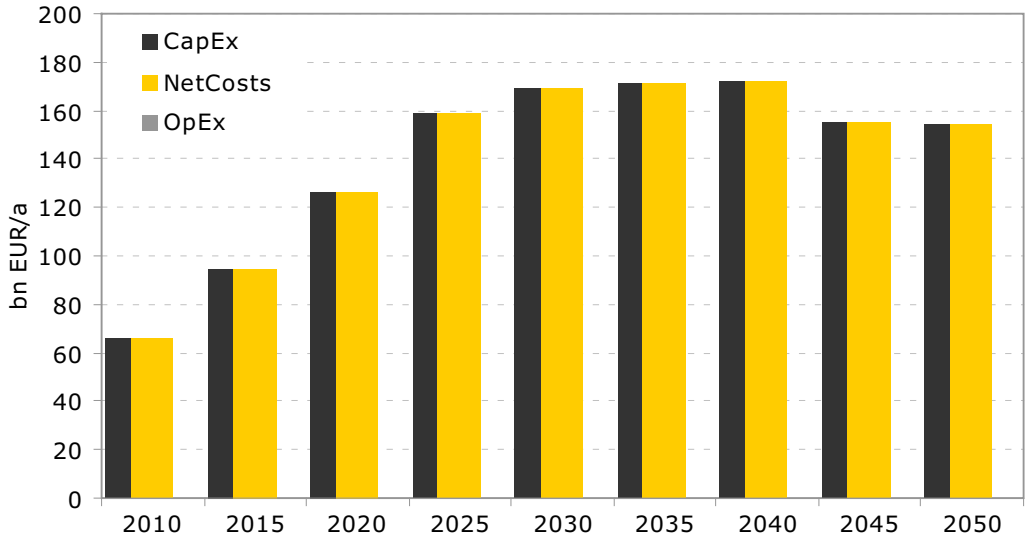

Figure 6 - 23 Results for research & development.

6.10 Sensitivity analysis on energy prices

Most of the sector approaches described above calculate OpEx costs based on fossil fuel prices. In many cases, OpEx costs consist of saved fossil fuel expenditures only.

Therefore, the set of fossil fuel prices for 2010-2050 is of significant importance for the overall results.
Price forecasts assumed here were examined against other studies and found to be comparable. A sensitivity analysis was also performed on the assumed price increases. The growth rates for the various fuels and sectors were varied by +50% and -50% for this sensitivity analysis. The resulting prices can be seen in Figure 6 - 24.

The results of the sensitivity analysis on overall Scenario costs are shown in Figure 6 - 25.[66] An increase in fossil fuel prices growth from the average annual 2% in the reference case to ~3%, leads only to small changes until 2025, but almost triples savings by 2050. In contrast, a decrease of the annual growth rate to an average of ~1.3% creates a scenario where investments outweigh savings until 2050.

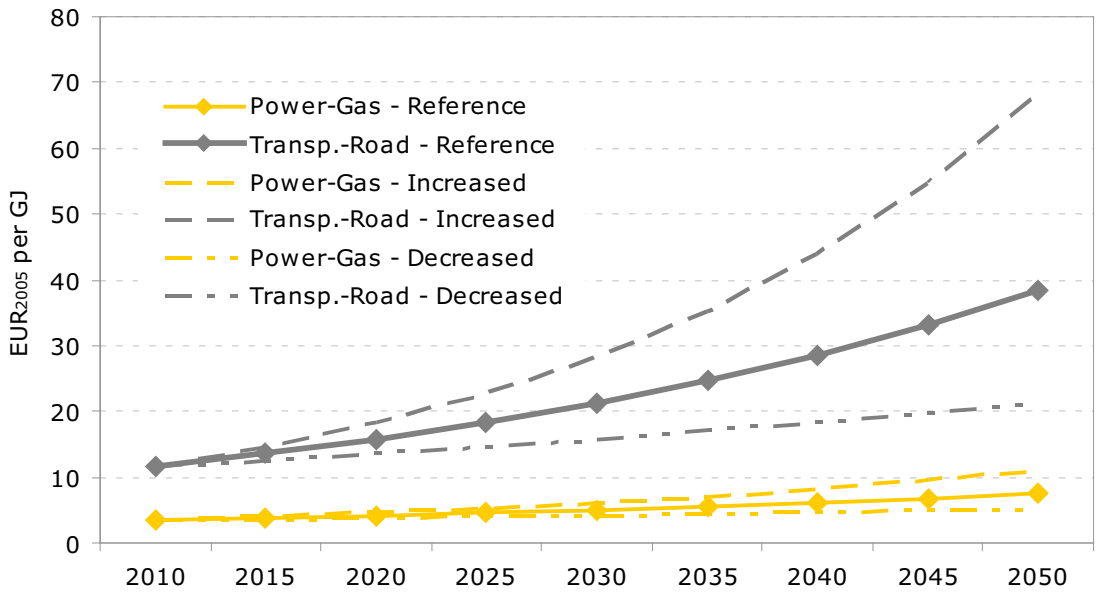

Figure 6 - 24 Energy price ranges used for the sensitivity analysis.

[66] The red columns of the reference prices-case in Figure 6 - 25 are identical with the yellow columns of total annual net results in Figure 6 - 3.

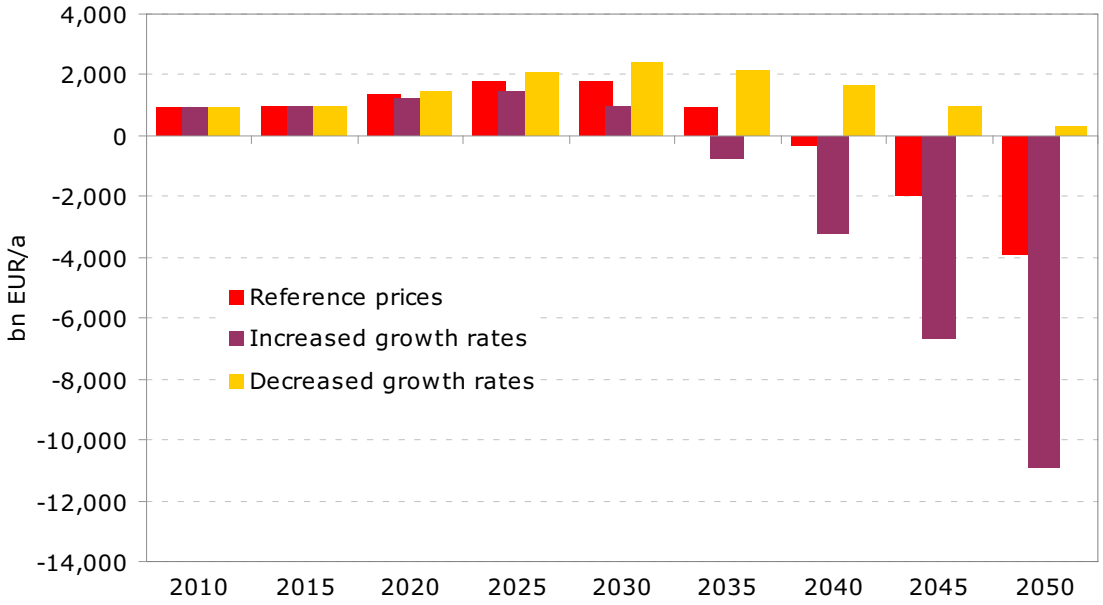

Figure 6 - 25 Net results for different energy price scenarios.

6.11 Concluding remarks

Sensitivities of results

For a correct understanding of the results of the cost calculations, the inherent uncertainties in some parameters need to be considered.

As discussed above, cost calculations for some sectors include progress ratios. These progress ratios have been estimated using literature values, Ecofys' expertise on technical potentials and developments for respective technologies, as well as all conditions related to the Energy Scenario (e.g. broad application, market trends to more efficient products, synergies from other sectors). Nevertheless, it cannot be omitted that progress ratios for certain technologies and scopes might stagnate at certain points in time or for much higher aggregated output quantities. The respective halt in price reductions would result in higher CapEx costs for most sectors. This effect might be offset by changed investment in, and development of, other technologies, e.g. if prices for PV modules cannot be reduced any further, higher investment in wind turbines may accelerate price reductions for wind power even more than estimated. In any case, future developments of progress ratios and respective market reactions are difficult to estimate.

Similar uncertainties apply to fossil and bioenergy fuel prices. In an international market, these prices depend on a sensitive balance between demand and supply. Economic cycles as well as new production routes can influence world-market prices considerably, although their influence might be relatively low in relation to overall

traded volumes. Therefore, even a small shift from low levels of surplus capacities to a relatively small amount of unmatched demand can lead to steep price increases.
It should also be noted that calculated fuel cost savings use fuel prices that are estimated within a baseline, i.e. higher dependence on and demand for fossil fuels. In this Energy Scenario, where fossil fuels are largely replaced by renewable energies, these prices could decrease considerably. However, since the costs calculated here are understood to be costs in comparison to a baseline, it is appropriate to use baseline fossil fuel prices to calculate these costs.

Conclusion

It should be taken into consideration that most cost calculations assume the most effective policies and measures will facilitate necessary changes in respective markets. This may include the application of research schemes, subsidies, additional taxes and other market-based incentive schemes. Although the Energy Scenario does not differentiate between certain groups of investors and beneficiaries, experience suggests that public funding is required in the early stages of a technology and market-based instruments that direct investment flows at later stages. The choice and implementation of policies and the resulting distribution of costs and benefits is, however, specific to sectoral, as well as national conditions and is beyond the scope of the Energy Scenario.

Perceived economic costs and benefits, both for investors and the general public are also a function of the overall economic investment climate for new technologies and infrastructures. In many countries, there is no economic or political level playing field between non-renewable and renewable energy systems. The required return on investments into a sustainable energy supply is therefore not secured, and investments into unsustainable technologies continue.

One key example is global fossil fuel subsidies. According to recent assessments by IEA and OECD [OECD, 2010], they amount to about $US 700 billion per year, representing ~20–50% of the CapEx need annually between now and 2025 for clean technologies. It is therefore important to build a level playing field. A shift of these subsidies to sustainable energy technologies could further help to mobilise the CapEx required to make the transition to the Scenario's energy system, while avoiding negative social consequences of the removal of energy subsidies.

7 Policy considerations

7.1 The need for policy

The Energy Scenario presents a radical departure from our current system of energy use. It postulates the fastest possible deployment of energy efficiency and sustainable energy options. It is clear that the current policy context would not be able to deliver on this Scenario. Instead, an adapted political and economic environment must be established to allow these developments to happen in the economic marketplace.

This will require detailed analysis of possible instruments and current best practices at regional level. In this section, we provide a brief overview and initial thoughts but this cannot replace a comprehensive analysis of policies required to deliver the Energy Scenario.

7.2 Policy objectives

The core conditions that allow the Energy Scenario to be actualised are presented in Table 7 - 1 and Table 7 - 2, and can be summarised as follows:

Public bodies at all levels have two key roles to play:

1. Creation of the correct framework for enabling the energy transition, e.g. mandating performance standards in all demand sectors, levelling the playing field for all energy sources and providing incentives for the deployment of renewable energy technologies
2. Investment in large infrastructure, particularly the public transport and power grids infrastructure, and early-stage R&D projects, to ensure continued innovation, both in demand and supply

Private actors, both consumers and companies, are also required to 'step up to the mark' by:

1. Operating under a long-term perspective, resulting in adoption of best practices in energy efficiency
2. Channelling investments into the most efficient and renewable energy options

Although a detailed policy discussion is beyond the scope of this report, we present in the following the minimum requirements the Energy Scenario asks of the policy environment in order for it to become reality.
For each key sector or sub-sector, the primary policy objective is presented, which aims to generate the pre-conditions that formed the premise for the creation of this Energy Scenario. For each objective, some possible policy design examples and potential obstacles are noted.

Table 7 - 1 Overview of critical public policy needs.

	Demand			Supply
	Buildings	**Transport**	**Industry**	
Setting consistent and ambitious regulatory **frame-works**	• Incentives to achieve **performance levels** of BAT[67] ○ In 5-10 years[68] for all new stock ○ In 20-30 years[68] for all existing stock (retrofit) • Dynamically increasing energy efficiency standards for all energy-consuming products based on BAT	• **Performance standards** on fuel efficiency for all transport modes • Incentives to shift to rail, especially for freight	• Incentives to achieve performance levels of BAT[67] ○ Now for all new plants ○ In 10-20 years[68] for all existing plants • Optimal recycling rates • Incentives to stimulate industry R & D • Research into, and deployment of, new renewable, long-lived materials	• Comprehensive, reliable and flexible support schemes to incentivise deployment of renewable energy technologies • Connection obligations for grid operators • Optimisation of planning processes • Incentives to stimulate grid infrastructure investments
Public **invest-ments**	• Investment support for building retrofits	• **Investments** into public transport, e.g. (electric) rail infrastructure	• R & D into new production processes • Recycling infrastructure	• R & D into dynamic grid stability and smart grids

[67] BAT (best available technology) in the context of buildings is understood to mean near zero-energy use buildings, akin to the passive house standard developed in Germany.

[68] Note that all time scales in this table refer to the global context. Some regions, notably industrialised regions, will be expected to move much more quickly.

Table 7 - 2 Overview of critical private sector efforts and required support policies.

	Demand			Supply
	Buildings	**Transport**	**Industry**	
Enabling private **leader-ship**	• Incorporating **highest performance levels** into all building projects	• Pushing the development and deployment of **highest performance** transport modes • Tax incentives or other financial incentives to **steer private sector investments towards plug-in hybrid and electric vehicles** (PHEV/BEV)	• Incorporating **highest performance** levels into all new plants • Improving performance of existing plants with **long-term vision**	• Pushing the **development and deployment** of renewable power sources
Directing invest-ment flows	• Public policies designed to create **leverage of private investments** through the innovation value chain of Research > Development > Demonstration > Deployment. • Emphasis on Public Private Partnerships to demonstrate, deploy and decrease costs for sustainable energy solutions. • Directing private investments to sustainable solutions by offering **low interest loans from government funds to banks.** • Raising of capital for **seed investment** in Clean Energy Technology ventures. Increasing VC funding flows to "cleantech" in early stages through **government backed match funding** that reduces risk aversion to "cleantech" on the capital market			

7.2.1 Demand

A range of demand policies would be required, to ensure ambitious energy efficiency adoption and increased electrification.
A few policy objectives and potential measures are detailed below.

In the **Buildings** sector, policy objectives include increasing the thermal efficiency of the building itself, as well as reducing energy demand from appliances and lighting.

Table 7 - 3 Demand-side policy suggestions for the Buildings sector: retrofit.

BUILDINGS	**THERMAL EFFICIENCY – RETROFIT**
POLICY OBJECTIVE	
• Retrofitting of entire existing housing stock by or before 2050, i.e. retrofit rates reaching 2–3% per year • Retrofit which results in a reduction of heat consumption by 80% or more on average and supplies the remaining demand mostly via solar thermal and heat pump systems	
EXAMPLES	**BARRIERS & THREATS**
• Public financing support initiatives • Partnerships with energy companies to finance measures via a fee on reduced energy bills	• Upfront investment support is required considering long payback times and large upfront cost • Principal agent problem[69]

Note that retrofit levels are currently 0.5–1% in most regions and therefore, the levels required in the Scenario present a considerable increase.

Table 7 - 4 Demand-side policy suggestions for the Buildings sector: new build.

BUILDINGS	**THERMAL EFFICIENCY – NEW BUILD**
POLICY OBJECTIVE	
• Progressively moving to a near-zero energy use new building standard by 2030	
EXAMPLES	**BARRIERS & THREATS**
• Ambitious building codes for new buildings • 'Walking the talk': Adopting the standard for all publicly procured buildings	• Upfront investment • Principal agent problem • Training requirements

[69] The principal agent problem, or 'landlord-tenant-problem' refers to the situation where the principal decision-maker for an investment is not the person which would benefit from the investment. This can lead to barriers to cost-effective investments being made. A classic example are energy-efficiency measures in buildings which are not owned by their occupiers: the investment has to be made by the owner, but the reduced energy bills are beneficial to the tenant.

Table 7 - 5 Demand-side policy suggestions for the Buildings sector: appliances etc.

BUILDINGS	APPLIANCES AND LIGHTING
POLICY OBJECTIVE	
• Aggressively moving to the most efficient technologies	
EXAMPLES	BARRIERS & THREATS
• Dynamically increasing energy efficiency standards based on BAT for all energy-consuming products, including lighting	• Bounded rationality[70] • Rebound effects in appliances' electricity use

In the Transport sector, there are four influential factors that apply to both passenger and freight transport and that need to be addressed by policies in this sector:

- Activity
- Structure (modal shift)
- Intensity
- Fuel

Table 7 - 6 Demand-side policy suggestions for the Transport sector: modal shift.

TRANSPORT	ACTIVITY AND STRUCTURE (INCL. MODAL SHIFT)
POLICY OBJECTIVE	
• Moving large volumes of current and future passenger travel from individual air and road modes to the most efficient modes, such as human-powered, rail or shared road modes • Moving to alternatives to provide services, such as video-conferencing for business travel and reduced commuter travel through regional planning	
EXAMPLES	BARRIERS & THREATS
• Policies delivering high-quality public transport at competitive prices • Dis-incentivising car use and incentivising other modes, e.g. congestion charging, public cycle hire schemes • Sustainable urban / land-use planning to sustain local and / or low-energy transport systems • High speed railway systems between large city centres to challenge short- and medium distance air travel	• Large investments to upgrade public transport systems • Public perception

[70] Bounded rationality is an understanding of decision-making processes that recognises that individuals or organisations may not always make the most rational choices, but rather that their decisions are highly dependent upon the information they have access to, the time they have to make the decision and even their cognitive limitations. In this context, we want to recognise that one of the barriers to the implementation of efficient appliances in households is insufficient information or simple lack of consideration.

Table 7 - 7 Demand-side policy suggestions for the Transport sector: electrification.

TRANSPORT	INTENSITY AND FUEL (INCL. ELECTRIFICATION)
POLICY OBJECTIVE	
• 100% of vehicles to be electric or plug-in hybrids before 2050 • 100% of 'last-mile' trucks to be electric before 2050 • 100% of rail transport to be electric by 2050 • Phasing in sustainably sourced biofuels (see also below)	
EXAMPLES	**BARRIERS & THREATS**
• Catalysing establishment of vehicle charging networks • Performance standards for vehicles	• Large investments to electrify rail systems, difficult in low-density regions • Investments in electric charging networks

In the **Industry** sector, many different policies can be visualised that aim at increasing both energy and material efficiency.

Table 7 - 8 Demand-side policy suggestions for the Industry sector.

INDUSTRY	ENERGY AND MATERIAL EFFICIENCY
POLICY OBJECTIVE	
• Minimise use of energy and materials for all industrial production • Re-use at the consumer end • Optimal recycling rates	
EXAMPLES	**BARRIERS & THREATS**
• Stringent performance standards for current and new installations • Re-use schemes, e.g. for glass bottles • State-of-the-art recycling infrastructures and management • New materials	• Investments required to upgrade existing installations • Investments required to increase recycling • R & D required to improve material efficiency

7.2.2 Supply side (excl. bioenergy)

Efforts are already underway in various parts of the world to spur the growth of renewable energy and the race is on to build technical expertise and capitalise on the economic and social benefits.

Table 7 - 9 Supply-side policy suggestions: renewable heat and power.

POWER	RENEWABLE HEAT AND POWER
POLICY OBJECTIVE	
• Continued rapid deployment of renewable sources for power and thermal use	
EXAMPLES	BARRIERS & THREATS
• Feed-in tariff systems to give long-term price signals • Streamlining of planning processes • R & D support	• Grid integration

As mentioned above, the key requirement for the power sector in this Energy Scenario is the readiness of power grids for a new era of a diversified power source mix.

Table 7 - 10 Supply-side policy suggestions: power grids.

POWER	POWER SYSTEM READINESS
POLICY OBJECTIVE	
• Ensure power systems are able to manage high shares of supply-driven power sources	
EXAMPLES	BARRIERS & THREATS
• Increasing transmission capacities • Provision of storage • R & D into smart power system management	• Re-thinking of power system management required • Large investments required into grid infrastructure

Rural energy supply in developing countries currently depends, to a large extent, on inefficient and pollution-heavy use of solid biomass fuel. In the Energy Scenario, the assumption is that a complete transition to a clean and efficient use of renewable energy will be made. To enable such a transition, the correct market incentives are required that, not only discourage the use of unsustainable energy, but also encourage the various uses of renewable energy. World Bank funding, ODA and other public funding can play a supporting role in this transition and should no longer be used to expand the use of fossil-based systems.

Table 7 - 11 Supply-side policy suggestions: energy transition for the rural poor.

POWER	ENERGY TRANSITION FOR THE RURAL POOR
POLICY OBJECTIVE	
• Create the right market environment for a transition to clean, reliable and affordable energy to the rural poor in developing countries	
EXAMPLES	BARRIERS & THREATS
• Direct use of solar heat • Efficient use of biomass resources	• Investment requirements • Established fossil fuel subsidies

7.2.3 Bioenergy

Section 5 of this report demonstrates that bioenergy can supply the necessary demand while being sustainable and achieving high greenhouse gas emission savings. Achieving this goal requires a strong policy framework to ensure that the bioenergy supply is developed in accordance with the sustainability criteria suggested in Section 5.2. This section provides background information and policy suggestions and examples for reaching this goal; it is not a comprehensive overview of all required policy. It is categorised around the four topics of bioenergy sustainability, (see Section 5.2):

- Land use and food security
- Agricultural and processing inputs
- Residues and waste
- Complementary fellings

Land use and food security

It is vital to provide human services such as food, animal feed, fibre, living space and energy in a sustainable way, ensuring that natural ecosystem functions are preserved. This means that international agreements must be made on land use management and agricultural policy necessary to meet this goal. These agreements need to be global and applied to all sectors, including the food sector and the chemical sector, as well as the bioenergy sector. Land use for human development should also be planned carefully to minimise expansion onto land that is highly suitable for agriculture. If only the bioenergy sector was regulated and other sectors neglected, leakage effects would occur from the bioenergy sector to the other, unregulated, sectors.

Should such agreements be made and effectively enforced globally, there would be limited need for individual sustainability certification schemes. However, certification schemes can be developed for, and applied in, the bioenergy sector complementary to policy development. This further safeguards sustainability and enhances experience with and dialogue on the topic. Table 7 - 12 provides further suggestions for, and examples of, required policy.

Table 7 - 12 Bioenergy policy suggestions and examples: land use.

BIOENERGY	LAND USE AND FOOD SECURITY
POLICY OBJECTIVE	
• Managing all new land use so that no displacement of important land functions occurs: biodiversity and ecosystem protection, carbon storage in carbon stock, human development, provision of feed, food and fibre. • Develop such a framework and accompanying certification schemes for biomass and bioenergy as a pioneer sector	
EXAMPLES	**BARRIERS & THREATS**
• International agreement on land use management • International R&D programme for sustainable agriculture • Biomass and bioenergy sustainability certification schemes complementary to policy development • For the example of sugar cane and cattle integration see Box 5 - 2	• Different national (economic) interests can slow international agreement • Need for comprehensive tracing system for bioenergy chains

Agricultural and processing inputs

Policy should be developed that provides incentives for minimising agricultural inputs and maximising recovery of these inputs. Table 7 - 13 contains further suggestions for, and examples of, such policy. In addition, policy that incentivises the deployment of renewable energy technologies should enable the nitrogen fertiliser industry to switch to sustainable energy and feedstock sources, as described in Section 5.4.

Table 7 - 13 Bioenergy policy suggestions and examples: agricultural and processing inputs.

BIOENERGY	AGRICULTURAL AND PROCESSING INPUTS
POLICY OBJECTIVE	
• Closing agricultural nutrient cycles • Closing water loops in processing plants	
EXAMPLES	**BARRIERS & THREATS**
• Incentives for minimising agricultural inputs by precision farming • Policy framework for nutrient collection from residue and waste streams	• Economic unattractiveness at low prices of agricultural fertilisers • Slow dissemination of agricultural knowledge needed for precision farming

Residues and waste

As residues and waste are a by-product of other processes, their maximum sustainable use for energy purposes is an important objective. Any policy effort should take into consideration which by-products already have another use, ensuring that the

use of residues and waste for energy purposes does not cause undesirable displacement effects. Another important aspect is to improve the infrastructure for collection of residues and waste, so that all residues and waste that are generated can be used in an efficient and cost effective way. This is summarised in Table 7 - 14.

Table 7 - 14 Bioenergy policy suggestions and examples: Residues and waste.

BIOENERGY	**RESIDUES AND WASTE**
POLICY OBJECTIVE	
• Making sustainable potential of residues and waste available for the energy sector to ensure full use of the sustainable[6] potential	
EXAMPLES	**BARRIERS & THREATS**
• Schemes incentivising the use of residues and waste for bioenergy	• Difficulty to determine definition that identifies only residues and waste materials that have no alternative use • Economic unattractiveness of residue and waste collection due to lack of infrastructure

Complementary fellings

New biomass is being created continuously in forests. A share of this growth can be harvested sustainably and used for energy purposes.

The Energy Scenario includes woody biomass from sustainable harvesting of additional forest growth and a share of biomass that was previously used as traditional biomass. This potential excludes wood from undisturbed forests and non-commercial species to safeguard forest and biodiversity conservation.

Policy concerning complementary fellings should therefore be aimed at identifying locations and amounts of forest growth that can be harvested sustainably and at ensuring that the remainder of forest is left intact. This policy approach can be complemented by certification schemes for properly managed forest resources. This is summarised in Table 7 - 15.

Table 7 - 15 Bioenergy policy suggestions and examples: Complementary fellings.

BIOENERGY	COMPLEMENTARY FELLINGS
POLICY OBJECTIVE	
• Identifying locations and amounts of forest growth that can be harvested sustainably and making sure that other forest is left intact.	
EXAMPLES	BARRIERS & THREATS
• Policy framework for sustainable management of forest resources • Certification schemes for properly managed forest resources	• Difficulty to do forest assessments and controlled harvesting, especially in remote locations

7.3 Recommendations

Although policies are necessary to address all sectors of the energy system, some policy needs are more pressing than others because they represent ***enabling factors***: failing to address them will have repercussions for the likelihood of success in one, or several, other sectors.

The two ***key enabling factors*** in this Energy Scenario are:

- Strong energy efficiency measures coupled with electrification for remaining demand.
- The preparation of our energy grids to cope with the increasing demand for renewable, often supply-driven, electricity.

In addition, a set of policy and market rules needs to be enforced, which ensures that the sustainability of biomass use for energy is safeguarded.

The remaining policy requirements cannot easily be prioritised: they all need to be addressed to allow this Scenario to become a reality and the ranking of objectives will depend strongly on the local context.
There are, however, some policies which either:

- have a long lag time to full implementation
- have effects for many decades to come,
- rely on mature technologies only, or
- have very short payback times

and could therefore be considered to warrant immediate attention. Policies in the built environment, addressing both retrofit and new build and investments in grid infrastructure could be considered to be candidates for such time critical policies.

It has been suggested that carbon pricing could deliver on all fronts because it is a single instrument that could be used to steer all sectors.[71] A silver bullet like this does

[71] Note that this is an Energy Scenario, primarily concerned with the establishment of a sustainable energy system, and only in the second instance with the reduction of

not exist. [72] In practice, a policy mix is always required to effectively incentivise the diversity of sectors and technologies. It is clear that new methods for integrating the risk and the true cost of our energy resources need to be found to ensure re-direction towards sustainable energy solutions.

The benefit of the Energy Scenario is that it could form the basis for a set of clear indicators of the impact of policies in each sector, e.g.

- What is the average amount of energy used in the economy to produce a tonne of steel?
- How far have we come in adopting 100% plug-in hybrid or electric car concept?
- What is the share of passenger travel effected via our rails rather than our roads?
- How many of our houses have been retrofitted to minimum energy standard and are we still allowing non-passive houses to be built?
- What is the share of renewable power in our local economy?
- How much of our bioenergy is sustainably sourced?

It must be stressed that many different policy designs can be envisaged and they could happen at many different levels of society; at the neighbourhood, town, regional, national or international level. Ultimately, it is not important which policy is used. The challenge is to find a set of instruments that addresses the policy needs in all sectors in a comprehensive and coordinated way. This is particularly critical if policies and measures are implemented at a regional or town level.

GHG emissions. While many policies aimed at reducing GHG emissions may also have an effect on the energy system, they often do not, and would thus miss the goal with respect to this Scenario.

[72] For example, for sectors with low price elasticity, a carbon price would not necessarily be the most effective instrument, depending on the sector and local circumstances.

8 Conclusions

A fully renewable global energy system is possible worldwide: we can reach a 95% sustainably sourced energy supply by 2050.
There are upfront investments required to make this transition in the coming decades (1–2% of global GDP), but they will turn into a positive cash flow after 2035, leading to a positive annual result of 2% of GDP in 2050.[73]

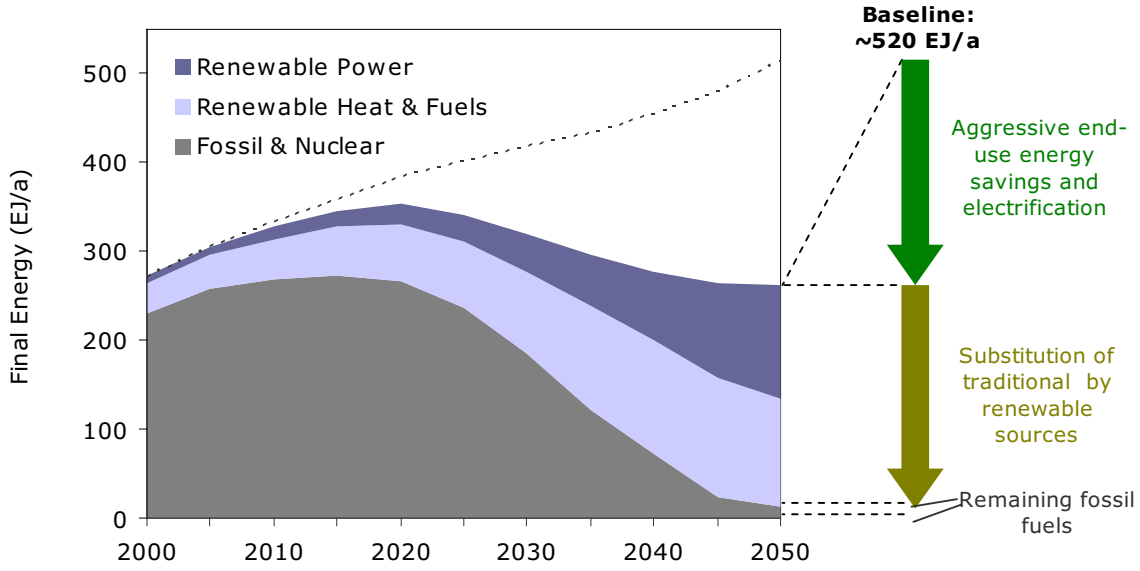

Figure 8 - 1 Evolution of energy supply in the Energy Scenario, showing the key developments.

The key challenges to achieving this transition, lie in the following factors:

- **Ambitious electrification** of all demand sectors to channel demand into electricity for which a multitude of renewable source options exist
- **Renewable fuel** supply, particularly for transport, as renewable options for fuel are limited to biomass, or hydrogen if the right infrastructure exists
- **Fast deployment** of the required technologies, fast enough to result in a fully sustainable energy system by 2050
- We can provide **enough sustainable biomass** for our fuel needs, but require
    - The land system to be suitably managed
    - Efficiency measures to be deployed at maximum rates

[73] Reductions in CO_2-emissions, during the period 2010-2050 and thereafter, represent an additional large economic value.

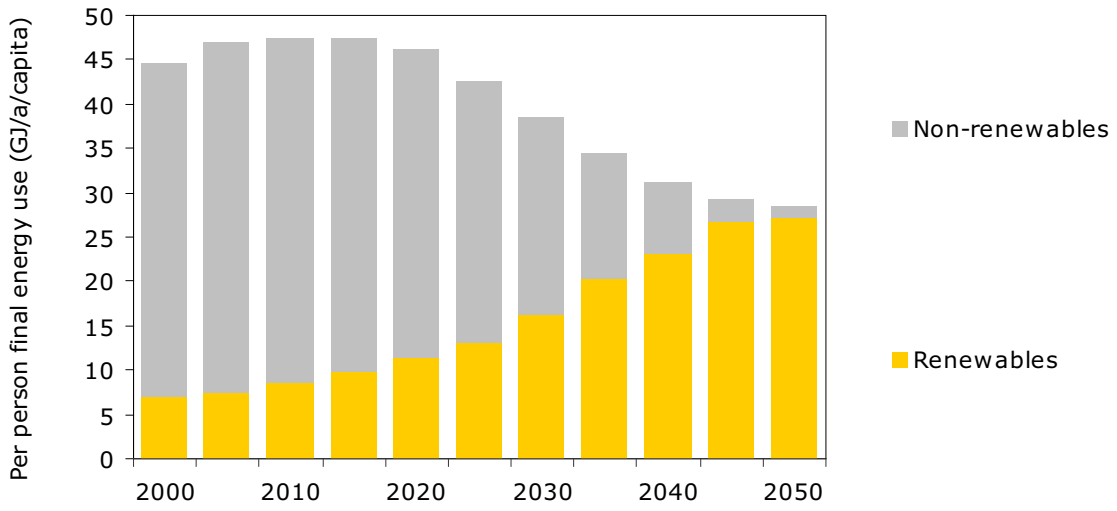

Figure 8 - 2 Evolution of per capita renewable and non-renewable energy demand.

Appendix A Key figures

Table A - 1 Global energy provided by source and year (EJ/a).

Source	2000	2010	2020	2030	2040	2050
Total electricity (EJ/a)	**45.7**	**60.0**	**71.9**	**85.7**	**103.5**	**127.4**
Wind power: On-shore	0.2	1.4	6.7	14.3	22.0	25.3
Wind power: Off-shore	0.0	0.0	0.5	1.3	3.4	6.7
Wave & Tidal	0.0	0.0	0.0	0.1	0.3	0.9
Photovoltaic solar	0.0	0.1	0.7	6.5	16.9	37.0
Concentrated solar: Power	0.0	0.1	0.6	3.9	13.7	21.6
Hydropower	7.9	11.3	13.4	14.4	14.8	14.9
Geothermal	0.1	0.3	0.7	1.7	3.4	4.9
Biomass	0.0	0.0	0.0	0.0	1.7	16.2
Coal	18.2	21.5	14.8	10.0	5.4	0.0
Gas	8.6	14.0	25.6	28.3	20.1	0.0
Oil	4.2	3.1	2.5	1.4	0.5	0.0
Nuclear	6.5	8.2	6.5	3.8	1.2	0.0
Industry fuels & heat (EJ/a)	**63.7**	**79.1**	**82.3**	**74.6**	**63.0**	**59.0**
Concentrated solar: Heat	0.0	0.0	0.1	0.4	2.6	8.8
Geothermal	0.0	0.1	0.2	0.6	1.6	2.9
Biomass	1.0	6.1	16.9	31.3	40.7	34.8
Fossil fuels	62.7	72.9	65.0	42.2	18.0	12.5
Building fuels & heat (EJ/a)	**77.7**	**86.0**	**87.4**	**67.8**	**47.4**	**24.1**
Solar thermal	0.0	0.7	3.3	11.9	16.0	12.6
Geothermal	0.2	0.5	1.5	4.1	10.5	8.4
Biomass	33.4	33.2	29.2	14.2	10.2	3.1
Fossil fuels	44.1	51.6	53.5	37.6	10.6	0.0
Transport fuels (EJ/a)	**86.2**	**102.6**	**111.6**	**91.3**	**62.3**	**50.8**
Biomass	0.7	4.8	12.9	29.7	45.7	50.8
Fossil fuels	85.5	97.8	98.8	61.7	16.6	0.0
Grand total (EJ/a)	**273.4**	**327.6**	**353.3**	**319.4**	**276.2**	**261.4**

Table A - 2 Global energy provided by source and year (EJ/a) - Percentages.

Source	2000	2010	2020	2030	2040	2050
Total electricity (EJ/a)	**45.7**	**60.0**	**71.9**	**85.7**	**103.5**	**127.4**
Wind power: On-shore	1%	2%	9%	17%	21%	20%
Wind power: Off-shore	0%	0%	1%	1%	3%	5%
Wave & Tidal	0%	0%	0%	0%	0%	1%
Photovoltaic solar	0%	0%	1%	8%	16%	29%
Concentrated solar: Power	0%	0%	1%	5%	13%	17%
Hydropower	17%	19%	19%	17%	14%	12%
Geothermal	0%	1%	1%	2%	3%	4%
Biomass	0%	0%	0%	0%	2%	13%
Coal	40%	36%	21%	12%	5%	0%
Gas	19%	23%	36%	33%	19%	0%
Oil	9%	5%	3%	2%	0%	0%
Nuclear	14%	14%	9%	4%	1%	0%
Industry fuels & heat (EJ/a)	**63.7**	**79.1**	**82.3**	**74.6**	**63.0**	**59.0**
Concentrated solar: Heat	0%	0%	0%	1%	4%	15%
Geothermal	0%	0%	0%	1%	3%	5%
Biomass	1%	8%	21%	42%	65%	59%
Fossil fuels	98%	92%	79%	57%	29%	21%
Building fuels & heat (EJ/a)	**77.7**	**86.0**	**87.4**	**67.8**	**47.4**	**24.1**
Solar thermal	0%	1%	4%	17%	34%	52%
Geothermal	0%	1%	2%	6%	22%	35%
Biomass	43%	39%	33%	21%	22%	13%
Fossil fuels	57%	60%	61%	56%	22%	0%
Transport fuels (EJ/a)	**86.2**	**102.6**	**111.6**	**91.3**	**62.3**	**50.8**
Biomass	1%	5%	12%	32%	73%	100%
Fossil fuels	99%	95%	88%	68%	27%	0%
Grand total (EJ/a)	**273.4**	**327.6**	**353.3**	**319.4**	**276.2**	**261.4**

Appendix B Demand assumptions

B 1 Industrial activity evolution

The future evolution of consumption per capita of industrial output is thought to be closely linked to GDP per capita. This relationship can be represented by, 'intensity of use' (IU) curves in which material consumption per unit of GDP is expressed as a function of GDP per capita. The intensity of use hypothesis postulates an increase in material consumption per unit of GDP with rising GDP/capita initially, followed by a decrease once an economy has developed sufficiently. The behaviour of the intensity of use curve has been observed empirically for some sectors[74] [Neelis, 2006; Groenenberg, 2002; Schenk, 2006].

As a result of technological progress, economies which develop later in time can be expected to exhibit a lower maximum point of industrial production/consumption (from [Schenk, 2006; Bernardini, 1993]). Figure B - 1 presents a stylised form of IU curves with these two elements:

- Rising intensity of use to a maximum, followed by a decrease once an economy has developed (i.e. a lot of materials are used to build the basic infrastructure of a developing economy)
- Overall lower material intensity the later an economy develops (i.e. it takes less material now to develop an economy than it did 100 years ago).

How these two elements translate into per capita consumption, is not straightforward. In accordance with [Neelis, 2006] we assume saturation of the per capita consumption in the long term.

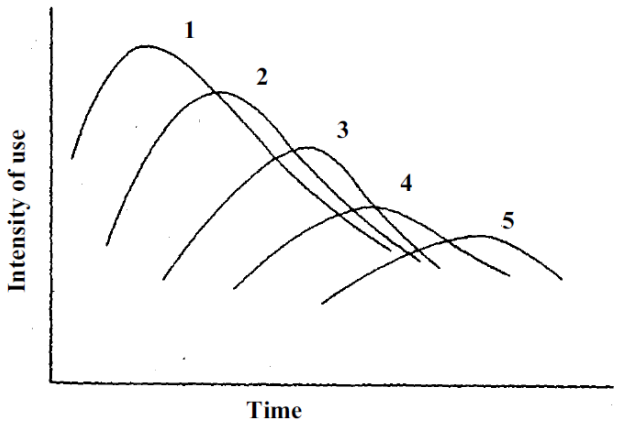

Figure B - 1 Stylised intensity of use curves (from [Bernardini, 1993]).

[74] Note that we are concerned with production in this Scenario, as it is related to energy use, whereas IU curves usually concern consumption. Since we look at the global level, the difference between these is negligible.

Although it must be noted that issues of trade, material substitution and many elements of societal change mean that these relationships are difficult to observe empirically, we have nevertheless used them to make more refined assumptions on future industrial production levels beyond simple extrapolation of historical trends.

B 2 Buildings activity evolution

The future evolution of residential floor space in the Energy Scenario is estimated by multiplying future population numbers with an estimation on future floor area per capita. The evolution of floor area per capita is thought to be closely linked to GDP per capita.

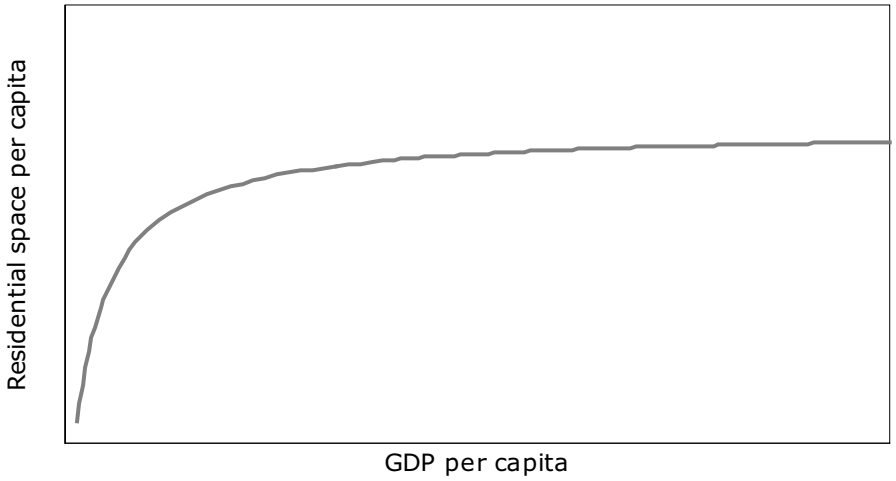

Figure B - 2 Stylised relationship between floor area and GDP per capita. [IEA, 2004]

Although reliable numbers for absolute floor space are not available for all world regions, the respective approximate growth rates of floor space per capita can be linked to such a relationship. This means that for developing regions, which are situated to the left of the curve, a larger growth rate of residential space per capita is estimated, but for developed regions, residential space per capita only grows very slowly, if at all.

Appendix C Bioenergy assumptions

The Energy Scenario uses the following primary inputs to perform the bioenergy modelling:

- The sustainable residues and waste potential described in Section 5.6. For the residue potential, estimations on the recoverable fraction of residues were used. These are specified in Appendix C 1.
- The sustainable energy crop hectare potential as described in Section 5.3.
- The sustainable complementary fellings potential as described in Section 5.5.
- The sustainable algae potential as described in Section 5.7.

To calculate the demand that can be supplied by the above, the Energy Scenario uses two additional data sources:

- The yields of the energy crops under the expected circumstances. An overview of these yields is given in Appendix C 2.
- The efficiencies of conversion technologies used in meeting the demand. An overview of these efficiencies is provided in Appendix C 3.

C 1 Recoverable fractions

We have undertaken a literature study to obtain potentials of the residues used in the Scenario. In some instances, these potentials could be found directly in literature however, in the majority of these cases, we calculated these potentials in our own analyses. In these cases, we sourced recoverable fractions (RF) from literature where possible. Ecofys expert estimates were used in case literature values were not available. Subsequently, we have adapted some of the obtained RF values to adapt them to Scenario principles and future developments.

In practice, this means that the following obstacles for residue availability were most often adapted:

- Economic feasibility: as (agricultural) infrastructure improves and the value of residues for energy purposes increases in the Scenario timeframe, economic barriers to residue collection diminish.
- Recycling of nutrients: primary agricultural residues are, in many cases, left on the land to recycle the nutrients contained in them. This practice can be adapted, according to the Scenario's framework for recycling nutrients after energy has been extracted from the residues, by returning digestate from digestion of residues to the land, for example. This means that these residues can be used to supply energy as well as recycle nutrients.

Table C - 1 provides an overview of the non-adapted RF and the adapted RF, including reasoning and sources for the values.

Table C - 1 Recoverable fractions of residues used in the Energy Scenario.

Crop	Region	Ori-ginal	Reasoning	Reference	Used here	Reasoning for change
Cereals	OECD	25%	15-25% ploughed back for sustainability reasons, use for animal bedding (estimated 30-50%), losses 10%, economically feasible/other uses 25-40%	Fischer 2007, Ericsson 2005	35%	Improved economic feasibility
	Non OECD	30%	15-25% ploughed back for sustainability reasons, use for animal bedding (estimated 20%), losses 10%, economically feasible/other uses (mainly rural electrification) 50-60%%	Fischer 2007, Lewandowski 2005, Ericsson 2005	40%	Improved economic feasibility
	China	21%	2% paper, 28% forage, 54% rural energy, 16% recycling & collection	Zeng 2007	30%	Improved economic feasibility
(Rice, as a sub-category of cereals)	All	21%	Based on cereals in China: 2% paper, 28% forage, 54% rural energy, 16% recycling & collection	Zeng 2007	30%	Improved economic feasibility
Rape-seed	OECD	25%	Equal to cereals	Fischer 2007, Ericsson 2005	35%	Improved economic feasibility
	Non OECD	30%	Equal to cereals	Fischer 2007, Lewandowski 2005, Ericsson 2005	40%	Improved economic feasibility
	China	21%	Equal to cereals	Zeng 2007	30%	Improved economic feasibility
Soy-beans	OECD	25%	Equal to cereals	Fischer 2007, Ericsson 2005	35%	Improved economic feasibility
	Non OECD	30%	Equal to cereals	Fischer 2007, Lewandowski 2005, Ericsson 2005	40%	Improved economic feasibility
	China	21%	Equal to cereals	Zeng 2007	30%	Improved economic feasibility
Cassava	All	25%	Similar to cereals, but instead of use for animal bedding there is use as animal feed and fertiliser	Fischer 2007, Ecofys expertise	50%	Improved economic feasibility; recycling of nutrients
Sugar beet	OECD	25%	Equal to cassava	Fischer 2007, Ecofys expertise	50%	Improved economic feasibility due to improved collection technology, for example; recycling of nutrients
	Non OECD	25%	Equal to cassava	Fischer 2007, Ecofys expertise	50%	Improved economic feasibility due to improved collection technology, for example; recycling of nutrients
Coffee – outer skins	All	25%	Estimate		75%	High potential economic feasibility because it is a secondary residue and because of infrastructure improvements; limited amount of competing uses
Palm oil - empty fruit bunches	All	25%	Estimate, includes return to field and incineration without energy recovery	Dehue, 2006	70%	High potential economic feasibility because it is a secondary residue Dehue, 2006 indicates that use as energy is economically more attractive than other uses.
Palm oil – Palm oil mill effluent (POME)	All	100%	Estimate based on fact that this is a waste which is collected in process water installations		100%	Estimate based on fact that this is a waste which is collected in process water installations
Sugar-cane - Bagasse	OECD	25%	Mostly used for processing plant energy demand, but less than in non-OECD regions	Maceido 2004, Damen 2001	19%	Scenario assumes maximum use for processing plant energy demand
	Non OECD	19%	Maximum use for processing plant energy demand	Maceido 2004, Damen 2001	19%	Scenario assumes maximum use for processing plant energy demand
Potatoes	OECD	25%	Estimate: secondary residue but large amount used in animal feed		50%	Secondary residue so high availability. We assumed use in animal feed is 40% and losses are 10%. Other 50% is available
	Non OECD	25%	Estimate: secondary residue but large amount used in animal feed		55%	Secondary residue so high availability. We assumed use in animal feed is 20% and losses (due to lack of infrastructure, for example) are 25%. Other 55% is available.
Animal fat	All	45%	Estimate based on European data on competing uses	Caparella 2009	45%	

C 2 Yield of energy crops

Table C - 2 Yields of energy crops used in the Energy Scenario.

Crop type	Range of yields across the regions (GJ/ha)	Comments
Oils + fats	25–35 (~0.5–1 tonne oil/ha)	• Equates to ~22-31 GJ/ha of transport fuel • Number includes ONLY primary oil yields; agricultural and fuel processing residues are included elsewhere • Marker crops: rapeseed, soybeans and oil palm
Sugar + starch	62 – 121 (~4–7 tonne of starch or sugar/ha)	• Equates to ~49-95 GJ/ha of transport fuel • Number includes ONLY primary starch/sugar yields; agricultural and fuel processing residues are included elsewhere • Marker crops: sugar cane and maize • Highest yields in South America due to suitability for sugar cane
(Ligno)cellulosic crops	160 – 230 (~8–12 tonne of dry matter/ha)	• Equates to ~61-88 GJ/ha of transport fuel • Number includes ALL primary biomass yields; fuel processing residues are included elsewhere

All yields in Table C - 2 are:

- Adapted for[75]:
  - Suitability of the sustainable land potential for growing that crop type
  - Rain-fed cultivation (no irrigation[38])
- Given in primary yield of the main product. Other biomass originating from the same hectare (e.g. the bagasse of sugar cane, the empty fruit bunches of oil palm) are included in the residues obtained during biomass processing. These are quantified in the conversion efficiencies table in Table C - 3.

C 3 Efficiencies of conversion technologies

The efficiencies of bioenergy conversion technologies used in the Energy Scenario are based on current best practices. Table C - 3 provides the used values and, if necessary, additional comments on the origin and application of these efficiency values.

All efficiencies in Table C - 3 are from primary biomass type to demand carrier. Any agricultural or processing inputs required in addition to the primary biomass type are included in the comments (e.g. processing heat and electricity, heat used for fertiliser production). Any processing residues resulting from the conversion are also included in the comments (e.g. residues such as the bagasse of sugar cane, the empty fruit

[75] Section 5.4 describes the methodology for adapting yields to land suitability for rainfed agriculture

bunches of oil palm). This should be noted when interpreting the data, for example, conversion efficiency of (ligno)cellulose through fermentation seems low, but the figure already includes all processing heat and electricity inputs.

Table C - 3 Conversion efficiencies of bioenergy technologies.

Technology	Biomass type	Conversion efficiency	Comments
Oil/fat to fuel	Oil from oil crops	88%	• Efficiency is fuel output compared to oil input • Additional inputs per MJ fuel: 0.14 MJ of heat, 0.01 MJ electricity • Additional outputs per MJ fuel: ~1.5 MJ of residues per MJ fuel
	Oil from algae	80%	• Efficiency is fuel output compared to oil input and includes processing heat and electricity inputs • Residues from algae are recycled in cultivation step
Fermentation	Starch or sugar	80%	• Efficiency is fuel output compared to sugar/starch input • Additional inputs per MJ fuel: 0.25 MJ of heat, <0.01 MJ electricity • Additional outputs per MJ fuel: ~1.4 MJ of residues per MJ fuel
	(Ligno)cellulose	39%	• Efficiency is fuel output compared to (ligno)cellulose input and includes processing heat and electricity inputs • Additional outputs per MJ fuel: ~1.0 MJ of residues per MJ fuel
Com-bustion[76]	Industrial direct fuel	100%	• The conversion efficiencies are effectively included in the industrial demand numbers • Valid for wood fuel for paper and cement kiln fuel
	Dry waste from municipal solid waste	78% (Low T heat) 73% (High T heat) 30% (Electricity)	• Low efficiencies assumed because of suboptimal fuel, suboptimal combustion process and necessary flue gas cleaning
	Other combustible biomass	95% (Low T heat) 90% (High T heat) 40% (Electricity)	• Based on current best practices
Digestion + upgrading to gas grid quality	All wet wastes	52%	• Based on 67% digestion efficiency • Reduced by losses because of gas cleaning and compression • End carrier is clean biogas which is equal to natural gas
Digestion + combustion	All wet wastes	60% (Low T heat) 57% (High T heat) 23% (Electricity)	• Based on 67% digestion efficiency • Combustion efficiency to end carrier equal to combustion of "other combustible biomass". Exception: 45% electric efficiency because gas engine can be used.
Charcoal production	All woody biomass	40%	• Based on current best practices

[76] Combustion as used here can be efficient direct combustion, but can also include gasification-based processes depending on the situation

Appendix D Sensitivity analyses on bioenergy

The Energy Scenario uses 250 Mha of land to grow bioenergy crops. A share of these crops is destined for fuel transport. It is therefore insightful to understand the relationship between transport demand assumptions and required land for bioenergy cropping.

Although a full multiple scenario analysis was beyond the scope of this work, some basic calculations have been made, based on the relative share of various demand sectors, in the total biocrop volume.

These are presented, together with the analysis on food demand and yield evolution, in Table D - 1.

Table D - 1 Basic sensitivity analysis on bioenergy from crops.

Metric	Example change	Cropland for bioenergy		Reduction in demand (EJ/a)	Equiv. area if supplied from biocrops
		available	used		
Energy Scenario (2050)		673 Mha	250 Mha		
Supply: Annual yield increase	0.4%–1.5% (instead of 1%)	300–1,080 Mha	n/a		
Demand: Animal production consumption	25%–75% instead of 50% meat consumption in OECD	350–1,270 Mha	n/a		
Balance of food demand and supply	Supply is 90%–110% of demand in 2005 instead of being equal	500–800 Mha	n/a		
Total freight transport	10% reduction	n/a	± 0 Mha*	1.6	~7 Mha
	30% reduction	n/a	± 0 Mha*	4.9	~21 Mha
Electrification of freight	50% instead of 30% electrification	n/a	± 0 Mha*	4.6	~20 Mha
Passenger air travel	10% reduction	n/a	- 4 Mha	1.4	~6 Mha
	30% reduction	n/a	- 11 Mha	4.2	~19 Mha

* by 2050 all road fuel in the Scenario is supplied from bioenergy streams other than crops

Appendix E Forestry overview

The diagram in Figure E - 1 is an overview of the flow of forest products through the global system. Additionally, it indicates which potentials of sustainable residues, waste and complementary fellings were included in the Energy Scenario biomass supply and under which conditions. In total four categories are included:

- Complementary fellings: biomass that can be sustainably harvested from additional forest growth or from biomass previously used for traditional uses. See also Section 5.5.
- Harvesting residues: residues that become available at the harvesting of fuelwood and industrial wood. 25% of these residues is deemed recoverable. See also Section 5.6.
- Processing residues: residues that become available at the processing of industrial wood, e.g. sawdust. 75% of these residues is deemed recoverable. See also Section 5.6.
- Wood waste: wood waste becoming available after use, e.g. wood waste from building demolition. See also Section 5.6.

For the latter three categories, competing demand from other sectors such as the panel board industry has been taken into consideration.

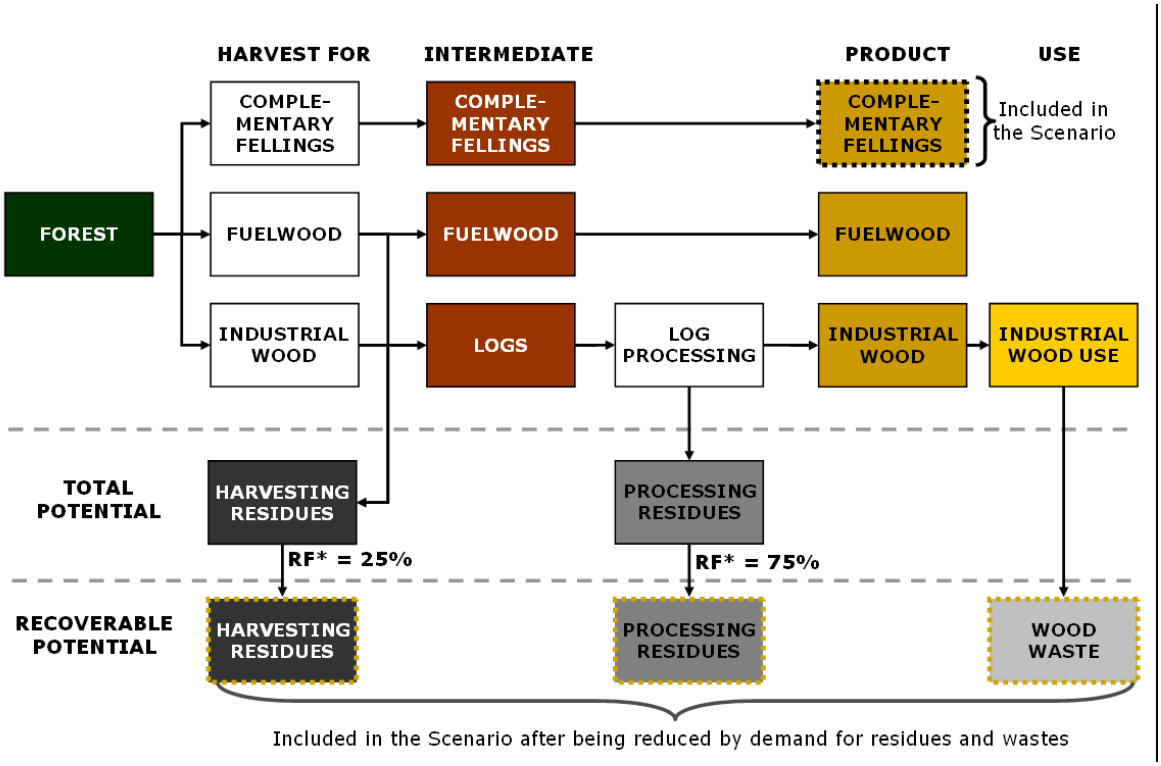

Figure E - 1 Schematic to show overview of flow of forest products into different bioenergy categories in the Scenario. (RF=recoverable fraction)

Appendix F Residues and waste categorisation overview

Figure F - 1 is a summary of residue and waste flows in the Energy Scenario. It illustrates the differentiation between primary, secondary and tertiary residues and waste made in Section 5.6.

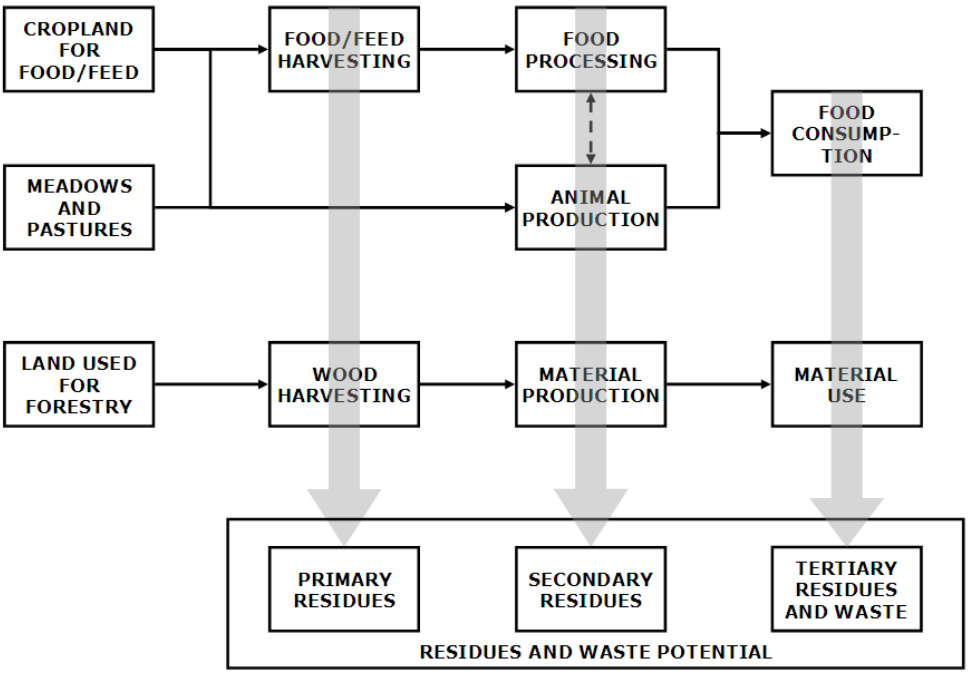

Figure F - 1 Schematic to show overview of residue and waste flows in the Scenario, differentiating between primary, secondary and tertiary residues and waste.

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Appendix H Glossary

BAT	best available technology
BAU	business as usual
CapEx	capital expenditures
CCS	carbon Capture and Storage
cleantech	collective term used to describe the ensemble of 'clean' or low-carbon / low-energy technologies
GAI	gross annual increment = equivalent to natural tree growth in a year in the forest
GDP	gross domestic product
GHG	greenhouse gas
GJ	giga joules
IEA	International Energy Agency
IU	Intensity of Use
kWh	kilo watt hour
J	joules, SI unit to express quantities of energy
Mha	mega hectare (10,000 km^2)
MWh	mega watt hour
MJ	mega joules
OpEx	operational expenditures
per capita	per person
period	period in the context of this study usually means 5-year period.
pkm	person-km (unit of activity in passenger transport)
PTW	Personal two- and three- wheelers
PHEV	Plug-in Hybrid Electric Vehicle
BEV	Battery-Electric Vehicle
region	here: region is a geographic area comprising one or several countries. The world contains 10 regions.
RES	Renewable Energy Sources
Residue	in this study: leftover biomass of production or processing of raw materials or use of products. Commonly split into primary residues of biomass production (e.g. straw), secondary residues of biomass processing (e.g. sawdust) and tertiary residues after product use (e.g. manure). Tertiary residues, especially when they no longer have an economic value, are often called waste

RF	recoverable fraction. Fraction of the totally generated residue that can be recovered for energy production.
sqm	square metres, unit used to express the amount of building area in the building sector
tkm	tonne-km (unit of activity in freight transport)
Waste	term used to refer to tertiary residues (see 'Residue'), especially when they no longer have an economic value
Wh	Watt-hours, alternative unit to measure the energy provided by electricity sources

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Others

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THE ENERGY REPORT - 100% renewable energy by 2050

FSC REPORT

A SCENARIO

Extensive electrification of transport; enhanced energy conservation; smart grids; sustainable energy for all

CHALLENGES

Conserving energy & reducing demand; electrification; equity; land/water/sea-use implications; lifestyle choices - behaviour changes & public attitudes; investment; innovation and R&D; governance

BENEFITS

Stop fossil fuel pollution; save money; address climate change; improve health; no nuclear risks; new jobs; innovation; protect nature

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A world powered by 100% renewable, sustainable energy by mid-century

SOLUTIONS

In all of our hands - policy-makers, corporate leaders, investors, communities and individuals

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