Energy [R]evolution

A SUSTAINABLE BELARUS
ENERGY OUTLOOK

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The study "Energy [R]evolution: a Sustainable Belarus Energy Outlook" was carried out in 2016 – 2018 with the support of the Heinrich Boell Foundation and in collaboration with civil society organisations, scientists and independent experts in Belarus. The report presents modelling results of the scenario on the transition of Belarus to the energy system with a high share of renewable energy and briefly describes policy decisions and technologies that can be used today to implement the Energy [R]evolution scenario.

HEINRICH BÖLL STIFTUNG

ECOHOME

GREEN NETWORK

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Foreword

Rapid climate change and negative environmental and economic consequences due to consumption of traditional energy sources pose the question on the urgent need for changes in the global energy system. Transition to renewable energy sources is an effective solution that can stabilise greenhouse gas emissions and provide additional impetus to economic growth. In addition, such a transition ensures energy independence for countries and regions. Considering a steady decline in solar, wind and other renewable technologies costs in recent years, it is not surprising that global trends indicate a continuous increase in the share of renewable energy sources.

Belarus has already taken certain steps to stimulate the development of the renewable energy sector and the implementation of energy efficiency measures. At the same time, the growth potential of the renewable energy sector in Belarus remains huge. Modelling results on the transition of Belarus to renewable energy sources presented in this report demonstrate complete feasibility of an alternative energy scenario based on sustainable development principles. We are confident that this publication will be useful to a wide range of stakeholders.

Sergej Sumlenny,
Heinrich Boell Foundation

Dear readers,

we, representatives of Belarusian environmental organisations, not only believe but also are convinced that the transition to renewable energy sources is absolutely realistic. This report presents a transition scenario, which can be implemented started from today.

Imagine our future where we will have clean air in cities, streets will be illuminated with solar energy, and transport will no longer need gasoline.

All that needs to be done is to abandon old stereotypical thinking and recognise that new technologies should not be ignored. By refusing renewable energy transition, we shift the responsibility for solving current problems to future generations. A belief that "it is enough (resources) for our century" can deprive our children of the possibility of equal development with their peers in our western country neighbours, not to mention enjoying the nature that we have.

Read this publication not as a theoretical report, but as instructions for assembling the future. While reading, start acting.

It is important to understand: the transition to renewable energy is a process that requires the will of policy-makers. We, civil society organisations, are ready to become reliable partners. This publication is our sincere and responsible contribution to the common cause.

We are pleased to present to your attention the report "Energy [R]evolution: a Sustainable Belarus Energy Outlook".

Enjoy the reading and design the future.

NGO "Ecohome",
partnership of environmental organisations
"Green Network"

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colleagues of the Center for Environmental Solutions,
representatives of the Belarusian National Platform of the Eastern Partnership Civil Society Forum.

Executive summary

An increasingly large number of civil society players, scientists, and governments worldwide view the transition from a current fossil fuel and nuclear-based energy system to a system primarily based on renewable energy sources as an ultimate solution to global climate change problem as well as local air pollution and energy security challenges.

Though it is not easy to shake conventional thinking about underpinning principles of the energy system, scenarios is a necessary tool to describe possible development paths and give decision-makers an understanding on how far they can shape the future energy system.

Inspired by the Greenpeace's Energy [R]evolution series developed for a range of countries, Heinrich Boell Foundation initiated a similar study for Belarus. This is the first time such an ambitious scenario was developed for Belarus in close consultation with scientists, experts and civil society organisations working in the field of energy and transport policy. Modelling work was carried out by the German Aerospace Center (DLR), Department of Systems Analysis and Technology Assessment at the Institute of Engineering Thermodynamics, while input data and results were reviewed by local experts.

Two scenarios are considered as alternative pathways for an energy system of Belarus in order to illustrate its potential and evaluate boundaries, in particular:

- a **Reference scenario**, reflecting a continuation of current trends and policies and
- the **Energy [R]evolution** scenario, designed to achieve a set of environmental policy targets resulting in an optimistic but still feasible pathway towards a widely decarbonized energy system until 2050 in close relation to basic framework assumptions of the Reference scenario.

In general, the Energy [R]evolution scenario by no means claims to predict the future; **it simply describes and compares potential development pathways out of the broad range of possible 'futures'**. The concept of the Energy [R]evolution scenario is designed to indicate the efforts and actions required to achieve ambitious objectives and to illustrate the options we have at hand to change our energy supply system into one that is more sustainable. At the same time, scenarios may serve as a consistent basis for further analyses of possible ways and concepts to implement pathways to an energy transition. Key results of modelling Reference and Energy [R]evolution scenarios for Belarus are presented below.

Key results

Projections on population development, GDP growth, and energy intensity determine future development pathways for Belarus's final energy demand. Under the Reference scenario, total final energy demand increases by 42% from the current 710 PJ/a to 1010 PJ/a in 2050. **In the Energy [R]evolution scenario, efficiency measures decrease final energy demand by 24% compared to current consumption to 540 PJ/a by 2050.**

Under the Energy [R]evolution scenario, due to economic growth, increasing living standards and electrification of the transport and heat sectors, overall electricity demand is expected to increase despite efficiency gains in all sectors. Total electricity demand will rise from about 30 TWh/a to 61 TWh/a by 2050 in the Energy [R]evolution scenario. **Compared to the Reference scenario, efficiency measures in the industry, residential and service sectors avoid the generation of about 20 TWh/a.**

Efficiency gains in the heating sector are even larger than in the electricity sector. Under the Energy [R]evolution scenario, consumption equivalent to about 300 PJ/a is avoided through efficiency gains by 2050 compared to the Reference scenario.

The development of the electricity supply sector is characterised by a dynamically growing wind and PV market, which more than compensate for the limited development of nuclear power in the Energy [R]evolution scenario. **By 2050, 92% of the electricity produced in Belarus will come from renewable energy sources in the Energy [R]evolution scenario.** The installed capacity of renewables will reach about 9 GW in 2030 and 50 GW by 2050.

The Energy [R]evolution scenario will lead to a high share of fluctuating power generation sources (PV & wind) of already 29% by 2030 and 77% of total generation by 2050. Therefore, smart grids, demand side management (DSM), energy storage capacities and other options need to be expanded in order to increase the flexibility of the power system for grid integration, load balancing and a secure supply of electricity.

The introduction of renewable technologies under the Energy [R]evolution scenario increases the future costs of electricity generation compared to the Reference scenario slightly in the beginning (0.1 US$ct/kWh without taking into account integration costs for storage or other load-balancing measures). **Because of increasing prices for conventional fuels and cost reduction in fluctuating renewables, electricity generation costs will become economically favourable just after 2020 under the Energy [R]evolution scenario.** By 2050, the cost will be 1.9 US$ct/kWh below those in the Reference case.

Around US$ 90 billion is required in investment for the Energy [R]evolution scenario to become a reality (including investments for replacement after the economic lifetime of the plants) – approximately US$ 2 billion per year, US$ 60 billion more than in the Reference scenario (US$ 30 billion).

Because renewable energy has no fuel costs, the fuel cost savings in the Energy [R]evolution scenario reach a total of US$ 63 billion up to 2050, US$ 1.6 billion per year. The total fuel cost savings, therefore, would cover more than the total additional investments compared to the Reference scenario.

Today, renewables meet around 10% of Belarus's energy demand for heating, the main contribution coming from the use of biomass. In the Energy [R]evolution scenario, renewables already provide 33% of Belarus's total heat demand in 2030 and 80% in 2050. **Energy efficiency measures help to reduce the currently growing energy demand for heating by 45 % in 2050** (relative to the Reference scenario), in spite of improving living standards and economic growth.

It is roughly estimated that **the Energy [R]evolution scenario in total requires around US$ 33 billion to be invested in renewable heating technologies up to 2050** (including investments for replacement after the economic lifetime of the plants) – approximately US$ 1 billion per year. Dedicated support instruments are required to ensure a dynamic development in particular for renewable technologies for buildings and renewable process heat production. For Belarus, this especially includes support to integrate solar and geothermal heat into district heat grids.

Due to GDP growth and higher living standards, energy demand from the transport sector is expected to only slightly increase in the Reference scenario by around 33% to 230 PJ/a in 2050. **In the Energy [R]evolution scenario, efficiency measures and modal shifts will save 45% (103 PJ/a) in 2050 compared to the Reference scenario.** By 2030, electricity will provide 8% of the transport sector's total energy demand in the Energy [R]evolution, while in 2050 the share will be 48%. A key target in Belarus is to introduce incentives for people to drive smaller cars and buy new, more efficient vehicle concepts. In addition, it is vital to shift transport use to efficient modes like rail, light rail, and buses, especially in the expanding metropolitan areas.

Overall, primary energy demand will decrease by 33% from today's 1010 PJ/a to around 680 PJ/a. Compared to the Reference scenario, overall primary energy demand will be reduced by 50% in 2050 under the E[R] scenario. Renewable primary energy share reaches 27% in 2030 and 80% in 2050 in the E[R]. **The share of renewables in the final energy demand is increasing from 6.8% in 2014 to 80.5% in 2050.**

Whilst Belarus`s emissions of CO2 will increase by 13% between 2014 and 2050 under the Reference scenario, **under the Energy [R]evolution scenario they will decrease from 55 million tonnes in 2014 to 8 million tonnes in 2050 and will be 93% below 1990 levels.** Annual per capita emissions will drop from 5.8 t to 0.9 t.

Abbreviations

CCS	Carbon capture and storage
CHP	Combined heat and power
CNG	Compressed natural gas
COP	Conference of the Parties
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DSM	Demand side management
E[R]	Energy [R]evolution scenario
EREC	European Renewable Energy Council
HDV	Heavy duty vehicle
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
GDP	Gross domestic product
GEF	Global Environment Facility
GHG	Greenhouse gas
GWEC	Global Wind Energy Council
IMF	International Monetary Fund
LCOE	Levelised cost of electricity
LDV	Light duty vehicle
LPG	Liquefied petroleum gas
MDV	Medium duty vehicle
NPP	Nuclear power plant
OECD	Organisation for Economic Co-operation and Development
PC	Private car
PV systems	Photovoltaic systems
PPP	Purchasing power parity
RE	Renewable energy
SPE	Solar Power Europe
SRREN	Special Report on Renewable Energy Sources
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollar
WEO	World Energy Outlook

Units of measure

EJ	exajoule
Gt	gigatonne
GW	gigawatt
km	kilometre
kW	kilowatt
kWh	kilowatt hour
MJ	megajoule
mln	million
Mt	million tonnes
MW	megawatt
Nm^3	Normal cubic meter
PJ	petajoule
p-km	passenger-km
ppm	parts per million
t	tonne
TWh	terawatt hour

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Introduction

After signing of the Paris Agreement in 2015, an increasingly large number of parties have been joining the global transition towards a 100% renewables in final consumption, which is a key to the successful implementation of the agreement. At COP 22 in Marrakesh, 48 member-states of the Climate Vulnerable Forum declared[1] their intention to achieve a 100% renewables in energy consumption. Cities and regions all over the world join this political decision and actively proceed with its implementation (including such major cities as Frankfurt, Vancouver, Copenhagen, Oslo and many others[2]). Global businesses do not stay aside and join the transition toward 100% renewable energy as well. Such companies as Apple, Google, Microsoft, IKEA, Adobe, BMW, Bank of America, eBay, Facebook, General Motors, Nike, Unilever etc. joined the RE 100[3] initiative and the progress they have made shows that the goal is achievable[4]. Thus, increasingly large number of civil society players, scientists and governments worldwide view the transition from a current fossil fuel and nuclear-based energy system to a system primarily based on renewable energy sources as an ultimate solution to global climate change problem as well as local air pollution and energy security challenges.

Though it is not easy to shake conventional thinking about underpinning principles of the energy system, scenarios is a necessary tool to describe possible development paths and give decision-makers an understanding on how far they can shape the future energy system.

Inspired by the Greenpeace's Energy [R]evolution series developed for a range of countries, Heinrich Boell Foundation initiated a similar study for Belarus. This is the first time such an ambitions scenario was developed for Belarus in close consultation with scientists, experts and civil society organisations working in the field of energy and transport policy. Modelling work was carried out by the German Aerospace Center (DLR), Department of Systems Analysis and Technology Assessment at the Institute of Engineering Thermodynamics, while input data and results were reviewed by local experts.

Two scenarios are considered as alternative pathways for an energy system of Belarus in order to illustrate its potential and evaluate boundaries, in particular:

- a **Reference scenario**, reflecting a continuation of current trends and policies and
- the **Energy [R]evolution** scenario, designed to achieve a set of environmental policy targets resulting in an optimistic but still feasible pathway towards a widely decarbonized energy system until 2050 in close relation to basic framework assumptions of the Reference scenario.

It should be noted that scenario is neither a plan nor strategy, its purpose is to broaden the boundaries of conventional energy policy. However, scenarios may serve as a consistent basis for further analyses of possible ways and concepts to implement pathways to an energy transition.

The gap between the Reference case, "business-as-usual" scenario and an ambitious Energy [R]evolution scenario illustrates the level of effort required in terms of policies and investments. Though Belarus has already achieved some progress on implementation of energy saving measures (see chapter 4.2) this study aims to encourage the government to take on more ambitious energy efficiency and renewable energy targets.

This study presents results of modelling of scenario on the transition of Belarus to an energy system with a high share of renewable energy and also outlines policy decisions and technologies available to date to make the Energy [R]evolution scenario a reality. The first chapter provides a brief information on obtained progress as well as current challenges in climate and energy policy at the global scale as well as technical and behavioural measures to reduce transport energy consumption. Energy [R]evolution concept is elucidated in chapter 2 while a review of the Greenpeace scenario projections of the past is presented in chapter 3. Chapter 4 provides an overview of climate and energy policy as well as perspectives for transport sector development of Belarus. Methodology, including scenario assumptions and data sources, is described in detail in chapter 5 while results are presented in chapter 6. A detailed overview of conventional energy technologies, as well as currently accessible renewable power, heating and cooling technologies, is provided in chapter 7. Finally, conclusions are summarised in chapter 8 followed by data tables in the Annexes.

[1] Climate Vulnerable Forum Commit to Stronger Climate Action at COP22, https://thecvf.org/cvf-2016-forum-press-release

[2] U.S. Mayors Back 100% Renewable Energy, Vow to Fill Climate Leadership Void, https://insideclimatenews.org/news/26062017/mayors-conference-supports-100-percent-renewable-energy-electric-vehicles-climate-change

[3] 111 RE100 companies have made a commitment to go '100% renewable', http://there100.org

[4] Apple moves closer to 100% renewable energy as it issues $1 billion green bond, https://9to5mac.com/2017/06/13/renewable-energy-1-billion-green-bond/

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1 Global trends in energy and transport sectors

- International climate and energy policy
- Global trends in the transport sector
- Technical and behavioural measures to reduce transport energy consumption
- Step 1: reduction of transport demand
- Step 2: changes in transport mode
- Step 3: technical efficiency improvements

Photo: ©flickr.com — National Renewable Energy Laboratory

1.1. International climate and energy policy

"Without urgent action to decarbonise our economies, climate change threats could become irreversible. Governments have agreed to keep the global average temperature rise below 2°C above pre-industrial levels. This means that global greenhouse gas emissions will have to peak and start declining before 2020 towards as close to zero as possible by mid-century" [5].

Recognising the global threats of climate change, governments adopted the UN Framework Convention on Climate Change (UNFCCC) in 1992. Since then, international cooperation on combating climate change was extended with the Kyoto Protocol agreed in 1997. The Protocol came into effect in the early 2015 and only one industrialised nation, the United States, did not ratify it[6].

In Copenhagen in 2009, 195 members of the UNFCCC were supposed to deliver a new climate change agreement. Unfortunately, they failed at this conference. At the Conference of the Parties in Durban in 2012, it was resolved to reach a new agreement by 2015[7].

In 2015, long-lasting international talks resulted in the Paris Agreement that will replace the Kyoto Protocol in 2020. The Paris Agreement is a universal agreement, which envisages that each country voluntarily will make a feasible but at the same time ambitious enough contribution to mitigating human impact on climate and adaptation to irreversible consequences of climate change.

As of September 2017, 197 countries have joined the Paris Agreement, and 166 countries have ratified this international treaty[8]. The agreement came into force in an unprecedentedly short period — less than a year after the COP 21 of the UNFCCC, 4 November 2016, demonstrating again that the global community takes its commitments seriously. However, according to the United Nations Environment Programme (UNEP), [9] even if fully implemented, current Paris commitments will result in limiting temperature increase to 3 °C by the end of the century in the best case, while the declared goal of the agreement is to keep the increase in global average temperature below 2°C. The UNEP's evaluation includes the commitments of the USA implementation of which remains uncertain. In early 2017, President Donald Trump announced the withdrawal of the United States from the Paris Agreement[10], which makes the achievement of the Paris agreement objectives even more challenging. Although the Paris Agreement requires that the commitments must be reviewed and more ambitious targets must be set every five years, the process is expected to be quite complex and will require political leadership and active actions to transform the global energy system both from the old and new leaders — the EU and China, and each party to the agreement.

Non-governmental entities are expected to play an important role in the achievement of the goals of the Paris Agreement: civil society, business, and local communities. It is the reaction of individual states and cities and large businesses in the USA to the plans of Donald Trump on withdrawal from the global agreement that offers hope that the commitments will be implemented regardless of the position of the federal government. It shows that they understand the importance and urgency of active climate action and take responsibility for their role in the global movement.

After the signing of the Paris Agreement in 2015, an increasingly large number of parties have been joining the global transition towards a 100% renewables in final consumption, which is a key to the successful implementation of the agreement. At COP 22 in Marrakesh, 48 member-states of the Climate Vulnerable Forum declared[11] their intention to achieve 100% renewables in energy consumption. Cities and regions all over the world join this political decision and actively proceed with its implementation (including such major cities as Frankfurt, Vancouver, Copenhagen, Oslo and many others[12]). Global businesses do not stay aside and join the transition toward 100% renewable energy as well. Such companies as Apple, Google, Microsoft, IKEA, Adobe, BMW, Bank of America, eBay, Facebook, General Motors, Nike, Unilever and others joined the RE 100[13] initiative and the progress they have made shows that the goal is achievable[14].

According to the International Energy Agency (IEA),[15] energy production accounts for the two-thirds of the

[5] Energy [R]evolution: a Sustainable Energy Outlook for Poland, http://www.energyblueprint.info/1821.0.html

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[10] Trump announces the US will be withdrawing from the Paris climate accord, http://www.bbc.com/russian/news-40120078

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[14] Apple moves closer to 100% renewable energy as it issues $1 billion green bond, https://9to5mac.com/2017/06/13/renewable-energy-1-billion-green-bond

[15] IEA 2015, World Energy Outlook Special Report: Energy and Climate Change, https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf

world's greenhouse-gas emissions. The achievement of goals of the Paris Agreement is therefore dependent on the transformation of the global energy system, taking into account the need to strengthen energy security and fast but socially just transition away from fossil fuels. In 2014, energy sector emissions stabilised, despite economic growth for the first time at least in the last 40 years. This tendency was observed in subsequent years as well[16]. The weakening of the relation between the economic growth and increase in energy-related emissions is due to the decline in the energy intensity of the global economy resulting from accelerated implementation of energy efficiency measures and explosive development of renewables.

Development of the renewables sector is led by China, the USA, Japan, and Germany. According to REN 21[17], newly installed renewable power generating capacity reached new record numbers in 2016: total capacity increased by more than 9% (161 GW) compared to 2015 and global renewables capacity reached 2017 GW. The largest share of new generating capacities is installed in developing countries (largely in China, the single largest developer of renewable energy in the world). Such a high growth of renewables is explained by the considerable decline in the cost of technologies. For instance, the cost of solar energy reduced to USD 0.05/kWh or even less. Moreover, renewable energy sector employed 9.8 million people in 2016.

However, the problem of energy-related emissions cannot be solved just by lowering the cost of renewables. Phase out of fossil fuels will require a much greater transformation of the energy system demanding strong political will.

1.2. Global trends in the transport sector

Economic losses, resulting from the lack of urban space, traffic jams, air pollution and health impacts, and road traffic injuries encourage municipal governments to optimize the functioning of the transport sector.

Similar to the energy sector, the transport sector in the EU countries undergo major changes that can be roughly grouped into three areas: the revolution of management strategies, the revolution of behavioural modes and revolution of technologies.

Management strategies revolution. Since the late 20th century, developed cities have been increasingly shifting from satisfying traffic demand (developing road network due to the increased number of motor vehicles) to managing it. It translates into the creation of targeted urban transport strategies and mobility plans — comprehensive documents covering all aspects of transport policy. Those strategies are implemented through the introduction of mechanisms aimed at reducing private transport use (for example, an adjustment of the tax system, paid parking, paid city entry, priority development of public transport, walking and cycling). In the world's major cities, town planning involves the improvement of access to public transport and the reduction of undesirable trips, both in number and travelling time. These plans and strategies are usually target-oriented (first, ambitious, but realistic, goals are set and then measures are defined to achieve these targets).

Implementation of the strategies and plans ultimately influences the **behaviour of people**. Urban inhabitants have been increasingly using car-sharing, cycling, and personal transport vehicles for economic and environmental reasons (i.e. to minimize adverse health effects of the transport sector). For example, in Copenhagen, it took just two years (from 2012 to 2014) for cycling trips for business purposes to increase from 36% to 45% (of total transport use)[18].

Having started ten years ago with the advent of electric cars, the **technological revolution** continues giving birth to Uber-like-taxi, car-sharing, car-pooling, bike-sharing, and quite a "zoo" of personal transport vehicles (segways, electric scooter, electric bikes etc.). New technologies that can impact demand for transportation include transportation of goods using drones, unmanned ground vehicles, 3D-printers (shifting the manufacture of products closer to consumers), the development of advanced, tailored logistic schemes (both for the delivery of goods and the disposal of waste). Unmanned electric cars are most promising for increasing the speed of transportation, reduction in the number of traffic injuries, waiting time, environmental load, parking space required, and demand for energy resources.

New technologies are undergoing their reality check and it is hard to know which of them will take the lead. It looks like each individual city will have its own "cocktail" of selected transport facilities as a function of climate, dimensions, topographic and cultural features, and the current state of urban development. There is no "one-size-fits-all recipe" for all cities or regions. However, all these trends are expected to create very good opportunities for the "greening" and quality improvement of transportations and the reduction in fuel use, both in the medium and long-term.

Future demand for transport infrastructure is influenced by a fair amount of uncertain factors such as the prev-

[16] IEA 2016, World Energy Outlook, http://www.worldenergyoutlook.org/publications/weo-2016

[17] Renewables 2017: Global Status Report, http://www.ren21.net/gsr-2017/pages/summary/summary

[18] The City of Copenhagen (2014). Copenhagen City of Cyclists: the Bicycle Account 2014. Retrieved 30.07.2017, http://www.cycling-embassy.dk/wp-content/uploads/2015/05/Copenhagens-Biycle-Account-2014.pdf

alence of distance work, the "virtualization" of life, urbanization and the popularization of living in suburbs, possible popularization of energy-intensive light aircrafts, etc. The reduction in the cost of transport services associated with their increased efficiency and the improved economic welfare of society could provoke an increase in transportations, which should be restrained by demand management mechanisms.

1.3. Technical and behavioural measures to reduce transport energy consumption

This section[19] describes technical and behavioural measures to reduce transport energy demand. Understanding people and behaviour is the key. Sustainability is about our lifestyle choices. It is about how people live their daily lives and, as humans, how we base our decisions on our surrounding environment. Most people make decisions based on what is convenient and inviting. The Energy [R]evolution transport pathways do not rely on the very few idealists who always do 'the right thing'. Therefore, cities, in particular, have to change so that making the 'right choice' will be also the 'easiest choice.'

Therefore we promote sustainable mobility via three different approaches:

1. Avoid: avoid transport where it is not necessary by embracing the 'compact city' model.
2. Shift: encourage the use of more sustainable transport (such as public transport, walking, cycling) and discourage use of private motorized transport.
3. Improve: the least efficient modes of transport (such as private cars) have to become as efficient as possible. The point of departure for an urban mobility strategic concept that promotes sustainable mobility is the quality of the public realm, with its streets and spaces that stimulate sustainable mobility choices to contribute to the quality of life — safe, economical, sustainable, inclusive (Greenpeace Germany 2015)[20]:
   - reduction of car dependency;
   - sustainable transportation modes;
   - more efficient land use by density;
   - a mixed-use development that forms mixed-modal urban hubs that are easily accessible destination points.

[19] This section is adopted from the "Energy [R]evolution: a Sustainable World Energy Outlook 2015" with the permission of the Greenpeace International.

[20] (Greenpeace Germany 2015): Greenpeace Strategy for Green Mobility; D. Moser /GPD; Gehl Architects Denmark 2015.

1.3.1. Step 1: reduction of transport demand

To use less transport overall means reducing the amount of 'passenger-km (p-km)' travelled per capita and reducing freight transport demand. The amount of freight transport is to a large extent linked to GDP development and therefore difficult to influence. However, improved logistics — for example, optimal load profiles for trucks and a shift to regionally produced goods — can reduce transport demand.

Passenger transport

Passenger transport by light-duty vehicles (LDV)[21], for example, is energy-demanding both in absolute and relative terms. Policy measures that enforce a reduction of passenger-km travelled by individual transport modes are an effective means to reduce transport energy demand. Policy measures for reducing passenger transport demand, in general, could include:

- charge and tax policies that increase transport costs for individual transport;
- price incentives for using public transport modes;
- installation or upgrading of public transport systems;
- incentives for working from home;
- stimulating the use of video conferencing in business;
- improved cycle paths in cities.

A shift from energy-intensive individual transport to low energy demand public transport goes align with an increase in low-energy public transport person-km.

Freight transport

It is difficult to estimate a reduction in freight transport. Energy [R]evolution scenarios do not include a model for reduced volume for required freight transport, but it is assumed that a modular shift from road to rail and/or to battery or fuel cell power transport vehicles takes place.

1.3.2. Step 2: changes in transport mode

Passenger transport

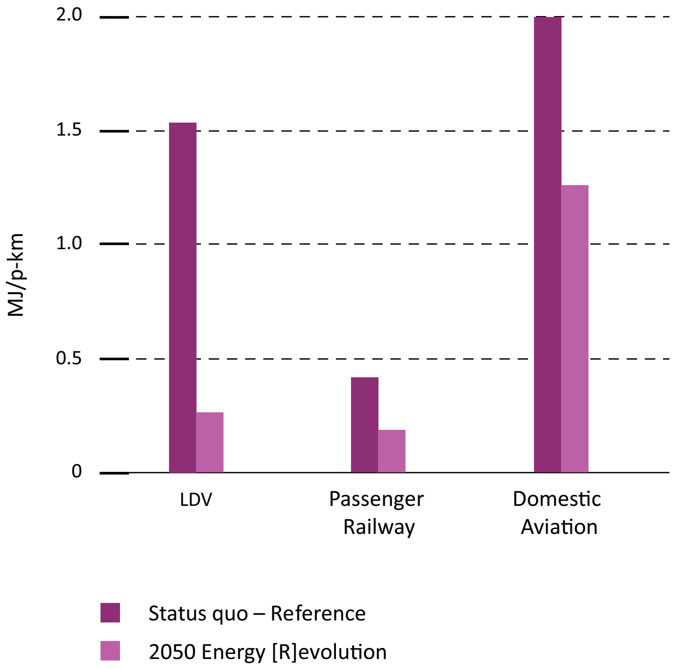
Travelling by rail is the most efficient — but car transport improves strongly. Figure 1.1 shows the worldwide average specific energy consumption (energy intensity) by transport mode in the base year and in the Energy [R]evolution scenario in 2050. This data differs for each

[21] This includes cars, small passenger vans (up to eight seats) and personal pickup trucks.

region. There is a large difference in specific energy consumption among the transport modes. Passenger transport by rail will consume 28% less energy in 2050 than car transport and 85% less than aviation on a per passenger-kilometre (p-km) basis, so shifting from road to rail can produce large energy savings.

From Figure 1.1, we can conclude that passengers will need to shift from cars and especially air transport to less energy intensive passenger rail transport in order to reduce transport energy demand. The Energy [R]evolution scenario assumes that a certain proportion of passenger-kilometre of domestic air traffic and intraregional air traffic (i. e., traffic between two countries of one IEA region) is suitable to be substituted by high-speed rail (HSR). For international aviation, there is obviously no substitution potential to other modes whatsoever.

Figure 1.1. World average (stock-weighted) passenger transport energy intensities for today and 2050



Modal shifts for transporting goods

In the Energy [R]evolution scenarios, as much road freight as possible should be shifted from road freight transport to less energy intensive freight rail to gain maximum energy savings from modal shifts.

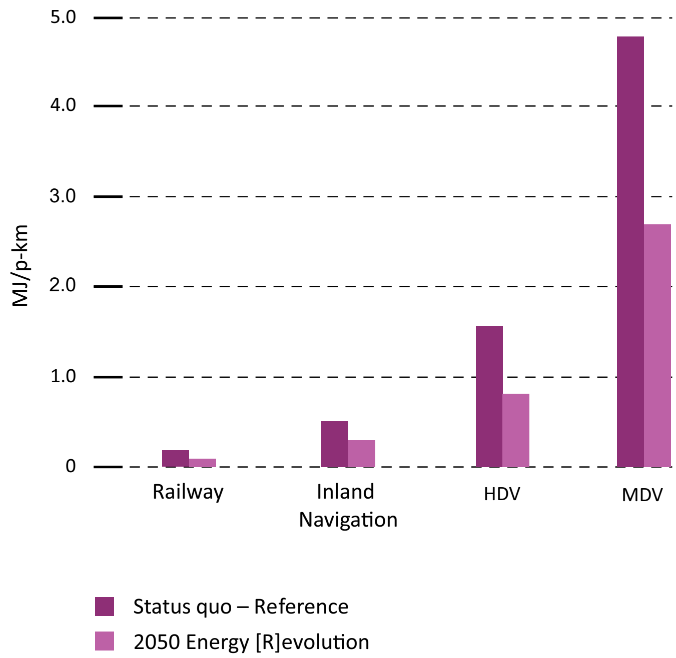
As the goods transported by medium duty vehicles are mainly going to regional destinations (and are therefore not suitable for the long distance nature of freight rail transport), no modal shift to rail is assumed for this transport type. For long-haul heavy duty vehicles transport, however, especially low value density, heavy goods that are transported on a long range are suitable for a modal shift to railways (Tavasszy 2011)[22].

[22] Tavasszy, L. and Van Meijeren, J. (2011): Modal shift target for freight transport above 300 km: an assessment, discussion paper, 17th ACEA SAG meeting.

Freight transport

Similar to Figure 1.1, which showed average specific energy consumption for passenger transport modes, Figure 1.2 shows the respective energy consumption for various freight transport modes in 2009 and in Energy [R]evolution scenarios 2050, the values are weighted according to stock and traffic performance. Energy intensity for all modes of transport is expected to decrease by 2050. In absolute terms, road transport has the largest efficiency gains whereas transport on the rail and on water remain the modes with the lowest relative energy demand per tonne-km. Rail freight transport will consume 80- 90% less energy per tonne-km in 2050 than long haul heavy duty vehicles (HDV). This means that large energy savings can be made following a shift from road to rail.

Figure 1.2. World average (stock-weighted) freight transport energy intensities for today and 2050



1.3.3. Step 3: technical efficiency improvements

Energy efficiency improvements are the third important way of reducing transport energy demand. In general, an integral part of an energy reduction scheme is an increase in the load factor — both for freight and passenger transport. As the load factor increases, fewer vehicles need to be employed, so the energy intensity decreases when measured per passenger-km or tonne-km. In aviation, there are already sophisticated efforts to optimize the load factor; however, for other modes such as road and rail freight transport there is still a room for improvement. For freight transport, logistics and supply chain planning can improve load factors, while enhanced capacity utilisation will do so in passenger transport.

Air transport

A study conducted by NASA[23] shows that the energy use of new subsonic aircrafts can be reduced by up to 58% up to 2035. Potentially, up to 81% reductions in CO_2 emissions are achievable when using biofuels. Akerman (2005)[24] reports that a 65% reduction in fuel use is technically feasible by 2050.

Technologies to reduce fuel consumption of aircrafts mainly comprise:

- Aerodynamic adaptations to reduce the drag of the aircraft, for example by improved control of laminar flow, the use of riblets and multi-functional structures, the reduction in fasteners, flap fairings and the tail size as well as advanced supercritical airfoil technologies.
- Structural technologies to reduce the weight of the aircraft while at the same time increasing stiffness. Examples include the use of new lightweight materials like advanced metals, composites and ceramics, the use of improved coatings, and the optimised design of multi-functional, integrated structures.
- Subsystem technologies, including advanced power management and generation along with optimised flight avionics and wiring.
- Propulsion technologies like advanced gas turbines for powering the aircraft more efficiently, possibly including:
  - improved combustion emission measures, improvements in cold and hot section materials, and the use of turbine blade/vane technology;
  - investigation of all-electric, fuel-cell gas turbine and electric gas turbine hybrid propulsion devices;
  - electric propulsion technologies comprise advanced lightweight motors, motor controllers and power conditioning equipment (ICAO 2008)[25].

The Energy [R]evolution scenario projects a 50% improvement in specific energy consumption on a per passenger-km basis for future aircrafts in 2050 based on today's energy intensities.

Passenger and freight trains

Transport of passengers and freight by rail is currently one of the most energy efficient means of transport. However, there is still the potential to reduce the specific energy consumption of trains. Apart from operational and policy measures to reduce energy consumption like raising the load factor of trains, technological measures to reduce the energy consumption of future trains are necessary, too. Key technologies are:

- Reducing the total weight of a train as the most significant measure to reduce traction energy consumption. By using lightweight structures and lightweight materials, the energy needed to overcome inertial and grade resistances as well as friction from tractive resistances can be reduced.
- Aerodynamic improvements to reduce aerodynamic drag, especially important when running on high velocity. A reduction of aerodynamic drag is typically achieved by streamlining the profile of the train.
- Switch from diesel-fuelled to more energy efficient electrically driven trains.
- Improvements in the traction system to further reduce frictional losses. Technical options include improvements of the major components and in energy management software.
- Regenerative braking to recover waste energy. The energy can either be transferred back into the grid or stored on board in an energy storage device. Regenerative braking is especially effective in regional traffic with frequent stops.
- Improved space utilisation to achieve more efficient energy consumption per passenger kilometre. The simplest way to achieve this is to transport more passengers per train – in other words, by a higher average load factor, more flexible and shorter train sets or by the use of double-decker trains on highly frequented routes.
- Improved accessory functions, such as for passenger comfort.

A high energy efficiency potential lies in the new design of heating and cooling equipment. Some strategies for efficiency include adjustments to cabin design, changes to air intakes, and using waste heat from traction. By researching technologies for advanced high-speed trains, the DLR's 'Next Generation Train' project aims to reduce the specific energy consumption per passenger-km by 50% relative to existing high-speed trains in the future. The Energy [R]evolution scenario uses energy intensity data of (Tosca 2011)[26] for electric and diesel fuelled trains in Europe as input for modelling scenarios. These data were available for 2009 and as forecasts for 2025 and 2050. The region-specific efficiency factors and shares of diesel/electric traction traffic performance were used to calculate energy

[23] Bradley, M. and Droney, C. (2011): Subsonic Ultra Green Aircraft Research: Phase I Final Report, issued by NASA.

[24] Akerman, J. (2005): Sustainable air transport – on track in 2050. Transportation research part d, 10, 111-126.

[25] (ICAO 2008): Committee on aviation environmental protection (CAEP), steering group meeting, FESG CAEP/8 traffic and fleet forecasts.

[26] Tosca (2011): Technology opportunities and strategies toward climate-friendly transport (reports).

intensity data per region (MJ/p-km) for 2012 and up to 2050. The same methodology was applied for rail freight transport. Electric trains as of today are about 2 to 3.5 times less energy-intensive than diesel trains depending on the specific type of rail transport, so the projections to 2050 include a massive shift away from diesel to electric traction in the Energy [R]evolution 2050 scenarios.

Heavy and medium duty vehicles (freight by road)

Freight transport on the road forms the backbone of logistics in many regions of the world. However, apart from air freight transport, it is the most energy-intensive way of moving goods around. However, gradual progress is being made in the fields of drivetrain efficiency, lightweight construction, alternative power trains and fuels and so on.

A major shift in the drivetrain market share of medium (MDV) and heavy duty vehicles (HDV) is envisioned in the Energy [R]evolution scenarios in the future. Today, the great majority of MDVs and HDVs have internal combustion engines, fuelled mainly by diesel and in MDV also by a small share of gasoline and gas (CNG and LPG). The Energy [R]evolution model includes a major shift to electric and fuel cell hydrogen powered vehicles by 2050.

The electric MDV stock in the model developed by (DLR 2012) is mainly composed of battery electric vehicles and a relevant share of hybrid electric vehicles. Hybrid electric vehicles will have also displaced conventional internal combustion engines in heavy duty vehicles. In addition to this, both electric vehicles supplied with current via overhead catenary lines and BEVs are modelled in the Energy [R]evolution scenario for HDV applications.

In addition to the electric truck fleet in the Energy [R]evolution scenario, HDV and MDV powered by fuel cells (FCV) were integrated into the vehicle stock, too. FCV are beneficial especially for long haul transports where no overhead catenary lines are available and the driving range of BEV would not be sufficient. Energy [R]evolution fleet average transport energy intensities for MDV and HDV were derived using region-specific IEA energy intensity data of MDV and HDV transport by 2050 (WBSCD 2004)[27].

Passenger cars

Many technologies can be used to improve the fuel efficiency of passenger cars. Examples include improvements in engines, weight reduction as well as friction and drag reduction. The impact of the various measures on fuel efficiency can be substantial. Table 1.1 summarises the energy efficiency improvement for passenger transport in the Energy [R]evolution 2050 scenario. The table shows that the potential for energy efficiency improvements ranges from 30% to 500% depending on the mode of transport. The greatest progress could be achieved in private cars and light duty vehicles. The transport sector in Belarus has a similar technological potential as Belarus imports ready assembled cars and produces commercial and passenger vehicles with performance characteristics comparable to European ones.

Table 1.1. Technical efficiency potential for world passenger transport

MJ/p-km	Status quo	E[R] 2050
LDV	1.5	0.3
Air (domestic)	2.5	1.2
Buses	0.5	0.3
Mini-busses	0.5	0.3
Two-wheels	0.5	0.3
Three-wheels	0.7	0.5
Passenger rail	0.4	0.2

[27] (WBSCD 2004) World Business Council for Sustainable Development.

2 The Energy [R]evolution concept

- Setting up an Energy [R]evolution scenario
- The Energy [R]evolution logic
- The "5 step implementation"
- Step 1: Energy efficiency and equity
- Step 2: The renewable energy revolution
- Step 3: The transport revolution
- Step 4: Smart infrastructure to secure renewables 24/7
- Step 5: New policies to enable new business models

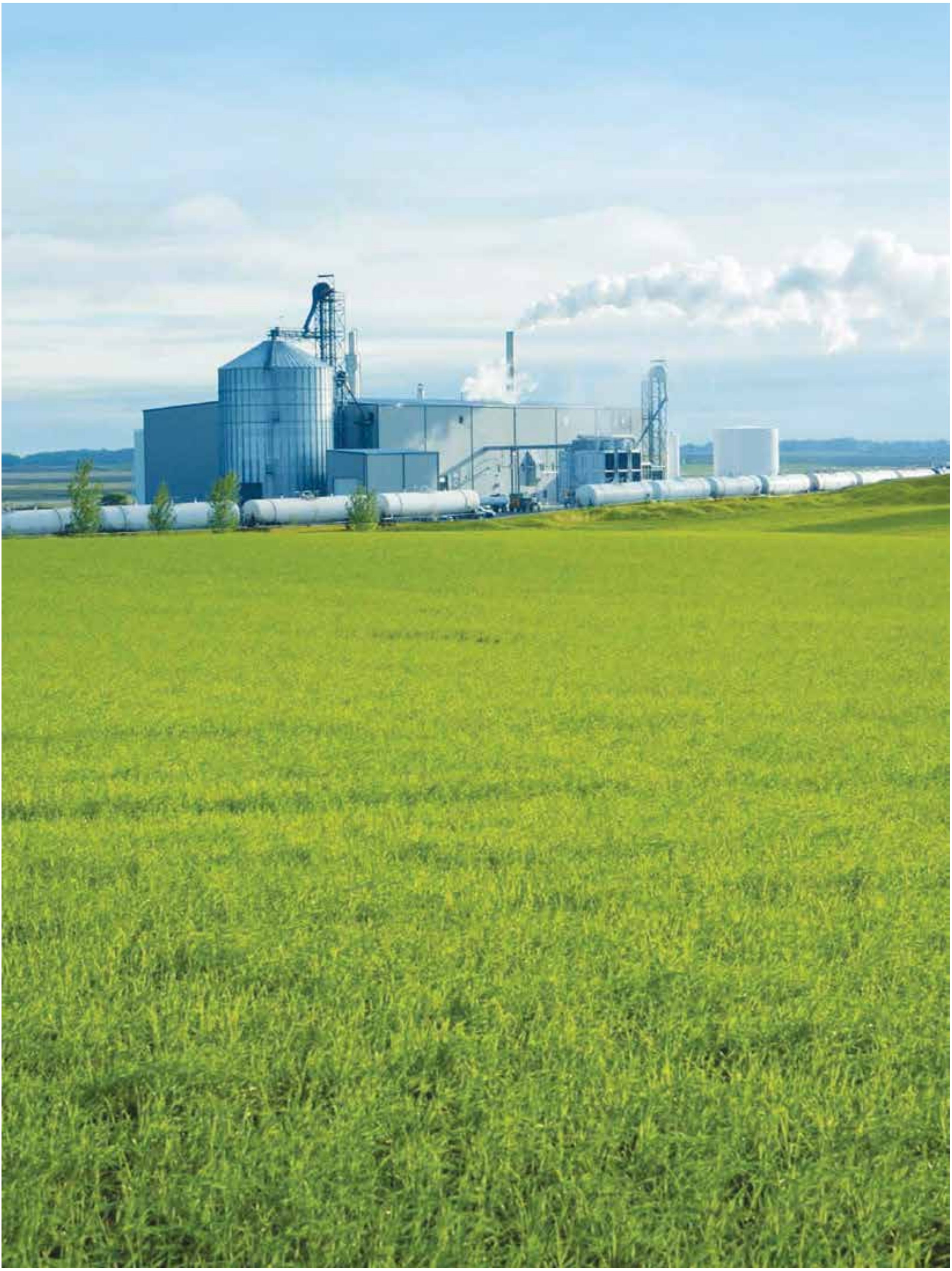


Photo: ©flickr.com — Jim Parkin

2.1. Setting up an Energy [R]evolution scenario

This section[28] explains the basic principles and strategic approach of the development of the Energy [R]evolution concept, which have served as a basis for the scenario modelling since the very first Energy [R]evolution scenario published by the Greenpeace International in 2005. The Energy [R]evolution scenario series for different countries and regions follows a "seven-step logic", which stretches from the evaluation of natural resource limits to key drivers for energy demand and energy efficiency potentials, an analysis of available technologies and their market development potential, and specific policy measures required to implement a theoretical concept on real markets. This concept, however, has been constantly improved as technologies develop and new technical and economical possibilities emerge.

The seven steps are:

1. define natural limits for the climate and fuel resources;
2. define renewable energy resource limits;
3. identify drivers for demand;
4. define efficiency potentials by sector;
5. establish timelines for implementation;
6. identify required infrastructure;
7. identify required policies.

2.2. The Energy [R]evolution logic

1. Define natural limits

The phase-out cascade for fossil fuels. Geological resources of coal could provide several hundred years of fuel, but we cannot burn them and keep within safe climate change limits. Thus, lignite as the most carbon intensive coal — must be phased-out first, followed by hard coal. The use of oil will be phased out in the pace of production depletion of existing oil wells, and no new deep sea and Arctic/Antarctic oil wells will be opened. Gas production follows the same logic as oil and will be phased out as the last fossil fuel.

Reduce energy-related carbon dioxide to zero by mid-century. There is only so much carbon that the atmosphere can absorb. Each year we emit almost 30 billion tonnes of carbon equivalents. The Energy [R]evolution scenario has a target to phase-out energy-related CO2 emissions by 2050. In addition, the regional transition towards carbon-free energy supply aims to achieve energy equity — shifting towards a fairer worldwide distribution of efficiently-used supply — as soon as technically possible. By 2040, the average per capita emission should be between 0.5 and 1 tonne of CO2.

2. Define renewable energy resource limits

Renewable energy resource — mapping the future energy mix. The 5 renewable energy resources (solar, wind, hydro, geothermal and ocean) are available in different quantities — both by region across the globe and by season. Specific renewable energy potential maps are available from a number of scientific research institutions for each country around the world. The German Aerospace Centre takes part in the global mapping project of the International Renewable Energy Agency (IRENA), which provides detailed data for all renewable energy resources (IRENA-Global Atlas 2015)[29]. The various regional renewable energy resources influence the projected energy mix in Energy [R]evolution scenarios. Review of renewable energy potential available in Belarus is provided in the chapter 5.2.6.

Bioenergy — an important resource with limited sustainable potential. Bioenergy is needed for fossil fuel replacement where no other technical alternative is available. Energy [R]evolution scenarios use bioenergy especially for industrial process heat, aviation, shipping and heavy machinery. Greenpeace identified the sustainable bioenergy potential globally in a scientific survey in 2008 at around 80 to maximum 100 EJ per year (DBFZ 2008)[30]. The overall sustainable bioenergy potential is, however, subject to change due to technical and scientific development and/or change of usage. An increased use of biomass for plastics, for example, would reduce the resources available for energy conversion.

3. Identify drivers for demand

Equity and fair access to energy for all. A focus for future energy demand projections lies on a fair distribution of benefits and costs between nations, and between the present and future generations. At one extreme, a third of the world's population has no access to electricity, whilst the most industrialised coun-

[28] This section is adopted from the relevant chapter of the "Energy [R]evolution: a Sustainable World Energy Outlook 2015" with the permission of the Greenpeace International.

[29] (IRENA-Global Atlas 2015) Global Atlas for Renewable Energy; International Renewable Energy Agency (IRENA); Abu Dhabi /UAE; Bonn/Germany; http://irena.masdar.ac.ae/#; July 2015.

[30] (DBFZ 2008); Global biomass potentials — investigation and assessment of data — remote sensing in biomass potential research — country specific energy crop potential; Seidenberger et. al; Deutsches Biomasseforschungszentrum; Leipzig/Germany, June 2008.

tries consume much more than their fair share. The Energy [R]evolution concept aims to supply energy for an equal living standard for every person by 2050 if required economic development is believed to take place.

Decouple growth from fossil fuel use. The projections for economic growth are based on the International Energy Agencies (IEA) World Energy Outlook projections. Starting in the developed countries, economic growth must be fully decoupled from fossil fuel usage. It is a fallacy to suggest that economic growth must be predicated on increased fossil fuel combustion.

4. Define efficiency potentials by sector

Energy not used is the cheapest; smart use of energy needed. Electrical appliances, industrial process, heating and cooling of buildings, and all forms of transport technologies still have significant efficiency potential. The latest available technologies in all sectors are implemented within the range of normal replacement rates. Energy [R]evolution scenarios focus on efficiency rather than sufficiency in the power and heating/cooling sector. The transport sector requires sufficiency especially in regard to usage of individual cars and aviation. A modular shift from road to rail and from air to rail where ever possible as an example of sufficiency.

5. Establish timelines for implementation

There is no renewable energy shortage as such. The sun sends more energy to the earth surface per day than we consume each year. However, renewable energy technologies need to be engineered, installed, and operated, which requires skilled labour, financial resources and adapted energy policies. The transition from a fossil to a largely renewable energy supply system will take time. Energy [R]evolution scenarios take past experiences into account in determining how fast renewable energy technologies can scale up. In particular, the experience of Denmark, Germany and China during the last decade showed that a certain time is needed to train workers and set up required industries and infrastructure. An overheated renewable industry with low-quality products does more damage than good to a long-term transition. Thus, Energy [R]evolution scenarios are ambitious but not unrealistic. The first decade of RE development pathways are based on industries projections such as from the Global Wind Energy Council (GWEC 2015)[31] and Solar Power Europe (SPE 2015)[32].

[31] (GWEC 2015) Global Wind Report: Annual Market Update; Market Projection 2015 – 2019; Brussels/Belgium; May 2015.

[32] (SPE 2015) Global Market Outlook for Solar Power 2015–2019; Solar Power Europe; Brussels/Belgium; May 2015.

6. Identify required infrastructure

Smart grids are key, as is solar and wind power integration. Increased shares of distributed solar photovoltaic and onshore wind in distribution and medium voltage grids and offshore wind and concentrated solar power generation connected to transmission grids require the development of infrastructure, both for the physical setup and for management (Brown et. al. 2014)[33]. Also, the distribution of generation capacities across different voltage levels has a significant influence on required grid expansion and/or dispatch capacities (Teske 2015)[34]. Existing gas pipelines and storage facilities might be available for the transport and storage of renewable hydrogen and/or methane. Existing gas power plants can, therefore, be used as dispatch plants to avoid stranded investments.

Storage – the next big thing. The development of electric vehicles has triggered more research in storage technologies, especially batteries. Increased shares of wind and solar caused another wave of research and market development for storage technologies, such as hydrogen, renewable methane and pumped hydropower plants. Storage technologies have thus improved significantly. Energy [R]evolution scenarios, however, aim to minimize storage needs for the next decade as costs are expected to remain high for that time frame. In the medium to long term, storage technologies are needed especially to replace fossil fuels with electricity in the transport sector.

7. Identify required policies

New energy markets need new energy policies. Climate and energy policy need to go hand in hand. The UNFCCC process (see chapter 1.1) is key to protect the global climate, just as national energy policies are key to implement the required emission reduction with renewables and energy efficiency. The Energy [R]evolution scenarios are based on the experience documented in policy analysis, such as from REN 21[35], IRENA[36] and the IEA.

[33] (Brown et. al. 2014) Optimising the European Transmission System for 77% renewables by 2030; Tom Brown, Peter-Philipp Schierhorn, Eckehard Tröster, Thomas Ackermann; Energynautics GMBH, Robert-Boschstrasse 7, 64293 Darmstadt, Germany.

[34] Teske (2015). Bridging the gap between energy- and grid models – developing an integrated infrastructural planning model for 100% renewable energy systems in order to optimize the interaction of flexible power generation, smart grids and storage technologies; dissertation; Europa Universität Flensburg/Germany, Sven Teske Dr. rer pol; dipl.-ing.; June 2015.

[35] REN21 (2015). Renewables 2015 Global Status Report, Paris: ch. 4; REN 21 Secretariat; www.ren21.net; ISBN 978-3-9815934-6-4.

[36] IRENA (2015). Renewable energy target setting, International Renewable Energy Agency; June 2015,

http://www.irena.org/documentdownloads/publications/irena_re_target_setting_2015.pdf

2.3. The "5 step implementation"

In 2015, renewable energy sources accounted for 19% of the world's final energy demand (see Figure 2.1). Modern renewables, such as solar, wind and geothermal energy, accounted for 10%, while traditional biomass contributed 9%. The latter often causes environmental damage and thus need to be replaced with new renewables as well. The share of renewable energy in electricity generation was 24.5% in 2015, a 4% increase over the past 6 years. About 78% of primary energy supply today still comes from fossil fuels – a decrease of about 2% over the past 6 years.

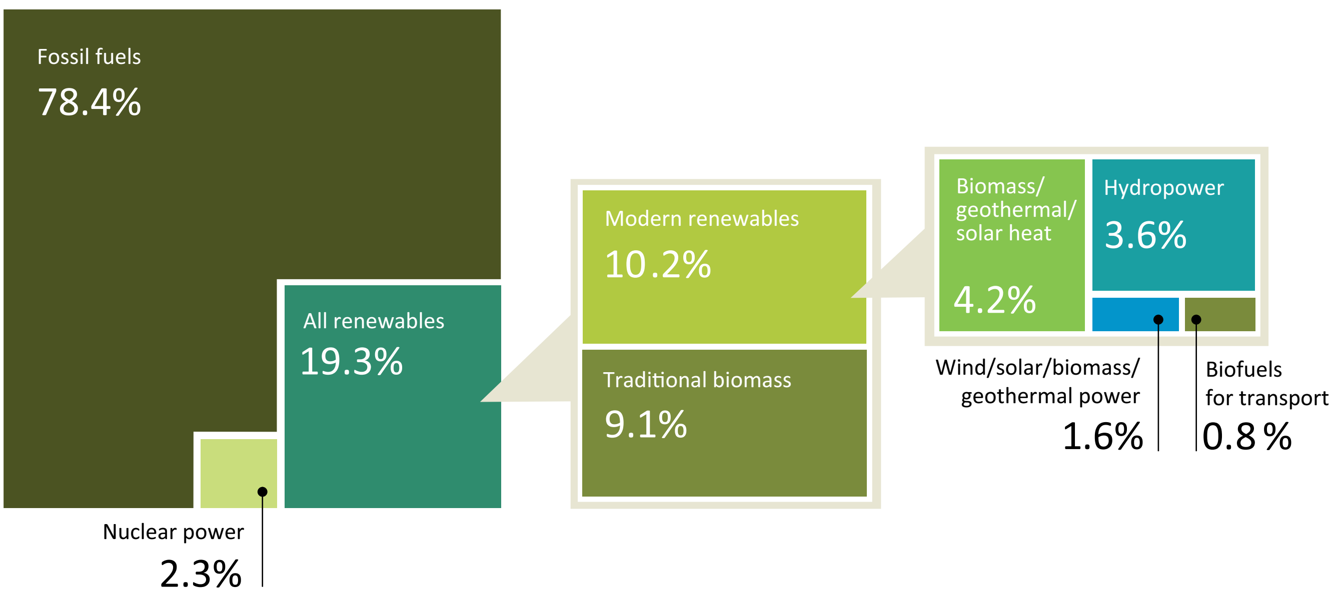
Worldwide, there is good news: PV and wind are growing strongly. In 2016, the largest ever annual increase of renewable capacity was observed (about 161 GW, 9% increase compared to 2015) of which solar energy accounted for 47% while wind and hydropower 34% and 15.5%, respectively. Total renewable capacity reached 2017 GW by the end of 2016. Overall, annual growth in renewable capacity is larger than annual additions in (net) fossil fuels capacity combined.

Within this decade, the power sector will decide how new electricity demand will be met, either by fossil and nuclear fuels or by the efficient use of renewable energy. The Energy [R]evolution scenario puts forwards a policy and technical model for renewable energy and cogeneration combined with energy efficiency to meet the world's needs.

Renewable energy and cogeneration – both as central-station power plants and distributed units – have to grow faster than overall global energy demand. Both approaches must replace old generating technologies and deliver the additional energy required in the developing world.

A transitional phase is required to build up the necessary infrastructure because it is not possible to switch directly from a large-scale fossil and nuclear energy system to a fully renewable energy supply. It should be noted that conventional natural gas, used in appropriately scaled cogeneration plants, is valuable as a transition fuel, and can also drive cost-effective decentralisation of the energy infrastructure. With warmer summers, tri-generation – which incorporates heat-fired absorption chillers to deliver cooling capacity in addition to heat and power – will become a valuable means of achieving emissions reductions. The Energy [R]evolution envisages a development pathway away from the present energy supply structure and towards a sustainable system.

Figure 2.1. Estimated renewable energy share of global final energy consumption in 2015



Source: REN21-2017.

2.3.1. Step 1: Energy efficiency and equity

The Energy [R]evolution requires an ambitious exploitation of energy efficiency. The focus is on current best practices and products, along with probable future technologies, assuming continuous innovation. The energy savings are fairly equally distributed over the three sectors industry, transport and domestic/business. Intelligent use, not abstinence, is the basic philosophy.

The most important energy saving options are improved heat insulation and building design, super-efficient electrical machines and drives, replacement of old style electrical heating systems by renewable heat production (such as solar collectors) and a reduction in energy consumption by vehicles used for goods and passenger traffic.

By the end of this decade, new buildings in Europe will have to be "nearly zero-carbon," which is an excellent step forward, though it comes a bit late — Passive House architecture was proven two decades ago. This energy efficient architecture can be used worldwide in almost all climates, both to reduce heating demand (such as in southern Canadian cities) as well as cooling demand (from Las Vegas to Dubai). However, the greatest gains are to be made not in new buildings, but in renovations. Here, governments must speed up the renovation rate of existing building stock, and all renovations must be ambitious in light of long building service lives. Moreover, the comfort gains from such architecture make these buildings a pleasure to live and work in; here, intelligent energy use is clearly about better living, not abstinence.

A dramatic reduction in primary energy demand compared to the Reference scenario — but with the same GDP and population development — is a crucial prerequisite for achieving a significant share of renewable energy sources in the overall energy supply, compensating for the phasing out of nuclear energy and reduction in fossil fuel consumption.

2.3.2. Step 2: The renewable energy revolution

Decentralised energy and large-scale renewables

Decentralised energy is connected to a local distribution network system, to which homes, offices, and small businesses are generally connected. Energy [R]evolution scenarios make extensive use of Distributed Energy (DE): energy generated at or near the point of use. We define distributed power generation as applications connected to low-and medium-voltage power lines with an average transport distance from several hundred meters up to around 100 kilometres. Several different distributed power plant technologies are available: solar photovoltaics, onshore wind turbines, run-of-river hydropower plants, bioenergy and geothermal power plants, and potentially near-shore ocean energy plants.

The dominant renewable electricity source is now wind power, but photovoltaics will catch up in the future. Significant cost reduction of solar photovoltaic roof-top systems is leading to "grid parity" in almost all industrialized countries. Households and small businesses can then produce their own solar power for the same or a lower cost than rates for grid electricity; onsite power generation — a term usually used for the industry — now makes economic sense for the private sector.

Distributed energy also includes stand-alone systems for heating/cooling either connected to district heating networks or for a single building supply, such as solar thermal collectors, bioenergy heat systems and (geothermal) heat pumps. A hybrid between renewables and energy efficiency, heat pumps convert one unit of electricity into up to 4 units of heat.

All these decentralized technologies can be commercialized for domestic users to provide sustainable, low-carbon energy. Increased shares of distributed generation technologies require adapted energy policies for "prosumers" — consumers who produce own energy.

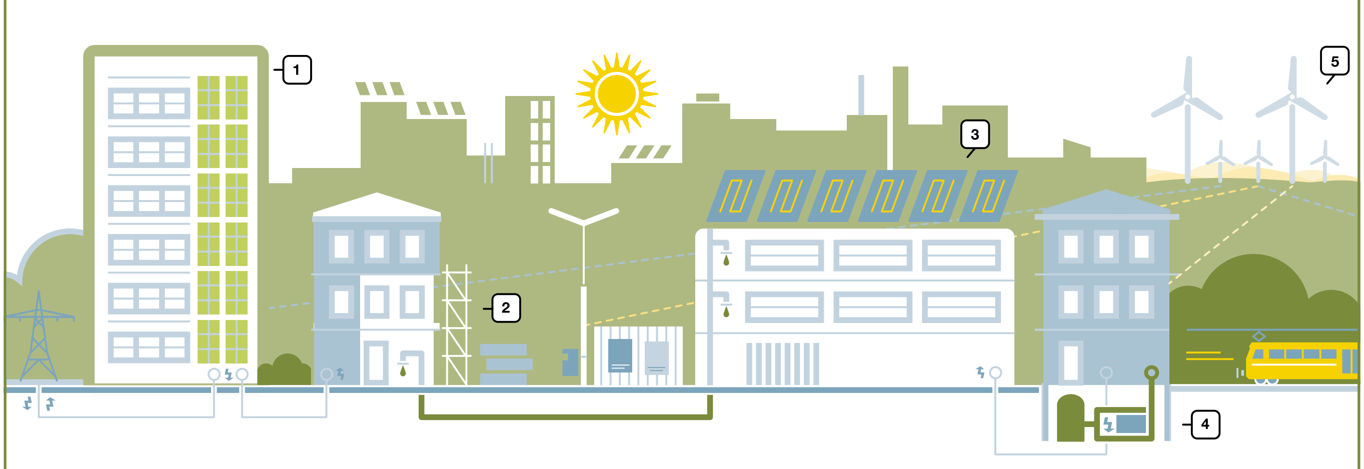
This option opens up a whole new market for solar photovoltaics and turns the business model for utilities on its head. Those who were once captive utility customers will become utility competitors. Energy [R]evolution scenarios assume that private consumer and small and medium enterprises (SME) will meet most of their electricity needs with solar photovoltaic and storage if space to set up the system is accessible.

Industry and business can use cogeneration power plants and co-generation batteries for on-site power generation to cover their own power needs. Surplus power will be sold to the grid, while excess heat can too be piped to nearby buildings, a system known as combined heat and power. For a fuel like biogas, almost all the input energy is used, not just a fraction as with traditional central-station fossil fuel electricity plants.

While a large proportion of global energy in 2050 will be produced by decentralised energy sources, large-scale renewable energy will still be needed for an energy revolution. Centralized renewable energy will also be needed to provide process heat for industry, to supply increase power demand for the heating and transport sector, and to produce synthetic fuels for the transport sector.

Figure 2.2. A decentralised energy future

Existing technologies, applied in a decentralised way and combined with efficiency measures and zero emission developments, can deliver low carbon communities as illustrated here. Power is generated using efficient cogeneration technologies producing both heat (and sometimes cooling) plus electricity, distributed via local networks. This supplements the energy produced by building integrated generation. Energy solutions come from local opportunities at both a small and community scale. The town shown here makes use of – among others – wind, biomass and hydro resources. Natural gas, where needed, can be deployed in a highly efficient manner.



1. **Photovoltaic, solar façades** will be a decorative element on office and apartment buildings. Photovoltaic systems will become more competitive and improved design will enable architects to use them more widely.
2. **Renovation can cut energy consumption of old buildings** by as much as 80% – with improved heat insulation, insulated windows and modern ventilation systems.
3. **Solar thermal collectors** produce hot water for both their own and neighbouring buildings.
4. **Efficient thermal power (CHP) stations** will come in a variety of sizes – fitting the cellar of a detached house or supplying whole building complexes or apartment blocks with power and warmth without losses in transmission.
5. **Clean electricity** for the cities will also come from farther afield. Offshore wind parks and solar power stations in deserts have enormous potential.

2.3.3. Step 3: The transport revolution

Moving around with different technologies and less energy

Switching to 100% renewables is most challenging in the transport sector. Today 92% of the transport energy comes from oil and only 1% from electricity (IEA 2015b)[37]. A simple "fuel switch" from oil to bioenergy and electricity is neither technically possible nor sustainable. While there is an urgent need to expand electric mobility – public and individual transport technologies such as trains, buses, cars, and trucks – we also need to re-think our current mobility concept as such. The design of (mega-) cities has a huge influence whether people have to commute long distances or if they can walk or bike to work (WFC 2014)[38]. On the other hand, increasing urban populations offer an opportunity to increase the usage of environmentally friendly mass transit systems. The transport of freight needs to move from road to rail and – if possible – from aviation to ships, which requires better logistics and new, more efficient transport technologies.

[37] IEA (2015). Energy and climate change – World Energy Outlook Special Report; International Renewable Energy Agency; May 2015.

[38] WFC (2014). Regenerative cities – Commission on Cities and Climate Change; Hafen City University, World Future Council; September 2014.

Cars evolve in Energy [R]evolution scenarios. All potentials to make cars lighter and the combustion engine more efficient are exploited first. By around 2025, the car market moves via hybrid drives towards fully electric drives. The e-vehicle market is nascent today, and technical uncertainties remain, especially in regard to the storage technologies. Thus, a real turnaround with significant oil reduction effect is not expected before 2025. However, the technical evolution must start now in order to be ready by then.

The use of biofuels is limited by the availability of sustainably grown biomass. It will primarily be committed to heavy machinery, aviation and shipping, where electricity does not seem to be an option for the next few decades. Outside the transport sector, biomass is needed for specific industries to supply process heat and carbon — not to mention as a raw material outside the energy sector. Electric vehicles will, therefore, play an even more important role in improving energy efficiency in transport and substituting for fossil fuels after 2025.

Overall, achieving an economically attractive growth of renewable energy sources requires a balanced and timely mobilisation of all technologies. Such a mobilisation depends on resource availability, cost reduction potential and technological maturity. And alongside technology-driven solutions, lifestyle changes — like simply driving less and using more public transport — have a huge potential to reduce greenhouse gas emissions. Fortunately, these new behaviour patterns will be perceived as improvements, not compromises; young people around the world already increasingly prefer to spend time on their smartphones and buses and trains rather than drive.

2.3.4. Step 4: Smart infrastructure to secure renewables 24/7

Because renewable energy relies mostly on natural resources, which are not available at all times, some critics say this makes it unsuitable for large portions of energy demand. Yet, Denmark got around 40 per cent of its electricity from wind power alone in 2014; Spain and Portugal, around a quarter. A complete transformation of the energy system will be necessary to accommodate the significantly higher shares of renewable energy expected under the Energy [R]evolution scenario. The grid network of cables and substations that brings electricity to our homes and factories was designed for large, centralised generators running at huge loads, providing 'base load' power. Until now, renewable energy has been seen as an additional slice of the energy mix and had to adapt to the grid's operating conditions. If the Energy [R]evolution scenario is to be realised, this situation will have to change.

Renewable energy supply 24/7 is technically and economically possible; it just needs the right policy and the commercial investment to get things moving and 'keep the lights on' (GP-EN 2014)[39]. The task of integrating renewable energy technologies into existing power systems is similar in all power systems around the world, whether they are large, centralized systems or island systems.

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

- fulfil defined power quality standards — voltage/frequency — which may require additional technical equipment in the power system and support from different ancillary services;

and

- survive extreme situations such as sudden interruptions of supply (such as a fault at a generation unit) or interruption of the transmission system.

Base load and system balancing

Power balance aims at keeping frequency in the system consistent. The mains frequency describes the frequency at which AC electricity is delivered from the generator to the end user, and it is measured in hertz (Hz). Frequency varies in a system as the load (demand) changes. In a power grid operating close to its peak capacity, there can be rapid fluctuations in frequency, and dramatic fluctuations can occur just before a major power outage. Typically, power systems were designed around large power stations providing base load capacity operating almost constantly at full output. These centralized units, typically nuclear or coal power plants, are inflexible generation resources — they don't "follow load" — change their output to match changing demand — as well as flexible gas turbines and hydropower units, for instance.

Power systems with large amounts of inflexible generation resources, such as nuclear power stations, also require a significant amount of flexible generation resources.

Priority dispatch for renewables ends "base-generation"

Renewable energy integrated into a smart grid changes the need for base load power. An energy switch based on renewables redefines the need for base load power generation. Instead, traditional base load power plants such as coal are replaced by a mix of flexible energy providers that can follow the load during the day and night (such as solar plus gas, geothermal, wind and demand management), without blackouts. The base load is therefore provided by a cascade of flexible power plants — instead of just base load generation.

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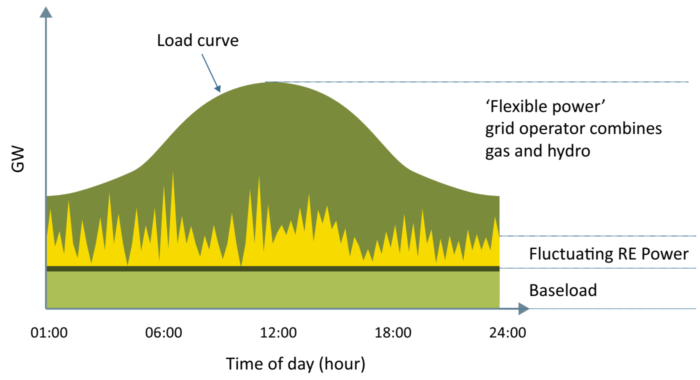
[39] GP-EN (2014). Powe[R] 2030 —. A European Grid for 3/4 renewable electricity by 2030; Greenpeace International/Energynautics; March 2014.

Figure 2.3. The evolving approach to grids

Current supply system:

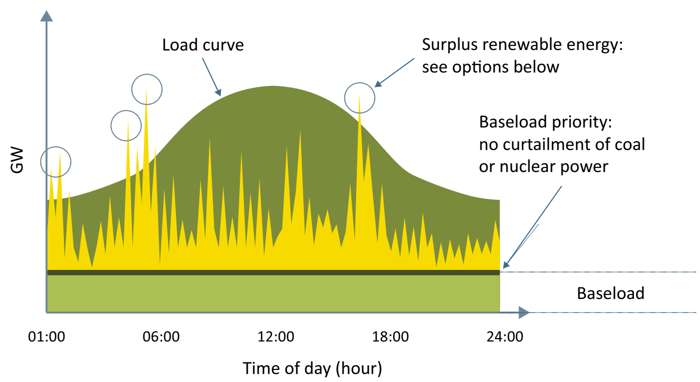
- Low shares of fluctuating renewable energy.
- The base load power is a solid bar at the bottom of the graph.
- Renewable energy forms a 'variable' layer because sun and wind levels change throughout the day.
- Gas and hydropower can be switched on and off in response to demand. This combination is sustainable using weather forecasting and clever grid management.
- With this arrangement, there is room for about 25 per cent variable renewable energy.



To combat climate change much more than 25% renewable electricity is needed.

Supply system with more than 25% fluctuating renewable energy > base load priority:

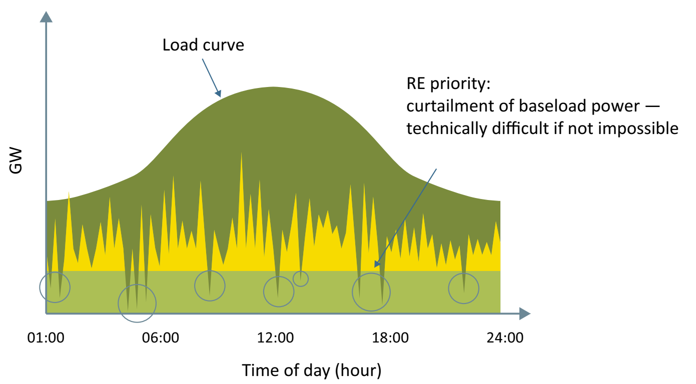
- This approach adds renewable energy but gives priority to base load.
- As renewable energy supplies grow they will exceed the demand at some times of the day, creating surplus power.
- To a point, this can be overcome by storing power, moving power between areas, shifting demand during the day or shutting down the renewable generators at peak times.



This approach does not work when renewables exceed 50% of the mix, and cannot provide renewable energy as 90- 100% of the mix.

Supply system with more than 25% fluctuating renewable energy > renewable energy priority:

- This approach adds renewables but gives priority to clean energy.
- If renewable energy is given priority to the grid, it "cuts into" the base load power.
- Theoretically, nuclear and coal need to run at reduced capacity or be entirely turned off in peak supply times (very sunny or windy).
- There are technical and safety limitations to the speed, scale and frequency of changes in power output for nuclear and CCS coal plants.

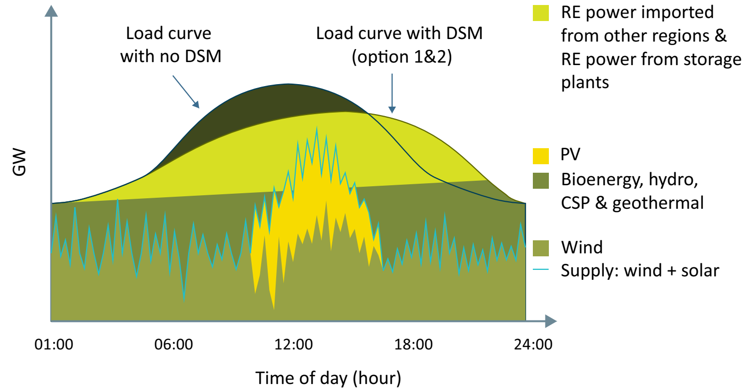


Technically difficult, not a solution.

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

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

Works!



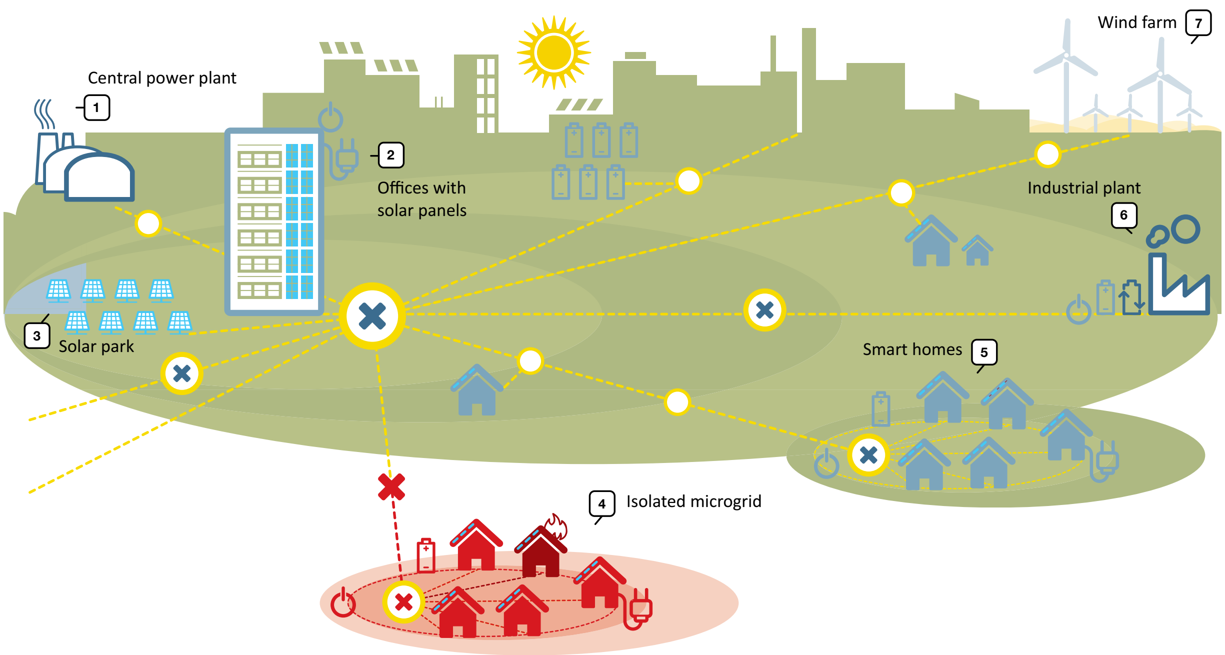
Source: Greenpeace Energy [R]evolution 2012.

The smart-grid vision for the Energy [R]evolution

Developing a power system based almost entirely on renewable energy sources will require a new overall power system architecture – including Smart-Grid Technology, which will need substantial amounts of work to emerge (ECOGRID)[40]. Figure 2.4 shows a very basic graphic representation of the key elements of future, renewable-based power systems using Smart Grid technology (GP-EN 2009)[41].

Figure 2.4. The smart-grid vision for the Energy [R]evolution

A vision for the future – a network of integrated microgrids that can monitor and heal itself



Processors
execute special protection schemes in microseconds

Sensors (on 'standby')
detect fluctuations and disturbances, and can signal for areas to be isolated

Sensors ('activated')
detect fluctuations and disturbances, and can signal for areas to be isolated

Disturbance
In the grid

Smart appliances
can shut off in response to frequency fluctuations

Demand management
use can be shifted to off peak times to save money

Generators
energy from small generators and solar panels can reduce overall demand on the grid

Storage energy
generated at off-peak times could be stored in batteries for later use

Source: Greenpeace Energy [R]evolution 2012.

[40] See also Ecogrid Phase 1 Summary Report, available at: http://www.energinet.dk/nr/rdonlyres/8b1a4a06-cba3-41da-9402-b56c2c288fb0/0/ecogriddk_phase1_summaryreport.pdf

[41] GP-EN 2009, European Renewable Energy Council/Greenpeace report, "[R]enewables 24/7: infrastructure needed to save the climate", November 2009.

2.3.5. Step 5: New policies to enable new business models

The Energy Revolution scenario will also result in a dramatic change in the business model of energy companies, utilities, fuel suppliers and manufacturers of energy technologies. Decentralised energy generation for self-supply along with utility-scale solar, onshore and offshore wind farms in remote areas will have a profound impact on the way utilities operate by 2020. For instance, these energy sources require no fuel, which will challenge vertically integrated utilities.

The current model is a relatively small number of large power plants owned and operated by utilities or their subsidiaries, generating electricity for the population. Under the Energy Revolution scenario, around 60 to 70% of electricity will be made by small but numerous distributed power plants. Ownership will shift away from centralised utilities towards more private investors, manufacturers of renewable energy technologies and EPC companies (engineering, procurement and construction). In turn, the value chain for power companies will shift towards project development, equipment manufacturing and operation and maintenance (Figure 2.5).

Simply selling electricity to customers will play a smaller role; power companies of the future will deliver a total power plant and the required IT services to customers, not just electricity.

They will therefore move towards becoming service providers for customers. The majority of power plants will also not require any fuel supply, so fuel production companies will lose their strategic importance.

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

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

Policy defines ownership and investment flows

In order to organize the transition towards a 100% renewable energy market, specific policies are required to provide planning and investment security for small and medium-size enterprises (SME). Those policies must first and foremost secure access to infrastructure – power lines, gas pipelines and district heating systems – so that electricity, hydrogen, renewable methane and/or renewable heat can be transported to customers. Priority dispatch in all networks is key for project developers and investors as well because the projected amount of renewable energy produced each year is a fundamental cornerstone for financial planning.

Future customer groups

The capacity demand for power and/or heat for different customer groups defines the voltage level they are connected to and whether they are connected to the distribution or transmission level of gas pipelines. The interface between customer and infrastructure opens a variety of technology and hence business options for energy service companies.

For households with access to a roof space, for example, the installation of solar photovoltaics is now very often the least cost option. The cost of photovoltaic electricity has decreased dramatically over the past few years. Parity with retail electricity and oil-based fuels has been reached in many countries and market segments and wholesale parity is approaching in some markets (Breyer 2015)[42].

Taking into account facts described in this chapter, it seems relatively clear that not changing the current conventional business model is not an option for utilities either.

German utilities are a good example of future challenges. In 2014, RWE – one of Germany's two biggest utilities along with Eon – posted a 45 per cent drop in profits. Power prices are down, and the share of conventional electricity is also falling, so these firms sell less power at lower prices. At RWE, power sales fell by 7.5 per cent in the 2014 year over year, for instance. The result was 29 per cent lower operating the profits from conventional power generation. The outlook is also dismal, with year-ahead prices dropping to the lowest level in a decade. RWE has responded partly by forming a partnership with EPC (Conergy) for significant investments in rooftop solar in Germany. Likewise, Eon is breaking up into two companies: one doing business with conventional energy, and the other with renewables and energy services. This plan is clear evidence that top utility experts understand the incompatibility of conventional energy with renewables. (PV-M 3-2015)[43].

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[42] Breyer 2015, PV LCOE in Europe 2014-30; Final report, July 2015; University Lappeenranta / Finland, Dr. Christian Breyer; PV Technology Platform; www.eupvplatform.org.

[43] PV-M 3-2015, PV Magazine, RWE Profits Slump Amid Crisis In Conventional Energy; 10TH March 2015; Ian Clover; http://www.pv-magazine.com/news/details/beitrag/rwe-profits-slump-amid-crisis-in-conventionalenergy_100018539.

Figure 2.5. Changing value chain for planning, construction and operation of new power plants

Task & market player	Project development	Manufacture of gen. equipment	Installation	Owner of the power plant	Operation & maintenance	Fuel supply	Transmission to the customer
Current situation power market	Coal, gas and nuclear power stations are larger than renewables. Average number of power plants needed per 1 GW installed only 1 or 2 projects			Relatively new power plants owned and sometimes operated by utilities		A few large multinational oil, gas and coal mining companies dominate: today approx. 75-80% of power plants need fuel supply.	Grid operation will move towards state-controlled grid companies or communities due to liberalisation.
Market player							
Power plant engineering companies							
Utilities							
Mining companies							
Grid operator							
2020 and beyond	Renewable power plants are small in capacity, the amount of projects for project development, manufacturers and installation companies per installed 1 GW is bigger by an order of magnitude. In the case of PV it could be up to 500 projects, for onshore wind still 25 to 50 projects.			Many projects will be owned by private households or investment banks in the case of larger projects		By 2050 almost all power generation technologies — accept biomass — will operate without the need of fuel supply.	Grid operation will move towards state-controlled grid companies or communities due to liberalisation
Market player							
Renewable power plant engineering companies							
Private & public investors							
Grid operator							

Source: Dr. Sven Teske / Greenpeace.

3

Review: Greenpeace scenario projections of the past

- The development of the global wind industry
- The development of the global solar photovoltaic industry
- How does the Energy [R]evolution scenario compare to other scenarios?

Greenpeace has published numerous projections in cooperation with Renewable Industry Associations and scientific institutions in the past decade. This section[44] provides an overview of the projections between 2000 and 2014 and compares them with real market developments and projections of the IEA World Energy Outlook – the basis for our reference scenario.

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[44] This section is adopted from the relevant chapter of the "Energy [R]evolution: a Sustainable World Energy Outlook 2015" with the permission of the Greenpeace International.

Photo: ©flickr.com — National Renewable Energy Laboratory

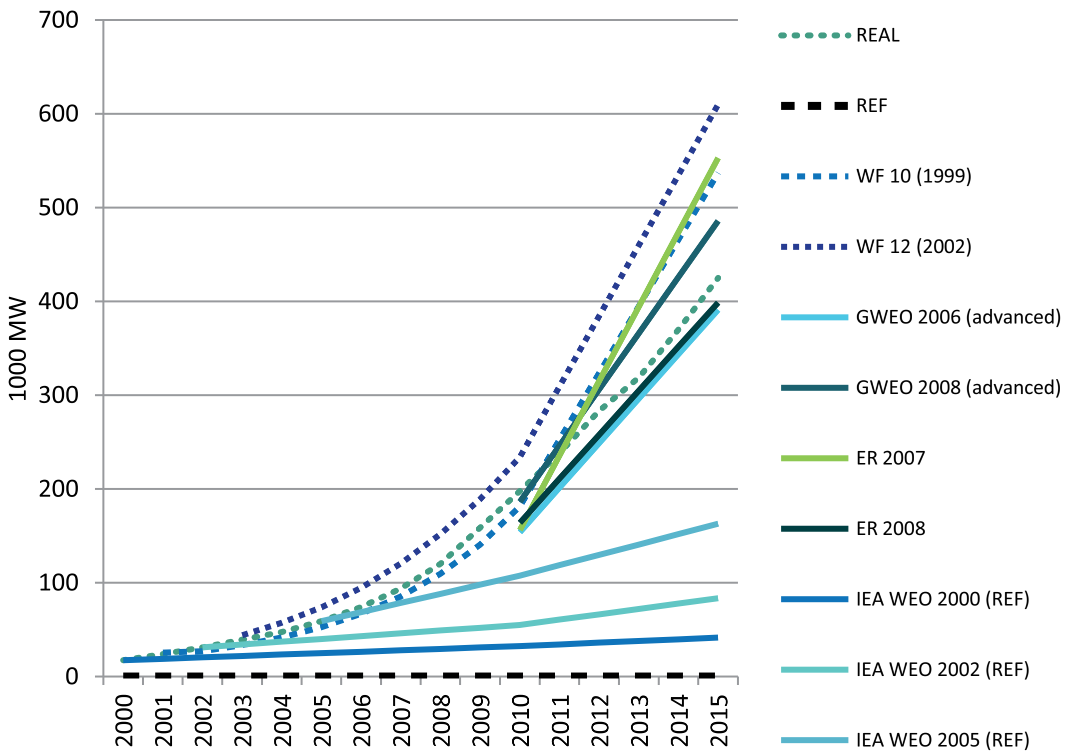
3.1. The development of the global wind industry

Greenpeace and the European Wind Energy Association published "Windforce 10" for the first time in 1999 – a global market projection for wind turbines until 2030. Since then, an updated prognosis has been published every second year. Since 2006 the report has been renamed into "Global Wind Energy Outlook" with a new partner – the Global Wind Energy Council (GWEC) – a new umbrella organisation of all regional wind industry associations. Figure 3.1 shows the projections made each year between 2000 and 2012 compared to the real market data. The graph also includes the first three Energy [R]evolution (ER) editions (published in 2007, 2008 and 2010) against the IEA's wind projections published in World Energy Outlook (WEO) 2000, 2002, 2005, 2008 and 2010.

The projections from the "Wind force 10" and "Windforce 12" were calculated by BTM consultants, Denmark. "Windforce 10" (2001 – 2011) exact projection for the global wind market published during this time, at 10% below the actual market development; also all following editions were around 10% above or below the real market. From 2006 onwards, the new "Global Wind Energy Outlook" had two different scenarios, a moderate and an advanced wind power market projection calculated by GWEC and Greenpeace International. The figures here show only the advanced projections, as the moderate were too low. However, these projections were the most criticised at the time, being called "overambitious" or even "impossible".

In contrast, the IEA "Current Policies" projections seriously underestimated the wind industry's ability to increase manufacturing capacity and reduce costs. In 2000, the IEA WEO published projections of global installed capacity for wind turbines of 32 500 MW for 2010. This capacity had been connected to the grid by early 2003, only two-and-a-half years later. In 2014, the annual global wind market was at 39 000 MW increasing the total cumulative capacity to around 370000 MW; around ten times more than the IEA's assumption a decade earlier.

Figure 3.1. Wind power – short-term prognosis vs real development – global cumulative capacity



Source: Greenpeace Energy [R]evolution: a Sustainable World Energy Outlook 2015.

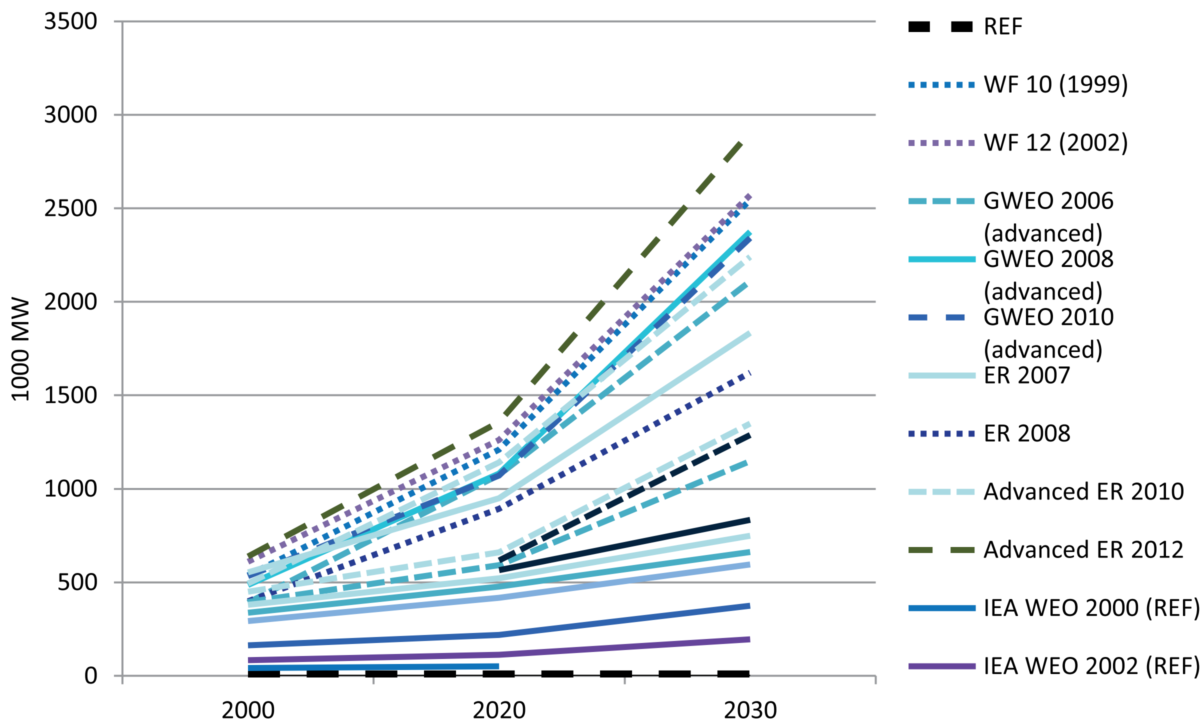
Only time will tell if the GPI/DLR/GWEC longer-term projections for the global wind industry will remain close to the real market. However, the IEA WEO projections over the past decade have been constantly increased and keep coming close to more progressive growth rates.

3.2. The development of the global solar photovoltaic industry

Inspired by the successful work with the European Wind Energy Association (EWEA), Greenpeace started to work with the European Photovoltaic Industry Association to publish "Solar Generation 10" — a global market projection for solar photovoltaic technology up to 2020 for the first time in 2001. Since then, six editions have been published and EPIA and Greenpeace constantly improved the calculation methodology with experts from both organisations. Figure 3.3 shows the actual projections for each year between 2001 and 2015 compared to the real market data, against the first two Energy [R]evolution editions (published in 2007, 2008, 2010 and 2012) and the IEA's solar projections published in World Energy Outlook (WEO) 2000, 2002, 2005, 2007, 2009, 2010 and 2011. The IEA did not make specific projections for solar photovoltaic in the first editions, instead used the category "Solar/Tidal/Other". In contrast to the wind projections, all the Solar Generation projections have been too conservative. The total installed capacity in 2014 was 175 000 MW more than twice as high as projected in Solar Generation 2 published a decade earlier. Even Solar Generation 5, published in 2008, underestimated the possible market growth of photovoltaic in the advanced scenario. In contrast, the IEA WEO 2000 estimations for 2010 were reached in 2004.

The long-term projections for solar photovoltaic are more difficult than for wind because the costs have

Figure 3.2. Wind power — long-term market projections until 2030



Source: Greenpeace Energy [R]evolution: a Sustainable World Energy Outlook 2015.

Box 3.1. Article from Meister Consultants Group "Renewable energy revolution"

The energy world is undergoing a massive transformation[45].

Installations of renewable energy have skyrocketed around the world, exceeding most predictions from less than a decade ago.

A record-breaking amount of wind and solar power was installed globally in 2014, in what the US Department of Energy has characterized as an "energy revolution" but how strong is this momentum? How much have renewable technologies like solar PV and wind actually grown in recent years?

Solar and wind: outpacing (most) expert projections.

Over the past 15 years, a number of predictions — by the International Energy Agency, the US Energy Information Administration, and others — have been made about the future of renewable energy growth. Almost every one of these predictions has underestimated the scale of actual growth experienced by the wind and solar markets. Only the most aggressive growth projections, such as Greenpeace's Energy [R]evolution scenarios, have been close to accurate. Greenpeace's projections have been predicated upon drastic structural, policy, and business changes. The recent moves seen by E.ON, China, and across countless other local and global institutions suggest that these changes are already underway.

What lies ahead?

No one knows what the future electricity mix will look like, and that uncertainty is mirrored more broadly in projections for the energy system as a whole. Approximately 13% of global primary energy demand is derived from renewable sources, and it is almost a certainty that renewables will continue to expand. The question is: by how much? Projections and scenarios range from 15% to 100% of global primary energy demand by 2050. To win in the future global marketplace, business leaders and policymakers will need to manage change effectively. The next phase in the renewable transformation will likely involve substantial changes to the structure of the global energy system. This means new policies, new business models, new grid management systems and the potential for massive disruption — all of which raise a number of questions:

- How can policymakers, businesses, and community leaders work together to effectively manage the transformation?
- How can leaders align stakeholder interests to implement the right policies and regulations across regions?
- What new business models need to be deployed to deliver greater levels of cost-effective renewable and energy efficiency projects?
- How can investors mobilize to finance major energy infrastructure?

Strategic questions such as these are at the forefront of energy discussions around the world. At the same time, they presume that energy stakeholders will have some degree of control over the changes that are coming. As has been seen in the past, however, renewable energy market growth has consistently surprised (on the upside) the analysts, planners, and policymakers who have attempted to predict the future.

[45] MCG (2015). Renewable Energy Revolution — Published in March 16, 2015, HTTP://WWW.MCGROuP.COM/WP-CONTENT/uPLOADS/2015/03/MCG-RENEWAbLE-ENERGy-REvOLuTION-INfOGRAPHIC.PDf

dropped significantly faster than projected. For most OECD countries, solar has reached grid parity with retail rates from utilities in 2014 and other solar technologies, such as concentrating solar power plants (CSP), are also headed in that direction. Therefore, future projections for solar photovoltaic do not just depend on cost improvements, but also on available storage technologies. Grid integration can actually be a bottle-neck to solar that is now expected much earlier than estimated.

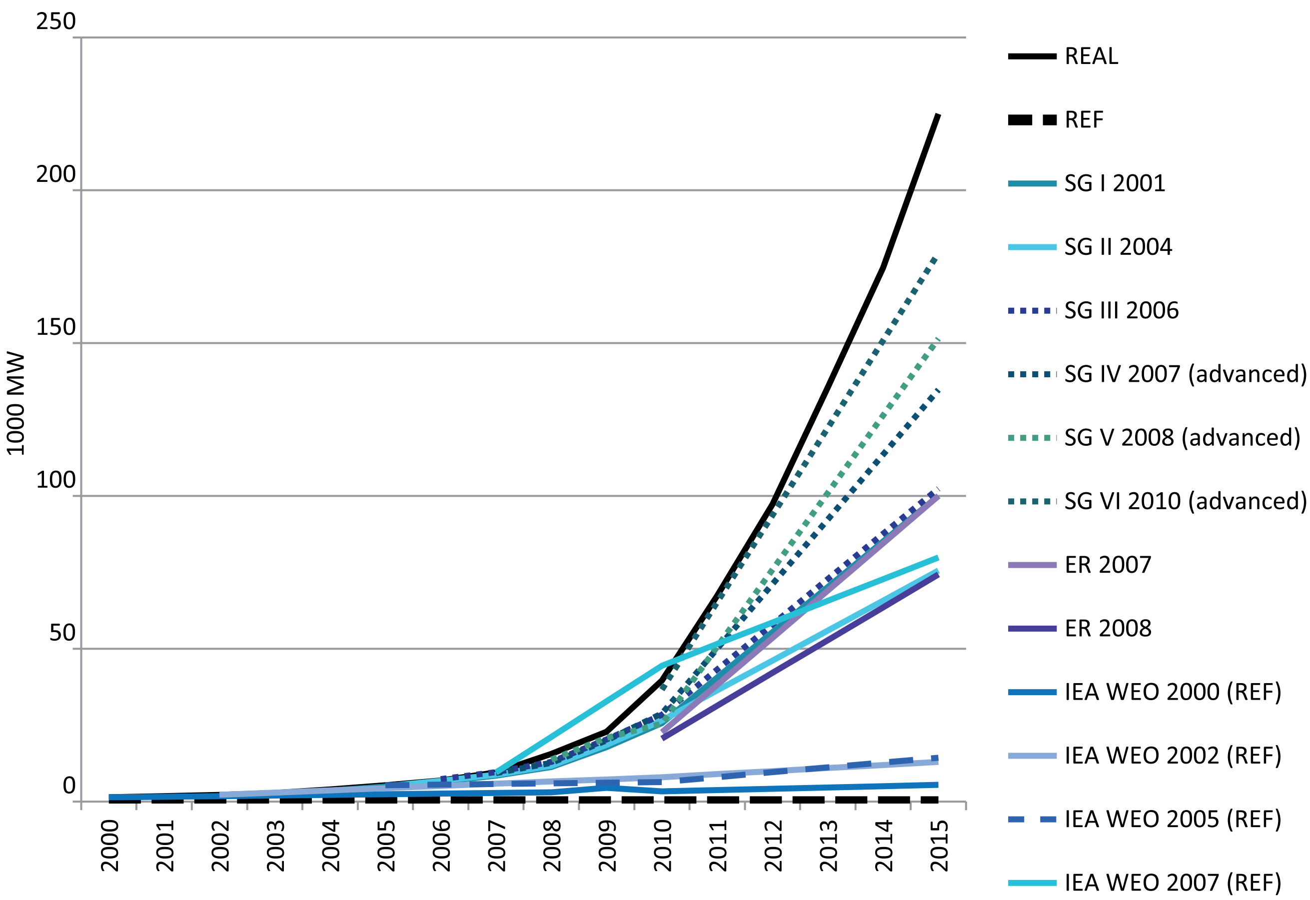
3.3. How does the Energy [R]evolution scenario compare to other scenarios?

The International Panel on Climate Change (IPCC) published a ground-breaking new "Special Report on Renewables" (SRREN) in May 2011. This report showed the most comprehensive analysis of scientific reports on all renewable energy resources and global scientifically accepted energy scenarios. The Energy [R]evolution was among three scenarios chosen as an indicative scenario for an ambitious renewable energy pathway. The following summarises the IPCC's view. Four future pathways, from the following models, were assessed intensively:

- International Energy Agency World Energy Outlook 2009, (IEA WEO 2009)
- Greenpeace Energy [R]evolution 2010, (ER 2010)
- (ReMIND-RECIPE)
- (MiniCam EMf 22)

The World Energy Outlook of the International Energy Agency was used as an example baseline scenario (least amount of development of renewable energy) and the other three treated as "mitigation scenarios", to address climate change risks. The four scenarios

Figure 3.3. Solar photovoltaic– short-term prognosis vs real development – global cumulative capacity



Source: Greenpeace Energy [R]evolution: a Sustainable World Energy Outlook 2015.

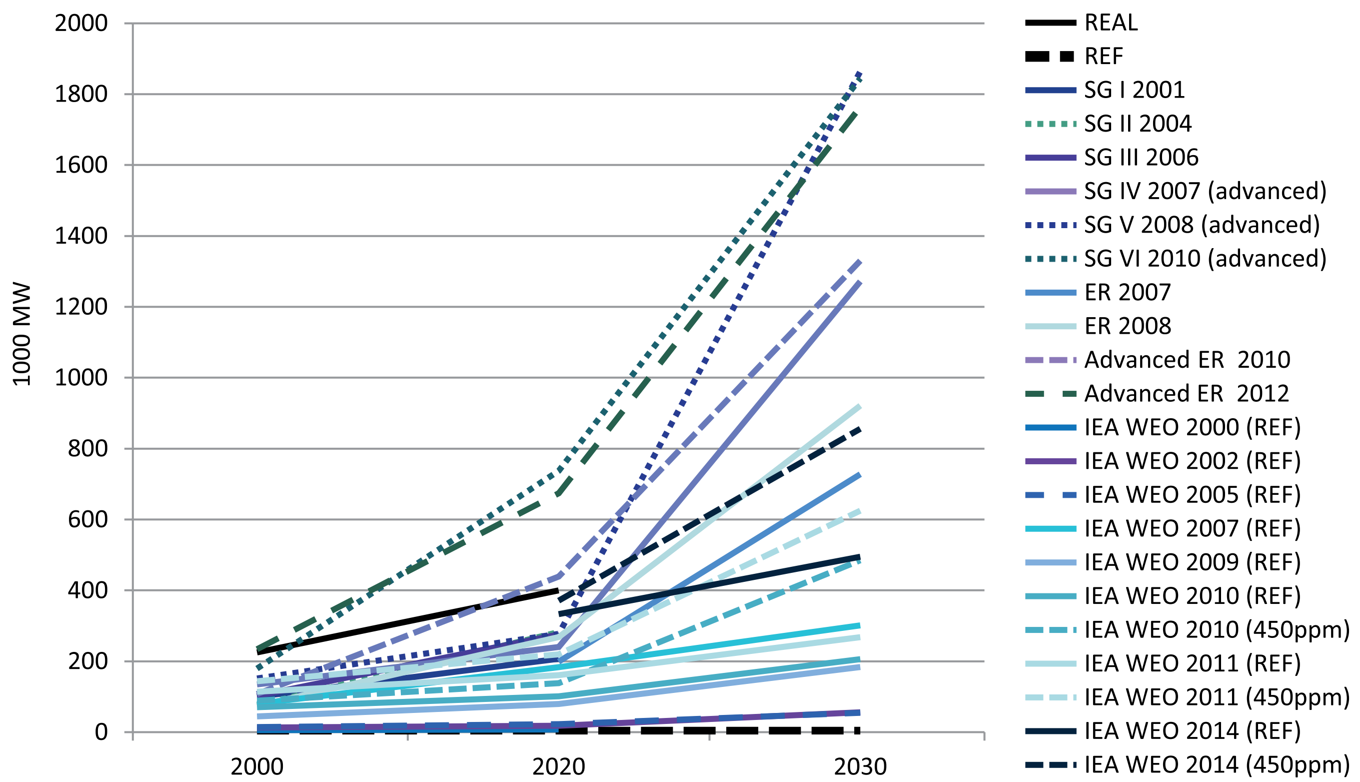
provide substantial additional information on a number of technical details, represent a range of underlying assumptions and follow different methodologies. They provide different renewable energy deployment paths, including Greenpeace's "optimistic application path for renewable energy assuming that the current high dynamic (increase rates) in the sector can be maintained".

The IPCC notes that scenario results are determined partly by assumptions, but also might depend on the underlying modelling architecture and model specific restrictions, so the scenarios analysed use different modelling architectures, demand projections and technology portfolios for the supply side. The full results are provided in the Table 3.1, but in summary:

- The IEA baseline has a high demand projection with low renewable energy development.
- ReMind-RECIPE, MiniCam EMF 22 scenarios portrays a high demand expectation and significant increase of renewable energy is combined with the possibility to employ CCS and nuclear.
- The ER 2010 relies on low demand (due to a significant increase in energy efficiency) combined with high renewable energy deployment, no CCS employment and a global nuclear phase-out by 2045.

Both population increase and GDP development are major driving forces on future energy demand and therefore at least indirectly determining the resulting shares of renewable energy. The IPCC analysis shows which models use assumptions based on outside inputs and what results are generated from within the models. All scenarios take a 50% increase of the global population into account on baseline 2009. Regards gross domestic product (GDP), all assume or calculate a significant increase in terms of the GDP. The IEA WEO 2009 and the ER 2010 model use forecasts of the International Monetary Fund (IMF 2009) and the Organisation of Economic Co-Operation and Development (OECD) as inputs to project GDP. The other two scenarios calculate GDP from within their model. Table 3.1 provides an overview of key parameters of the IPCC analysis and puts them in the context of scenarios from IEA and Greenpeace, which have been published in the aftermath of the SRREN.

Figure 3.4. Solar photovoltaic — long-term market projections until 2030



Source: Greenpeace Energy [R]evolution: a Sustainable World Energy Outlook 2015.

Table 3.1. Overview of key parameters of the illustrative scenarios based on exogenous assumptions

Category		Status quo	Baseline				Category iii+iv (>440 — 600 ppm)		Category i+ ii (<440 ppm)		Category i+ii (<440 ppm)			
Scenario name		IEA ETP	IEA WEO 2009		IEA WEO 2011		ReMind		MiniCam		E[R] 2010		E[R] 2012	
Model							ReMind		EMF22		MESAP/PlaNet		MESAP/PlaNet	
Year of publication		2015	2009		2011		20xx		20xx		2010		2012	
	units		2030	2050*	2030	2050*	2030	2050	2030	2050	2030	2050	2030	2050
Technology pathway (-) technology not included (+) technology included														
Renewables			all**	all	all**	all	PV and CSP not differentiated		PV and CSP not differentiated, ocean energy not included		all	all	all	all
CCS			(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(-)
Nuclear			(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(-)
Population	billion	6.67	8.31	9.15	8.31	9.15	8.32	9.19	8.07	8.82	8.31	9.15	8.31	9.15
GDP/capita**	k$2005/capita	-	17.4	24.3	-	-	12.4	18.2	9.7	13.9	17.4	24.3	-	-
Energy demand (direct equivalent)	EJ/y	568	645	749	694	805	590	674	608	690	474	407	526	481
Energy intensity	MJ/$2005	-	4.5	3.4	-	-	5.7	4.0	7.8	5.6	3.3	1.8	-	-
Renewable energy	%	13	14	15	14	16	32	48	24	31	39	77	41	82
Fossil & industrial CO_2 emissions	GT CO_2/y	32.2	38.5	44.3	39.2	45.3	26.6	15.8	29.9	12.4	18.4	3.7	20.1	3.1
Carbon intensity	kG CO_2/Gj	-	57.1	56.6	-	-	45.0	23.5	49.2	18.0	36.7	7.1	-	-

* IEA (2009) does not cover the years 2031 till 2050. As the IEA's projection only covers a time horizon up to 2030 for this scenario exercise, an extrapolation of the scenario has been used that was provided by the German Aerospace Agency (DLR) by extrapolating the key macroeconomic and energy indicators of WEO 2009 forward to 2050 (Teske et al., 2010c).

** The data are either input for the model or endogenous model results.

*** Solar photovoltaics, concentrated solar power, solar water heating, wind (on- and offshore), geothermal power, heating and cogeneration, bioenergy power, hydropower, ocean energy.

4 Overview of climate and energy policy as well as perspectives for transport sector development of Belarus

- Climate policy of Belarus
- Energy policy of Belarus
- Perspectives for transport sector development of Belarus

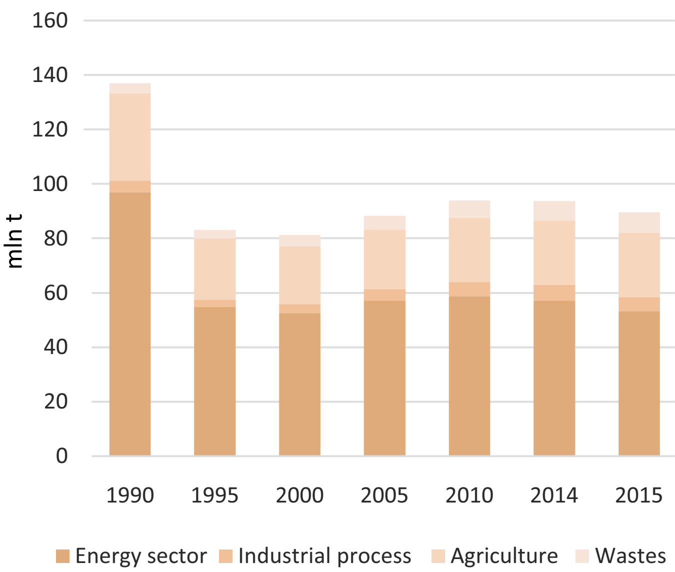
Photo: ©flickr.com — NRMA

4.1. Climate policy of Belarus

For many years, Belarus has been perceived controversially when it comes to the global climate policy. As a party to Annex I of the UNFCCC, Belarus should bear the main burden of commitments to mitigate climate change on equal terms with other parties to Annex I. However, it is questionable whether the official position of the country[46] and actions taken by the Belarusian Government under the UNFCCC and the Kyoto Protocol really aim to mitigate climate change[47].

After the collapse of the USSR, the disruption of economic relations between the republics and long-lasting economic stagnation resulted in the decline of greenhouse gas emissions of Belarus by more than 40% from 1990 to early 2000-s. Starting from 2000, the levels of greenhouse gas emissions have stabilised with slight growth due to measures taken by the Republic of Belarus to reduce the energy intensity of the economy and develop renewable energy sources (see Figure 4.1).

Figure 4.1. Change in GHG emissions by sector, 1990 -2015



Note: data on emissions without including land use, land-use change, and forestry (LULUCF).

Source: National GHG Inventory of Belarus, 2017.

However, Belarus proposed a target for the first commitment period of the Kyoto Protocol, which looked insufficiently ambitious, arguing that the economy in the transition phase: 8% reduction by 2012 compared to the reference 1990[48] while actual emissions in 2012 were 35.8% below the 1990 emissions. Under the Protocol, excessive quotas (the difference between an actual reduction in emissions and pledges) could be sold to other countries, implying that Belarus intended to participate in the emission trading mechanism without making sufficient efforts to achieve additional reduction in emissions.

Given that Belarus was acceding the Protocol later than the other parties, Belarus did not obtain access to flexible mechanisms, including joint implementation, for a prospective implementation of which the country developed relevant legislative framework. Belarus did not ratify the Doha Amendment (determines conditions of the second commitment period of the Kyoto Protocol – from 2012 to 2020) adopted at the COP 18 of the UNFCCC in 2012, because it required Belarus to adopt a much higher target[49] and it was practically not possible to use flexible mechanisms during the second commitment period of the Kyoto Protocol.

In November 2015, Belarus joined the Paris Agreement and ratified the agreement in September 2016. Intended nationally determined contributions of Belarus indicates a target to reduce greenhouse gas emissions by 28% from 1990 level by 2030[50]. The above commitments of the Republic of Belarus are based on the country's internal capacity only and have been accepted without any reservations. A considerable increase in the country's commitments is primarily based on plans to put into operation the Ostrovets NPP and further measures aimed at the reduction of carbon intensity of the national economy, but the potential of renewables is hardly taken into account (Belarus targets are 8% renewables by 2030 and 9% renewables by 2035[51]). In accordance with the forecast prepared to support the development of nationally determined contributions of Belarus, greenhouse gas emissions will continue to increase after 2030 and will reach their peak in 2035.

[46] The European Union in International Climate Change Negotiations, https://books.google.by/books?id=ekYlDwAAQBAJ&pg=PA133&lpg=PA133&dq=belarus+climate+change+hot+air&source=bl&ots=q-ywN_19IA&sig=I-sVaMHItihVbpJ4vSG-rWhcrSM&hl=ru&sa=X&ved=0ahUKEwiJ2uahmeTVAhWmCpoKHSO8CWoQ6AEIWjAF#v=onepage&q=belarus%20climate%20change%20hot%20air&f=false

[47] Climate Action Tracker: Belarus, http://climateactiontracker.org/countries/belarus.html

[48] Decision 10/CMP.2 of the Conference of the Parties to the UNFCCC, Kenya, November 2006, http://unfccc.int/resource/docs/2006/cmp2/eng/10a01.pdf#page=36

[49] The Doha Dead End? Transition Economies and the New Kyoto rules, https://www.fni.no/getfile.php/132203/Filer/Publikasjoner/FNI-Climate-Policy-Perspectives-9.pdf

[50] Intended Nationally Determined Contributions of the Republic of Belarus, http://www4.unfccc.int/Submissions/INDC/Published%20Documents/Belarus/1/Belarus_INDC_Eng_25.09.2015.pdf

[51] Resolution of the Council of Ministers of Belarus No. 1084 of 23 December 2015, approving the Concept of the Energy Security of the Republic of Belarus, http://minenergo.gov.by/wp-content/uploads/%D0%9F23.12.2015%E2%84%961084-%D0%B8-%D0%BA%D0%BE%D0%BD%D1%86%D0%B5%D0%BF%D1%86%D0%B8%D1%8F.pdf

While the energy intensity of the Belarusian economy declined fourfold over the period from 1990 to 2014[52] and came close to that of the developed nations in similar climatic conditions (being the highest rate of transition to low-carbon development in Europe), the government recognizes that many sectors of the economy still have large mitigation potential. Compared to scenarios based on current policies resulting in a 20-22% decline in emissions by 2030 from the reference year, it is estimated that greenhouse gas emissions can be reduced additionally by 25-30 million tonnes of CO2 equivalent over the period from 2015 to 2030, and Belarus included this possibility in its commitments.

Belarus is currently implementing the National Mitigation Programme for 2012-2020[53]. Approved in early 2017 Action Plan for the implementation of the Paris Agreement envisions that[54] legal framework for new national climate policy should be developed in the period between 2016 and 2020 as well as programmes for key economic sectors development for 2020-2030, including measures designed to regulate and reduce greenhouse gas emissions. In particular, it is planned to develop the Low Carbon Emission Development Strategy of the Republic of Belarus by 2050 and the National Climate Adaptation Action Plan.

However, the GDP per capita in purchasing-power-parity remains quite low compared to other countries of Annex I to the UNFCCC (18 000 USD according to the 2016 data of the International Monetary Fund — the 67th rank in the global rating[55]), while investments in the capital stock are insufficient to ensure the extension of production. Belarus, therefore, has limited financial resources to accelerate implementation of best international practices and best available techniques. Considering current conditions of high marginal costs and low economic growth rates, the country's capacity to raise capital and ensure additional investments in low-carbon technologies is limited.

4.2. Energy policy of Belarus

Over 27 years of existence of the independent state of Belarus, the national energy system and energy management policy has changed. However, such changes are anything but structural and significant transformations as the country still rely on the Soviet-era approaches. Determining factor of the Belarusian energy system is its dependence on imported energy resources. Currently, imports from Russia account for almost 90% of fuels used in the energy sector. What is more important is that electric power production in Belarus is almost completely dependent on natural gas supplied from Russia[56].

Adopted in the late 2015, the Concept of Energy Security of Belarus specifies that the dependence on external suppliers remains critical and sets specific targets to reduce the reliance on supplies from abroad. In particular, it is expected that Russia's share in energy imports will decrease by 20% (from 90% to 70%) in 2035. This reduction will be achieved primarily due to a decrease in the consumption of imported natural gas for the production of electric power and heat from 90% to 50%. However, the key point is that gas will be substituted by energy produced by the Ostrovets Nuclear Power Plant using uranium purchased from Russia, while the share of renewables is likely to increase only slightly compared to the growth of renewables in the developed countries — from the current level of 5% to the planned target of 9% in 2035. Thus, it seems that the Belarusian Government's strategy substitutes types of imported fuels but fails to ensure real changes in the energy security of Belarus and preserves the status-quo of dependence on Russia.

It is also should be mentioned that important targets of the Concept of Energy Security of Belarus are phase-out of cross-subsidisation in the electricity tariffs and gas prices, and the improvement of the tariff-setting system to incentivize more energy efficient consumption. Social policy of Belarus envisions provision of energy services to consumers at understated prices for a long time while the difference between production costs and tariff for households is incorporated in the tariff for enterprises. This situation adversely affected consumption habits of Belarusians and drew criticism from international creditors. Phase out of subsidies will result in an increase of utility prices for consumers, which is expected to promote changes in the culture of household energy consumption and stimulate interest for application of renewable energy technologies at the household level. In addition, Belarus is going to extend the use of flexible tariffs system designed to balance the consumption during periods of peak and off-peak load, which is of particular importance in the context of prospective commissioning of the Ostrovets NPP.

In addition, further improvement of energy efficiency

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52 International Energy Agency: Key World Energy Statistics 2016, https://www.iea.org/publications/freepublications/publication/KeyWorld2016.pdf

53 Resolution No. 510 of the Council of Ministers of Belarus as of 21 June 2013, approving the National Mitigation Programme for 2012-2020, http://www.pravo.by/document/?guid=3871&p0=C21300510&p1=1

54 Action Plan for the Implementation of the Paris Agreement to the UNFCCC, http://minpriroda.gov.by/uploads/files/Utv-PLAN-meroprijatij-Parizhskoe-soglashenie.pdf

55 IMF. 2017. World Economic Outlook Database

56 Resolution No. 1084 of the Council of Ministers of Belarus as of 23 December 2015, approving the Concept of the Energy Security of the Republic of Belarus, http://minenergo.gov.by/wp-content/uploads/%D0%9F23.12.2015%E2%84%961084-%D0%B8-%D0%BA%D0%BE%D0%BD%D1%86%D0%B5%D0%BF%D1%86%D0%B8%D1%8F.pdf

remains one of the most important priorities of the energy policy of Belarus. The Republic of Belarus has been systematically implementing energy saving policy since 1993 with a long-term objective to reduce the energy intensity of country's GDP to the world's average level and certain progress towards this goal has been achieved to date. According to the International Energy Agency[57], in 2014 the energy intensity of the Belarusian GDP was 0.17 tonnes of oil equivalent per USD 1000 (in purchasing power parity and 2005 prices), representing a twofold reduction against the 2000 level (0.38 tonnes of oil equivalent per USD 1000) and achieving a level similar to that of the developed nations in a relatively similar climatic conditions like Canada and Finland. At the same time, the energy intensity of the Belarusian GDP is still 1.5 times higher than the average level in the countries of the Organisation for Economic Cooperation and Development and is 1.2 times higher than the world's average.

Belarus developed legislation promoting improvement of the energy efficiency (for example, the Law on Energy Saving, dated 2015,[58] and the President's Directive No. 3 "Savings and Thriftiness – Key Factors of the National Economic Security")[59] and put in place a relevant government authority – the Energy Efficiency Department responsible for the formulation of the national energy saving programmes (two programmes were implemented and the third one for 2016-2020 is being implemented)[60]. The implementation of the National Energy Saving Programme for the period from 2011 to 2015 allowed for reducing consumption of energy and fuels of 7.79 a million tonnes of oil equivalent over five years.

According to current National Energy Saving Programme, the energy intensity of the Belarusian GDP must be additionally reduced by 2% by 2021 compared to 2015. Planned measures include decommissioning of inefficient energy sources, reduction of energy production and transportation costs, modernisation and technical re-equipment of enterprises and reorientation of production to less energy-intensive products, reduction of energy losses in heating networks by 10% by 2020 due to annual replacement of networks (owned by organizations of housing and communal services) at least 4% of their length, designing and construction of primarily energy efficient buildings, including the use of innovative renewable energy technologies, installation of automatic heat control and water consumption systems and lighting control systems in multi-apartment buildings, etc.

More than 100 of national and international standards, 90% of which meet international and European requirements, were developed under the Programme for the Development of the Energy Saving Technical Regulation, Standardisation and Verification System for the period from 2011 to 2015. Within the EU technical assistance project "Support to Belarus in the field of norms and standards related to energy efficiency of consumer goods and industrial products" 48 national standards of the Republic of Belarus are being developed based on the EU regulations and directives, which set requirements for energy efficiency of products, their labelling and test techniques. An energy audit was conducted for 55 residential buildings and 3 pilot energy-efficient multiple-flat buildings were built in Minsk, Hrodna, and Mahilou under the UNDP/GEF project "Energy Efficiency Improvement in Residential Buildings in the Republic of Belarus". The experience gained from the project allowed the development of a number of technical requirements for energy efficiency in the housing construction sector[61].

RES Policy

The development of the renewable energy sector is an integral part of the national energy security and climate change mitigation policy of Belarus. Renewables targets are specified in the Concept of the Energy Security of the Republic of Belarus. The share of renewables is expected to reach 9% in total energy consumption by 2035 (5% in 2014[62]). Principles of implementation of the renewables policy, including generation and consumption of renewable energy and government support and incentives to this sector are set forth in the Belarusian Law on Renewables of 27 December 2010[63].

The following measures are taken by the Belarusian government to promote the development of this energy sector:

- guaranteed connection to the state electricity grids and purchase of the produced electricity by the state energy utility;

[57] IEA 2017, Key World Energy Statistics 2016, https://www.iea.org/publications/freepublications/publication/KeyWorld2016.pdf

[58] Belarusian Law No. 239-3 on Energy Saving, dated 8 January 2015, http://minenergo.gov.by/dfiles/000437_303862_ob_energosberezhenii_2015.pdf

[59] Directive No. 3 of 14 June 2007 (as amended by Decree No. 26 on the Priorities of National Economic Security Strengthening, dated 26 January 2016), http://president.gov.by/ru/official_documents_ru/view/direktiva-3-ot-14-ijunja-2007-g-1399/

[60] Belarusian Council of Ministers Resolution No. 248 of 28 March 2016, approving the National Programme "Energy Saving" for 2016-2020, http://www.pravo.by/document/?guid=3871&p0=C21300510&p1=1

[61] UNDP/GEF project "Energy Efficiency Improvement in Residential Buildings": Annual Project Review, http://www.by.undp.org/content/dam/belarus/docs/EE-in-buildings/APR-2015_Eng_EERB77154.pdf

[62] UNECE Renewable Energy Status Report: 2017, http://www.ren21.net/wp-content/uploads/2017/06/REN21_UNECE_Renewable_Energy_Status_Report_2017_Report_FINAL.pdf

[63] Law of the Republic of Belarus No. 204-3 on Renewables, dated 27 December 2010, http://energoeffekt.gov.by/downloads/laws/act/Istochniki_27122010.doc

- confirmation of renewable origin of energy with certificates;
- tax exemptions and other benefits, including possible exemption of equipment from customs duties;
- application of stimulating multiplying coefficients to the price of energy produced from renewables compared to energy generated using traditional sources (in accordance with the Resolution No. 100 of the Ministry of Economy of the Republic of Belarus On Tariffs for Electric Power Produced from Renewable Energy Sources, as of 30 June 2011[64]).

In addition, foreign investors are allowed to own renewable generating capacities, with the government guaranteeing the purchase of energy. However, end users are able to purchase electricity only centrally from the national regulator (direct purchase from private energy producers is not possible).

A distinctive feature of regulation of the renewable energy sector of Belarus is the quota mechanism for new renewables installations. Resolution No. 662 of the Belarusian Council of Ministers, as of 6 August 2015, regulates setting of quotas[65]. The quota mechanism was a reaction to high renewable energy development rates due to multiplying factors and mandatory purchase of energy by the state with insufficient budgetary funds available for such purposes. Due to this mechanism, the number of investors and new installations (with the exception of installations used in business activities only and not for the sale of energy produced) is limited. At the same time, investors that have been given quotas will enjoy guaranteed multiplying factors during ten years after their installations are put into operation.

Currently, the number of applications for quotas on the construction of new renewables installations exceeds by several times the limits set by the government. For example, received applications reached 770 MW, while only 117.42 MW of quotas were available for distribution in the period from 2017 to 2019. The quota mechanism (as well as multiplying factors) was criticised on numerous occasions, including by government authorities of Belarus, as ineffective and limiting sector's growth[66].

4.3. Perspectives for transport sector development of Belarus

As of 2014, the transport sector currently accounts for 24% of Belarus's total energy consumption (see Annex 5). This indicator is comparable to the global one (29%[67]). Meanwhile, the share of fuel oil consumption for 2014 is at 86% (148 PJ), which is considerably lower than the global indicator — 92%.

As of 2015, over 3 million cars are registered in Belarus. The average annual growth rate is 2% (approx. 70 000 cars per year)[68]. As of August 2017, about 100 electric cars are registered and seven charging stations operate in Belarus[69]. The Draft Programme On the Development of Charging Infrastructure and Electric Transport in the Republic of Belarus for 2016 — 2025 sets forth two scenarios for the development of electric transport[70]. According to the optimistic scenario, the number of electric cars in Belarus may increase to 32.8 thousand (including 1880 electric buses) while under a pessimistic scenario, their number may increase to approx. 10 thousand (including 590 electric buses). Electrification of passenger cars will result in significant savings of both fuel oil and primary energy. Belarus is a rather small country, and the already existing electric car models with a 300-400 km driving range per charge can well satisfy drivers' needs.

Utility services and municipal heavy vehicles are usually medium-duty vehicles (MDV). They are easy targets for gasification and electrification (short haul distances, average vehicle weight, and proximity of charging stations). Due to their impact on the quality of urban air, utility service vehicles should become a primary focus of the transition to cleaner types of fuel. Electrification or gasification of freight vehicles is also possible but most required technologies are yet at the development stage.

Rail is one of the most energy efficient types of transport. In Belarus, railway transport accounts for 32% of all cargo transportations and 30% of all passenger transportations in the public transport segment (i.e.

[64] Resolution No. 100 of the Ministry of Economy of Belarus On Tariffs for Electric Power Produced from Renewable Energy Sources, as of 30 June 2011, http://pravo.newsby.org/belarus/postanov3/pst926.htm

[65] Belarusian Council of Ministers Resolution No. 662 as of 6 August 2015 (as amended by Resolution No. 305 of the Belarusian Council of Ministers, as of 26 April 2017), http://www.government.by/upload/docs/file0cfe298f6918f16b.PDF

[66] The investors' applications for the construction of new renewables installations in 2017-2019 were seven times higher than the total quota https://doingbusiness.by/zayavki-investorov-na-vvedenie-novih-moshnostei-vie-v-7-raz-previsili-razmer-obshei-kvoti

[67] IEA World Energy Balance, 2014, https://www.iea.org/Sankey/

[68] Statistical Report "Transport and Communications in the Republic of Belarus", 2016, http://www.belstat.gov.by/ofitsialnaya-statistika/publications/izdania/public_compilation/index_5100/

[69] Sputnik.by, 2017. Traffic Police: nearly 100 electric cars are registered in Belarus, https://sputnik.by/society/20170825/1030483295/gai-v-belarusi-zaregistrirovano-okolo-100-ehlektromobilej.html

[70] Ministry of Energy of the Republic of Belarus, Draft Programme On the Development of Charging Infrastructure and Electric Transport in the Republic of Belarus for 2016 — 2025.

excluding passenger cars)[71] as of 2015. Low railway density[72] prevents the more effective use of the railway transport. The railway electrification rate is much lower than the share of transportation by electric locomotives (as of 2016, only 21% of the railway lines are electrified).[73]

As of 2015, Belarusian public transport fleet consists of 4680 buses and 1700 trolleybuses, 322 trams and 361 subway cars[74]. Use of trams (one of the most energy-efficient types of municipal transport), is limited in Belarusian cities[75].

National strategy (2013-2020) on the reduction of transport-caused air pollution is currently being implemented. One of the objectives of this strategy is to increase the share of electric transport (including railway and motor transport) from the current 45% to 50% of total municipal passenger transportations in large cities.

Achievement of this objective is technically possible as battery-powered electric buses for 60-80 passengers and a driving range of 250 km are already available. The draft Programme On the Development of Charging Infrastructure and Electric Transport provides estimates of potential growth in the number of electric buses and their electricity consumption rates. Under the optimistic scenario, by 2025 Belarus will have approx. 1900 electric buses with an aggregate electricity consumption of 0.14 TWh.

Belarus is not a leader in the implementation of modern municipal transport policies. However, it is starting to follow all major trends in this area though with some delay comparing to EU countries with better developed infrastructure. An example of successful transport management strategies is the effectiveness of measures aimed at reducing the number of road traffic accidents. For example, implementation of the Minsk City Concept of Road Traffic Safety has decreased the number of deaths by 2.5 times over 10 years.[76]

Achievement of ambitious municipal transport-related goals is possible because currently this sector in Belarus is highly unoptimised and has a big potential for development in all aspects. For example, a private car in a city is not used usually for 20-22 hours a day and occupies 18 m² of the urban space. On the road, a private car occupies 60 m² per passenger, carries 1.5 passengers on the average and has the overall efficiency of approx. 30%. A bus, or even an electric taxi, have much better efficiency indicators. Privately owned vehicles currently account for 67% of all transportations in Belarus.

Taking into account considerable uncertainties of transport sector development, it is important not to determine which type of municipal transport will dominate, but rather focus on the following issues:

- whether the municipal authorities have defined criteria of a convenient transport system (e.g., transport frequency, regularity, accessibility, ergonomic efficiency, road accident rate, etc.);
- whether the capacity of municipal transport system has been determined (e.g., how many cars can be parked in a day in a certain quarter, targeted gas pollution rate for each street), and whether respective mechanisms have been created to facilitate meeting city capacity limits;
- whether transport system objectives and indicators have been defined and reflected in the respective strategy, and whether priorities have been set for further development of various types of transport;
- whether proper conditions have been created for the management of the transport demand and for the achievement of respective objectives (state policy instruments and regulatory mechanisms), and whether proper conditions have been created for the development of the priority types of transport.

Table 4.1. presents an analysis on the use of prospective state policy instruments, which are necessary to implement the Energy [R]evolution scenario, in the transport sector of Belarus and provides recommendations on what instruments should be introduced.

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[71] Statistical Report "Transport and Communications in the Republic of Belarus", 2016, http://www.belstat.gov.by/ofitsialnaya-statistika/publications/izdania/public_compilation/index_5100/

[72] According to the Report "Transport and Communications in the Republic of Belarus", railway density in Belarus is 26 km per 1000 km2, which is five times lower compared to Germany, https://ru.wikipedia.org/wiki/%D0%96%D0%B5%D0%BB%D0%B5%D0%B7%D0%BD%D0%BE%D0%B4%D0%BE%D1%80%D0%BE%D0%B6%D0%BD%D0%B0%D1%8F_%D1%81%D0%B5%D1%82%D1%8C

[73] Statistical Report "Transport and Communications in the Republic of Belarus", 2016, http://www.belstat.gov.by/ofitsialnaya-statistika/publications/izdania/public_compilation/index_5100/

[74] Statistical Report "Transport and Communications in the Republic of Belarus", 2016, http://www.belstat.gov.by/ofitsialnaya-statistika/publications/izdania/public_compilation/index_5100/

[75] Total length of tram routes in Belarusian cities is 62 km, which is, for example, less than in Helsinki (91 km) or Berlin (190 km).

[76] http://baes.by/index.php/dobraia-doroga/%D0%B0%D0%BD%D0%B0%D0%BB%D0%B8%D0%B7

Table 4.1. Prospective state policy instruments in the transport sector

Policy or instrument	**Application in Belarus**	**What should be implemented?**
Municipal and national transport strategies, plans	• Strategy On the Reduction of Air Pollution from Transport in the Republic of Belarus Until 2020[77] • State Programme On the Development of the Transport System of the Republic of Belarus for 2016 — 2020[78] • Republican Programme On the Development of Logistics System and Transit Potential for 2016 — 2020[79]	Municipal and national strategy documents do not have clearly stated priorities for further development of the transport sector: first of all, steps should be taken to develop pedestrian and cycling infrastructure, portable means of transport and public passenger transport, and then privately owned vehicles. There are no complex municipal transport strategies (except for the Mobility Plans which are currently being developed for two cities — Polotsk and Novopolotsk).
Mechanisms for managing the transport demand	Partially implemented — paid parking lots in cities	• A paid parking area should be created in the centre of all big cities; • introduce paid entry to cities; • prohibit transit traffic through cities; • certain streets should become pedestrian; speed limits in cities should be reduced to 30 and 50 km per hour.
Urban development projects reducing the need for travel of city residents	Not implemented	Multifunctional real estate development projects should be promoted to reduce the need for residents to travel.
Economic instruments for compensation of adverse environmental impacts of transport	Not implemented	• methodologies should be developed to estimate the total social cost of travel by various means of transport; • a financial mechanism should be developed to compensate to society for the implicit subsidy associated with the use of a vehicle and provide citizens with incentives to use those types of transport, which are more environmentally, energy and economically efficient.
Smart logistics for product deliveries	Not implemented	Logistical micro-hubs should be created in cities, online shopping should be promoted.
Municipal passenger transport development	Concept On Quality Improvement of Public Passenger Transportation Services in Minsk in 2015 — 2020[80]	Incentives should be provided to improve the quality and speed of passenger transport and its electrification.
Multimodality	Not implemented	A transport system should be created where various types of transport could be easily combined.
Car-sharing, car-pooling	Not implemented	Various forms of car-sharing should be developed, car owners should be incentivised to give up exclusive ownership of their cars.
Driverless cars	Not defined by the law	A proper regulatory framework should be developed to promote this technology.
Electric cars	Programme On the Development of Charging Infrastructure and Electric Transport in the Republic of Belarus for 2016 — 2025[81].	The Draft Programme should be approved and implemented.
Cycling transport and bike sharing	Concept On Urban Cycling Transport System Development in Minsk[82].	Ambitious targets should be set for cycling transport development, relevant programmes should be developed, incentives should be provided for cycling, and urban bike rental services should be set up.
Pedestrian traffic and personal transport development	Not implemented	• Incentives should be provided for the use of scooters, segways, hoverboards, and other personal transportation devices; • new pedestrian streets should be established, and those existing streets which are more suitable for pedestrian traffic should be pedestrianised; • respective regulations should be revised.

[77] Strategy On the Reduction of Air Pollution from Transport in the Republic of Belarus Until 2020, http://www.minpriroda.gov.by/ru/new_url_2009876790-ru/

[78] State Programme On the Development of the Transport System of the Republic of Belarus for 2016 — 2020, http://www.government.by/upload/docs/file591cd03b057946c1.PDF

[79] Republican Programme On the Development Logistics System and Transit Potential for 2016 — 2020, http://government.by/ru/solutions/2556

[80] Concept On Quality Improvement of Public Passenger Transportation Services in Minsk in 2015 — 2020, http://baes.by/images/documents/concept/concept_opt_2015-2020.pdf

[81] Ministry of Energy of the Republic of Belarus, Draft Programme On the Development of Charging Infrastructure and Electric Transport in the Republic of Belarus for 2016 — 2025.

[82] Concept On Urban Cycling Transport System Development in Minsk, https://minsk.gov.by/ru/normdoc/3302/koncepciya.shtml

5 Methodology

- Introduction to the scenario approach
- Scenario storylines and main premises
- Scenario approach
- Main scenario assumptions
- Oil and gas price projections
- Demand development
- Cost projections for efficient fossil fuel generation and CO_2 emissions
- Projections for renewable energy technologies
- Renewable heating technologies
- Renewable energy potentials

Photo: ©flickr.com — Asian Development Bank

5.1. Introduction to the scenario approach

A pathway toward a more sustainable energy system requires a low carbon energy supply that equally avoids environmental impacts as well as impacts on human health. Action against climate change requires a long-term perspective. Energy infrastructure takes time to build up; new energy technologies take time to develop. Policy shifts often also need many years to take effect. A transition towards a predominantly renewable energy system, however, promises tremendous economic benefits in the long term, due to much lower consumption of increasingly expensive, rare or imported fuels. Any analysis that seeks to tackle energy and environmental issues, therefore, needs to look ahead at least until the mid of the century.

Scenarios are a necessary tool to describe possible development paths, to give decision-makers a broad overview and indicate how far they can shape the future energy system. In order to evaluate the boundaries of the future energy system, we are developing two scenarios here to show the wide range of possible pathways for a future energy supply system:

- a **Reference scenario**, reflecting a continuation of current trends and policies and
- the **Energy [R]evolution scenario**, designed to achieve a set of environmental policy targets resulting in an optimistic but still feasible pathway towards a widely decarbonized energy system until 2050 in close relation to basic framework assumptions of the Reference scenario.

In general, the Energy [R]evolution scenario by no means claims to predict the future; it simply describes and compares potential development pathways out of the broad range of possible 'futures'. The concept of all Energy [R]evolution scenarios is designed to indicate the efforts and actions required to achieve their ambitious objectives and to illustrate the options we have at hand to change our energy supply system into one that is more sustainable. The scenarios may serve as a consistent basis for further analyses of possible ways and concepts to implement pathways to an energy transition.

5.1.1. Scenario storylines and main premises

The **Reference scenario** (REF) follows an explorative approach. It is based on the latest global Energy [R]evolution Scenario report[83] for the Eurasia region. It is based on the Current Policies scenarios published by the International Energy Agency (IEA) in World Energy Outlook 2014[84], taking only existing international energy and environmental policies into account. Additionally, the scenario is adapted to the Belarus case by an extensive analysis of national energy policy and programs, specifically focusing on efficiency and renewable energy development[85]. The Reference scenario does not include additional policies to reduce greenhouse gas emissions and was reviewed by national experts[86]. The Reference scenario provides a baseline for comparison with the Energy [R]evolution scenario.

The **Energy [R]evolution scenario** (E[R]) is a target-oriented scenario. It is based on the latest global update of the E[R] scenario for Eurasia published in 2015, which followed the key target to reduce worldwide carbon dioxide emissions from energy use down to a level of around 4 Gigatonnes per year by 2050 in order to hold the increase in global temperature under +2°C. A second objective is the global phasing out of nuclear energy. The E[R] scenario aims at strong efforts towards a predominantly renewable energy supply and a reduced dependency on imported gas in Belarus. The scenario includes significant efforts to fully exploit the large potential for energy efficiency, using currently available best practice technology. At the same time, proven renewable energy sources are integrated to a large extent for heat and electricity generation, as well as the production of biofuels and hydrogen. The general framework parameters for population and GDP growth remain unchanged from the Reference scenario.

Due to higher efficiencies of new vehicle concepts and the assumption of modal split changes compared to the previous global E[R], the resulting final energy demand for transportation decreases strongly. However, this scenario requires fundamental changes in mobility patterns and behaviour as well as infrastructural needs to compensate for the high energy losses associated with the production of hydrogen based on renewable electricity. The latter also plays an increasing role in the heating sector, increasingly substituting for the remaining gas. Therefore, electricity generation from renewable energy sources is supposed to be the main "primary energy" of the future.

The scenario building for the Energy [R]evolution scenario follows a framework of targets and main premises that strongly influences the development of individual technological and structural pathways for each region

[83] Teske, S., S. Sawyer, O. Schäfer, T. Pregger, S. Simon, et al. (2015). Energy [R]evolution — A sustainable world energy outlook 2015. S. Teske, S. Sawyer and O. Schäfer, Greenpeace International.

[84] IEA (2014). World Energy Outlook 2014. Paris, International Energy Agency, Organisation for Economic Co-operation and Development.

[85] Filiutsich, I. (2016). Data collection and review of the Reference scenario for the Energy [R]evolution report Belarus. unpublished, Institute of Power Engineering of the National Academy of Sciences of Belarus.

[86] Filiutsich, I., A. J. Grebenkov and S. Nikitin (2017). Review of the Energy [R]evolution Scneario, Institute of Power Engineering of the National Academy of Sciences of Belarus, United Nations Development Programme.

and each sector. The main premises considered for this scenario building process are described below.

In general, strong efficiency improvements and dynamic expansion of renewable energies in all sectors are the main strategies to meet the overall target of CO_2 emissions reduction. CCS technologies are not implemented and nuclear power is eventually phased out. Based on current knowledge about potentials, costs and recent trends of renewable energy deployment (see next section on 'Scenario approach') a dynamic further growth of capacities for renewable heat and power generation is assumed.

The quantities of biomass power generators and large hydropower remain limited in the global Energy [R]evolution scenario, for reasons of ecological sustainability. Wind power and solar PV power are expected to become important pillars of the future power supply, complemented by smaller contributions from biomass for backup and a small expansion of small and medium-sized hydropower. Eventually, the scenario introduces hydrogen as an option to balance the increasing share of fluctuating power generation and to maintain a sufficient share of controllable, secured capacity.

Sustainable biomass potential of Belarus is assumed to be limited to less than 250 PJ for power, heat and biofuel production[87] according to Institute of Power Engineering of the National Academy of Sciences of Belarus. However, a limited import of sustainably produced biofuels from neighbouring countries such as the Ukraine and Russia or from the EU seems feasible and will be largely determined via biomass markets. Traditional biomass use is largely replaced by state-of-the-art technologies, primarily high-efficient cogeneration plants.

Efficiency savings in the transport sector are a result of the modal shift, propagation of highly efficient vehicle concepts such as electric vehicles but also assumed changes in driving patterns and the implementation of efficiency measures for combustion engines. According to local experts, these measures are already partially targeted in current policies in Belarus.[88] However, the speed of dissemination along these measures increases significantly in the Energy [R]evolution scenario.

The Energy [R]evolution scenario also foresees a shift in the heat sector towards an increasing direct use of electricity, thanks to the larger potential for renewable power and the limited availability of renewable fuels for high-temperature process heat in industry. In addition, a fast expansion of district and solar heating is assumed, supplemented by an introduction of geothermal heat pumps. This all leads to an increasing electricity demand.

The increasing shares of fluctuating renewable power generation from wind farms and photovoltaics implicitly require the implementation of smart grids, a fast expansion of transmission grids, an extension of storage or other load balancing capacities. Other infrastructural needs result e.g. from an increasing role of electric mobility.

5.1.2. Scenario approach

The Energy [R]evolution scenario in this report was commissioned by the Heinrich-Boell-Stiftung from the German Aerospace Center (DLR), Department of Systems Analysis and Technology Assessment at the Institute of Engineering Thermodynamics.

The Energy [R]evolution scenario for Belarus is a target-oriented scenario. Therefore, it must not be interpreted as a "forecast" of the future development of the energy systems. Similar to all the other Energy [R]evolution Scenarios, the Belarus scenario is developed using a primarily "bottom-up" approach (technology driven). Assumed growth rates for population, GDP, specific energy demand and the deployment of renewable energy technology are important drivers. Based on these drivers new energy demand projections were developed by national experts[89] based on an analysis of the future potential for energy efficiency measures until 2050.

The supply scenarios were calculated using the Mesap/PlaNet simulation model adopted in the previous Energy [R]evolution studies[90]. This model does not use a cost optimization approach for the calculation of energy technology expansion. Rather it requires a consistent exogenous definition of feasible developments in order to meet the targets. Using assumptions and background information about technical and structural options for the transformation of the energy system, and taking into account – as far as possible – potential barriers and limits, consistent development paths are defined and integrated into the model database. The model as an accounting framework then calculates the energy balances of the future for all sectors as well as related investments and costs in the power sector. Quantified targets for transforming the energy systems set the framework for its design. The backbone of the model is the technology database, providing techno-economical data for all sectors (see Figure 5.1).

87 Filiutsich, I. (2016). Data collection and review of the Reference scenario for the Energy [R]evolution report Belarus. unpublished, Institute of Power Engineering of the National Academy of Sciences of Belarus.

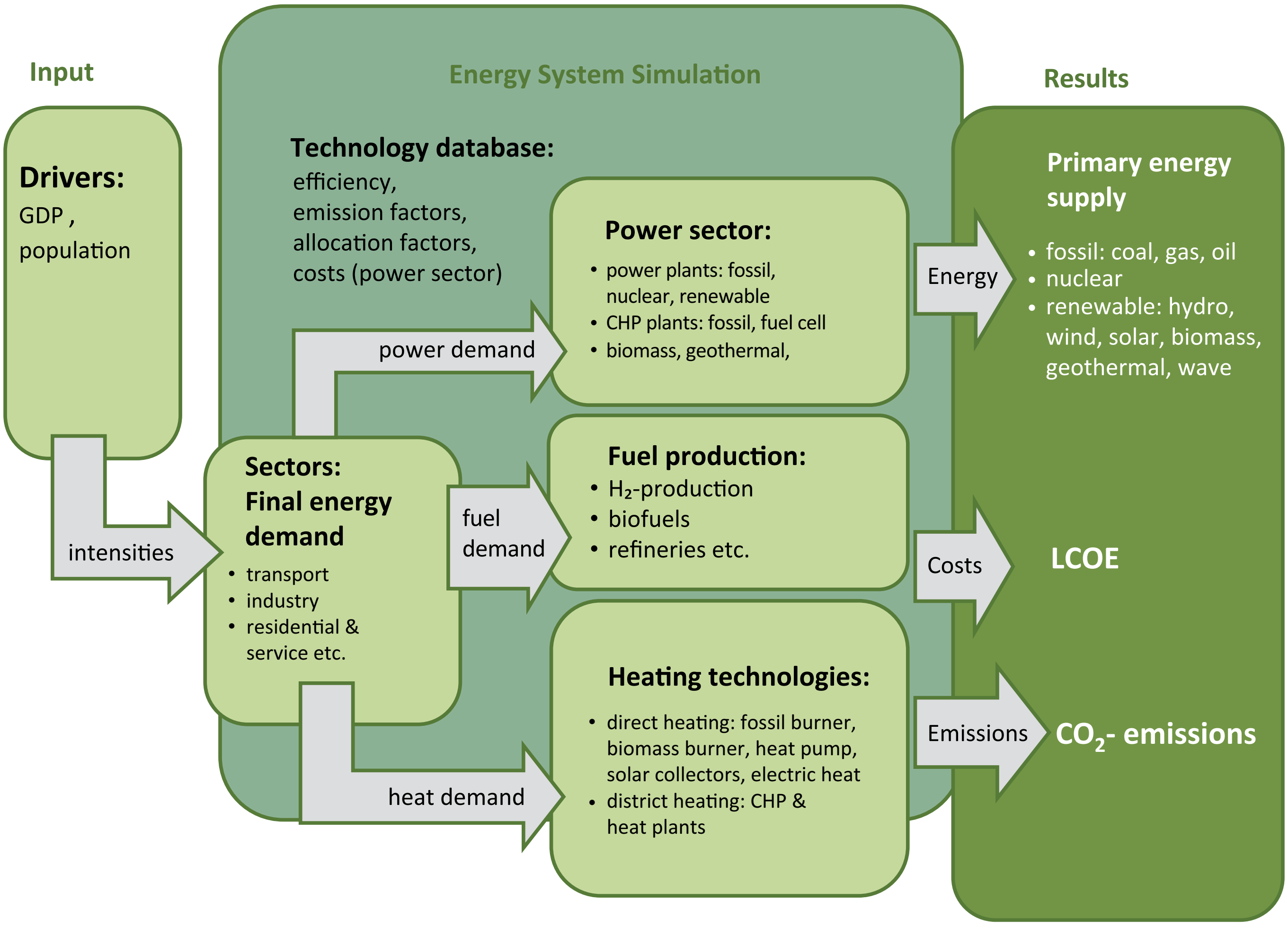
88 Harbunou, P. (2016). Review of Belarus electric transport. Workshop on the Belarus Energy [R]evolution Scenario, Center for environmental solutions. Minsk, Belarus.

89 Filiutsich, I. (2016). Data collection and review of the Reference scenario for the Energy [R]evolution report Belarus. unpublished, Institute of Power Engineering of the National Academy of Sciences of Belarus, Harbunou, P. (2016). Review of Belarus electric transport. Workshop on the Belarus Energy [R]evolution Scenario, Center for environmental solutions. Minsk, Belarus.

90 Teske, S., S. Sawyer, O. Schäfer, T. Pregger, S. Simon, et al. (2015). Energy [R]evolution – A Sustainable World Energy Outlook 2015. S. Teske, S. Sawyer and O. Schäfer, Greenpeace International.

Teske, S., T. Pregger, S. Simon, T. Naegler, M. O'Sullivan, et al. (2012). Energy [R]evolution – a Sustainable World Energy Outlook – 4th edition 2012. S. Teske, J. Muth and S. Sawyer, Greenpeace International, Global Wind Energy Council (GWEC).

Figure 5.1: Overview of the Mesap/PlaNet model structure



Structure and initial parametrisation of the energy system is extracted from the extended energy balances published in 2014 by International Energy Agency (IEA)[91]. For the base year, 2014 statistical data is adjusted based on national statistics[92].

The dynamic expansion of renewable energies defined in the scenario is based on recent technology trends[93], market development projections of the renewable energy industry[94] and current knowledge about renewable energy potentials of Belarus (compare section 5.2.6) and costs for their deployment in Europe[95].

Technology and cost projections for the heating sector are adopted from a background study commissioned by EREC from DLR about the current renewable heating technology markets, market forecasts, cost projections and state of the technology development. Details can be found as well in the global Energy [R]evolution study of 2012.

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[91] IIEA (2016). Worlg Energy Balances (2016 edition), IEA energy statistics (Beyond 20/20). Paris, International Energy Agency.

[92] Filiutsich, I. (2016). Data collection and review of the Reference scenario for the Energy [R]evolution report Belarus. unpublished, Institute of Power Engineering of the National Academy of Sciences of Belarus.

[93] REN21 (2016). Renewables 2016 Global Status Report. Paris, REN21 Secretariat (Renewable Energy Policy Network for the 21st Century).

[94] EPIA (2014). Market Report 2013, European Photovoltaic Industry Association.

GWEC (2014). Global Wind Statistics 2013, Global Wind Energy Council.

WEC (2015). World Energy Resources – Charting the Upsurge in Hydropower Development 2015, World Energy Council.

[95] Pietzcker, R. C., D. Stetter, S. Manger and G. Luderer (2014). "Using the sun to decarbonize the power sector: The economic potential of photovoltaics and concentrating solar power." Applied Energy 135: 704-720.

Deng, Y. Y., M. Haigh, W. Pouwels, L. Ramaekers, R. Brandsma, et al. (2015). "Quantifying a realistic, worldwide wind and solar electricity supply." Global Environmental Change 31: 239-252.

IRENA (2015). Renewable Power Generation Costs in 2014, International Renewable Energy Agency.

DLR (2016): REMix Endat modelling results provided by the German Aerospace Center, Institute of Engineering Thermodynamics.

5.2. Main scenario assumptions

5.2.1. Demand development

Population development and economic growth are the main drivers for the development of the energy demand. Since 1971, each 1% increase in global Gross Domestic Product (GDP) has been accompanied by a 0.6% increase in primary energy consumption[96]. The following sections describe the population and economic development which serve as a set input into the modelling for both scenarios for Belarus.

Population development

Future population development is an important factor in energy scenario building, affecting size and composition of energy demand, directly and through its impact on economic growth and development. For the Energy [R]evolution scenario, we applied the United Nations Development Programme (UNDP) projections for population development up to 2050[97].

Table 5.1: Population development projection for Belarus

	2014	2020	2025	2030	2040	2050
million	9.5	9.4	9.2	9.0	8.5	8.1

Source: prepared based on UNDP development projections, medium variant.

Table 5.1 shows that the Belarus population is expected to decrease by 0.4% per year on average over the period 2014 to 2050, from 9.5 million people in 2014 to 8.1 million by 2050. Satisfying the energy needs of the population and transforming the infrastructure in an environmentally friendly manner is a fundamental challenge to achieve a more sustainable energy supply.

Economic growth

Economic growth is a key driver for energy demand. The decoupling of energy demand and GDP growth is, therefore, a prerequisite for an Energy [R]evolution. However, GDP growth is expected to slow gradually over the coming decades.

For our modelling, we use purchasing power parity (PPP) exchange rates to provide comparability of costs on a global level. Although PPP assessments are still relatively imprecise compared to statistics based on national income and product trade and national price indexes, they are considered to be a better basis for a scenario development[98]. Thus, all data on economic development in WEO 2014 refers to purchasing power adjusted GDP. National GDP development for Belarus is based on the World Energy Outlook 2014[99], with growth rates of 3.25% until 2020 and 3.18% until 2040. However, as WEO 2014 only covers the time period up to 2040, we apply the growth rate for Eurasia from the Energy [R]evolution Scenario 2015 at 2.25% afterwards until 2050.

Demand scenarios and efficiency potentials

Resulting energy intensities for industries and other sectors were compared and reviewed on the basis of regional values for Eurasia from the global Energy [R]evolution scenario 2015.

5.2.2. Oil and gas price projections

The fluctuations in global oil prices have been significant during the last years and with influence on price projections. Under the 2004 'high oil and gas price' scenario from the European Commission, for example, an oil price of just $34 per barrel was assumed in 2030. More recent projections of oil prices by 2040 in the IEA's WEO 2014 range from $$_{2013}$100/bbl in the 450 ppm scenario up to $$_{2013}$155/bbl in the Current Policies scenario.

Since the first Energy [R]evolution study was published in 2007, the actual price of oil has moved over $100/bbl for the first time, and in July 2008 reached a record high of more than $140/bbl. Oil prices then fell back to $100/bbl in September 2008 and around $80/bbl in April 2010, but afterwards again increased to more than $110/bbl in early 2012. Beginning in 2014 the oil price has seen a sharp decrease down to values between 40 and 60 $/bbl in 2015, due to the global economic situation and market reasons. Taking into account expected growth in global energy demand in mid-term and long-term projections, the 2015 revision of the Energy [R]evolution scenarios assumed fossil fuel price projections according to the World Energy Outlook 2014. In contrast to the previous E[R] editions, this study uses different assumptions for the Reference scenario compared to the Energy [R]evolution scenarios (see Table 5.2).

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[96] IEA (2014). World Energy Outlook 2014. Paris, International Energy Agency, Organisation for Economic Co-operation and Development.

[97] UNPD. (2015). "World Population Prospects: The 2015 Revision." http://esa.un.org/unpp/.

[98] Nordhaus, W, Alternative Measures of Output in Global Economic-Environmental Models: Purchasing Power Parity or Market Exchange Rates?, report prepared for IPCC Expert Meeting on Emission Scenarios, US-EPA Washington DC, January 12-14, 2005.

[99] IEA (2014). World Energy Outlook 2014. Paris, International Energy Agency, Organisation for Economic Co-operation and Development.

Table 5.2: Development projections for fossil fuel and biomass prices in €2013 for Belarus based on assumptions for Eurasia

	Scenario	Unit	2014	2020	2030	2040	2050
Crude Oil	REF	€/GJ	13.9	15.2	18.2	20.3	19.6
	E[R]	€/GJ	13.9	15.2	14.6	13.1	12.8
Hard coal	REF	€/GJ	3.7	3.7	4.1	4.3	4.6
	E[R]	€/GJ	3.7	3.7	2.9	2.7	2.6
Natural Gas	REF	€/GJ	9.0	9.7	11.2	11.8	12.5
	E[R]	€/GJ	9.0	9.6	8.9	7.8	7.1
Biomass	REF and E[R]	€/GJ	3.4	3.7	4.2	4.6	5.1

As the supply of natural gas is limited by the availability of pipeline infrastructure, there is no world market price for gas. In most regions of the world, the gas price is directly tied to the price of oil. For Belarus, fossil fuel prices are based on the assumptions for Eurasia from the global Energy [R]evolution study 2015[100].

5.2.3. Cost projections for efficient fossil fuel generation and CO2 emissions

Specific investment and operation costs of coal, gas, lignite and oil power plants are assumed according to the WEO 2014 Special report on investments[101]. Because they are at an advanced stage of technology and market development, the potential for cost reductions is limited. More details can be found in the global Energy [R]evolution edition of 2015.

The Energy [R]evolution Scenario does not consider nuclear decommissioning costs. On the one hand, this is due to the fact, that even the current energy system does not account for the complete cost of decommissioning. On the other hand, this is due to the lack of data regarding these costs, which is also the reason for neglecting these costs in the current system.

Prospects for establishing an effective global carbon emissions trading system across all world regions are currently at best unclear. In contrast to the previous global Energy [R]evolution scenarios, the revision from 2015 onwards set aside CO2 pricing altogether. It is also not considered in the Energy [R]evolution scenario for Belarus. Cost comparisons between the scenarios thus only rely on investment, operation and maintenance and fuel costs.

Table 5.3 summarizes our assumptions on the technical and economic parameters of future fossil fuel power plant technologies. Based on estimates from WEO 2014, we assume that further technical innovation will not prevent an increase in future investment costs because raw material costs and technical complexity will continue to increase. Also, improvements in power plant efficiency are outweighed by the expected increase in fossil fuel prices. These would make electricity generation costs increase significantly.

Table 5.3: Development of efficiency and investment costs for selected new power plant technologies; exemplary data for Belarus

		2014	2020	2030	2040	2050
Gas fired power plant	efficiency (%)	42	43	45	47	49
	investment costs (€/kW)	546	534	515	517	539
Gas fired combined cycle CHP plant	efficiency (%)	75	80	82	85	86
	investment costs (€/kW)	841	841	841	841	841

Source: prepared based on WEO 2014 and own assumptions of authors.

[100] Teske S., S. Sawyer, O. Schäfer, T. Pregger, S. Simon, et al. (2015). Energy [R]evolution – A sustainable world energy outlook 2015. S. Teske, S. Sawyer and O. Schäfer, Greenpeace International.

IEA (2014). World Energy Outlook 2014. Paris, International Energy Agency, Organisation for Economic Co-operation and Development.

[101] IEA (2014). IEA World Energy Investment Outlook 2014 – Power Generation in the New Policies and 450 Scenarios – Assumed investment costs, operation and maintenance costs and efficiencies. Paris, International Energy Agency, Organisation for Economic Co-operation and Development.

5.2.4. Projections for renewable energy technologies

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

It is possible to develop a wide spectrum of options to market maturity, using the individual advantages of the different technologies, linking them with each other, and integrating them step by step into the existing supply structures. This approach will provide a complementary portfolio of environmentally friendly technologies for heat and power supply and the provision of transport fuels.

Many of the renewable technologies employed today are at a relatively early stage of market development. It is expected, however, that large cost reductions can come from technical advances, manufacturing improvements and large-scale production, unlike conventional technologies. The dynamic trend of cost developments over time plays a crucial role in identifying economically sensible expansion strategies for scenarios spanning several decades.

To identify long-term cost developments, learning curves have been applied to the model calculations to reflect how the cost of a particular technology change in relation to the cumulative production volumes. Assumptions on future costs for renewable electricity are based on the cost assumptions of the global Energy [R]evolution scenario 2015. For Belarus cost assumptions for 2050 were reviewed by national experts. In this report, we discuss only the technologies, which were identified as relevant for a local installation[102]: specifically power from hydro, PV & wind and geothermal heat pumps and solar applications for heat production. Above that, biomass and hydrogen are included as storable energy carriers for all energy sectors.

The resulting investment costs are integrating information form learning curve studies, for example by Lena Neij,[103] from the analysis of technology foresight and road mapping studies, including the European Commission funded NEEDS project (New Energy Externalities Developments for Sustainability)[104] or the IEA Energy Technology Perspectives 2008, projections by the European Renewable Energy Council published in April 2010 ("Re-Thinking 2050") and discussions with experts from different sectors of the renewable energy industry.

Photovoltaics

The worldwide photovoltaics (PV) market has been growing at 25% per annum in recent years, reaching 40 GW of new installed capacity in 2014[105] and is now making a significant contribution to electricity generation. Photovoltaic is important because of its decentralized/centralized variability, its flexibility for use in an urban environment and huge potential for cost reduction. The PV industry has been increasingly exploiting this potential during the last few years, with installation prices more than halving in the last few years. Current development is focused on improving existing modules and system components by increasing their energy efficiency and reducing material usage. Technologies like PV thin film (using alternative semiconductor materials) or dye sensitive solar cells are developing quickly and present a huge potential for cost reduction. The mature technology crystalline silicon, with a proven lifetime of 30 years, is continually increasing its cell and module efficiency (by 0.5% annually), whereas the cell thickness is rapidly decreasing (from 230 to 180 microns over the last five years). Commercial module efficiency varies from 14 to 21%, depending on silicon quality and fabrication process.

The learning factor for PV modules has been fairly constant over the last 30 years with costs reducing by 20% each time the installed capacity doubles, indicating a high rate of technical learning. Based on global installations, in the Energy [R]evolution scenario for Belarus we can expect generation costs of around 6 cents/kWh by 2050. PV has already become competitive with retail electricity prices in some parts of the world, and will become competitive with fossil fuel costs soon.

Wind power

Within a short period of time – just since the last decade – the dynamic development of wind power has resulted in

[102] Raslavičius, L. (2012). "Renewable energy sector in Belarus: A review", Renewable and Sustainable Energy Reviews 16(7): 5399-5413. Korotinsky, V., W. Tanas and K. Garkusha (2013). Prospects of development of bioenergetics in Belarus, Teka Komisji Motoryzacji i Energetyki Rolnictwa 13(1).

[103] Neij, L. (2008). Cost development of future technologies for power generation—a study based on experience curves and complementary bottom-up assessments, Energy policy 36(6): 2200-2211.

[104] NEEDS. (2009). The NEEDS Life Cycle Inventory Database, the European reference life cycle inventory database of future electricity supply systems, http://www.needs-project.org/needswebdb/index.php.

[105] EPIA (2014). Market Report 2013, European Photovoltaic Industry Association.

[106] GWEC (2014). Global Wind Statistics 2013, Global Wind Energy Council.

the establishment of a flourishing global market of over 50 GW in 2014[106]. In Europe, favourable policy incentives were the early drivers for the global wind market. However, since 2009 more than three-quarters of the annual capacity installed was outside Europe and this trend is likely to continue. The boom in demand for wind power technology has nonetheless led to supply constraints and stagnating markets. As a consequence, the cost of new systems has increased. The industry is continuously expanding production capacity, however, so it is already resolving the bottlenecks in the supply chain and in 2014 market development again gained speed and increased by 6-10 GW compared to the years before. Taking into account market development projections, learning curve analysis and industry expectations, investment costs for wind turbines are reduced in the Energy [R]evolution scenario for Belarus by 10% by 2050 compared to 2014.

Biomass

The crucial economic factor for applying bioenergy is the feedstock cost, which currently ranges from a negative for waste wood (based on credit for waste disposal costs avoided) through inexpensive residual materials to the more expensive energy crops. The resulting spectrum of energy generation costs is correspondingly broad. One of the most economic options is the use of wood waste in combined heat and power (CHP) plants. Gasification of solid biomass, on the other hand, which has a wide range of applications, is still relatively expensive. In the long term, it is expected that using wood gas in micro CHP units (engines and fuel cells) will have the most favourable electricity production costs.

A large potential for exploiting modern biomass technologies exists in Belarus in both stationary appliances and the transport sector. In the long term, biomass use will mainly have to rely on agricultural and forest residues, industrial wood waste and straw. However, (limited) imports of sustainable biomass fuels is an additional option to serve for grid stability and transport needs. Here feedstock markets will set the limits for domestic biomass use.

Hydropower

Hydropower is a minor electricity source in Belarus and rather limited potentials are available for development. Sustainable hydropower makes an effort to integrate plants with river ecosystems while reconciling ecology with economically attractive power generation.

Hydrogen production

In the Energy [R]evolution scenarios, hydrogen is introduced as a renewable fuel with small shares after 2040. Hydrogen is assumed to be produced via electrolysis, resulting in an additional electricity demand which is fully supplied by extra renewable power production capacities mainly from wind and PV. It thus can serve as a backup for fluctuating electricity production from wind and PV, securing electricity supply at all times. Providing additional fuels for the heat and transport sector, hydrogen also serves for reducing costly curtailment in PV and wind installations.

Summary of renewable energy cost development

Table 5.4 summarizes the cost trends for renewable power technologies derived from the respective learning curves. It is important to note that the expected cost reduction is not a function of time, but of cumulative capacity (production of units), so dynamic market development is required. Most of the technologies will be able to reduce their specific investment costs to between 30% and 60% of current once they have achieved full maturity (after 2040).

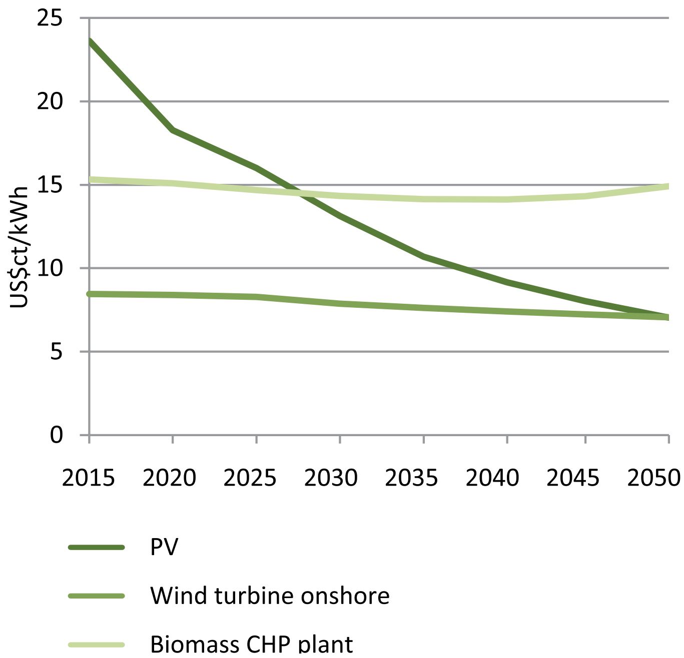
Table 5.4: Assumptions of cost development of renewable power technologies in the Energy [R]evolution scenario

		2014	2020	2030	2040	2050
Photovoltaics	€/kW	1600	1251	939	744	550
Wind onshore	€/kW	1238	1205	1173	1142	1117
Biomass CHP	€/kW	2718	2686	2643	2713	2733
Hydro small	€/kW	2152	2168	2230	2289	2337
Hydrogen produc-tion	€/kW	1238	1083	774	583	510
	Efficiency %	67	68	71	71	71

Source: prepared based on Fraunhofer ISE (2015): Current and Future Cost of Photovoltaics. Long-term Scenarios for Market Development, System Prices and LCOE of Utility-Scale PV Systems. Study on behalf of Agora Energiewende

Reduced investment costs for renewable energy technologies lead directly to reduced heat and electricity generation costs, as shown in Figure 5.2. For Belarus in the long term, levelized cost of electricity for PV and wind are expected to converge at around 5-6 €ct/kWh, with biomass being significantly more expensive at about 13 €ct/kWh (calculated without heat credits for CHP). These estimates depend on site-specific conditions such as the local wind regime or solar irradiation, the availability of biomass at reasonable prices or the credit granted for heat supply in the case of combined heat and power generation.

Figure 5.2: Expected development of electricity generation costs from renewable power generation in the Energy [R]evolution scenario



Note: electricity generation costs are provided depending on the assumed development of full load hours per year, an example for OECD Europe (US$ct/kWh, biomass CHP costs without heat credits).

Additional costs will arise for the system integration of renewable power. However, the current Energy [R]evolution Scenario for Belarus does not quantify costs for additionally necessary grid and storage infrastructure. Previous studies showed a limited effect of these costs to the overall system costs, depending on the integration with neighbouring energy systems and the share of variable renewables. Within an integrated European energy system, Scholz et al. (2016) showed, that system integration costs are stable for balanced wind and PV power supply between up to 60 – 80% of variable renewable power at around 1.5-2 €ct/kWh[107].

5.2.5. Renewable heating technologies

Renewable heating has the longest tradition of all renewable technologies. Although no specific cost calculation for the heat sector was conducted for the Energy [R]evolution scenario for Belarus, the following sections give an overview of relevant technologies and costs based on international experience. For the previous Energy [R]evolution report 2012[108] EREC and DLR carried out a joint survey on costs of renewable heating technologies in Europe. The report analysed installation costs of renewable heating technologies, ranging from direct solar collector systems to geothermal and ambient heat applications and biomass technologies. Some technologies are already mature and compete in the market – especially simple heating systems in the domestic sector. However, more sophisticated technologies, which can provide higher shares of heat demand from renewable sources, are still under development and rather expensive. Market barriers slow down the further implementation and cost reduction of the renewable heating system. Nevertheless, significant learning rates can be expected if renewable heating is increasingly implemented as projected in the Energy [R]evolution scenario for Belarus.

Solar thermal technologies

Solar collectors depend on direct solar irradiation, so the yield strongly depends on the location. In very sunny regions (e.g. in the Mediterranean), simple thermosiphon systems can provide total hot water demand in households at around 400 €/m² installation costs. In regions with less sun as in Belarus, where additional space heating is needed, installation cost for pumped systems is twice as high. In these areas, economies of scales can decrease solar heating costs significantly. Large-scale solar collector system is known from 250-600 €/m², depending on the share of solar energy in the whole heating system and the level of storage required.

Heat pumps

Heat pumps typically provide hot water or space heat for heating systems with relatively low supply temperature or can serve as a supplement to other heating technologies. They have become increasingly popular for underfloor heating in buildings. Economies of scale are less important than for deep geothermal, so there is focus on small household applications with investment costs from 500-1600 €/kW for groundwater systems and higher costs from 1200-3000 €/kW for the ground source or aerothermal systems.

Biomass applications

There is a broad portfolio of modern technologies for heat production from biomass, ranging from small-scale single room stoves to heating or CHP-plants in MW scale. Investments costs show a similar variety: simple log wood stoves can be obtained from 100 €/kW, more sophisticated automated heating systems that cover the whole heat demand of a building are significantly more expensive. Logwood or pellet boilers range from 400-1200 €/kW, with large applications being cheaper than small systems.

Heat from cogeneration (CHP) is another option with a broad range of technologies at hand. It is a very varied energy technology – applying to co-firing in large coal-fired cogeneration plants; biomass gasification combined with CHP or biogas from wet residues. But the costs for heat are often mainly dependent on the power production.

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[107] Scholz, Y., H. C. Gils and R. Pietzcker (2016). Application of a high-detail energy system model to derive power sector characteristics at high wind and solar shares. Energy Economics.

[108] Energy [R]evolution – a sustainable world energy outlook. Alexandra Dawe, Rebecca Short and C. Aubrey. Amsterdam, Greenpeace International, European Renewable Energy Council (EREC), Global Wind Energy Council (GWEC), Deutsches Zentrumfür Luft- und Raumfahrt (DLR).

5.2.6. Renewable energy potentials

The potentials for renewable energy production are a vital input for the modelling of the energy system. For Belarus, the potentials rely on a combination of literature and expert assumptions as well as specific assessment of renewable energy potential.

Wind potentials from literature span a broad range from 3-96 GW. PV potential calculations are also available at a broad range from 280-570 GW[109]. As the input parameters of the respective studies are not all transparent, the Energy [R]evolution Scenario relies on a specific assessment with the REMix Endat[110] model, which is developed at DLR. The model calculates the potential e.g. of PV and onshore Wind on the basis of spatially resolved climate and weather data for each hour of the year. The model provides hourly wind and solar power production profiles, which were calculated on a national level for Belarus (see full load hours potential curves in Figure 5.3). For PV the model assesses a large potential of 164 GW with a small variation in irradiation (980-1050 FLH). For wind FLH range between 2200 and 2600, providing up to 26 GW of capacity.

Expansion of hydro is strictly limited to small additional potentials from small to medium-sized power plants. Here an additional 250-300 MW could be developed[111]. Also, the geothermal potential in Belarus is rather limited, mainly to applications using low enthalpy sources[112]. Therefore, geothermal heat is mainly applied in geothermal heat pumps and district heat applications, which are already developed in several places in Belarus.

There is also a significant biomass potential available in

[109] IEA/OECD (2016). The Clean Energy Technology Assessment Methodology Pilot Study Belarus, International Energy Agency.

Meißner, F., F. Ueckerdt and J. Schenk (2010). Erneuerbare Energien in Belarus: Herausforderung für Versorgungssicherheit, FDI und Klimaschutz, PP/04/2010], GET German Economic Team, Berlin/Minsk.

UNDP (2014). Renewable Energy Snapshot Belarus, United Nations Development Program.

[110] Stetter, D. (2014). Enhancement of the REMix energy system model: global renewable energy potentials, optimized power plant siting and scenario validation Hochschulschrift, Univ.

[111] UNDP (2014). Renewable Energy Snapshot Belarus, United Nations Development Program.

Meißner, F., F. Ueckerdt and J. Schenk (2010). Erneuerbare Energien in Belarus: Herausforderung für Versorgungssicherheit, FDI und Klimaschutz, PP/04/2010, GET German Economic Team, Berlin/Minsk.

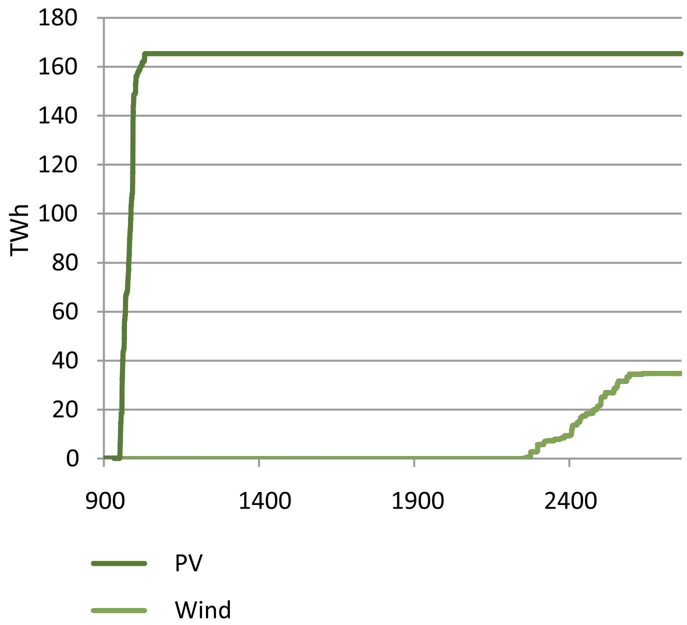
[112] Zui, V. I. and O. Martynova (2015). Geothermal resources, country update for Belarus. Proceedings, World Geothermal Congress.

[113] UNDP (2014). Renewable Energy Snapshot Belarus, United Nations Development Program.

Korotinsky, V., W. Tanas and K. Garkusha (2013). "Prospects of development of bioenergetics in Belarus." Teka Komisji Motoryzacji i Energetyki Rolnictwa 13(1).

INFORSE (2010). A vision for Belarus based on INFORSE's Vision2050 International Network for Sustainable Energy.

Figure 5.3: Full load hour potential curves for wind and PV in Belarus



Belarus. However, the available literature is rather diverse regarding the included biomass sources and applications[113]. That results in a high variation in potentials from 70 PJ of wood to an overall potential of 300 PJ. For example, wood potentials range from 67 PJ to 190 PJ and biogas potentials from 7 PJ to 24 PJ. However, the technically available wood potential is limited to non-contaminated biomass, outside the fall out region of Chernobyl[114], which accounts for 17% of the forest area, according to national experts[115].

To provide a renewable supply for back up capacity and in the transport sector, Biomass is a vital component of the Energy [R]evolution Scenario for Belarus. However, it is not yet clear, how future biomass demand for food & feed, raw materials in industry or for construction will additionally restrict biomass availability.

While we limited the primary biomass supply in the Energy [R]evolution Scenario for Belarus to a maximum of 230 PJ, we are well aware, that this might not all be provided domestically. Existing sustainable biomass potentials in neighbouring countries such as Ukraine and Russia but also from the EU might provide biofuels, wood pellets or other biobased energy carriers in the long run. Here supply will be mainly determined via biomass markets, which are not addressed within our study.

Based on assumptions described in this section and renewable energy potentials the transition pathways are developed and simulated, to provide a predominantly renewable energy supply for Belarus.

[114] Gerasimov, Y. and T. Karjalainen (2010). "Atlas of the forest sector in Belarus." Metlan työraportteja 170.

[115] Filiutsich, I. (2016). Data collection and review of the Reference scenario for the Energy [R]evolution report Belarus. unpublished, Institute of Power Engineering of the National Academy of Sciences of Belarus.

Photo: ©flickr.com — Mike Steinhoff

6 Results of the Energy [R]evolution scenario modelling for Belarus

- Final energy demand by sector
- Electricity generation
- Future costs of electricity generation
- Future investments in the power sector
- Energy supply for heating
- Future investments in the heating sector
- Transport
- Primary energy consumption
- Development of CO_2 emissions

Photo: ©Sergej Kravchenko

6.1. Final energy demand by sector

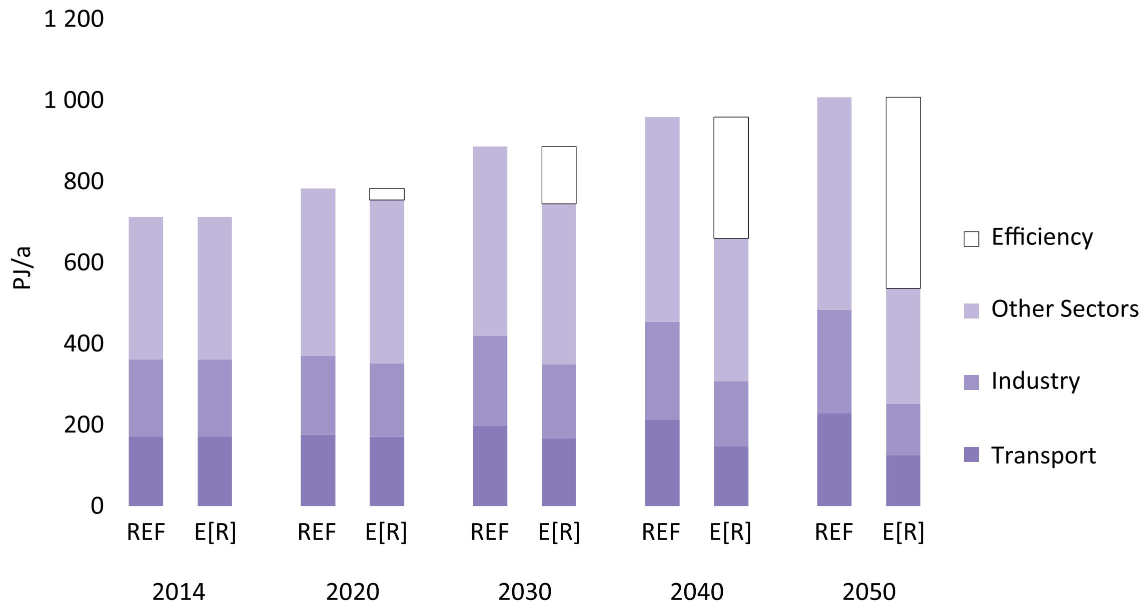
Combining projections on the population development, GDP growth, and energy intensity results in future development pathways for Belarus's final energy demand. These are shown in Figure 6.1 for the Reference and Energy [R]evolution scenario. Under the Reference scenario, total final energy demand increases by 42% from the current 710 PJ/a to 1010 PJ/a in 2050. In the Energy [R]evolution scenario, final energy demand decreases by 24% compared to current consumption and is expected to reach 540 PJ/a by 2050.

Under the Energy [R]evolution scenario, due to economic growth, increasing living standards and electrification of the transport and heat sectors, overall electricity demand is expected to increase despite efficiency gains in all sectors (see Figure 6.2). Total electricity demand will rise from about 30 TWh/a to 61 TWh/a by 2050 in the Energy [R]evolution scenario. Compared to the Reference scenario, efficiency measures in the industry, residential and service sectors avoid the generation of about 20 TWh/a.

This reduction can be achieved in particular by introducing highly efficient electronic devices using the best available technology in all demand sectors. Electricity will become the major renewable 'primary' energy, not only for direct use for various purposes but also for the generation of synthetic fuels for fossil fuels substitution. Around 20 TWh are used in 2050 for electric vehicles and rail transport in 2050 in the E[R] scenario (see Figure 6.4).

Efficiency gains in the heating sector are even larger than in the electricity sector (see Figure 6.3). Under the Energy [R]evolution scenario, consumption equivalent to about 300 PJ/a is avoided through efficiency gains by 2050 compared to the Reference scenario. As a result of energy-related renovation of the existing stock of residential buildings, the introduction of low energy standards and 'passive climatisation' for new buildings, as well as highly efficient air conditioning systems, enjoyment of the same comfort and energy services will be accompanied by much lower future energy demand.

Figure 6.1. Projection of total final energy demand by sector



Note: estimates without non-energy use and heat from CHP autoproducers.

Figure 6.2. Development of electricity demand by sector in the E[R] scenario

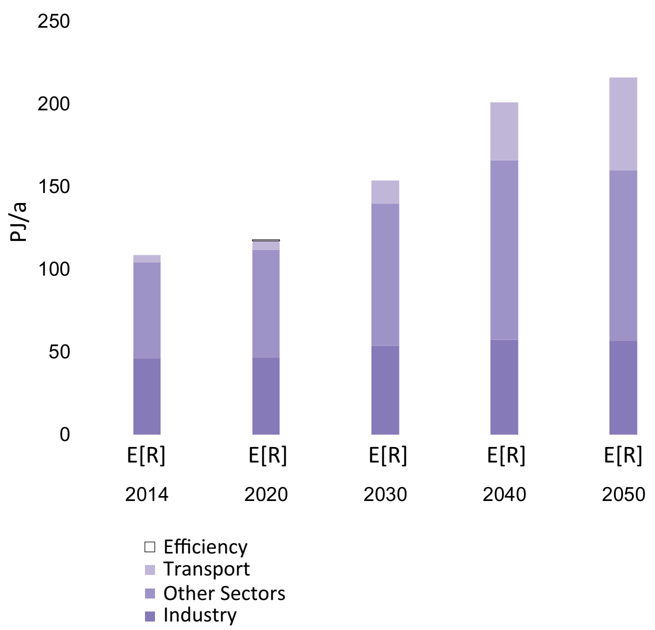


Figure 6.3. Development of heat demand by sector in the E[R] scenario

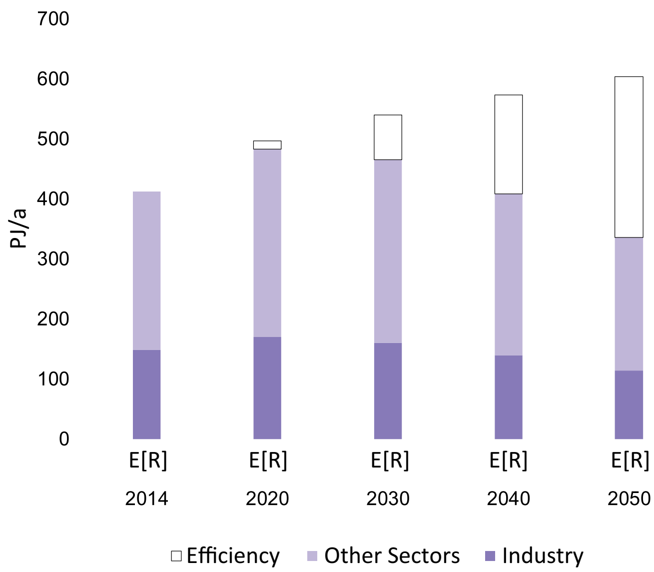
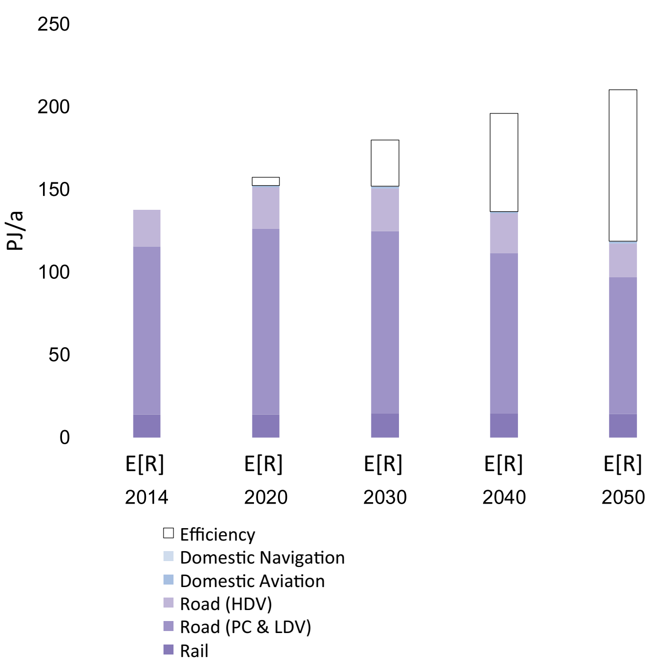


Figure 6.4. Development of the final energy demand for transport by sector in the E[R] scenario



6.2. Electricity generation

The development of the electricity supply sector is characterised by a dynamically growing wind and PV market and a strongly increasing share of renewable electricity. This trend will more than compensate for the limited development of nuclear power in the Energy [R]evolution scenario. Additionally, the number of fossil fuel-fired power plants will continuously decrease as well. By 2050, 92% of the electricity produced in Belarus will come from renewable energy sources in the Energy [R]evolution scenario (see Figure 6.5).

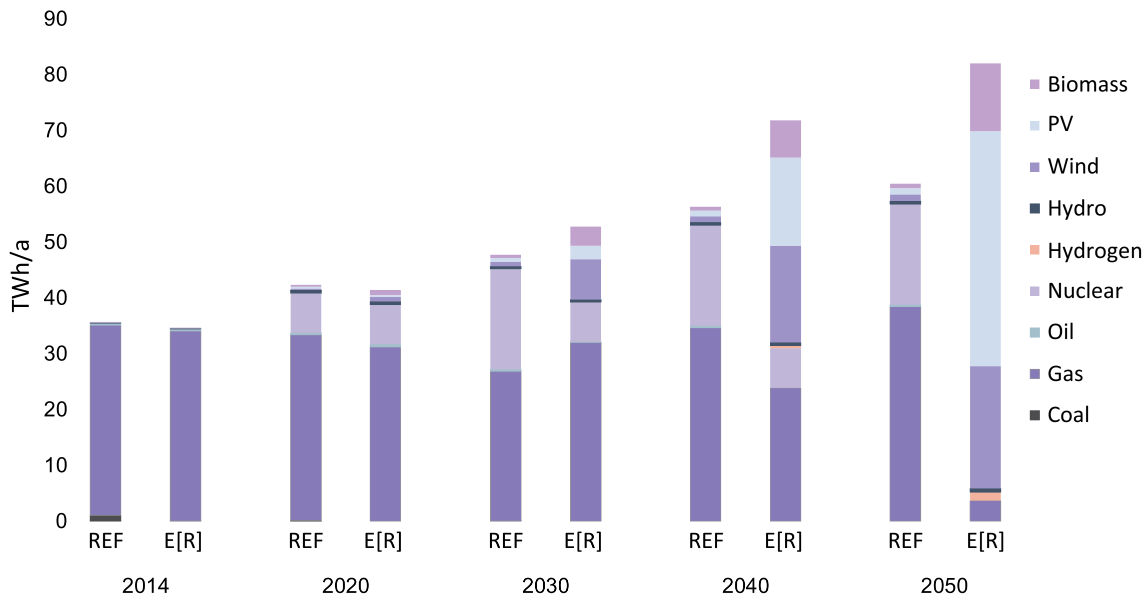
PV and wind will contribute 77% to the total electricity generation by 2050. Already by 2030, the share of renewable electricity production will be 35%. The installed capacity of renewables will reach about 9 GW in 2030 and 50 GW by 2050.

Table 6.1 shows the comparative evolution of the different renewable technologies in Belarus over time. Up to 2020 wind and PV will become the main contributors to the growing market, backed up by increasing installations of biomass from 2030 on. The Energy [R]evolution scenario will lead to a high share of fluctuating power generation sources (PV & wind) of already 29% by 2030 and 77% of total generation by 2050. Therefore, smart grids, demand side management (DSM), energy storage capacities and other options need to be expanded in order to increase the flexibility of the power system for grid integration, load balancing and a secure supply of electricity. Additionally, the remaining gas capacity and the newly installed biomass plants (around 7 GW combined) will serve for secured capacity.

Table 6.1. Projection of renewable electricity generation capacity under the Reference and the Energy [R]evolution scenario in MW

		2014	2020	2030	2040	2050
Hydro	REF	25	164	164	164	164
	E[R]	25	164	164	173	179
Biomass	REF	39	105	184	242	273
	E[R]	39	300	919	2111	3407
Wind	REF	4	122	311	428	504
	E[R]	5	326	4997	8037	13 905
Geothermal	REF	0	0	0	0	0
	E[R]	0	0	0	0	0
PV	REF	1	293	733	1009	1139
	E[R]	1	242	3043	14 452	32 540
Total	REF	70	684	1392	1843	2079
	E[R]	70	1033	9122	24 773	50 031

Figure 6.5. Development of electricity generation structure



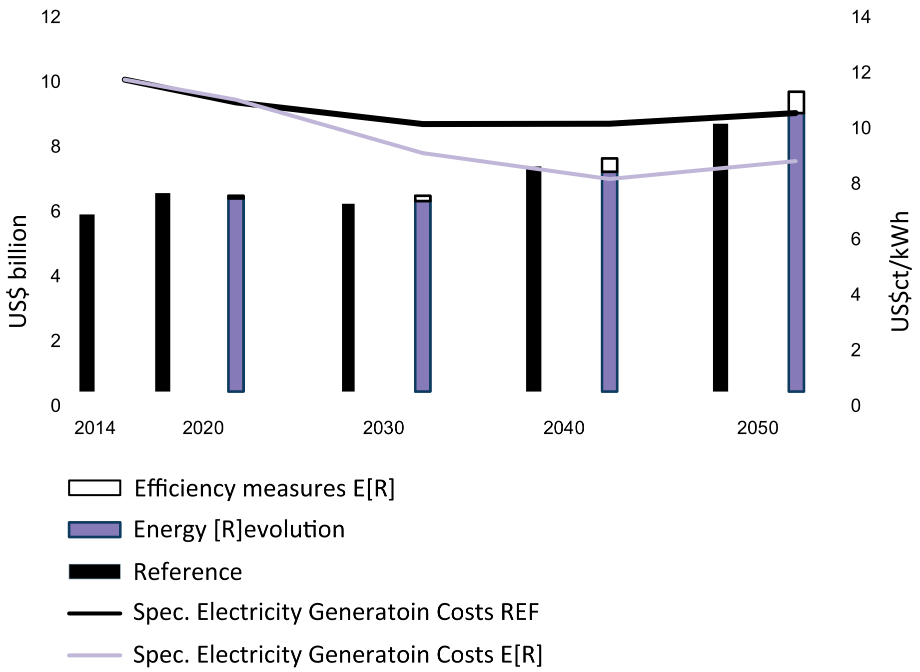
6.3. Future costs of electricity generation

Figure 6.6 shows that the introduction of renewable technologies under the Energy [R]evolution scenario increases the future costs of electricity generation compared to the Reference scenario slightly in the beginning. This difference in full cost of generation will be around 0.1 US$ct/kWh, without taking into account integration costs for storage or other load-balancing measures. Because of increasing prices for conventional fuels and cost reduction in fluctuating renewables, electricity generation costs will become economically favourable just after 2020 under the Energy [R]evolution scenario. By 2050, the cost will be 1.9 US$ct/kWh below those in the Reference case.

Under the Reference scenario growth in demand and increasing fossil fuel prices result in total electricity supply costs rising from today's US$ 6 billion per year to more than US$ 9 billion in 2050.

Increasing energy efficiency and shifting energy supply to renewables lead to long-term costs for electricity supply that are only 4% higher in the Energy [R]evolution scenario than in the Reference scenario despite a 39% increase in electricity production.

Figure 6.6. Development of total electricity supply costs and specific electricity generation costs in the scenarios



6.4. Future investments in the power sector

Around US$ 90 billion is required in investment for the Energy [R]evolution scenario to become reality (including investments for replacement after the economic lifetime of the plants) — approximately US$ 2 billion per year, US$ 60 billion more than in the Reference scenario (US$ 30 billion) (see Table 6.2). Under the Reference scenario, the levels of investment in conventional power plants add up to almost 58% while approximately 42% would be invested in renewable energies and cogeneration until 2050 (see Figure 6.7).

Under the Energy [R]evolution scenario, however, Belarus would shift almost 95% of the entire investment towards renewables and cogeneration, respectively. Additional costs for transmission and storage are not accounted for, but an integration with neighbouring power grids can reduce these costs significantly. Scholz, Gils et al. (2016) calculated the additional cost of 2-3 $/MWh for comparable power systems[116].

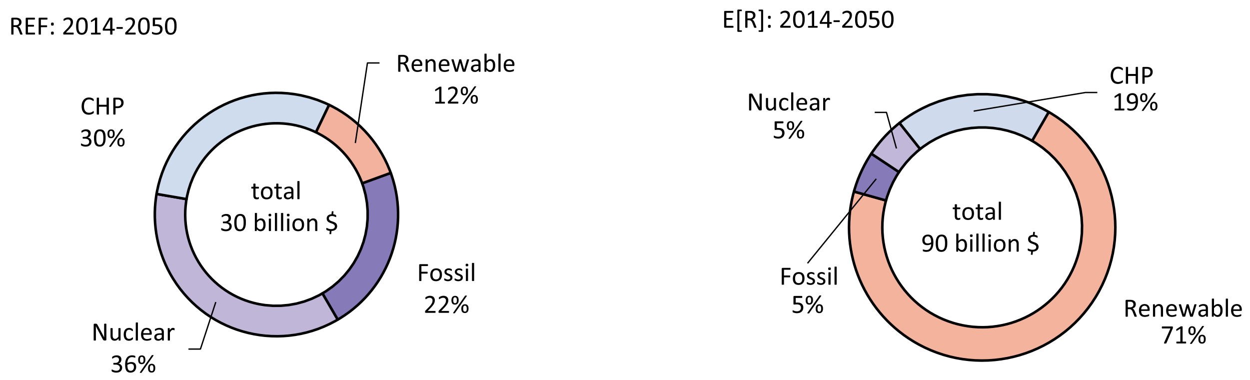
Because renewable energy has no fuel costs, the fuel cost savings in the Energy [R]evolution scenario reach a total of US$ 63 billion up to 2050, US$ 1.6 billion per year. The total fuel cost savings, therefore, would cover more than the total additional investments compared to the Reference scenario. Renewable energy sources would then go on to produce electricity without any further fuel costs beyond 2050, while costs for coal and gas will continue to be a burden on national economies.

Table 6.2. Accumulated investment costs for electricity generation and fuel cost savings

	2014-2020	2021-2030	2031-2040	2041-2050	2014-2050	2014-2050 average per year
Accumulated investment costs (additional in E[R] compared to REF), billion $	-0.8	-6.9	-18.8	-34.4	-61.0	-1.6
Accumulated fuel cost savings (savings cumulative E[R] versus REF), billion $	-8.8	3.5	22.5	45.8	63.0	1.6
of which						
fuel oil	-0.2	0.4	0.8	0.9	2.0	0.1
gas	-8.6	1.7	19.6	41.9	54.6	1.4
nuclear energy	0.0	1.4	2.1	3.0	6.4	0.2

[116] Scholz, Y., H. C. Gils and R. Pietzcker (2016). Application of a high-detail energy system model to derive power sector characteristics at high wind and solar shares. Energy Economics.

Figure 6.7. Investment shares — Reference versus the Energy [R]evolution scenario



6.5. Energy supply for heating

Today, renewables meet around 10% of Belarus's energy demand for heating, the main contribution coming from the use of biomass. Dedicated support instruments are required to ensure a dynamic development in particular for renewable technologies for buildings and renewable process heat production. For Belarus, this especially includes support to integrate solar and geothermal heat into district heat grids. In the Energy [R]evolution scenario, renewables already provide 33% of Belarus's total heat demand in 2030 and 80% in 2050 (see Figure 6.8).

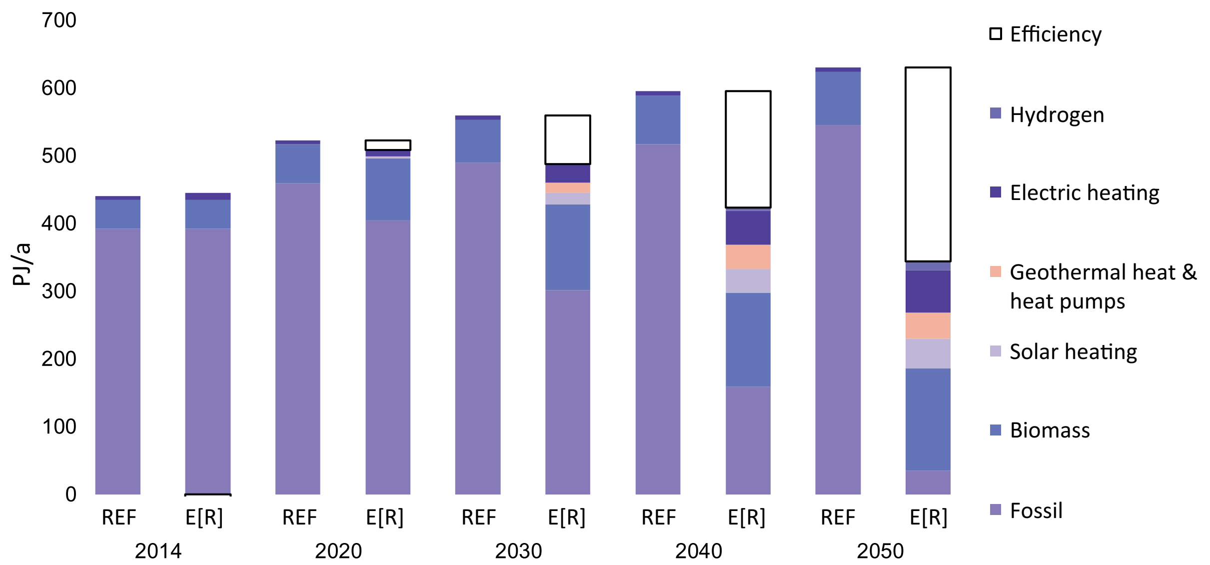
- Energy efficiency measures help to reduce the currently growing energy demand for heating by 45% in 2050 (relative to the Reference scenario), in spite of improving living standards and economic growth.
- In the industry sector solar collectors, geothermal energy (specifically heat pumps), as well as electricity and hydrogen from renewable sources, are increasingly substituting for fossil fuel-fired systems.
- A shift from natural gas to biomass and hydrogen gas in the remaining applications leads to a further reduction of CO_2 emissions.

Table 6.3 shows the development of different renewable technologies for heating in Belarus over time. Up to 2030 biomass remains the main contributor to the growing market share. After 2030, the continuing growth of solar collectors and a growing share of (shallow) geothermal and environmental heat, as well as heat from renewable hydrogen, will further reduce the dependence on fossil fuels.

Table 6.3. Projection of renewable heat supply under the Reference and Energy [R]evolution scenario, in PJ/a

		2014	2020	2030	2040	2050
Biomass	REF	42	58	64	73	80
	E[R]	42	92	121	137	121
Solar heating	REF	0	0	0	0	0
	E[R]	0	2	17	35	45
Geothermal heat & heat pumps	REF	0	0	0	0	0
	E[R]	0	1	13	32	37
Hydrogen	REF	0	0	0	0	0
	E[R]	0	0	0	2	14
Total	REF	42	58	64	73	80
	E[R]	42	95	151	207	218

Figure 6.8. Projection of heat supply by energy carrier



6.6. Future investments in the heating sector

Also in the heating sector, the Energy [R]evolution scenario would require a major revision of current investment strategies in heating technologies. In particular, solar thermal, geothermal and heat pump technologies need an enormous increase in installations if these potentials are to be tapped for the heating sector (see Table 6.4). The use of biomass for heating purposes will be redirected in the Energy [R]evolution scenario to more efficient and sustainable biomass heating technologies. Eventually, biomass will be increasingly used to secure power supply and biofuels.

Renewable heating technologies are extremely variable, from low-tech biomass stoves and unglazed solar collectors to very sophisticated enhanced geothermal and solar systems. Thus, it can only be roughly estimated that the Energy [R]evolution scenario in total requires around US$ 33 billion to be invested in renewable heating technologies up to 2050 (including investments for replacement after the economic lifetime of the plants) — approximately US$ 1 billion per year (see Figure 6.9, Table 6.5).

Table 6.4. Installed capacities for renewable heat generation under the scenarios, GW

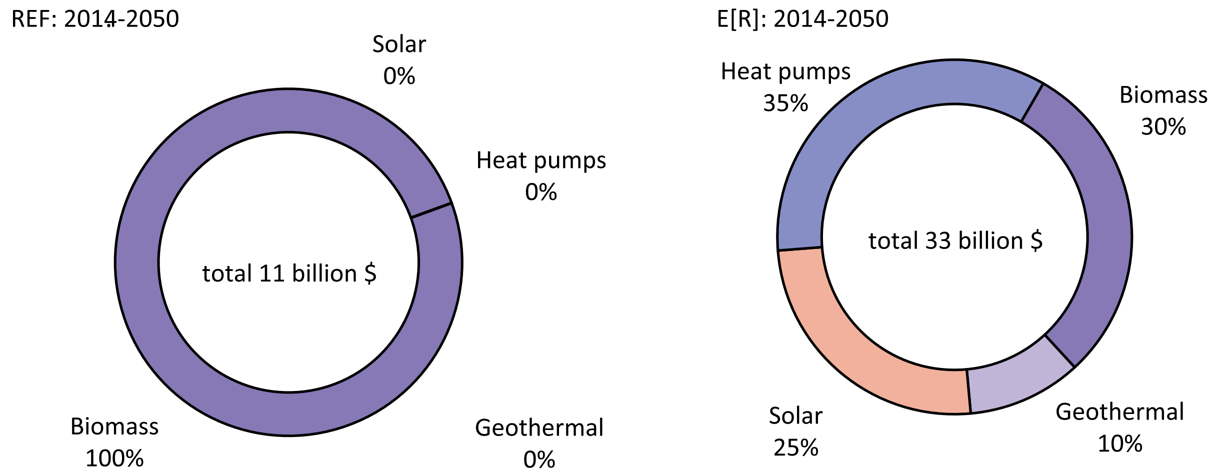
		2014	2020	2030	2040	2050
Biomass	REF	8	10	11	12	13
	E[R]	8	12	15	13	9
Geothermal	REF	0	0	0	0	0
	E[R]	0	0	1	2	2
Solar heating	REF	0	0	0	0	0
	E[R]	0	0	4	8	10
Heat pumps	REF	0	0	0	0	0
	E[R]	0	0	2	4	5
Total *	REF	8	10	11	12	13
	E[R]	8	13	21	27	26

*Note: *excluding direct electric heating.*

Table 6.5. Accumulated investment costs for heat generation

Accumulated investment costs (difference E[R] minus REF), billion $	2014-2020	2021-2030	2031-2040	2041-2050	2014-2050	2014-2050 average per year
Renewable	2.5	6.0	7.0	6.0	21.5	0.6

Figure 6.9. Development of investments for renewable heat generation technologies



6.7. Transport

Due to GDP growth and higher living standards, energy consumption in the transport sector is expected to increase in the Reference scenario by around 33% to 230 PJ/a in 2050 (see Figure 6.10). Without a considerable change in the state policy (Reference scenario), current trends in the transport sector will be preserved and share of fuel oil in energy consumption in absolute terms increases by 28% from base year to 2050.

In particular, distribution of different transport modes will virtually remain unchanged (see Annex 6, Table 6.6). Thus, the share of rail is expected to account for 7-8% of total transportations. The share of electric trains is expected to increase marginally (from 30.9% to 31.6%) while the use of biofuels is not foreseen. The share of road transport is expected to increase slightly: from 81% in 2014 to 84% by 2050. The share of advanced technologies (electric, hybrid and biohybrid vehicles) in the sector of private cars and light-duty vehicles is rather low, while approximately 86% of vehicles in this sector is expected to still use gasoline and diesel. Electrification rate in the sector of heavy duty vehicles and heavy passenger transport is likely to increase from current 2.5% (largely trolleybuses) to 3.7%.

According to the Energy [R]evolution scenario, efficiency measures and modal shifts will save 45% of energy (92 PJ/a) in 2050 compared to the Reference scenario. This number is comparable to 13% of Belarus's total energy consumption in the reference year 2014 (see Table 6.6 and Annex 5).

A key target in Belarus is to introduce incentives for people to drive smaller cars and buy new, more efficient vehicle concepts. In addition, it is vital to shift transport use to efficient modes like rail, light rail, and buses, especially in the expanding metropolitan areas. Along with rising prices for fossil fuels, these changes reduce the further growth in car sales projected under the Reference scenario.

Electrification of transport is a key step towards its higher energy efficiency: efficiency of combustion engine cars is approx. 30%, while efficiency of electric transport is estimated at 66-81% (cumulative efficiency of electric transport is estimated as the product of overall efficiency of an electric car, which equals to 80-90%,[117] the efficiency of the power grid, which is equal to 90%[118] in Belarus, and the efficiency of the battery charging cycle, which equals to approx. 90%[119] for cars using batteries rather than contact network).

[117] Energy [R]evolution: a Sustainable World Energy Outlook 2015.
[118] Data available from the Ministry of Energy of Belarus.
[119] https://en.wikipedia.org/wiki/Supercapacitor

Highly efficient propulsion technology with hybrid, plug-in hybrid and battery-electric power trains will bring about large efficiency gains. By 2030, electricity will provide 8% of the transport sector's total energy demand in the Energy [R]evolution, while in 2050 the share will be 48%. Electrification of the entire transport sector would double the electricity consumption rate calculated for the Energy [R]evolution scenario, which means another 60 PJ or 17-20 TWh.

By 2025, the number of electric cars can reach approx. 17000 (0.6% of the car fleet) under the Reference scenario and approx. 54000 (1.8% of the car fleet) under the Energy [R]evolution scenario. Estimates under these two scenarios are more ambitious than calculations made in the Draft Programme On the Development of Electric Transport in Belarus. Within the same period of time, the number of electric cars can reach 9370 according to the pessimistic scenario and 30820 according to the optimistic scenario[120].

Under the Energy [R]evolution scenario, electric transport will account for 45% of the entire segment of private cars and light vehicles by 2050. In addition, the market for hybrid vehicles, biofuel vehicles and hydrogen fuel cell powered vehicles will continue to develop. Only 5% of private cars and 21% of freight vehicles will use petrol or diesel fuel. The share of railway transportations will also increase slightly (from 7.5 % in 2014 to 11.5% in 2050) while the share of electric trains in railway transportations grows from 9% to 42% (see Annex 6).

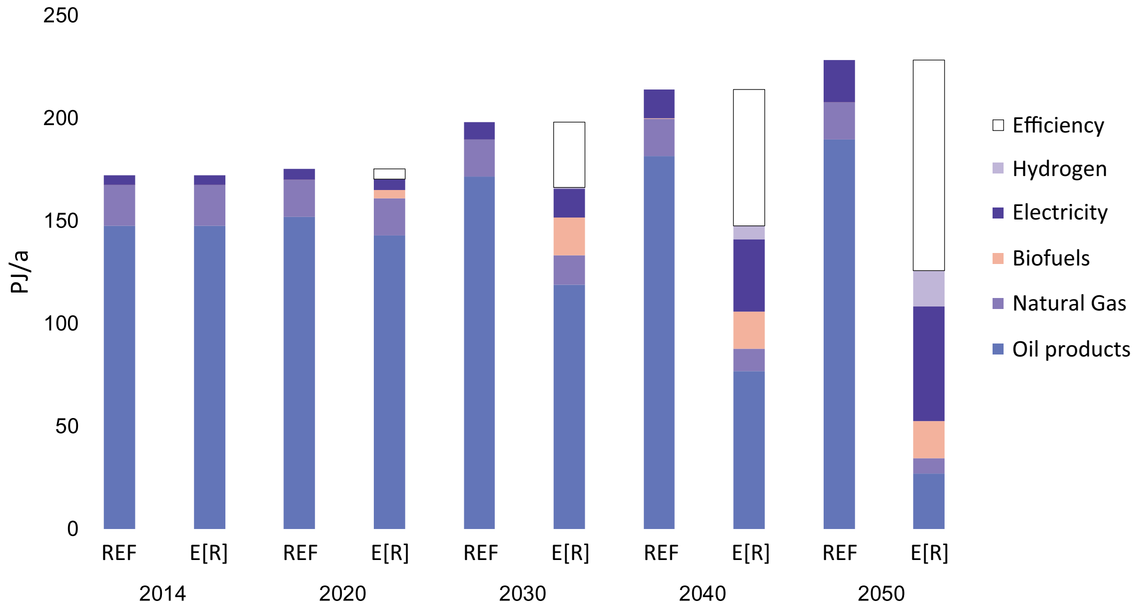
Biofuels will additionally help reducing GHG emissions, if produced under sustainability criteria, e.g. as regulated in the EU. Hydrogen generated from renewable electricity is a complementary option to further increase the renewable share in the transport sector after very high shares of renewable power are available. With limited potentials of domestic renewable power and biomass, the transport sector might still rely on energy imports, however at much lower shares and absolute amounts.

Table 6.6. Projection of transport energy demand by mode in the Reference and the Energy [R]evolution scenario, in PJ/a

		2014	2020	2030	2040	2050
Rail	REF	13	14	15	16	17
	E[R]	13	14	15	15	14
Road	REF	139	142	164	179	192
	E[R]	139	137	136	121	103
Domestic aviation	REF	1	1	1	1	1
	E[R]	1	1	1	1	1
Total	REF	153	157	180	196	211
	E[R]	153	152	152	137	119

[120] Ministry of Energy of the Republic of Belarus, Draft Programme for Charging Infrastructure and Electric Transport Development in the Republic of Belarus for 2016 – 2025.

Figure 6.10. Final energy consumption of transport

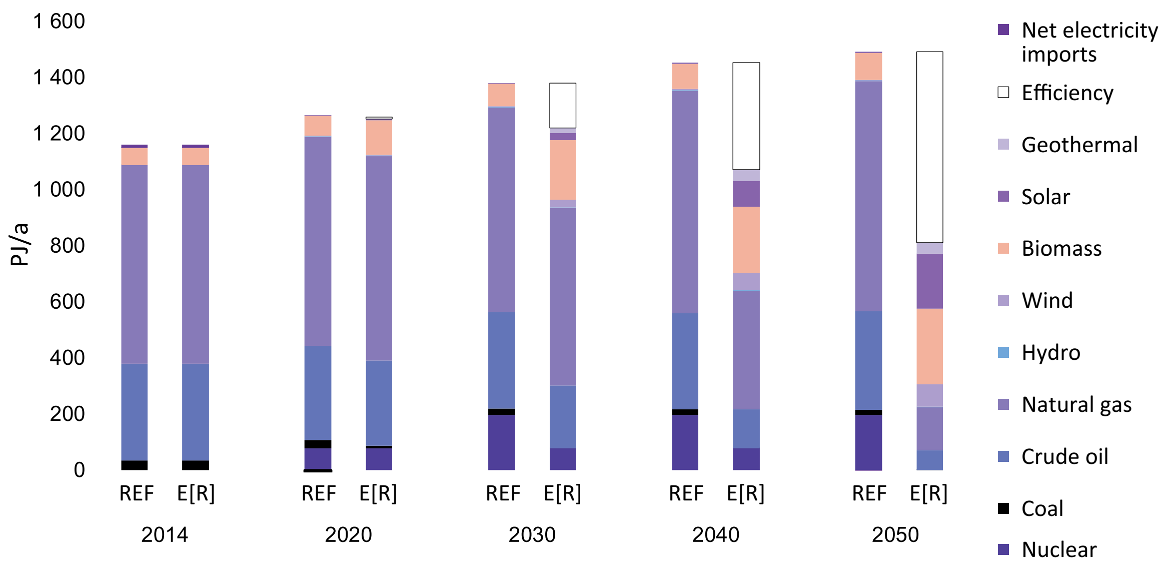


6.8. Primary energy consumption

Taking into account the assumptions discussed in the Methodology section 5, the resulting primary energy consumption under the Energy [R]evolution scenarios is shown in Figure 6.11. Under the E[R] scenario, primary energy demand will decrease by 33% from today's 1010 PJ/a to around 680 PJ/a. Compared to the Reference scenario, overall primary energy demand will be reduced by 50% in 2050 under the E[R] scenario (REF: around 1360 PJ in 2050).

The Energy [R]evolution scenario aims to phase out oil and reduce natural gas as fast as technically and economically possible by the expansion of renewable energies and a fast introduction of very efficient vehicle concepts in the transport sector to replace oil based combustion engines. This leads to an overall renewable primary energy share of 27% in 2030 and 80% in 2050 in the E[R] (excl. non-energy consumption). The share of renewables in the final energy demand is increasing from 6.8% in 2014 to 80.5% in 2050. In contrast to the REF scenario, no new nuclear power plants will be built after 2020 in Belarus in the Energy [R]evolution scenario.

Figure 6.11. Projection of total primary energy demand by energy carrier

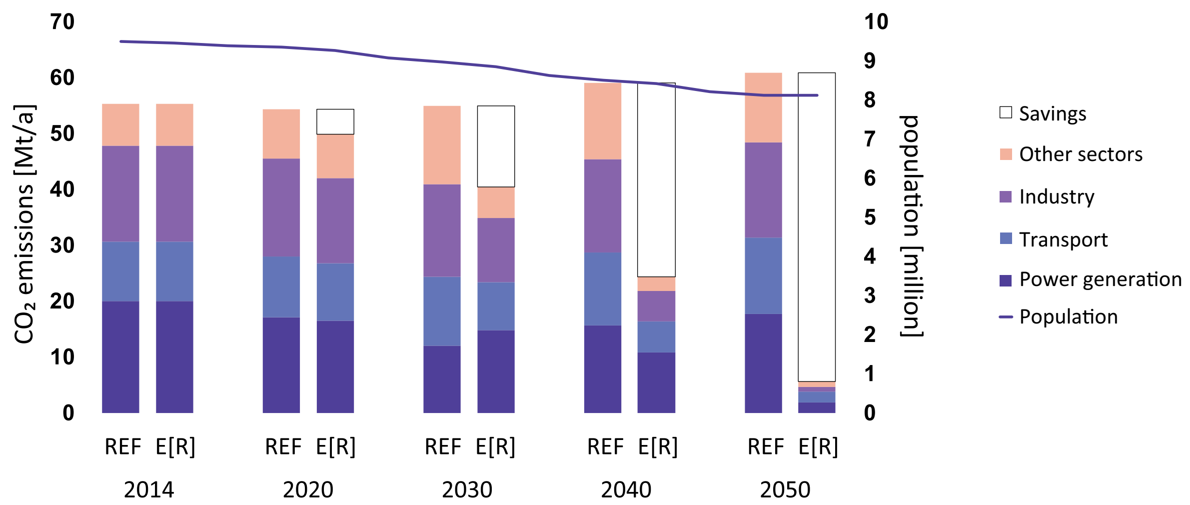


6.9. Development of CO_2 emissions

Whilst Belarus`s emissions of CO2 will increase by 13% between 2014 and 2050 under the Reference scenario, under the Energy [R]evolution scenario they will decrease from 55 million tonnes in 2014 to 8 million tonnes in 2050 (see Figure 6.12). Annual per capita emissions will drop from 5.8 t to 0.9 t. In spite of limiting nuclear power production and increasing power demand, CO2 emissions will decrease in the electricity sector. In the long-run efficiency gains and the increased use of renewable electricity in vehicles strongly reduce emissions in the transport sector as well. With a 55% share in total CO2 emissions, the power generation sector will remain the largest source of emissions in 2050 in the E[R] scenario. By 2050, Belarus´s CO2 emissions are 93% below 1990 levels in the Energy [R]evolution scenario.

Figure 6.12 shows that the Energy [R]evolution scenario not only complies with Belarus´s CO2 reduction targets but also helps to reduce import dependency by increasingly providing power from domestic sources.

Figure 6.12. Development of CO2 emissions by sector



Note: 'Efficiency' reduction compared to the Reference scenario.

7 Energy technologies

- Gas combustion technologies
- Nuclear technologies
- Renewable power technologies and heating technologies
- Power grid technologies — infrastructure for renewables
- Renewable heating and cooling technologies

This chapter[121] describes the range of technologies available now and in the future to satisfy the world's energy demand. The energy revolution scenario is focused on the potential for energy savings and renewable sources, primarily in the electricity and heat generating sectors.

[121] This section is adopted from the relevant chapter of the "Energy [R]evolution: a Sustainable World Energy Outlook 2015" with the permission of the Greenpeace International.


Photo: ©flickr.com — James Moran

7.1. Gas combustion technologies

Natural gas can be used for electricity generation through the use of either gas or steam turbines. For the equivalent amount of heat, gas produces about 45% (IEA ETP 2014)[122] less carbon dioxide during its combustion than coal.

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

Particularly high electric efficiencies can be achieved by combining gas turbines with a steam turbine in combined cycle mode. In a combined cycle gas turbine (CCGT) plant, a gas turbine generator produces electricity and the exhaust gases from the turbine are then used to make steam to generate additional electricity. The efficiency of modern CCGT power stations can be up to 60 (IEA ETP 2014). Most new gas power plants built since the 1990s have been of this type.

Historically, a major driver of technology development for a gas-fired generation has been the quest for increased efficiency. However, the effort to raise power plant efficiency is not the only technical objective; other criteria, such as part-load efficiency, ramp rate and start-up times, are important aspects for future flexible power generation systems as well (IEA-ETP 2014). During the transition period to 100% renewable flexible and quick starting gas turbines play an important role to integrate high shares of wind and solar.

In the case of low gas prices, CCGT power stations are the cheapest option for electricity generation in many countries. Capital costs have been substantially lower than for coal and nuclear plants and construction time shorter.

7.2. Nuclear technologies

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

Across the world, over the last two decades, there has been a general slowdown in building new nuclear power stations because of concern about a possible nuclear accident (following the events at Three Mile Island, Chernobyl, Monju and Fukushima) and increased scrutiny of economics and environmental factors, such as waste management and radioactive discharges.

Nuclear reactor designs: evolution and safety issues

By mid-2015 there were 391 nuclear power reactors operating in 31 countries around the world.

Nuclear plants are commonly divided into four generations. There are no clear definitions of design categories (Scheider/Froggatt 2015)[123].

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

Generation II: mainstream reactor designs in commercial operation worldwide.

Generation III: new generation reactors now being built.

Generation III+ and IV: reactors developed or significantly modified after the Chernobyl disaster.

Generation III+ reactors include the so-called advanced reactors, three of which are already in operation in Japan, with more under construction or planned. About 20 different designs are reported to be under development[124], most of the 'evolutionary' designs developed from Generation II reactor types with some modifications, but without introducing drastic changes. Some of them represent more innovative approaches.

According to the World Nuclear Association, reactors of Generation III are characterised by the following:

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

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

[122] (IEA ETP 2014) Energy technology perspective – harnessing electricities potential; IEA May 2014.

[123] (Scheider/Froggatt 2015) The World Nuclear Industry – Status Report 2015; Paris, London, July 2015; © A Mycle Schneider Consulting Project.

[124] (IAEA 2004; WNO 2004)

Of the new reactor types, the European Pressurised Water Reactor (EPR) has been developed from the most recent Generation II designs to start operation in France and Finland (Schneider/Froggatt 2015). Its stated goals are to improve safety levels – in particular, to reduce the probability of a severe accident by a factor of ten, achieve mitigation from severe accidents by restricting their consequences to the plant itself, and reduce costs. Compared to its predecessors, however, the EPR displays several modifications which constitute a reduction of safety margins, including:

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

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

The World Nuclear Association (WNA) claims that: "Newer advanced reactors [Generation III+] now being built have simpler designs which reduce capital cost. They are more fuel efficient and are inherently safer". In more detail, it lists some of the design characteristics of which the most relevant to this analysis are (Schneider/Froggatt 2015):

- a standardized design for each type to expedite licensing, reduce capital cost and reduce construction time,
- a simpler and more rugged design, making them easier to operate and less vulnerable to operational upsets,
- the further reduced possibility of core melt accidents,
- the substantial grace period, so that following shutdown the plant requires no active intervention for (typically) 72 hours,
- resistance to serious damage that would release radioactivity after an aircraft impact.

Price rises occur throughout the period from project announcement to operation. For example, in 2003, the French Industry Ministry estimated that construction costs for an EPR would be just over €1 billion (US$ 1.2 billion) per reactor. The price tag had tripled by the time the contract was signed for the Flamanville plant in 2007, and by 2012, the estimated cost had reached €8.5 billion (US$ 10.6 billion) (Schneider/Froggatt 2015).

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

7.3. Renewable power technologies and heating technologies

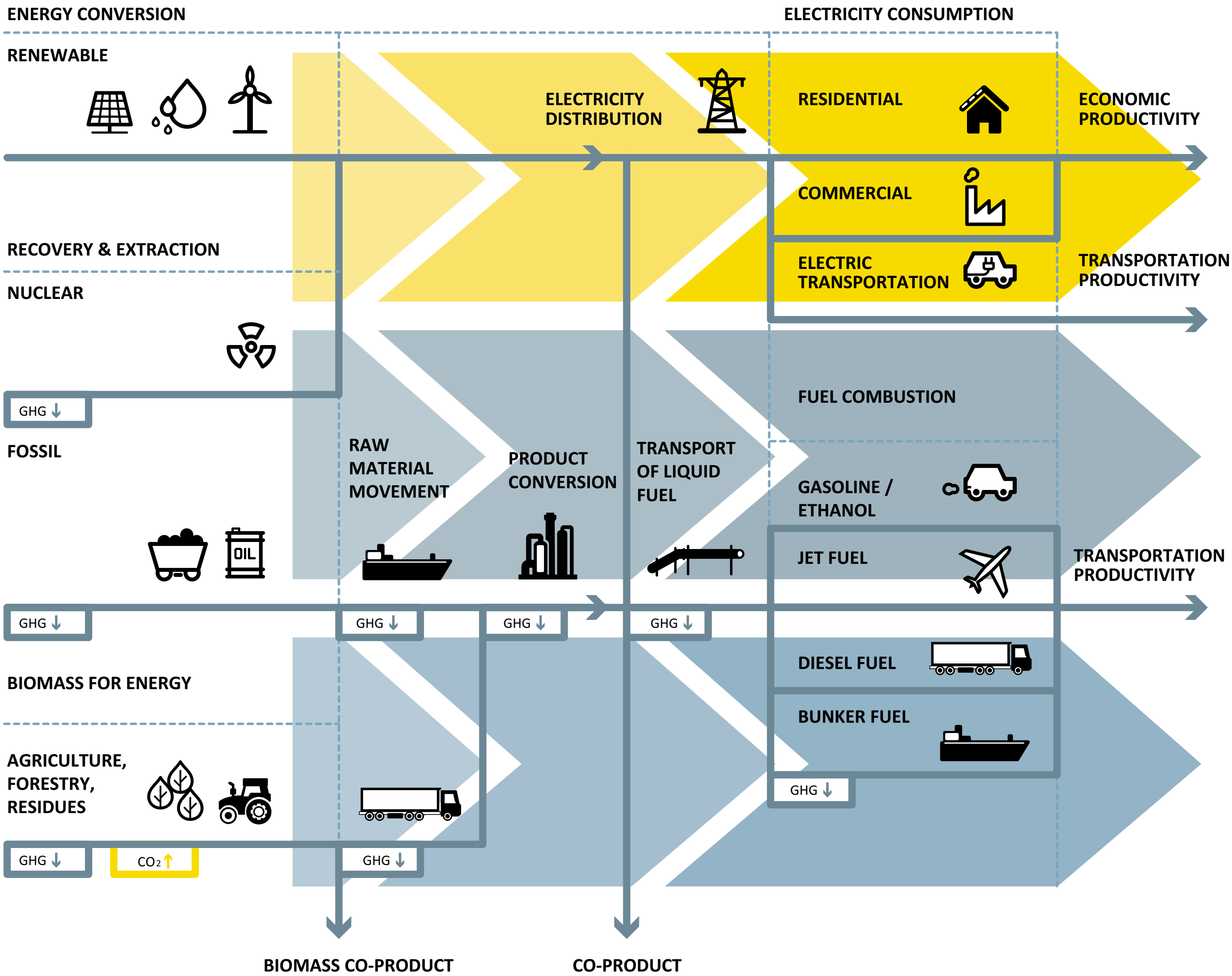
Renewable energy covers a range of natural sources which are constantly renewed and therefore, unlike fossil fuels and uranium, will never be exhausted. Most of them derive from the effect of the sun and moon on the earth's weather patterns. They also produce none of the harmful emissions and pollution associated with 'conventional' fuels. Although hydroelectric power has been used on an industrial scale since the middle of the last century, the serious exploitation of other renewable sources has a more recent history. Figure 7.1. illustrates the role of renewable energy sources along with traditional energy sources.

Box 7.1. Definition of renewable energy

"Renewable energy is any form of energy from solar, geophysical or biological sources that is replenished by natural processes at a rate that equals or exceeds its rate of use. RE is obtained from the continuing or repetitive flows of energy occurring in the natural environment and includes resources such as biomass, solar energy, geothermal heat, hydropower, tide and waves and ocean thermal energy, and wind energy. However, it is possible to utilize biomass at a greater rate than it can grow, or to draw heat from a geothermal field at a faster rate than heat flows can replenish it. On the other hand, the rate of utilization of direct solar energy has no bearing on the rate at which it reaches the Earth. Fossil fuels (coal, oil, natural gas) do not fall under this definition, as they are not replenished within a time frame that is short relative to their rate of utilization."

IPCC definition for renewable energy (Source IPCC, Special Report Renewable Energy /SRREN Renewables for Power Generation.

Figure 7.1. An illustrative system for energy production and use illustrating the role of RE along with other production options



Source: IPCC-SRREN 2012.

7.3.1. Solar power (photovoltaics)

There is more than enough solar radiation available all over the world to satisfy a vastly increased demand for solar power systems. The sunlight, which reaches the earth's surface, is enough to provide 7,900 times as much energy as we can currently use. On a global average, each square metre of land is exposed to enough sunlight to produce 1,700 kWh of power every year. The average irradiation in Europe is about 1,000 kWh per square metre and 1,800 kWh in the Middle East.

Photovoltaic (PV) technology involves the generation of electricity from light. Photovoltaic systems contain cells that convert sunlight into electricity. Inside each cell, there are layers of a semi-conducting material. Light falling on the cell creates an electric field across the layers, causing electricity to flow. The intensity of the light determines the amount of electrical power each cell generates. A photovoltaic system does not need bright sunlight in order to operate. It can also generate some electricity on cloudy and rainy days from diffuse sunlight.

The most important parts of a PV system are the cells which form the basic building blocks, the modules which bring together large numbers of cells into a unit, and, in some situations, the inverters used to convert the electricity generated into a form suitable for everyday use. When a PV installation is described as having a capacity of 3 kWp (peak), this refers to the output of the system under standard testing conditions, allowing comparison between different modules.

In Central Europe a 3 kWp rated solar electricity system, with a surface area of approximately 27 square metres, would produce enough power to meet the electricity demand of an energy conscious household.

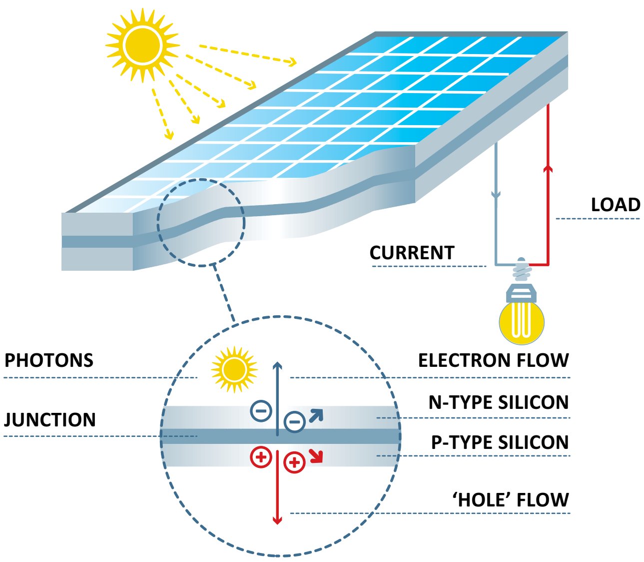
There are several different PV technologies and types of installed system.

PV systems can provide clean power for small or large applications. They are already installed and generating energy around the world on individual homes, housing developments, offices and public buildings.

Today, fully functioning solar PV installations operate in both built environments and remote areas where it is difficult to connect to the grid or where there is no energy infrastructure. PV installations that operate in isolated locations are known as stand-alone systems. In built areas, PV systems can be mounted on top of roofs (known as Building Adapted PV Systems – or BAPV) or can be integrated into the roof or building facade (known as Building Integrated PV Systems – or BIPV).

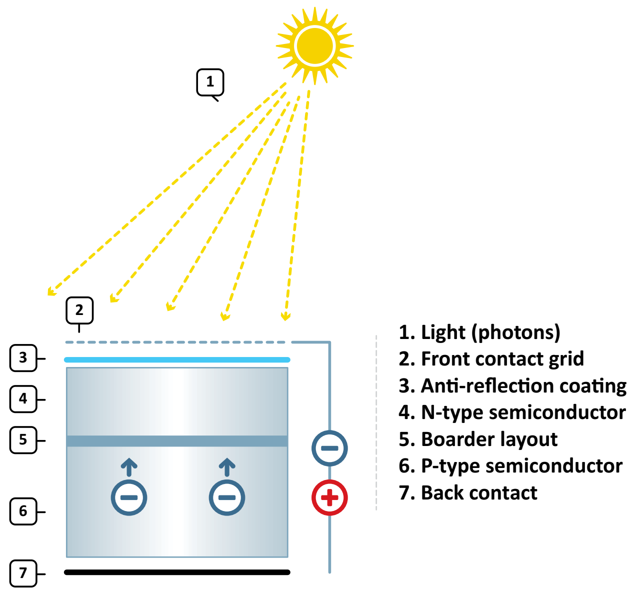
Modern PV systems are not restricted to square and flat panel arrays. They can be curved, flexible and shaped to the building's design. Innovative architects and engineers are constantly finding new ways to integrate PV into their designs, creating buildings that are dynamic, beautiful and provide free, clean energy throughout their life.

Figure 7.2. Example of the photovoltaic effect



Source: EPIA.

Figure 7.3. Photovoltaic technology



Source: EPIA.

7.3.2. PV cells and modules

Crystalline silicon technology

Crystalline silicon cells are made from thin slices cut from a single crystal of silicon (monocrystalline) or from a block of silicon crystals (polycrystalline or multicrystalline). This technology is the most common, representing about 80% of the market today. In addition, it also exists in the form of ribbon sheets (Hoffmann/Teske 2012).[125]

Thin film technology

Thin film modules are constructed by depositing extremely thin layers of photosensitive materials onto a substrate such as glass, stainless steel or flexible plastic. The latter opens up a range of applications, especially for building integration (roof tiles) and end-consumer purposes. Four types of thin film modules are commercially available at the moment: Amorphous Silicon, Cadmium Telluride, Copper Indium/Gallium Diselenide/Disulphide and multi-junction cells.

Other emerging cell technologies (at the development or early commercial stage)

These include concentrated photovoltaic, consisting of cells built into concentrating collectors that use lens to focus the concentrated sunlight onto the cells, and Organic Solar Cells, whereby the active material consists at least partially of an organic dye, small, volatile organic molecules or polymer.

Cells are connected to form larger units called modules

Thin sheets of EVA (Ethyl Vinyl Acetate) or PVB (Polyvinyl Butyral) are used to bind cells together and provide weather protection. The modules are normally enclosed between a transparent cover (usually glass) and a weatherproof backing sheet (typically made from a thin polymer). Modules can be framed for extra mechanical strength and durability. Thin film modules are usually encapsulated between two sheets of glass, so a frame is not needed (EPIA 2011).[126]

[125] (Hoffmann/Teske 2012) Preparation for EPIA/Greenpeace Solar Generation report series (Edition I — VI).

[126] (EPIA 2011) Solar Generation 6 — EPIA-Greenpeace report; European Photovoltaic Industry Association (EPIA); GPI, Brussels/Amsterdam; 2011.

Table 7.1. Typical type and size of applications per market segment

Type of application	Residential < 10 kWp	Commercial 10 kWp — 100 kWp	Industrial 100 kWp — 1 MWp	Utility-scale > 1 MWp
Ground-mounted	-	-	YES	YES
Roof-top	YES	YES	YES	
Integrated to façade/roof	YES	YES	-	

7.3.3. PV systems

The key parts of a solar energy generation system are:

- photovoltaic modules to collect sunlight;
- an inverter to transform direct current (DC) to alternate current (AC);
- a set of batteries for stand-alone PV systems;
- support structures to orient the PV modules toward the sun.

The system components, excluding the PV modules, are referred to as the balance of system (BOS) components.

Industrial and utility-scale power plants

Large industrial PV systems can produce enormous quantities of electricity at a single location. Such power plants have outputs ranging from hundreds of kilowatts (kW) to hundreds of megawatts (MW).

The solar panels for industrial systems are usually mounted on frames on the ground. However, they can also be installed on large industrial buildings, such as warehouses, airport terminals and railways stations. The system can make double use of an urban space and put electricity into the grid where energy-intensive consumers are located.

Residential and commercial systems

Grid connected

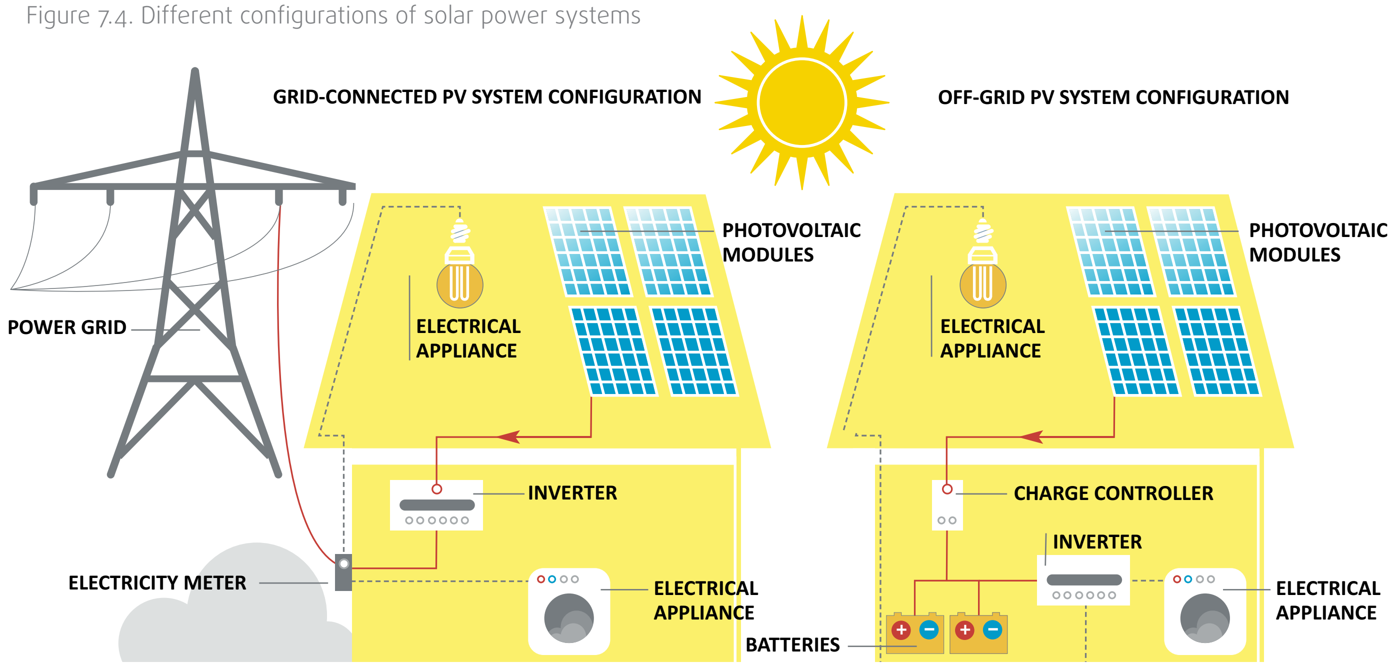
Grid connected arrays are the most popular type of solar PV systems for homes and businesses in the developed world. Connected to the local grid, they allow any excess power produced to be sold to the utility. When solar energy is not available, electricity can be drawn from the grid. An inverter is used to convert the DC power produced by the system to AC power for running normal electrical equipment. This type of PV system is referred to as being 'on-grid.' A 'Grid Support' system can be connected to the local grid along with a backup battery. Any excess solar electricity produced after the battery has been charged is then sold to the grid. This system is ideal for use in areas of unreliable power supply.

Stand-alone, off-grid systems

Off-grid PV systems have no connection to a grid. An off-grid system usually has batteries, so power can still be used at night or after several days of low sun. An inverter is needed to convert the DC power generated into AC power for use in appliances. Typical off-grid applications described below.

- **Off-grid systems for rural electrification.** Grid typical off-grid installations bring electricity to remote areas or villages in developing countries. They can be small home systems, which cover a household's basic electricity needs, or larger solar mini-grids, which provide enough power for several homes, a community or small business use.
- **Off-grid industrial applications.** Off-grid industrial systems are used in remote areas to power repeater stations for mobile telephones (enabling communications), traffic signals, marine navigational aids, remote lighting, highway signs and water treatment plants. Both full PV and hybrid systems are used. Hybrid systems are powered by the sun when it is available and by other fuel sources during the night and extended cloudy periods. Off-grid industrial systems provide a cost-effective way to bring power to areas very far from existing grids. The high cost of installing cabling makes off-grid solar power an economical choice.
- **Consumer goods.** PV cells are now found in many everyday electrical appliances such as watches, calculators, toys, and battery chargers (as for instance embedded in clothes and bags). Services such as water sprinklers, road signs, lighting and telephone boxes also often rely on individual PV systems.
- **Hybrid systems.** A solar power system can be combined with another source of power – such as a biomass generator, a wind turbine or diesel generator — to ensure a consistent supply of electricity. A hybrid system can be grid-connected, standalone or grid-supported.

Figure 7.4. Different configurations of solar power systems



Source: EPIA 2011.

7.3.4. Wind power

Wind energy has grown faster than all other electricity sources in the last 20 years, and turbine technology has advanced sufficiency that a single machine can have a capacity of 7 Megawatt. In Europe, wind farms are generally well integrated into the environment and accepted by the public. Smaller models can produce electricity for areas that are not connected to a central grid, through use of battery storage.

Wind turbine design

Modern wind technology is available for low and high wind speeds and in a variety of climates. A variety of onshore wind turbine configurations have been investigated, including both horizontal and vertical axis designs (see Figure 7.5). The horizontal axis design dominates, and most designs now centre on the three-blade, upwind rotor; locating the turbine blades upwind of the tower prevents the tower from blocking wind flow onto the blades and producing extra aerodynamic noise and loading (EWEA 2008).[127]

Figure 7.5. EWEA early wind turbine designs

Source: South et.al. 1983/EWEA 2008.

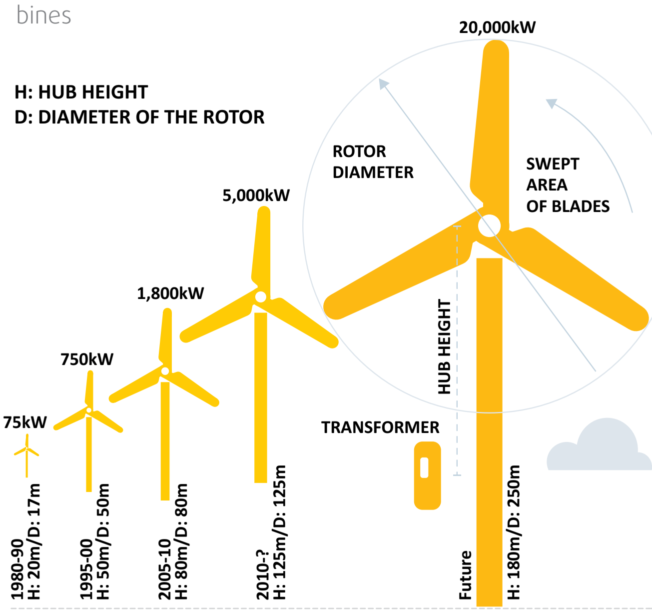
[127] (EWEA 2009) Wind energy – the facts; European Wind Energy Association; Brussels/Belgium; http://www.wind-energy-the-facts.org.

The blades are attached to a hub and main shaft, which transfers power to a generator, sometimes via a gearbox (depending on design). The electricity output is channelled down the tower to a transformer and eventually into the local grid. The main shaft and main bearings, gearbox, generator and control system are contained within a housing called the nacelle. As turbine size has increased over time, turbine output is controlled by pitching (i.e., rotating) the blades along their long axis.[128]

Reduced cost of power electronics allowed for variable speed wind turbine operation, which helps maintain production in variable and gusty winds, keeps large wind power plants generating during electrical faults, and provides reactive power. Modern wind turbines typically operate at variable speeds using full-span blade pitch control. Over the past 30 years, the average wind turbine size has grown significantly (Figure 7.6), with most onshore wind turbines installed globally in 2014 having a rated capacity of 3.5 to 7.5 MW; the average size of turbines installed in 2014 was at around 2.5 – 3.0 MW. As of 2015, wind turbines used on land typically have 80 to 120 – m tall towers, with rotors between 80 to 125 m in diameter. The average tower installed in 2014 in Germany, for example, was 93 m tall (STATISTICA 2015).[129] Some commercial machines have diameters and tower heights above 125 m, and even larger models are being developed. Modern turbines operate spin at 12 to 20 revolutions per minute (RPM), much slower than the models from the 1980's models, which spun at 60 RPM. Modern rotors are slower, less visually disruptive and less noisy. Onshore wind turbines are typically grouped together into wind power plants, with between 5 – 300 MW generating capacity, and are sometimes also called wind farms. Turbines have been getting larger to help reduce the cost of generation (reach better quality wind), reduce investment per unit of capacity and reduce operation and maintenance costs (EWEA 2014).[130]

For turbines in the land, there will be engineering and logistical constraints to size because the components have to travel by road. Modern wind turbines have nearly reached their theoretical maximum (0.59) of aerodynamic efficiency, measured by the coefficient of performance (0.44 in the 1980's to about 0.50 by the mid-2000's).

Figure 7.6. Growth of size of typical commercial wind turbines



Source: EWEA 2008/2014.

7.3.5. Biomass energy

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

Biological power sources are renewable, easily stored, and, if sustainably harvested, CO2 neutral. The gas emitted during their transfer into useful energy is balanced by the carbon dioxide absorbed when they were growing plants. It is of great importance that bioenergy lower greenhouse gas emissions; only then the use of bioenergy makes ecologic sense.

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

[128] EWEA 2009.

[129] (STATISTICA 2015); Online statistical research tool; http://www.statista.com/statistics/263905/evolutionof-the-hub-height-of-german-wind-turbines.

[130] (EWEA 2014) Wind energy scenarios for 2020; European Wind Energy Association; July 2014; www.ewea.org

7.3.6. Biomass technology

A number of processes can be used to convert energy from biomass: thermochemical processes (direct combustion of solids, liquids or a gas via pyrolysis or gasification) and biological systems, (decomposition of solid biomass to liquid or gaseous fuels by processes such as anaerobic digestion and fermentation).

Thermochemical processes

Direct combustion

Direct biomass combustion is the most common way of converting biomass into energy for both heat and electricity, accounting for over 90% of biomass generation. Combustion processes are well understood; in essence, when carbon and hydrogen in the fuel react with excess oxygen to form CO_2 and water and release heat. In rural areas, many forms of biomass are burned for cooking. Wood and charcoal are also used as a fuel in industry. A wide range of existing commercial technologies is tailored to the characteristics of the biomass and the scale of their applications (IEA Bio – 2009).

The technologies types are fixed bed, fluidised bed or entrained flow combustion. In fixed bed combustion, such as a grate furnace, air first passes through a fixed bed for drying, gasification and charcoal combustion. The combustible gases produced are burned after the addition of secondary air, usually in a zone separated from the fuel bed. In fluidised bed combustion, the primary combustion air is injected from the bottom of the furnace with such high velocity that the material inside the furnace becomes a seething mass of particles and bubbles. Entrained flow combustion is suitable for fuels available as small particles, such as sawdust or fine shavings, which are pneumatically injected into the furnace.

Gasification

Biomass fuels are increasingly being used with advanced conversion technologies, such as gasification systems, which are more efficient than conventional power generation. Biomass gasification occurs when a partial oxidation of biomass happens upon heating, producing a combustible gas mixture (called producer gas or fuel gas) rich in CO and hydrogen (H_2) that has an energy content of 5 to 20 MJ/Nm^3 (depending on the type of biomass and whether gasification is conducted with air, oxygen or through indirect heating). This energy content is roughly 10 to 45% of the heating value of natural gas (IPCC SRREN 2011).[131]

Fuel gas can then be upgraded to a higher-quality gas mixture called biomass synthesis gas or syngas (Faaij 2006).[132] A gas turbine, boiler or steam turbine can be used to employ unconverted gas for electricity co-production. Coupled with electricity generators, syngas can be used as a fuel in place of diesel in suitably designed or adapted internal combustion engines. Most commonly available gasifiers use wood or woody biomass, specially designed gasifiers can convert non-woody biomass materials (Yokoyama and Matsumura 2008).[133] Compared to combustion, gasification is more efficient, providing better-controlled heating, higher efficiencies in power production and the possibility of coproducing chemicals and fuels (Kirkels and Verbong 2011).[134] Gasification can also decrease emission levels compared to power production with direct combustion and a steam cycle.

Pyrolysis

Pyrolysis is the thermal decomposition of biomass occurring in the absence of oxygen (anaerobic environment) that produces a solid (charcoal), a liquid (pyrolysis oil or bio-oil) and a gas product. The relative amounts of the three co-products depend on the operating temperature and then residence time used in the process. Lower temperatures produce more solid and liquid products and higher temperatures more biogas. Heating the biomass feedstock to moderate temperatures (450°C to 550°C) produce oxygenated oils as the major products (70 to 80%), with the remainder split between a biochar and gases (IEA Bio-2009).

Biological systems

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

Anaerobic digestion

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

Fermentation

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

Biomass power station capacities typically range up to 15 MW, but larger plants are possible. However, biomass power station should use the heat as well, in order to use the energy of the biomass as much as possible, and therefore the size should not be much larger than 25 MW (electric). This size could be supplied by local bioenergy and avoid unsustainable long-distance fuel supply.

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[131] (IPCC-AR5-SPM) International Panel on Climate Change – 5th Assessment Report; Climate Change 2014, Summary for Policy Makers; http://ipcc.ch/pdf/assessment-report/ar5/syr/ar5_syr_final_spm.pdf
[132] (Faaij 2006).
[133] (Yokoyama and Matsumura 2008).
[134] Kirkels and Verbong 2011.

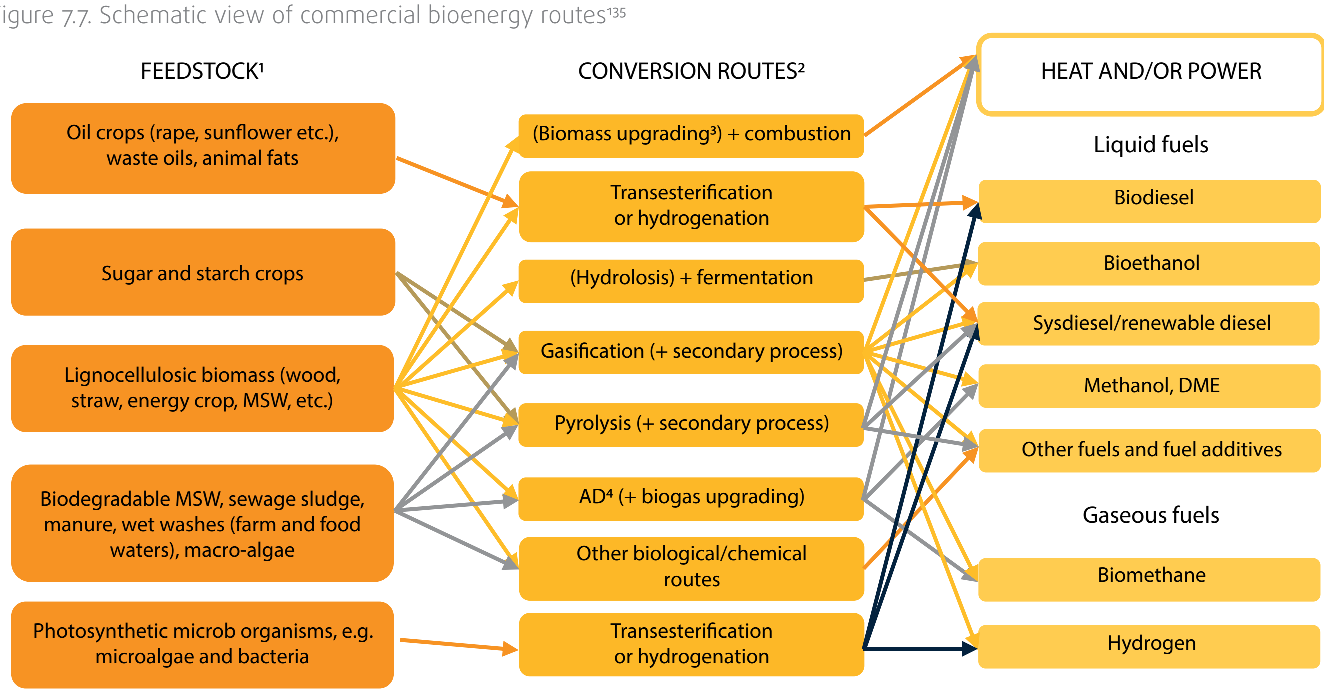
Biofuels

Converting crops into ethanol and biodiesel made from rapeseed methyl ester (RME) currently takes place mainly in Brazil, the USA and Europe. Also, processes to produce synthetic fuels from 'biogenic synthesis' gases will play a larger role in the future, especially for aviation and marine transport systems. Theoretically, biofuels can be produced from any biological carbon source, although the most common are photosynthetic plants. Various plants and plant-derived materials are used for biofuel production. Globally, biofuels are most commonly used to power vehicles but can also be used for other purposes. The production and use of biofuels must result in a net reduction in carbon emissions compared to the use of traditional fossil fuels to have a positive effect on climate change mitigation. Sustainable biofuels can reduce the dependency on petroleum and thereby enhance energy security.

- Bioethanol is a fuel manufactured through the fermentation of sugars. Sugars are used directly (sugar cane or beet) or by breaking down starch in grains such as wheat, rye, barley or maize. In the European Union, bioethanol is mainly produced from grains, with wheat as the dominant feedstock. In Brazil, the preferred feedstock is sugar cane, whereas in the USA it is corn (maize). Bioethanol produced from cereals has a byproduct, a protein-rich animal feed called Dried Distillers Grains with Soluble (DDGS). For every tonne of cereals used for ethanol production, on average one third will enter the animal feed stream as DDGS. Because of its high protein level, DDGS is currently used as a replacement for soy cake. Bioethanol can either be blended into gasoline (petrol) directly or be used in the form of ETBE (Ethyl Tertiary Butyl Ether).
- Biodiesel is a fuel produced from vegetable oil sourced from rapeseed, sunflower seeds or soybeans along with used cooking oils or animal fats. If used vegetable oils are recycled as feedstock for biodiesel production, pollution from discarded oil is reduced, providing a new way of transforming a waste product into transport energy. Blends of biodiesel and conventional diesel are the most common products distributed in the retail transport fuel market.
- Most countries use a labelling system to explain the proportion of biodiesel in any fuel mix. Fuel containing 20% biodiesel is labelled B20, while pure biodiesel is referred to as B100. Blends of 20% biodiesel with 80% petroleum diesel (B20) can generally be used in unmodified diesel engines. Used in its pure form, B100 may require certain engine modifications. Biodiesel can also be used as a heating fuel in domestic and commercial boilers. Older furnaces may contain rubber parts that would suffer from biodiesel's solvent properties but can otherwise burn it without any conversion.

There are many different biomass feedstock types and numerous conversion technologies to produce fuels for heat and/or power and transport technologies; Figure 7.7 provides a simplified overview.

Figure 7.7. Schematic view of commercial bioenergy routes[135]



[1] Parts of each feedstock, e.g. crop residues, could also be used in other routes.
[2] Each route also gives co-products.
[3] Biomass upgrading includes any one of the densification processes) pelletisation, pyrolysis, torrefaction, etc.).
[4] AD = anaerobic digestion.

Source: IEA-Bio 2009.

[135] (IEA Bio-2009) Bioenergy – a sustainable and reliable energy source main report; International Energy Agency.

7.3.7. Hydropower

Water has been used to produce electricity for about a century. Even today, it covers around one-fifth of the world's power demand. The main requirement for hydropower is to create an artificial head of water that has sufficient energy to power a turbine when diverted into a channel or pipe.

Classification by head and size

The 'head' in hydropower refers to the difference between the upstream and the downstream water levels, which determines the water pressure on the turbines. Along with discharge, the pressure level determines what type of hydraulic turbine is used. The classification of 'high head' and 'low head' varies from country to country, and there is no generally accepted scale. Broadly, Pelton impulse turbines are used for high heads (where a jet of water hits a turbine and reverses direction). Francis reaction turbines are used to exploit medium heads (which run full of water and in effect generate hydrodynamic 'lift' to propel the turbine blades). For low heads, Kaplan and Bulb turbines are applied.

Classification according to refers to installed capacity measured in MW. Small-scale hydropower plants are more likely to be run-of-river facilities than are larger hydropower plants, but reservoir (storage) hydropower stations of all sizes use the same basic components and technologies. It typically takes less time and effort to construct and integrate small hydropower schemes into local environments[136] so their deployment is increasing in many parts of the world. Small schemes are often considered in remote areas where other energy sources are not viable or are not economically attractive.

Classification by facility type

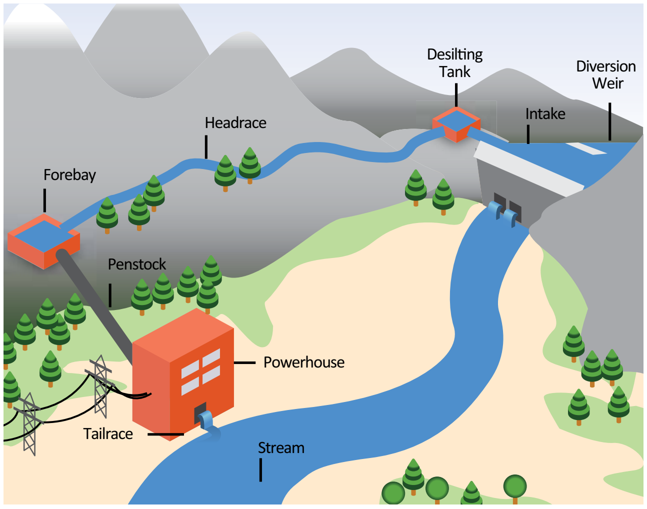
Hydropower plants are also classified in the following categories according to operation and type of flow:

- run-of-river (RoR);
- storage (reservoir);
- pumped storage, and
- in-stream technology, a young and less-developed technology.

Run-of-river

These plants draw the energy for electricity mainly from the available flow of the river and do not collect significant amounts of stored water. They may include some short-term storage (hourly, daily), but the generation profile will generally be dictated by local river flow conditions. Because generation depends on rainfall, it may have substantial daily, monthly or seasonal variations, especially when located in small rivers or streams with widely varying flows. In a typical plant, a portion of the river water might be diverted to a channel or pipeline (penstock) to convey the water to a hydraulic turbine connected to an electricity generator (see Figure 7.8). RoR projects may form cascades along a river valley, often with reservoir-type hydropower plants in the upper reaches of the valley. Run-of-river installation is relatively inexpensive. Facilities typically have lower environmental impacts than similar-sized storage hydropower plants.

Figure 7.8. Run-of-river hydropower plant



Source: IPCC 2012: Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press.

Storage hydropower

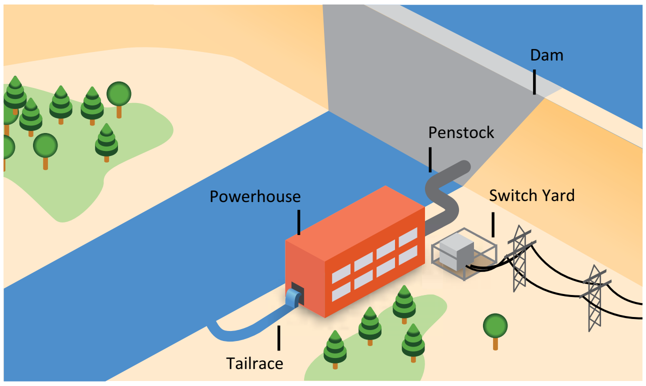
Hydropower projects with a reservoir are also called storage hydropower. The reservoir reduces dependence on the variability of inflow, and the generating stations are located at the dam toe or further downstream, connected to the reservoir through tunnels or pipelines (Figure 7.9).

Reservoirs are designed according to the landscape. In many parts of the world, river valleys are inundated to make an artificial lake. In geographies with mountain plateaus, high altitude lakes are another kind of reservoir that retains many of the properties of the original lake. In these settings, the generating station is often connected to the reservoir lake via tunnels (lake tapping). For example, in Scandinavia, natural high-altitude lakes create high-pressure systems where the heads may reach over 1,000 m. A storage power plant may have tunnels coming from several reservoirs and may also be connected to neighbouring watersheds or

[136] Egre and Milewski, 2002

rivers. Large hydroelectric power plants with concrete dams and extensive collecting lakes often have very negative effects on the environment, requiring the flooding of habitable areas.

Figure 7.9. Typical hydropower plant with reservoir

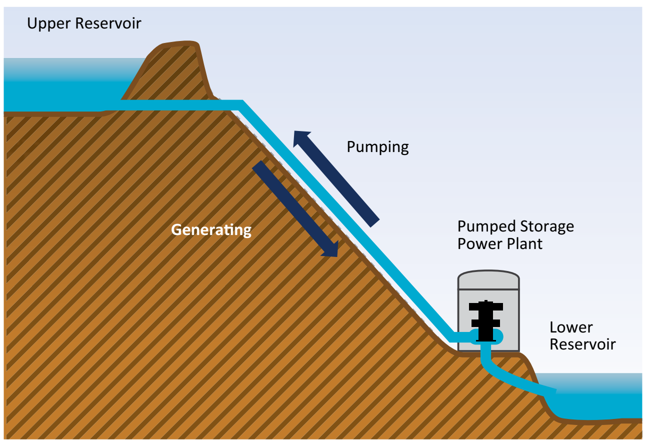


Source: IPCC 2012: Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press.

Pumped storage

Pumped storage plants generate electricity but are energy storage devices. In such a system, water is pumped from a lower reservoir into an upper reservoir (Figure 7.10), usually during off-peak hours when electricity is cheap. The flow is reversed to generate electricity during the daily peak load period or at other times of need. The plant is a net energy consumer overall because it uses power to pump water; however, the plant provides system benefits by helping to meet fluctuating demand profiles. Pumped storage is the largest-capacity form of grid energy storage now readily available worldwide.

Figure 7.10. Typical pumped storage power plant

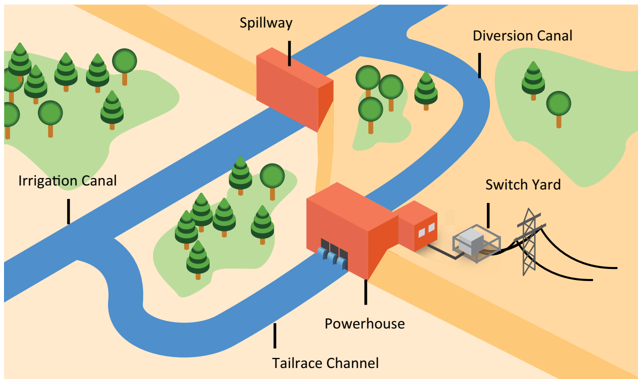


Source: IPCC 2012: Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press.

In-stream technology using existing facilities

To optimize existing facilities like weirs, barrages, canals or falls, small turbines or hydrokinetic turbines can be installed for electricity generation. These basically function like a run-of-river scheme, as shown in Figure 7.11. Hydrokinetic devices being developed to capture energy from tides and currents may also be deployed inland for free-flowing rivers and engineered waterways.

Figure 7.11. Typical in-stream hydropower plant



Source: IPCC 2012: Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press.

Hydropower – future developments

A relatively small number of equipment suppliers dominate the market for large hydropower plants (above 10 megawatts). The basic equipment remains the same, though IT has improved efficiency, with additional services ranging from monitoring and diagnostics to advanced control systems. More R&D is needed to produce further progress and reduce the considerable impact of large hydropower on environmental systems and local communities (IRENA-Hydro-2015).[137] The local population must be consulted before projects are further developed. There are 3 classes of hydropower plants:

- large hydropower (>10 MWelectric);
- small hydropower (≤10 MWelectric);
- mini-hydro (100 kWe to 1 MWelectric).

Small-scale hydropower (from 1 MW to 10 MW) has a much wider range of designs, equipment, and material. Therefore, expertise in a wider range of fields is crucial towards tapping the potential of local resources affordably and without a detrimental environmental impact (IRENA-Hydro-2015).

[137] (IRENA-Hydro 2015) Hydropower — Technology Brief; IEA-ETSAP and IRENA Technology Brief — February 2015. www.etsap.org — www.irena.org; International Renewable Energy Agency (IRENA); Energy Technology Systems Analysis Programme.

Upgrades are an excellent way of getting more energy from existing hydropower facilities – and often the least-cost option. Realistically, 5-10 per cent more electricity can be generated at a modest cost. Legal and technical hurdles may, however, hamper repowering, for instance when there is limited documentation from decades ago. Today, it is possible to accurately analyse local geology and hydrology in advance in order to assess potential gains from upgrades (IRENA-Hydro-2015). In Energy [R]evolution scenarios, upgrading of existing hydropower plants is of particular importance and preferred to new builds, especially for large power plants.

7.4. Power grid technologies — infrastructure for renewables

With increasing market shares of renewable power generation, there will be less space for base load power plants. As a result, conventional power plants cannot run in base load mode anymore, which increases costs of operation and therefore lowers the profit on each kWh sold. The integration of large-scale renewable energy requires a variety of existing grid technologies applied in a new context and with new operational concepts. This section provides a short overview of technologies and operational concepts used for the integration of large shares of renewables and is based on Greenpeace international's reports about power grids published between 2009 and 2014 (GPI- EN 2014)[138].

Smart-grid technology will play a significant role, in particular by integrating demand-side management into power system operation. The future power supply will not consist of a few centralized power plants, but of numerous smaller generation units, such as solar panels, wind turbines and other renewable units, partly on the distribution network and partly concentrated in large power plants (such as offshore wind farms). Smart-grid solutions will help to monitor and integrate this diversity into power system operation and at the same time will make interconnection simpler.

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

Smart grids use information and communication technology (ICT) to enable a power system based on renewable energy sources.

ICT in smart grids is used to:

- easily interconnect a large number of renewable generation assets into the power system (plug and play);
- create a more flexible power system through large-scale demand-side management and by integrating storage to balance the impact of variable renewable generation resources;
- provide the system operator with a better information about the state of the system, which so they can operate the system more efficiently;
- minimize network upgrades using of network assets efficiently and supporting an efficient coordination of power generation over very large geographic areas needed for renewable energy generation.

7.4.1. Demand side management

In reality, the load varies over time, which means that additional flexible power generation resources are required to provide the right amount of power. For rural areas, typical technologies are combined-cycle gas turbines (CCGT) or hydropower stations with a sufficient storage capacity to follow the daily load variations. In conventional island power systems, typically a number of small diesel generators (gensets) are used to provide 24/7 supply. Several gensets have to operate continuously at the point of their highest efficiency, while one is used to follow the load variations.

The impact of adding renewable power generation to a conventionally centralized or island power system will affect the way in which a conventionally designed electricity system runs. The level of impact depends on the renewable energy technology: biomass, geothermal-, concentrated solar- and hydropower with storage can regulate power output and therefore can supply base load as well as peak load.

Hydropower without storage (run-of-river), photovoltaic and wind power depends on the available natural resources, so the power output is variable. Sometimes these renewable energy sources are sometimes described as 'intermittent' power sources; however, the terminology is not correct as intermittent stands for

[138] (GPI-EN2014) Powe[r] 2030 -. A European Grid for 3/4 Renewable Electricity by 2030; Greenpeace International/Energynautics; March 2014.

uncontrollable, i.e. non-dispatchable, but the power output of these generation plants can be forecasted, so they can be dispatched.

Furthermore, they can always be ramped down if needed. There are two main types of impacts to consider when introducing renewable energy to micro-grids: the balancing impact and reliability impact.

Balancing impact relates to the short-term adjustments needed to manage fluctuations over a period ranging from minutes to hours before the time of delivery. In power systems without variable power generation, there can be a mismatch between demand and supply. The reasons could be that the energy load was not forecasted correctly, or a conventional power plant is not operating as it is scheduled, for instance, when a power station trips due to a technical problem. Adding a variable power generation source increases the risk that the forecast power generation in the power system will not be reached, for instance, due to a weather system moving faster than predicted into the area. The overall impact on the system depends on how large and how widely distributed the variable power sources are. A certain amount of wind power distributed over a larger geographical area will have a lower impact on system balancing than the same amount of wind power concentrated in one single location, as geographical distribution will smoothen out the renewable power generation.

System balancing is relevant to:

- Day-ahead planning, which needs to make sure that sufficient generation is available to match expected demand taking into account forecasted generation from variable power generation sources (typically 12 to 36 hours ahead);
- Short-term system balancing, which allocates balancing resources to cover events such as a mismatch between forecasted generation/demand or sudden loss of generation (typically seconds to hours ahead planning).

In island power systems, both aspects must be handled automatically by the system.

Reliability impact is the extent to which sufficient generation will be available to meet peak demands at all times. No electricity system can be 100% reliable since there will always be a small chance of major failures in power stations or transmission lines when demand is high. As renewable power production is often more distributed than conventional large-scale power plants, it reduces the risk of sudden dropouts of major individual production units. On the other hand, variable renewable power generation reduces the probability that generation is available at the time of high demand, thus adding complexity to system planning. Reliability is important for long-term system planning, which assesses the system adequacy typically two to 10 years ahead. Long-term system planning with variable generation sources is a challenge, because of the actual geographical location of the resource. To get a high level of renewable energy into the system, it ideally must be situated at some distance from each other, for example using solar power from southern Europe when there is no or limited wind power available in Northern Europe.

In island power systems, all power generation is typically close to each other, which means that there must be a mix of different generation technologies in the island system or that they must be partly over-designed to make sure that there is always sufficient generation capacity available. This is typically done by adding some back-up diesel gensets. In addition, island power systems can adjust power demand to meet power supply, rather than the other way round. This approach is called demand-side management. An example of a "flexible" load in island systems for demand-side management is water pumps and irrigation pumps, which can be turned on and off depending on how much electricity supply there is.

7.4.2. "Super grid" – the interconnection of smart grids

Based on the current technology development of energy storage technologies, it is difficult to envision that energy storage could provide a comprehensive solution to this challenge. While different storage technologies such as electrochemical batteries are already available today, it is not clear whether large-scale electricity storage, other than pumped hydropower described in the previous section, will become technically and economically viable. Feasible storage systems would have to cover most of the European electricity supply during up to two successive weeks of low solar radiation and little wind – difficult to envision based on current technology development. To design a power system that can adequately react to such extreme situations, a substantial amount of planning is needed in order to ensure available generation capacity together with sufficient network capacity to match demand. Different timescales must be considered:

- long-term system plans to assess the system adequacy over the coming years (typically a time horizon of 2 to 10 years ahead);
- day-ahead planning, making sure that sufficient generation is available to match expected demand (typically 12 to 36 hours ahead);

- short-term balancing, covering events such as a mismatch between forecasted generation/demand or sudden loss of generation (typically seconds to hours-ahead planning).

Benefits of a super grid

Starting around 1920, each load centre in Europe had its own isolated power system. With the development of transmission lines using higher voltages, the transport of power over larger distances became feasible. Soon, the different centres were interconnected. In the beginning, only stations in the same region were interconnected. Over the years, a technology developed further, and the maximum possible transmission line voltage increased step by step.

There were two main drivers of extending network structure:

- Larger transmission networks and high voltage lines meant suppliers could follow the aggregated demand of a large number of customers, instead of the demand variation of one customer — which can change significantly over time — with one generation resource. The demand of those aggregated customers became easier to predict and generation scheduling therefore significantly easier.
- The larger transmission networks created economies of scale by installing larger generation units. In the 1930s, the most cost-effective size of thermal power stations was about 60 MW. In the 1950s, it was 180 MW, and by the 1980s about 1000 MW. This approach made only economic sense because extending the power system was cheaper than adding local generation capacity.

The approach includes some major risks, like the failure of a large power station or the interruption of a major transmission line, which can interrupt the power system over a large area. To be better prepared for such situations national transmission systems in Europe and elsewhere were interconnected across borders. Countries can help each other in case of emergency situations by cooperating in the organization of spinning reserve, reserve capacity and frequency control.

Shifting to an energy mix with over 90% of the electricity supply coming from renewable energy sources will also require a significant redesign of the transmission network to adapt to the needs of the new generation structure. The right kind of grid provides an economical, reliable and sustainable energy supply.

In principle, over-sizing local generation locally would reduce the need for large-scale renewable generation elsewhere as well as upgrading the transmission network. In this case, the local power system will evolve into a hybrid system that can operate without any outside support. However, making local plants bigger (over-sized) is less economical than installing large-scale renewable energy plants at a regional scale and integrating them into the power system via extended transmission lines. The allocation of 70% distributed renewable generation and 30% large-scale renewable generation is not based on a detailed technical or economic optimization; in each location, the optimum mix is specific to local conditions. Further detailed studies on regional levels will be needed to better quantify the split between distributed and large-scale renewable generation. An appropriately designed transmission system is the solution in both cases as it can be used to transmit the required electricity from areas with a surplus of generation to areas that have an electricity deficit. In general, the transmission system must be designed to cope with:

- Long-term issues: extreme variations in the availability of natural resources from one year to another; for instance, the output of wind turbines in any given area can vary by up to 30% from one year to the next. For hydropower, the variations can be even larger.
- Medium-term issues: extreme combinations in the availability of natural resources, such as no wind over main parts of Europe during the winter, when solar radiation is low.
- Short-term issues: significant mismatch between forecasted wind or solar production and actual production with significant impact on power system operation in the range of 15 minutes to 3 hours.
- Loss of a significant amount of generation due to unscheduled break-down or network interruption, impact within milliseconds. The mainland European power system is currently designed to cope with a maximum sudden generation loss of 3,000 MW. Whether this level is sufficient for the future depends, for example, on the maximum transmission capacity of a single transmission line. Most likely the maximum transmission capacity of a single transmission in the future HVDC Super Grid will exceed a capacity of 3,000 MW; hence, sufficient spare generation and/or network capacity must be considered when redesigning the power system (considered in the simulation report by loading the super Grid to a maximum of 70%).

In principle, different technical options exists for the redesign of the onshore transmission network such as:

- HVAC (High Voltage Alternating Current);
- HVDC LCC (High voltage direct current system using a line commutated converter);
- HVDC VSC (High voltage direct current system using a voltage source converter);
- Other technical solutions.

7.5. Renewable heating and cooling technologies

Renewable heating and cooling have a long tradition in human culture. Heat can come from the sun (solar thermal), the earth (geothermal), ambient heat and plant matter (biomass). Solar heat for drying processes and wood stoves for cooking has been used for so long that they are labelled "traditional", but today's technologies are far from old-fashioned. Over the last decade, there have been improvements to a range of traditional applications, many of which are already economically competitive with fossil-fuel based technologies or starting to be.

This chapter presents the current range of renewable heating and cooling technologies and gives a short outlook of the most sophisticated technologies, integrating multiple suppliers and users in heat networks or even across various renewable energy sources in heating and cooling systems. Some of the emerging areas for this technology are space heating/cooling and industrial process heat.

7.5.1. Solar thermal technologies

Solar thermal energy has been used for the production of heat for centuries but has become more popular and developed commercially for the last thirty years. Solar thermal collecting systems are based on a centuries-old principle: the sun heats up water contained in a dark vessel.

The technologies on the market now are efficient and highly reliable, providing energy for a wide range of applications in domestic and commercial buildings, swimming pools, for industrial process heat, in cooling and the desalination for drinking water.

Although mature products exist to provide domestic hot water and space heating using solar energy, in most countries they are not yet the norm. A big step towards an Energy [R]evolution is integrating solar thermal technologies into buildings at the design stage or when the heating (and cooling) system is being replaced, lowering the installation cost.

Swimming pool heating

Pools can make simple use of free heating, using unglazed water collectors. They are mostly made of plastic, have no insulation and reach temperatures just a few degrees above ambient temperature. Collectors used for heating swimming pools and are either installed on the ground or on a nearby rooftop, and they pump swimming pool water through the collector directly. The size of such a system depends on the size of the pool as well as the seasons in which the pool is used. The collector area needed is about 50 % to 70 % of the pool surface. The average size of an unglazed water collector system installed in Europe is about 200 m² [139].

Domestic hot water systems

The major application of solar thermal heating so far is for domestic hot water systems. Depending on the conditions and the system's configuration, most of a building's hot water requirements can be provided by solar energy. Larger systems can additionally cover a substantial part of the energy needed for space heating. Two major collector types are:

Vacuum tubes

The absorber inside the vacuum tube absorbs radiation from the sun and heats up the fluid inside. Additional radiation is picked up from the reflector behind the tubes. Whatever the angle of the sun, the round shape of the vacuum tube allows it to reach the absorber. Even on a cloudy day, when the light is coming from many angles at once, the vacuum tube collector can still be effective. Most of the world's installed systems are this type, especially in the world's largest market: China. This collector type consists of a row of evacuated glass tubes with the absorber placed inside. Due to the evacuated environment, there are fewer heat losses. The systems can reach operating temperatures of at least 120 °C; however, the typical use of this collector type is in the range of 60°C to 80°C. Evacuated tube collectors are more efficient than standard flat-plate collectors but generally also more costly.

Flat plate or flat panel

This is basically a box with a glass cover which sits on the roof like a skylight. Inside is a series of copper or aluminium tubes with copper fins attached. The entire structure is coated with a black substance designed to capture the sun's rays. In general, flat plate collectors are not evacuated. They can reach temperatures of about 30°C to 80°C[140] and are the most common collector type in Europe. There are two different ways how the water flow is handled in solar heating, which influences the overall system cost.

Thermo-siphon systems

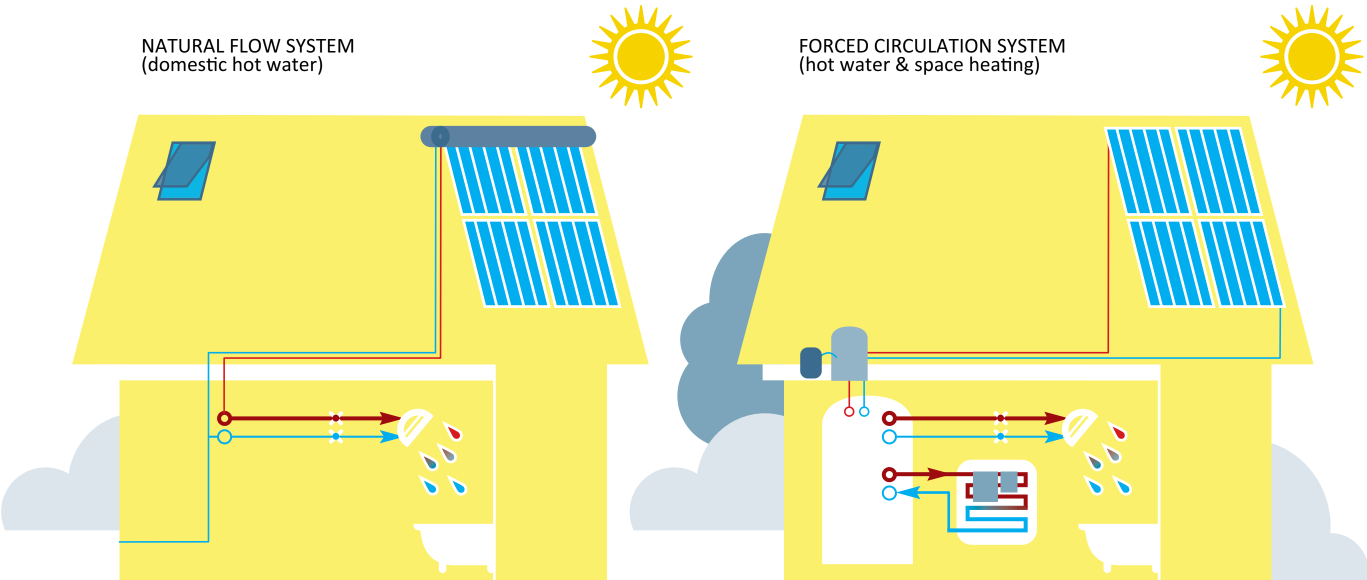
The simple form of a thermosiphon solar thermal system uses gravity as a natural way to transfer hot water from the collector to the storage tank. No pump or control station is needed, and many are applied as direct systems without a heat exchanger, which reduces system costs. The thermo-siphon is relatively

[139] Weiss, W. et al. (2011): Solar heat worldwide – markets and contribution to the energy supply 2009. IEA Solar Heating And Cooling Programme, May 2011. International Energy Agency (IEA), Paris, France

[140] Weiss, W., et al. (2008): Process heat collectors – state of the art. IEA Heating and Cooling Programme and IEA Solarpaces Programme, 2008. International Energy Agency (IEA), Paris, France.

compact, making installation and maintenance quite easy. The storage tank of a thermosiphon system is usually applied right above the collector on the rooftop and directly exposed to the seasons. These systems are typical in warm climates, due to their lower efficiency compared with forced circulation systems. The most common problems are heat losses and the risk of freezing; they are therefore not suitable for areas where temperatures drop below freezing. In southern Europe, a system like this is capable of providing almost the total hot water demand of a household. However, the largest market for thermosiphon systems is China. In Europe, thermo-siphon solar hot water systems are 95% of private installations in Greece[141], followed by 25% and 15% of newly installed systems in Italy and Spain newly in 2009[142].

Figure 7.12. Natural flow systems vs. forced circulation systems



Source: EPIA.

Pumped systems

The majority of systems installed in Europe are forced circulation (pumped) systems, which are far more complex and expensive than thermosiphon systems. Typically, the storage tank is situated inside the house (for instance in the cellar). An automatic control pump circulates the water between the storage tank and the collector. Forced circulation systems are normally installed with a heat exchanger, which means they have two circuits. They are mostly used in areas with low outside temperatures, and antifreeze additives might have to be added to the solar circuit to protect the water from freezing and destroying the collector.

Even though forced circulation systems are more efficient than thermosiphon systems, they are mostly not capable of supplying the full hot water demand in cold areas and are usually combined with a back-up system, such as heat pumps, pellet heaters or conventional gas or oil boilers. Solar coverage levels depend on the heat demand, the outside temperature and the system design. For hot water production, a solar coverage of 60% in Central Europe is common at the current state of technology development. The typical collector area installed for a domestic hot water system in a single-family house in the EU is 3-6 m². For multifamily houses and hotels, the size of installations is much bigger, with a typical size of 50 m² [143][144][145].

Domestic heat systems

Besides domestic hot water systems, solar thermal energy for space heating systems is becoming increasingly

[141] Travasaros, C. (2011): The Greek solar thermal market and industrial applications – overview of the market situation. Greek Solar Industry Association, World sustainable energy days 2011, Wels, 3.3.2011, http://www.wsed.at/fileadmin/redakteure/wsed/2011/download_presentations/travasaros.pdf.

[142] Weiss, W. et al. (2011): Solar heat worldwide – markets and contribution to the energy supply 2009. IEA
Solar Heating And Cooling Programme, May 2011. International Energy Agency (IEA), Paris, France.

[143] Weiss, W. et al. (2011): Solar heat worldwide – markets and contribution to the energy supply 2009. IEA Solar Heating And Cooling Programme, May 2011. International Energy Agency (IEA), Paris, France.

[144] Nitsch, J. et al. (2010): Leitstudie 2010 – Langfristszenarien und strategien für den ausbau der erneuerbaren energien in Deutschland bei berücksichtigung der entwicklung in Europa und global.
Stuttgart, Kassel, Teltow, Deutsches Zentrum für Luft- und Raumfahrt, Fraunhofer Institut für Windenergie und Energiesystemtechnik (IWES), Ingenieurbüro für Neue Energien (IFNE).

[145] Jager, D. et al. (2011): Financing renewable energy in the European energy market. Brussels, Ecofys NL, Fraunhofer ISI, TU Vienna EEG, Ernst &Young, European Commission (DG Energy).

relevant in European countries. In fact, the EU is the largest market for this application at the moment, with Germany and Austria as the main driving forces. The collectors used for these applications are, however, the same as for domestic hot water systems for solar space heating purposes, though only pumped systems are suitable. Effectively most systems used are so called combi-systems that provide space as well as water heating.

So far, most installations are built on single-family houses with a typical system size between 6 and 16 m² and a typical annual solar coverage of 25% in Central Europe.

Solar combi-systems for multiple family houses are not yet used very frequently. These systems are about 50 m², cost approximately 470-550 €/m² and have annual solar coverage of 25% in Central Europe. Large scale solar thermal applications connected to a local or district heating grids with a collector area above 500 m² are not so common. However, since 1985, an increasing number of such systems have been installed per year in the EU with a typical annual solar coverage of 15% in Central Europe. To get a significant solar share, large storage is needed. The typical solar coverage of such a system including storage is around 50% today. With seasonal storage, the coverage may be increased to about 80%. Another option for domestic heating systems is air collector systems (not described here). The largest markets for air collectors are in North America and Asia; these systems have a very small penetration on the European market, though it has been increasing in recent years.

Process heat

Solar thermal use for industrial process heat is receiving some attention for development, although it is hardly in use today. Standardized systems are not available because industrial processes are often individually designed. Also, solar thermal applications are mostly not capable of providing 100% of the heat required over a year, so another non-solar heat source would be necessary for commercial use. Depending on the temperature level needed, different collectors have been developed to serve the requirements for process heat. Flat plates or evacuated tube collectors provide a temperature range up to 80°C. A large number are available on the market.

For temperatures between 80°C and 120°C advanced flat-plate collectors are available, such as with multiple glazing, antireflective coatings, evacuated tubes, and an inert gas filling. Other options are flat-plate and evacuated tube collectors with compound parabolic concentrators (CPC). These collectors can be stationary and are generally constructed to concentrate solar radiation by a factor of 1 to 2. They can use most diffuse radiation, which makes them especially attractive for areas with low direct solar radiation.

There are a few conceptual designs to reach higher temperatures between 80°C and 180°C, primarily using a parabolic trough or linear concentrating Fresnel collectors. These collector types have a higher concentration factor than CPC collectors, are only capable of using direct solar radiation, and have to be combined with sun tracking systems. The collectors especially designed for heat use are most suitable for a temperature range between 150°C and 250 °C.[146] Air collector systems for process heat are limited to lower temperatures, being mostly used for drying purposes (hay, etc.); they are not discussed here.

Cooling

Solar chillers use thermal energy to produce cooling and/or dehumidify the air in a similar way to a refrigerator or conventional air-conditioning. This application is well suited to solar thermal energy, as the demand for cooling is often greatest when there is most sunshine. Solar cooling has been successfully demonstrated. Large-scale use can be expected in the future but is still not common.

The option to use solar heat this way makes sense because hot regions require more cooling for comfort. Solar thermal cooling is mostly designed as a closed-loop sorption system (see Box 7.2). The most common application, however, is a solar absorption cooling unit. The system requires temperatures above 80°C, which means evacuated tube collectors, advanced flat-plate collectors and compound parabolic concentrators. The solar field required for a cooling unit is about 4 m² per kW of cooling capacity.

[146] Weiss, W., et al. (2008): Process heat collectors – state of the art. IEA Heating and Cooling Programme and IEA Solarpaces Programme, 2008. International Energy Agency (IEA), Paris, France.

Box 7.2. Sorption cooling units

A thermo-chemical refrigerant cycle (sorption) provides cold by either absorption or adsorption cooling. Absorption occurs when a gaseous or liquid substance is taken up by another substance, such as the solution of a gas in a liquid. Adsorption takes place when a liquid or gaseous substance is bound to the surface of a solid material. The absorption cooling circle can be described as follows: a liquid refrigerant with a very low boiling point is vaporized at low pressure, withdrawing heat from its environment and therefore providing the desired cooling. The gaseous refrigerant is then absorbed by a liquid solvent, mostly water. The refrigerant and solvent are separated again by adding (renewable) heat to the system, making use of the different boiling points. The gaseous refrigerant is now condensed, released and returned to the beginning of the process. The heat needed in the process can be provided by firing natural gas, combined heat and power plants, solar thermal collectors, etc.

7.5.2. Heat pump technology

A heat pump is a device that transfers heat from one fluid at a lower temperature to another at a higher temperature. Thus, it allows heat to be carried from a lower to a higher temperature level. The function of the heat pump may, therefore, be compared to that of a water pump positioned between two water basins connected to each other but located at different altitudes: water will naturally flow from the higher to the lower basin. It is, however, possible to return water to the higher basin by using a pump, which draws water from the lower one.

A heat pump consists of a closed circuit through which a special fluid (refrigerant) flows. This fluid takes on a liquid or gaseous state according to temperature and pressure conditions. The condenser and the evaporator consist of heat exchangers, i.e. special tubes placed in contact with service fluids (such as air) in which the refrigerant flows. The latter transfer heat to the condenser (the high temperature side) and takes it away from the evaporator (the low temperature side). Electric power is required to operate heat pumps, making them an efficient way of electric heating.

Heat pumps have become increasingly important in buildings but can also be used for industrial process heat. Industrial heat pumps (IHPs) offer various opportunities to all types of manufacturing processes and operations and use waste process heat as the heat source, deliver heat at a higher temperature for use in industrial processes, heating or preheating, or for space heating and cooling in industry. The introduction of heat pumps with operating temperature below 100°C is state of the art technologies while higher temperature applications still require additional R&D activities[147].

Heat pumps use the refrigeration cycle to provide heating, cooling and sanitary hot water. They employ renewable energy from ground, water and air to move heat from a relatively low temperature reservoir (the "source") to the temperature level of the desired thermal application (the "output"). Heat pumps commonly use two types of refrigeration cycles:

- Compression heat pumps use mechanical energy, most commonly electric motors or combustion engines to drive the compressor in the unit. Consequently, electricity, gas or oil is used as auxiliary energy.
- Thermally driven heat pumps use thermal energy to drive the sorption process – either adsorption or absorption – to make ambient heat useful. Different energy sources can be used as auxiliary energy: waste energy, biomass, solar thermal energy or conventional fuels.

Compression heat pumps are most commonly used today; however, thermally driven units are seen as a promising future technology. The "efficiency" of a heat pump is described by the coefficient of power (cop) – the ratio between the annual useful heat output and the annual auxiliary energy consumption of the unit. In the residential market, heat pumps work best for relatively warm heat sources and low temperature applications such as space heating and sanitary hot water. They are less efficient for providing higher temperature heat and can't be used for heat over 90°C. For industrial applications, different refrigerants can be used to provide heat from 80°C to 90°C efficiently, so they are only suitable for part of the energy requirements of the industry.

Heat pumps are generally distinguished by the heat source they exploit:

- Ground source heat pumps use the energy stored in the ground at depths from around hundred meters up to the surface. They are used for deep borehole heat exchangers (300 – 3000m), shallow borehole heat exchangers (50 – 250m) and horizontal borehole heat exchangers (a few meters deep).
- Water source heat pumps are coupled to a (relatively warm) water reservoir of around 10°C, such as wells, ponds, rivers, and the sea.
- Aero-thermal heat pumps use the outside air as a heat source. As outside temperatures during the heating period are generally lower than soil and water temperature, ground source and water source heat pumps typically more efficient than aero-thermal heat pumps.

Heat pumps require additional energy apart from the environmental heat extracted from the heat source, so the environmental benefit of heat pumps depends on both their efficiency and the emissions related to the production of the working energy. Where the heat pump has a low cop and a high share of electricity from coal power plants, for example, carbon dioxide emissions relative to useful heat production might be higher than conventional gas condensing boilers. On the other hand, efficient heat pumps powered with "green" electricity are 100% emission-free solutions that contribute significantly to the reduction of greenhouse gas emissions when used in place of fossil-fuel fired heating systems.

[147] Weiss, W. et al. (2011): Solar heat worldwide – markets and contribution to the energy supply 2009. IEA Solar Heating And Cooling Programme, May 2011. International Energy Agency (IEA), Paris, France

Box 7.3. Typical heat pump specifications

Usually provide hot water or space heat at lower temperatures, around 35°C.

Example uses: underfloor/wall heating.

Typical size for space heating a single family house.

Purposes: approx. 5-10 kW thermal.

Typical size for space heating a large office building: >100 kW thermal.

Aero-thermal heat pumps do not require drilling, which significantly reduces system costs compared to other types. If waste heat from fossil fuel fired processes is used as heat source for this technology, the heat provided cannot be classified as "renewable" – it becomes merely an efficient way of making better use of energy otherwise wasted.

Heat pumps for cooling

Reversible heat pumps can be operated both in heating and in cooling mode. When running in cooling mode in summer, heat is extracted from the building and "pumped" into the underground reservoir, which is then heated. In this way, the temperature of the warm reservoir in the ground is restored after its exploitation in winter. Alternatively, renewable cooling could be provided by circulating a cooling fluid through the relatively cool ground before being distributed in a building's heating/cooling system ("free cooling"). However, this cooling fluid must not be based on chemicals that are damaging to the upper atmosphere, such as HFCs (a strong greenhouse gases) or CFCs (ozone depleting gases). In principle, high enthalpy geothermal heat might provide the energy needed to drive an absorption chiller. However, only a very limited number of geothermal absorption chillers are in operation worldwide.

7.5.3. Biomass heating technologies

There is a broad portfolio of technologies for heat production available from biomass, a traditional fuel source. A need for more sustainable energy supply has led to the development of modern biomass technologies. A high variety of new or modernised technologies and technology combinations can serve space and hot water needs and eventually also provide process heat even for industrial processes. Biomass can provide a large temperature range of heat and can be transported over long distances, which is an advantage compared to solar thermal or geothermal heat. However, sustainable biomass imposes limits on volume and transport distance. Another drawback of bioenergy is exhaust emissions and the risk of greenhouse gas emissions from energy crop cultivation. These facts lead to two approaches to biomass development:

- towards improved, relatively small-scale, decentralized systems for space heat and hot water;
- development of various highly efficient and upgraded biomass cogeneration systems for industry and district heating.

Small applications for space heat and hot water in buildings

In the residential sector, traditional biomass applications have been strongly improved over the last decades for efficient and comfortable space heating and hot water supply. The standard application is direct combustion of solid biomass (wood), for example in familiar but improved firewood stoves for single rooms. For average single homes and small apartment houses, firewood and pellet boilers are an option to provide space heat and hot water. Wood is easy to handle, and standardized quality and pellet systems can be automated along the whole chain; refuelling can then be reduced to a few times a year. Automatically fed systems are more easily adaptable to variations in heat demand, such as between summer and winter. Another advantage is lower emissions of air pollutants from pellet appliances compared to firewood[148]. Pellet heating systems are gaining importance in Europe.

Handfed systems are common for smaller applications below 50 kW. Small applications for single rooms (around 5 kW capacity) are usually handfed wood stoves with rather low efficiency and low cost. Technologies are available for central heating in single and semi-detached houses and are also an option for apartment complexes. Wood boilers provide better combustion with operating efficiencies of 70-85% and fewer emissions than stoves with a typical size of 10-50 kW [149 150 151].

[148] Gemis (2011): Globales emissions-modell integrierter systeme (Gemis), version 4.6, Öko-Institut.
[149] Nitsch, J. et al. (2010): Leitstudie 2010 – Langfristszenarien und strategien für den ausbau der erneuerbaren energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und Global. Stuttgart, Kassel, Teltow, Deutsches Zentrum für Luft- und Raumfahrt, Fraunhofer Institut für Windenergie und Energiesystemtechnik (IWES), Ingenieurbüro für Neue Energien (IFNE).
[150] Gemis (2011): Globales emissions-modell integrierter systeme (Gemis), version 4.6, Öko-Institut.
[151] AEBIOM (2011b): Review of investment cost data for biomass heating technologies. G. A. Center. Brussels.

Larger wood boilers can heat large buildings such as apartment blocks, office buildings and other large buildings in service, commerce and industry with space heat and hot water.

Direct heating technologies

Large applications for district or process heat rely on automatic feeding technologies, due to constant heat demand at a defined temperature. Direct combustion of biomass can provide temperatures up to 1000°C, with higher temperatures from wood and lower temperatures from straw, for instance. Automatically fed systems are available for wood chips, pellets, and straw. Three combustion types are[152]:

Cogeneration technologies

Cogeneration increases the efficiency of using biomass if the provided heat can be used efficiently. The size of a plant is limited due to the lower energy content of biomass compared to fossil fuels and resulting difficulties in fuel logistics. Selection of the appropriate cogeneration technology depends on the available biomass. In several Scandinavian countries – with an extraordinarily high potential of forest biomass – solid biomass is already a main fuel for cogeneration processes. Finland gets more than 30% and Sweden even 70% of its co-generated electricity from biomass[153].

Direct combustion technologies

The cogeneration processes can be based on direct combustion types (fixed bed combustion, fluidised bed combustion, pulverised fuel combustion). While steam engines are available from 50 kW electric steam turbines normally cover the range above 2 MWel, with special applications available from 0.5 MW electric. The heat is typically generated at 60-70% efficiency depending on the efficiency of the power production process, which in total can add up to 90%[154]. Thus, small and medium cogeneration plants provide three to five times more heat than power, with local heat demand often being the limiting factor for the plant size.

Upgraded biomass

There are various conversion technologies available to upgrade biomass products for the use in specific applications and for higher temperatures. Common currently available technologies are (upgraded) biogas production and gasification. Other technologies such as pyrolysis and the production of synthetic gases and oils are under development.

Gasification is especially valuable in the case of biomass with low caloric value and when it includes moisture. Partial oxidation of the biomass fuel provides a combustible gas mixture mainly consisting of carbon monoxide (CO). Gasification can provide higher efficiency along the whole biomass chain, but at the expense of additional investments in this more sophisticated technology. There are many different gasification systems based on varying fuel input, gasification technology and combination with gas turbines. The literature shows a large cost range for gasification cogeneration plants.

Other upgrading processes are biogas upgrading for exports of natural gas network and the production of liquid biomass, such as plant oil, ethanol or second generation fuels. Those technologies can be easily exchangeable with fossil fuels, but the low efficiency of the overall process and energy input needed to produce energy crops are disadvantages for sustainability.

7.5.4. Biogas

Biogas plants use anaerobic digestion of bacteria for the conversion of various biomass substrates into biogas. This gas mainly consists of methane (a gas of high caloric value), CO_2, and water. Anaerobic digestion can be used to upgrade organic matter with low energy density, such as organic waste and manure. These substrates usually contain large water contents and appear liquid. "Dry" substrates need additional water.

Liquid residues like wastes and excrements are energetically unused. Biogas taps into their calorific potential. The residue of the digestion process is used as a fertilizer, which has a higher availability of nitrogen and is more valuable than the input substrates[155].

Methane is a strong greenhouse gas, so biogas plants need airtight covers for the digestate to maintain low emissions[156]. Residues and wastes are preferable for biogas compared with energy crops such as corn silage, which require energy and fertilizer inputs while growing and thus create greenhouse gas emissions.

Biogas plants usually consist of a digester for biogas production and a cogeneration plant. Plants vary in size and are normally fed by a mixture of substrates for ex-

[152] Kaltschmitt, M. et al., eds. (2009): Energie aus biomasse – Grundlagen, Techniken und Verfahren. Berlin, Heidelberg, Springer.

[153] IEA (2011b): Cogeneration and renewables. International Energy Agency (IEA), Paris, France.

[154] Kaltschmitt, M. et al., eds. (2009): Energie aus biomasse – Grundlagen, Techniken und Verfahren. Berlin, Heidelberg, Springer.

[155] Kaltschmitt, M. et al., eds. (2009): Energie aus biomasse – grundlagen, techniken und verfahren. Berlin, Heidelberg, Springer.

[156] Pehnt, M. et al. (2007): Biomasse und effizienz – vorschläge zur erhöhung der energieeffizienz von §8 und §7-anlagen im erneuerbare-energien-gesetz. Arbeitspapier nr. 1 im rahmen des projektes "Energiebalance – optimale systemlösungen für erneuerbare energien und energieeffizienz". Heidelberg, Institut für Energie und Umweltforschung Heidelberg Gmbh (IFEU).

ample manure mixed with maize silage, grass silage, other energy crops and/or organic waste[157].

Normally biogas is used in cogeneration. In Germany, the feed-in tariff means biogas production currently is mostly for power. The majority of biogas plants are on farms in rural areas. Small biogas plants often use the produced heat for local space heating and process heat, such as for drying processes. Larger biogas plants need access to a heat network to make good use of all the available heat. However, network access is often not available in rural areas, so there is still untapped potential of heat consumption from biogas. Monitoring of German biogas plants showed that 50% of available heat was actually wasted[158]. The conditioning and enriching of biogas and subsequent export to the gas network have been promoted lately and should become an option to use biogas directly at the location of heat demand.

Upgrading technologies for biomass do bear the risk of additional methane emissions, so tight emission standards are necessary to achieve real reductions in greenhouse gas emissions[159].

7.5.5. Storage technologies

As the share of electricity provided by renewable sources increases around the world, the technologies and policies required to handle their variability are also advancing. Along with the grid-related and forecasting solutions, energy storage is a key part of the Energy [R]evolution.

Once the share of electricity from variable renewable sources exceeds 30-35%, energy storage is necessary in order to compensate for generation shortages or to store possible surplus electricity generated during windy and sunny periods. Today storage technology is available for different stages of development, scales of projects, and for meeting both short and long-term energy storage needs. Short-term storage technologies can compensate for output fluctuations that last only a few hours, whereas longer term or seasonal storage technologies can bridge the gap over several weeks.

Short-term options include batteries, flywheels, and compressed air power plants and pump storage power stations with high-efficiency factors. The latter is also used for long term storage. Perhaps the most promising of these options are electric vehicles (EVS) with vehicle-to-grid (V2G) capability, which can increase the flexibility of the power system by charging when there is surplus renewable generation and discharging while parked to take up peaking capacity or ancillary services to the power system. Vehicles are often parked close to main load centres during peak times (e.g., outside factories) so there would be no network issues. However, battery costs are currently very high and significant logistical challenges remain.

Seasonal storage technologies include hydro pumped storage and the production of hydrogen or renewable methane. While the latter two options are currently in the development with several demonstration projects mainly in Germany, pumped storage has been in use around the world for more than a century.

Pumped storage

Pumped storage is the largest-capacity form of grid energy storage now available and currently the most important technology to manage high shares of wind and solar electricity. It is a type of hydroelectric power generation that stores energy by pumping water from a lower elevation reservoir to a higher elevation during times of low-cost, off-peak electricity and releasing it through turbines during high demand periods. While pumped storage is currently the most cost-effective means of storing large amounts of electrical energy on an operating basis, capital costs and appropriate geography are critical decision factors in building new infrastructure. Losses associated with the pumping and water storage process make such plants net consumers of energy; accounting for evaporation and conversion losses, approximately 70-85% of the electrical energy used to pump water into the elevated reservoir can be recaptured when it is released.

Renewable methane

Both gas plants and cogeneration units can be converted to operate on renewable methane, which can be made from renewable electricity and used to effectively store energy from the sun and wind. Renewable methane can be stored and transported via existing natural gas infrastructure and can supply electricity when needed. Gas storage capacities can close electricity supply gaps of up to two months, and the smart link between power grid and gas network can allow for grid stabilisation. Expanding local heat networks, in

[157] IEA (2007): Renewables for heating and cooling. International Energy Agency (IEA), Paris, France.
Nitsch, J. et al. (2010): Leitstudie 2010 – langfristszenarien und strategien für den ausbau der erneuerbaren energien in Deutschland bei berücksichtigung der entwicklung in Europa und global. Stuttgart, Kassel, Teltow, Deutsches Zentrum für Luft- und Raumfahrt, Fraunhofer Institut für Windenergie und Energiesystemtechnik (IWES), Ingenieurbüro für Neue Energien (IFNE).

[158] DBFZ (2010): Monitoring zur wirkung des erneuerbare-energien-gesetzes (EEG) auf die entwicklung der stromerzeugung aus biomasse (unveröffentlichter entwurf). Leipzig, Deutsches Biomasseforschungszentrum.

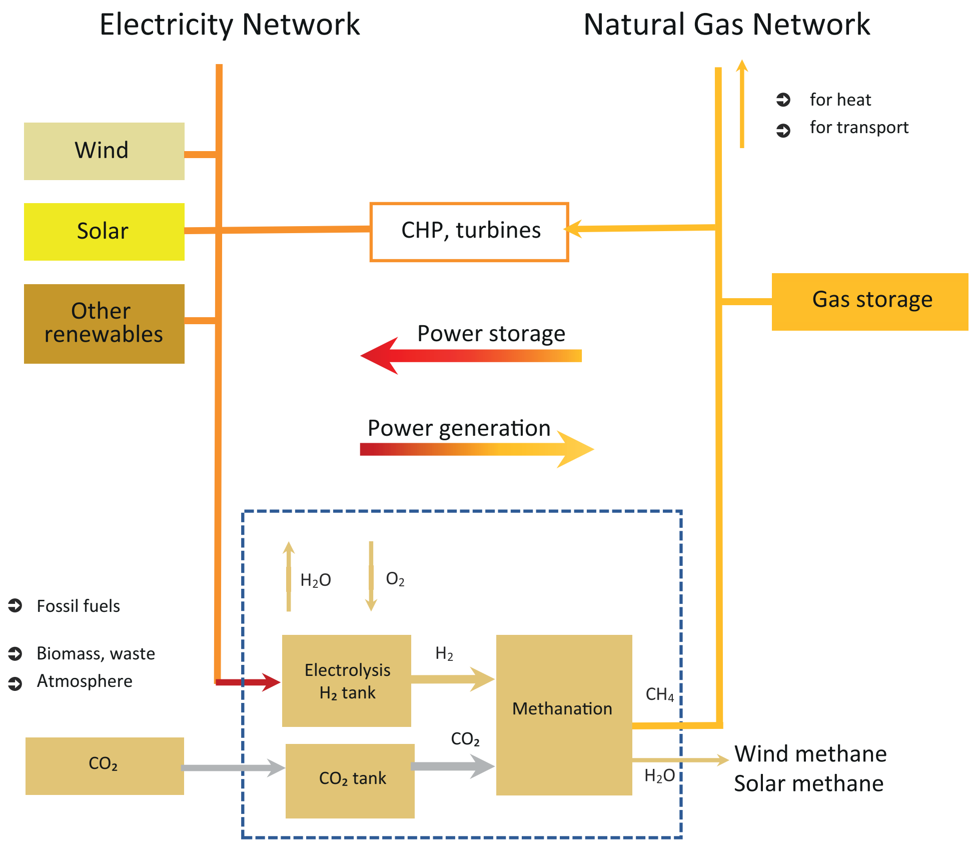
[159] Gärtner, S. et al. (2008): Optimierungen für einen nachhaltigen ausbau der biogaserzeugung und – nutzung in Deutschland, materialband e: ökobilanzen. Heidelberg, Institut für Energie- und Umweltforschung.

[160] (F-IWS 2010) Fraunhofer IWS, Erneuerbares methan kopplung von strom- und gasnetz. M.Sc. Mareike Jentsch, Dr. Michael Sterner (IWES), Dr. Michael Specht (ZSW), tu Chemnitz, Speicherworkshop Chemnitz, 28.10.2010.

connection with power grids or gas networks, would enable the electricity stored as methane to be used in cogeneration units with high overall efficiency factors, providing both heat and power[160]. There is currently several pilot projects in Germany in the range of one to two-megawatt size, but not in a larger commercial scale yet. If those pilot projects are successful, a commercial scale can be expected between 2015 and 2020. However, policy support, to encourage the commercialisation of storage is still lacking.

Figure 7.13. Renewable (power) (to) methane — renewable gas

Storing renewable power as natural gas by linking electricity and natural gas networks



Source: Fraunhofer Institut, 2010.

Battery storage

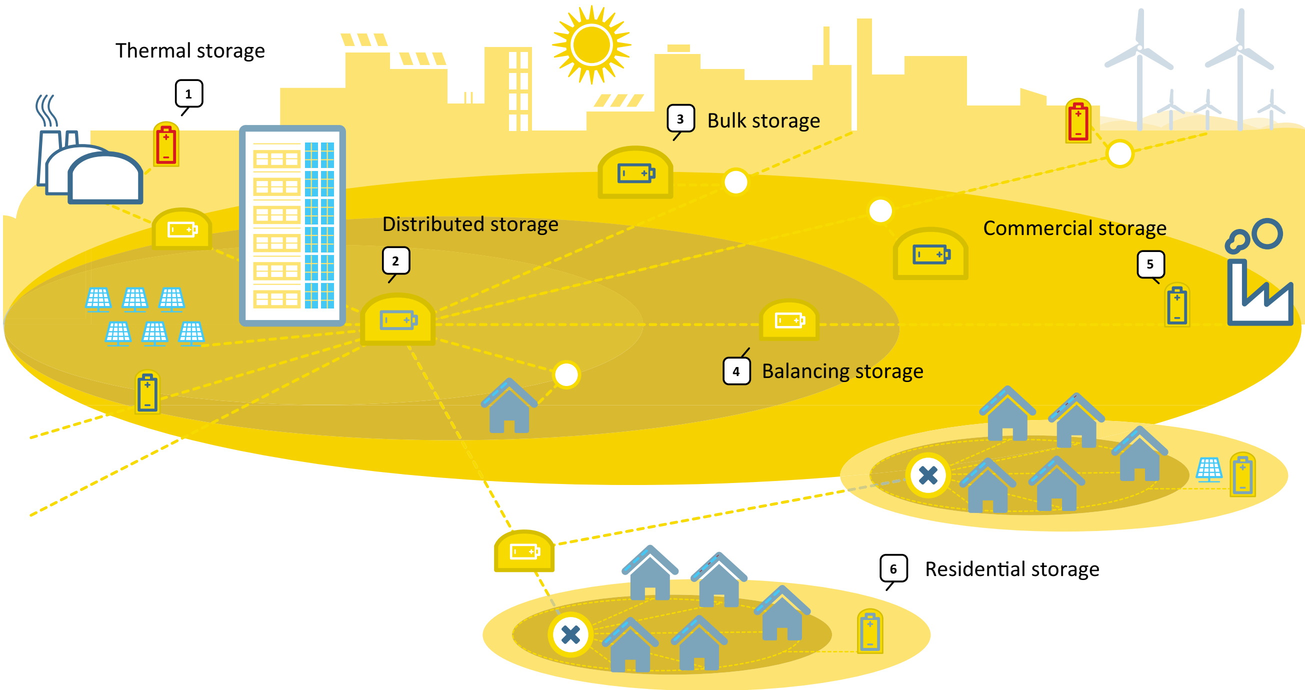
There are numerous battery technologies on the market and the increasing demand for electric vehicles triggered the battery development significantly of the past decade. Especially lithium batteries are currently under discussion and a new generation of large scale lithium-metal and lithium-ion batteries (LIB) as well as small scale application such as Tesla's "PowerWall" will increasingly complement renewable power generation. Besides that, mobile energy storage devices form the basis for not only future oriented drive systems such as vehicles with hybrid drive and all electrically driven vehicles but also hydrogen storage and fuel cell technologies. Battery systems like lithium-sulfur and lithium-air have a great potential to reach the highest capacity and energy density values (DLR-Wagner)[161]. In order to increase battery safety, reliability and to reduce costs partly through economies of scale, battery research and development activities have significantly expanded worldwide. Many energy experts see new battery technology in combination with low cost solar photovoltaic power generation as a potentially disruptive technology, which can change future energy markets dramatically.

Storage technologies — the cascade approach

There is no "one-size-fits-all" technology for storage. Along the entire supply and demand chain, different storage technologies are required to cover the exact needs in regard to storage time – from the second reserve for frequency stability to seasonal storage of several months. A cascade of different storage technologies is required to support the local integration of power generation from variable renewable energy (VRE) in distribution networks. Figure 7.14 shows a whole range of storage technologies.

[161] (DLR-Wagner 2015) Dr. Rer.Nat. Norbert Wagner; http://www.dlr.de/tt/en/desktopdefault.aspx/tabid-7197/

Figure 7.14. Potential locations and applications of electricity storage in the power system



Source: IRENA – storage 2015[162].

[162] (IRENA – storage 2015) Renewables and electricity storage – a technology roadmap. International Renewable Energy Agency (IRENA). IRENA Innovation and Technology Centre, Robert-Schuman-Platz 3, 53175 Bonn, Germany, June 2015

Photo: ©flickr.com — Walmart

Conclusions

Modelling of an ambitious Energy [R]evolution scenario for Belarus produced inspiring results indicating that transition to the energy system with a high share of renewables is a feasible pathway, which also delivers multiple environmental and economic benefits for Belarusians. In particular, energy system based primarily on locally available energy sources will guarantee energy security, which is one of the key objectives of the current energy policy of the Belarusian government. Transition to renewables will also reduce electricity production costs straight after 2020, which will enable electricity supply to households at lower tariffs than would be based on conventional energy mix. Moreover, the Energy [R]evolution scenario demonstrates the scope for the strengthening of current climate policy of Belarus, which should help attracting required for the transition to renewables investments.

Considerable investments and policy efforts are certainly required to make Energy [R]evolution scenario a reality but maintaining conventional energy system also requires huge capital and fuel costs (even without considering environmental and health impacts of fossil fuels), which should be taken into an account in decision-making. In fact, results of this study demonstrate that savings of fuel costs under Energy [R]evolution scenario more than outweigh the required investments to make this scenario a reality.

Key figures and specific results of modelling Reference and Energy [R]evolution scenarios for Belarus are as follows:

- Under the Reference scenario, total final energy demand increases by 42% from the current 710 PJ/a to 1010 PJ/a in 2050. **In the Energy [R]evolution scenario, final energy demand decreases by 24% compared to current consumption and is expected to reach 540 PJ/a by 2050,** which is achieved by an ambitious energy policy measure.
- Total electricity demand will rise from about 30 TWh/a to 61 TWh/a by 2050 in the Energy [R]evolution scenario as a result of economic growth, increasing living standards and electrification of the transport and heat sectors. However, **efficiency measures in the industry, residential and service sectors avoid the generation of about 20 TWh/a compared to the Reference scenario.**
- Efficiency gains in the heating sector are even larger than in the electricity sector. Under the Energy [R]evolution scenario, consumption equivalent to about 300 PJ/a is avoided through efficiency gains by 2050 compared to the Reference scenario.
- The development of the electricity supply sector is characterised by a dynamically growing wind and PV market, which more than compensate for the limited development out of nuclear power in the Energy [R]evolution scenario. **By 2050, 92% of the electricity produced in Belarus will come from renewable energy sources in the Energy [R]evolution scenario.** The installed capacity of renewables will reach about 9 GW in 2030 and 50 GW by 2050.
- The Energy [R]evolution scenario will lead to a high share of fluctuating power generation sources (PV & wind) of already 29% by 2030 and 77% of total generation by 2050. Therefore, smart grids, demand side management, energy storage capacities and other options need to be expanded in order to increase the flexibility of the power system for integration of renewables and a secure supply of electricity.
- The introduction of renewable technologies under the Energy [R]evolution scenario increases the future costs of electricity generation compared to the Reference scenario slightly in the beginning (0.1 US$ct/kWh without taking into account integration costs for storage or other load-balancing measures). **Because of increasing prices for conventional fuels and cost reduction in fluctuating renewables, electricity generation costs will become economically favourable just after 2020 under the Energy [R]evolution scenario.** By 2050, the cost will be 1.9 US$ct/kWh below those in the Reference case.
- **Around US$ 90 billion is required in investment for the Energy [R]evolution scenario to become a reality** (including investments for replacement after the economic lifetime of the plants) — approximately US$ 2 billion per year, US$ 60 billion more than in the Reference scenario (US$ 30 billion).
- **However, the fuel cost savings in the Energy [R]evolution scenario reach a total of US$ 63 billion up to 2050, which is US$ 1.6 million per year.** Thus, total fuel cost savings would cover all additional investments compared to the Reference scenario.
- Today, renewables meet around 10% of Belarus's energy demand for heating, the main contribution coming from the use of biomass. In the Energy [R]evolution scenario, renewables already provide 33% of Belarus's total heat demand in 2030 and 80% in 2050. **Energy efficiency measures help to reduce**

the currently growing energy demand for heating by 45% in 2050 (relative to the Reference scenario), in spite of improving living standards and economic growth.

- It is roughly estimated that **the Energy [R]evolution scenario in total requires around US$ 33 billion to be invested in renewable heating technologies up to 2050** (including investments for replacement after the economic lifetime of the plants) – approximately US$ 1 billion per year.
- Due to population decrease, GDP growth and higher living standards, energy demand from the transport sector is expected to only slightly increase in the Reference scenario by around 33% to 230 PJ/a in 2050. **In the Energy [R]evolution scenario, efficiency measures and modal shifts will save 45% (103 PJ/a) in 2050 compared to the Reference scenario.**
- By 2030, electricity will provide 8% of the transport sector's total energy demand in the Energy [R]evolution, while in 2050 the share will be 48%.
- Overall, primary energy demand will decrease by 33% from today's 1010 PJ/a to around 680 PJ/a. Compared to the Reference scenario, overall primary energy demand will be reduced by 50% in 2050 under the E[R] scenario. Renewable primary energy share is of 27% in 2030 and 80% in 2050 in the E[R]. **The share of renewables in the final energy demand is increasing from 6.8% in 2014 to 80.5% in 2050.**
- Whilst Belarus's emissions of CO_2 will increase by 13% between 2014 and 2050 under the Reference scenario, **under the Energy [R]evolution scenario they will decrease from 55 million tonnes in 2014 to 8 million tonnes in 2050 and will be 93% below 1990 levels.** Annual per capita emissions will drop from 5.8 t to 0.9 t.

Photo: ©flickr.com – James Moran

Annexes

- Electricity generation and installed capacity under Reference scenario
- Heat supply under Reference scenario
- Primary energy demand under Reference scenario
- Final energy demand under Reference scenario
- Key input data for transport sector
- Final energy consumption in transport under Reference scenario
- CO_2 emissions under Reference scenario
- Electricity generation and installed capacity under Energy [R]evolution scenario
- Heat supply under Energy [R]evolution scenario
- Primary energy demand under Energy [R]evolution scenario
- Final energy demand under Energy [R]evolution scenario
- Final energy consumption in transport under Energy [R]evolution scenario
- CO_2 emissions under Energy [R]evolution scenario

Photo: ©Sergej Kravchenko

Annex 1. Electricity generation in TWh/a under Reference scenario

	2014	2020	2025	2030	2035	2040	2045	2050
Power plants	**14**	**22**	**29**	**33**	**36**	**39**	**39**	**39**
Hard coal and non-renewable waste	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	0
Gas	14	13	9	12	15	18	18	18
Oil	0	0	0	0	0	0	0	0
Diesel	0	0	0	0	0	0	0	0
Nuclear	0	7	18	18	18	18	18	18
Biomass and renewable waste	0	0	0	0	0	0	0	0
Hydro	0	1	1	1	1	1	1	1
Wind	0	0	1	1	1	1	1	1
PV	0	0	1	1	1	1	1	1
Geothermal	0	0	0	0	0	0	0	0
Solar thermal power plants	0	0	0	0	0	0	0	0
Combined heat and power plants	**21**	**21**	**15**	**15**	**16**	**17**	**19**	**21**
Hard coal and non-renewable waste	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	0
Gas	20	20	14	14	15	17	18	20
Oil	0	0	0	0	0	0	0	0
Biomass and renewable waste	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0
Hydrogen	0	0	0	0	0	0	0	0
Total generation	**35**	**42**	**44**	**48**	**52**	**56**	**59**	**61**
Fossil	34	34	24	27	31	35	37	39
Hard coal and non-renewable waste	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	0
Gas	34	33	23	27	31	35	37	38
Oil	0	0	0	0	0	0	0	0
Diesel	0	0	0	0	0	0	0	0
Nuclear	0	7	18	18	18	18	18	18
Renewables (w/o renewable hydrogen)	0	1	2	3	3	3	4	4
Hydro	0	1	1	1	1	1	1	1
Wind	0	0	1	1	1	1	1	1
PV	0	0	1	1	1	1	1	1
Biomass and renewable waste	0	0	0	1	1	1	1	1
Geothermal	0	0	0	0	0	0	0	0
Solar thermal power plants	0	0	0	0	0	0	0	0
Import	8	3	4	4	4	4	4	4
Import RES	0	0	0	0	0	0	0	0
Export	4	4	4	4	4	4	4	4
Distribution losses	3	2	2	2	2	2	2	3
Own consumption electricity	5	6	6	6	5	5	5	5
Electricity for hydrogen production	0	0	0	0	0	0	0	0
Electricity for synfuel production	0	0	0	0	0	0	0	0
Final energy consumption (electricity)	**30**	**33**	**36**	**40**	**44**	**49**	**51**	**53**
Fluctuating RES (PV, Wind)	0	1	1	1	2	2	2	2
Share of fluctuating RES	0.0%	1.4%	2.8%	3.1%	3.6%	3.6%	3.8%	3.8%
RES share (domestic generation)	0.7%	3.4%	5.2%	5.4%	5.9%	5.9%	6.1%	6.1%

Annex 2. Installed capacity in GW under Reference scenario

	2014	2020	2025	2030	2035	2040	2045	2050
Power plants	**4**	**6**	**6**	**7**	**7**	**8**	**9**	**9**
Hard coal and non-renewable waste	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	0
Gas	4	4	3	3	3	4	4	5
Oil	0	0	0	0	0	0	0	0
Diesel	0	0	0	0	0	0	0	0
Nuclear	0	1	2	2	2	2	2	2
Biomass and renewable waste	0	0	0	0	0	0	0	0
Hydro	0	0	0	0	0	0	0	0
Wind	0	0	0	0	0	0	0	1
PV	0	0	1	1	1	1	1	1
Geothermal	0	0	0	0	0	0	0	0
Solar thermal power plants	0	0	0	0	0	0	0	0
Combined heat and power plants	**6**	**6**	**5**	**4**	**4**	**4**	**5**	**5**
Hard coal and non-renewable waste	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	0
Gas	6	6	5	4	3	4	4	5
Oil	0	0	0	0	0	0	0	0
Biomass and renewable waste	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0
Total generation	**10**	**12**	**11**	**11**	**11**	**12**	**13**	**14**
Fossil	10	10	8	7	7	8	9	10
Hard coal and non-renewable waste	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	0
Gas	10	10	8	7	7	7	9	10
Oil	0	0	0	0	0	0	0	0
Diesel	0	0	0	0	0	0	0	0
Nuclear	0	1	2	2	2	2	2	2
Renewables	0	1	1	1	2	2	2	2
Hydro	0	0	0	0	0	0	0	0
Wind	0	0	0	0	0	0	0	1
PV	0	0	1	1	1	1	1	1
Biomass and renewable waste	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0
Solar thermal power plants	0	0	0	0	0	0	0	0
Fluctuating RES (PV, Wind)	0	0	1	1	1	1	2	2
Share of fluctuating RES	0.1%	3.4%	7.8%	9.8%	12.0%	12.2%	12.0%	11.4%
RES share (domestic generation)	**0.7%**	**5.7%**	**10.6%**	**13.1%**	**15.6%**	**15.6%**	**15.2%**	**14.4%**

Annex 3. Heat supply in PJ/a under Reference scenario

	2014	2020	2025	2030	2035	2040	2045	2050
District heating plants	**104**	**129**	**116**	**117**	**120**	**125**	**130**	**135**
Fossil fuels	87	105	93	93	95	98	101	106
Biomass	17	24	22	24	25	27	29	30
Solar collectors	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0
Heat from CHP[a]	**151**	**170**	**115**	**112**	**116**	**128**	**141**	**157**
Fossil fuels	149	167	112	109	111	123	135	150
Biomass	3	3	3	4	4	5	6	7
Geothermal	0	0	0	0	0	0	0	0
Direct heating	**186**	**224**	**304**	**330**	**345**	**343**	**345**	**339**
Fossil fuels	158	186	264	287	299	296	296	288
Biomass	22	32	34	37	39	41	43	44
Solar collectors	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0
Heat pumps[b]	0	0	0	0	0	0	0	0
Electric direct heating	6	6	6	6	6	6	7	7
Total heat supply[c]	**441**	**523**	**535**	**560**	**580**	**596**	**616**	**631**
Fossil fuels	393	459	469	489	506	517	532	544
Biomass	42	58	60	64	69	73	77	80
Solar collectors	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0
Heat pumps[b]	0	0	0	0	0	0	0	0
Electric direct heating	6	6	6	6	6	6	7	7
RES share (including RES electricity)	**9.6%**	**11.1%**	**11.3%**	**11.6%**	**11.9%**	**12.3%**	**12.6%**	**12.8%**

Notes:
a — public CHP and CHP autoproduction;
b — heat from ambient energy and electricity use;
c — incl. process heat, cooking.

Annex 4. Primary energy demand in PJ/a under Reference scenario

	2014	2020	2025	2030	2035	2040	2045	2050
Total	1148	1277	1346	1392	1435	1471	1500	1523
Total excl. non energy use	**1008**	**1117**	**1186**	**1232**	**1275**	**1311**	**1340**	**1363**
Fossil	**948**	**961**	**907**	**947**	**984**	**1015**	**1039**	**1059**
Hard coal and non-renewable waste	21	20	18	17	16	15	15	14
Lignite	13	8	7	5	4	4	3	3
Natural gas	652	689	634	673	713	745	766	782
Crude oil	262	244	249	251	251	250	254	260
Nuclear	**0**	**77**	**196**	**196**	**196**	**196**	**196**	**196**
Renewables	**60**	**78**	**83**	**89**	**95**	**100**	**105**	**108**
Hydro	0	2	2	2	2	2	2	2
Wind	0	1	2	3	3	4	4	4
Solar	0	1	2	3	3	4	4	4
Biomass and renewable waste)	60	74	77	81	86	90	95	98
Geothermal	0	0	0	0	0	0	0	0
Net electricity imports (final energy)	12	-7	-1	0	0	0	-1	-1
net RES electricity import	0	0	0	0	0	0	0	0
Total RES incl. electr. & synfuel import	**60**	**78**	**83**	**89**	**95**	**100**	**105**	**108**
RES share excl. non energy use	**7.2%**	**6.4%**	**6.9%**	**7.2%**	**7.4%**	**7.6%**	**7.7%**	**7.8%**
Total incl. net elec. and synfuel import	**1160**	**1270**	**1345**	**1392**	**1435**	**1471**	**1499**	**1522**
of which non-energy use	140	160	160	160	160	160	160	160

Annex 5. Final energy demand in PJ/a under Reference scenario

	2014	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-energy use)	852	943	997	1046	1088	1119	1145	1167
Total energy use[a]	712	783	837	886	928	959	985	1007
Transport	172	175	187	198	207	214	221	229
Oil products	148	152	163	172	178	182	185	190
Natural gas	20	18	18	18	18	18	18	18
Biofuels	0	0	0	0	0	0	0	0
Synfuels	0	0	0	0	0	0	0	0
Electricity	5	5	6	8	11	14	18	21
RES electricity	0	0	0	0	1	1	1	1
RES share in Transport	0.1%	0.2%	0.2%	0.3%	0.4%	0.5%	0.6%	0.6%
Industry	189	195	209	222	232	240	248	255
Electricity	46	49	52	56	58	60	62	64
RES electricity	0	2	3	3	3	4	4	4
Public district heat	63	65	69	74	77	80	82	85
RES district heat	3	6	8	9	10	10	11	11
Hard coal and lignite	21	19	18	17	16	15	15	14
Oil products	8	7	8	8	9	9	9	9
Gas	50	53	59	65	70	73	77	80
Solar	0	0	0	0	0	0	0	0
Biomass	2	2	2	2	3	3	3	3
Geothermal	0	0	0	0	0	0	0	0
RES share Industry	2.6%	5.1%	6.4%	6.7%	6.9%	6.9%	6.9%	6.8%
Other Sectors	351	412	441	466	488	504	516	524
Electricity	58	64	71	80	90	101	103	106
RES electricity	0	2	4	4	5	6	6	6
Public district heat	150	166	106	104	109	124	139	157
RES district heat	6	16	13	13	14	16	18	20
Hard coal and lignite	8	6	6	5	4	4	3	3
Oil products	38	35	36	37	38	39	40	40
Gas	70	102	180	196	201	190	182	167
Solar	0	0	0	0	0	0	0	0
Biomass	28	40	42	44	46	48	49	50
Geothermal	0	0	0	0	0	0	0	0
RES share Other Sectors	9.7%	14.0%	13.3%	13.3%	13.5%	13.8%	14.2%	14.5%
Total RES	39	68	72	77	83	87	91	95
RES share excl. non-energy use	5.5%	8.7%	8.6%	8.7%	8.9%	9.1%	9.3%	9.4%
Non energy use	140	160	160	160	160	160	160	160
Oil	82	93	93	93	93	93	93	93
Gas	58	66	66	66	66	66	66	66
Coal	1	1	1	1	1	1	1	1

Note: a – excluding heat produced by CHP autoproducers.

Annex 6. Key input data for transport sector

	Current level	Reference Scenario		Energy [R]evolution Scenario	
	2014	2025	2050	2025	2050
Ratios between flows					
Hybrid vehicle ratio electricity (PC + LDV) (in final energy cons.)	1.0%	1.0%	1.0%	10.0%	45.0%
Road share (biofuel + synfuel)/(diesel + gasoline) (PC, LDV, HDV)	0.1%	0.1%	0.1%	7.0%	60.0%
Rail share biofuel/synfuel vs. diesel	0.0%	0.0%	0.0%	5.0%	65.0%
Market shares transport					
Aviation domestic	0.5%	0.6%	0.6%	0.6%	0.9%
Pipeline Transport	11.2%	9.6%	7.9%	9.5%	5.6%
Rail	7.5%	7.7%	7.3%	8.0%	11.5%
including:					
Electric train etc.	30.9%	30.2%	31.6%	32.9%	42.1%
Diesel train	69.1%	69.8%	68.4%	67.1%	57.9%
Road: total (PC + LDV + HDV)	80.7%	82.0%	84.2%	81.8%	81.9%
including:					
PC + LDV (in total road)	82.1%	81.4%	80.1%	81.4%	80.1%
HDV (in total road)	17.9%	18.6%	19.9%	18.6%	19.9%
Road: PC + LDV	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**
including:					
Electric vehicle	0.0%	0.6%	9.0%	1.8%	45.0%
Gas vehicle	0.3%	0.0%	0.0%	0.1%	0.1%
Gasoline/diesel car + others	99.6%	98.3%	85.9%	86.5%	5.2%
Hybrid vehicle	0.0%	1.0%	5.0%	5.0%	30.0%
Hydrogen car	0.0%	0.0%	0.0%	0.1%	12.0%
Road: HDV	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**
including:					
Biofuel/Synfuel vehicle	0.0%	0.1%	0.1%	6.7%	32.1%
Electric vehicle (Trolleytruck etc.)	2.5%	2.7%	3.7%	3.7%	20.0%
Gas vehicle	0.1%	0.1%	0.1%	0.1%	3.5%
Gasoline/diesel car + others	97.4%	97.1%	96.1%	89.1%	21.4%
Hybrid vehicle	0.0%	0.0%	0.0%	0.3%	11.0%
Hydrogen car	0.0%	0.0%	0.0%	0.0%	12.0%

Annex 7. Final energy consumption in transport in PJ/a under Reference scenario

	2014	2020	2025	2030	2035	2040	2045	2050
Road:	**139**	**142**	**154**	**164**	**173**	**179**	**185**	**192**
fossil fuels	138	141	152	160	166	169	173	177
biofuels	0	0	0	0	0	0	0	0
synfuels	0	0	0	0	0	0	0	0
natural gas	0	0	0	0	0	0	0	0
electricity	1	1	1	4	6	9	12	15
Rail:	**13**	**14**	**14**	**15**	**15**	**16**	**16**	**17**
fossil fuels	9	10	10	10	11	11	11	11
biofuels	0	0	0	0	0	0	0	0
synfuels	0	0	0	0	0	0	0	0
electricity	4	4	4	5	5	5	5	5
Navigation:	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Aviation:	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
fossil fuels	1	1	1	1	1	1	1	1
biofuels	0	0	0	0	0	0	0	0
synfuels	0	0	0	0	0	0	0	0
Total (incl. pipelines):	**172**	**175**	**187**	**198**	**207**	**214**	**221**	**229**
fossil fuels	148	152	163	172	178	182	185	190
biofuels (incl. biogas)	0	0	0	0	0	0	0	0
synfuels	0	0	0	0	0	0	0	0
natural gas	20	18	18	18	18	18	18	18
electricity	5	5	6	8	11	14	18	21
Total RES	**0**	**0**	**0**	**1**	**1**	**1**	**1**	**1**
RES share	**0.1%**	**0.2%**	**0.2%**	**0.3%**	**0.4%**	**0.5%**	**0.6%**	**0.6%**

Annex 8. CO_2 emissions in mln t/a under Reference scenario

	2014	2020	2025	2030	2035	2040	2045	2050
Condensation power plants	**6**	**6**	**4**	**5**	**7**	**7**	**7**	**7**
Gas	6	6	4	5	7	7	7	7
Oil	0	0	0	0	0	0	0	0
Diesel	0	0	0	0	0	0	0	0
Combined heat and power plants	**16**	**15**	**11**	**10**	**11**	**12**	**13**	**14**
Gas	16	15	10	10	11	12	13	14
Oil	0	0	0	0	0	0	0	0
CO_2 emissions power and CHP plants	**22**	**21**	**15**	**16**	**17**	**19**	**20**	**22**
CO_2 intensity (g/kWh)								
without credit for CHP heat								
CO_2 intensity fossil electr. generation	651	637	619	584	560	550	551	555
CO_2 intensity total electr. generation	647	508	335	332	333	342	348	356
CO2 emissions by sector	**55**	**55**	**53**	**55**	**58**	**60**	**61**	**62**
% of 1990 emissions (102.2 mln t)	54%	54%	52%	54%	57%	59%	60%	61%
Industry[a]	7	9	9	9	9	9	9	9
Other sectors[a]	8	9	13	14	14	14	13	12
Transport	11	11	12	12	13	13	13	14
Power generation[b]	20	17	11	12	14	16	18	19
Other conversion[c]	10	9	8	8	8	8	8	9
Population (mln)	9.5	9.4	9.2	9.0	8.7	8.5	8.3	8.1
CO_2 emissions per capita (t/capita)	**5.8**	**5.9**	**5.7**	**6.2**	**6.6**	**7.0**	**7.4**	**7.7**

Notes:
a — incl. CHP autoproducers;
b — incl. CHP public;
c — district heating, refineries, coal transformation, gas transport.

Annex 9. Electricity generation in TWh/a under Energy [R]evolution scenario

	2014	2020	2025	2030	2035	2040	2045	2050
Power plants	**14**	**21**	**30**	**37**	**47**	**54**	**63**	**69**
Hard coal and non-renewable waste)	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	0
Gas	14	12	14	14	13	11	8	1.9
of which from H_2	0	0	0	0	0	0	1	1
Oil	0	0	0	0	0	0	0	0
Diesel	0	0	0	0	0	0	0	0
Nuclear	0	7	7	7	7	7	7	0
Biomass and renewable waste	0	0	0	1	1	2	2	2
Hydro	0	1	1	1	1	1	1	1
Wind	0	1	4	12	16	19	26	32
PV	0	0	3	3	9	15	20	33
Geothermal	0	0	0	0	0	0	0	0
Solar thermal power plants	0	0	0	0	0	0	0	0
Combined heat and power plants	**21**	**21**	**16**	**15**	**15**	**15**	**15**	**15**
Hard coal and non-renewable waste	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	0
Gas	20	20	15	13	12	10	9	6
of which from H_2	0	0	0	0	0	0	1	1
Oil	0	0	0	0	0	0	0	0
Biomass and renewable waste	0	1	1	2	4	5	6	8
Geothermal	0	0	0	0	0	0	0	0
Total generation	**35**	**42**	**46**	**53**	**62**	**69**	**78**	**84**
Fossil	34	32	29	27	25	21	16	7
Hard coal and non-renewable waste	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	0
Gas	34	32	29	27	25	21	16	7
Oil	0	0	0	0	0	0	0	0
Diesel	0	0	0	0	0	0	0	0
Nuclear	0	7	7	7	7	7	7	0
Hydrogen	0	0	0	0	0	0.2	2	2
— of which renewable H_2	0	0	0	0	0	0	1	2
Renewables (w/o renewable hydrogen)	0	2	9	19	30	41	54	75
Hydro	0	1	1	1	1	1	1	1
Wind	0	1	4	12	16	19	26	32
PV	0	0	3	3	9	15	20	33
Biomass and renewable waste)	0	1	2	3	5	7	8	10
Geothermal	0	0	0	0	0	0	0	0
Solar thermal power plants	0	0	0	0	0	0	0	0
Import	8	3	4	4	4	4	4	4
Import RES	0	1	1	2	2	3	3	4
Export	4	3	4	4	4	4	4	4
Distribution losses	3	3	4	5	5	6	6	6
Own consumption electricity	5	6	5	5	5	4	3	2
Electricity for hydrogen production	0	0	0	0	1	3	10	14
Electricity for synfuel production	0	0	0	0	0	0	0	0
Final energy consumption (electricity)	**30**	**33**	**36**	**43**	**51**	**56**	**59**	**61**
Fluctuating RES (PV, Wind)	0	1	7	15	25	34	46	65
Share of fluctuating RES	0.0%	2.5%	15.5%	28.5%	39.8%	48.8%	58.2%	77.2%
RES share (domestic generation)	0.7%	6.0%	20.4%	35.2%	48.3%	59.5%	70.3%	91.9%
Efficiency savings (compared to Ref.)[a]	0	0	0	-1	-3	-1	-1	3

Note: a — in industry and other sectors.

Annex 10. Installed capacity in GW under Energy [R]evolution scenario

	2014	2020	2025	2030	2035	2040	2045	2050
Power plants	**4**	**6**	**10**	**13**	**21**	**27**	**35**	**49**
Gas (incl. H_2)	0	0	0	0	0	0	0	0
Oil	0	0	0	0	0	0	0	0
Diesel	4	4	4	4	4	3	3	2
Nuclear	0	0	0	0	0	0	0	0
Biomass and renewable waste	0	0	0	0	0	0	0	0
Hydro	0	1	1	1	1	1	1	0
Wind	0	0	0	0	0	1	1	1
PV	0	0	0	0	0	0	0	0
Geothermal	0	0	2	5	6	8	11	14
Solar thermal power plants	0	0	3	3	9	14	19	33
Combined heat and power plants	**6**	**6**	**5**	**4**	**4**	**5**	**4**	**4**
Hard coal and non-renewable waste	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	0
Gas (incl. H_2)	6	6	5	3	3	3	2	2
Oil	0	0	0	0	0	0	0	0
Biomass and renewable waste	0	0	0	1	1	2	2	3
Geothermal	0	0	0	0	0	0	0	0
Total generation	**10**	**13**	**15**	**17**	**25**	**32**	**40**	**53**
Fossil	10	10	9	7	7	6	5	3
Hard coal and non-renewable waste	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	0
Gas (w/o H_2)	10	10	9	7	6	6	5	3
Oil	0	0	0	0	0	0	0	0
Diesel	0	0	0	0	0	0	0	0
Nuclear	0	1	1	1	1	1	1	0
Hydrogen (gas power plants, gas CHP)	0	0	0	0	0	0	1	1
Renewables	0	1	5	9	17	25	33	50
Hydro	0	0	0	0	0	0	0	0
Wind	0	0	2	5	6	8	11	14
PV	0	0	3	3	9	14	19	33
Biomass and renewable waste	0	0	1	1	1	2	2	3
Geothermal	0	0	0	0	0	0	0	0
Solar thermal power plants	0	0	0	0	0	0	0	0
Fluctuating RES (PV, Wind)	0	1	5	8	16	22	31	46
Share of fluctuating RES	0.1%	4.5%	30.8%	47.2%	63.2%	70.5%	77.2%	86.8%
RES share (domestic generation)	**0.7%**	**8.3%**	**35.6%**	**53.5%**	**69.9%**	**77.7%**	**83.8%**	**93.5%**
Peak load coverage								
Peak load	6	7	8	9	10	10	11	11
Secured capacity	12	10	11	10	11	11	12	12
Share of secured capacity	208%	149%	147%	109%	116%	107%	117%	111%

Annex 11. Heat supply in PJ/a under Energy [R]evolution scenario

	2014	2020	2025	2030	2035	2040	2045	2050
District heating plants	**104**	**124**	**119**	**129**	**106**	**84**	**59**	**38**
Fossil fuels	87	88	82	80	54	30	13	0
Biomass	17	36	33	41	39	39	30	22
Solar collectors	0	0	2	5	7	8	9	9
Geothermal	0	0	1	3	5	7	6	6
Heat from CHP[a]	**151**	**175**	**155**	**137**	**140**	**136**	**134**	**131**
Fossil fuels	149	158	116	105	92	83	75	53
Biomass	3	17	39	31	47	51	53	66
Geothermal	0	0	0	0	0	0	0	0
Hydrogen	0	0	0	0	0	1	7	13
Direct heating	**190**	**210**	**223**	**222**	**214**	**204**	**189**	**176**
Fossil fuels	158	158	155	124	80	54	26	12
Biomass	22	39	43	49	49	47	43	33
Solar collectors	0	2	4	12	21	27	33	36
Geothermal	0	0	0	0	0	0	0	0
Heat pumps[b]	0	1	5	11	20	25	29	31
Electric direct heating	10	10	15	27	44	50	58	63
Hydrogen	0	0	0	0	0	1	1	2
Total heat supply[c]	**445**	**509**	**496**	**488**	**459**	**424**	**382**	**345**
Fossil fuels	393	404	353	310	226	168	115	64
Biomass	42	92	115	121	136	137	126	121
Solar collectors	0	2	7	17	28	35	41	45
Geothermal	0	0	1	3	5	7	6	6
Heat pumps[b]	0	1	5	11	20	25	29	31
Electric direct heating	10	10	15	27	44	50	58	63
Hydrogen	0	0	0	0	1	2	8	14
RES share (including RES electricity)	**9.5%**	**18.8%**	**26.7%**	**33.4%**	**46.5%**	**56.2%**	**65.5%**	**79.8%**
electricity consumption heat pumps (TWh/a)	0.0	0.1	0.4	0.8	1.6	1.9	2.0	2.1
'Efficiency' savings (compared to Ref.)	-5	14	39	72	121	172	234	286

Notes:
a — public CHP and CHP autoproduction;
b — heat from ambient energy and electricity use;
c — incl. process heat, cooking.

Annex 12. Primary energy demand in PJ/a under Energy [R]evolution scenario

	2014	2020	2025	2030	2035	2040	2045	2050
Total	**1148**	**1247**	**1213**	**1184**	**1123**	**1047**	**956**	**807**
Total excl. non energy use	1008	1088	1061	1037	983	911	825	679
Fossil	948	879	780	683	547	418	287	135
Hard coal and non-renewable waste	21	0	0	0	0	0	0	0
Lignite	13	9	1	0	0	0	0	0
Natural gas	652	652	586	527	424	329	233	115
Crude oil	262	219	193	156	123	89	54	20
Nuclear	**0**	**77**	**77**	**77**	**77**	**77**	**77**	**0**
Renewables	**60**	**131**	**203**	**276**	**358**	**415**	**461**	**544**
Hydro	0	2	2	2	2	2	2	2
Wind	0	3	14	43	56	69	94	115
Solar	0	3	18	28	61	88	112	163
Biomass and renewable waste	60	123	163	190	213	224	219	227
Geothermal	0	1	6	13	25	32	34	36
Net electricity imports (final energy)	12	0	0	0	0	0	0	0
net RES electricity import	0	0	0	0	0	0	0	0
Total RES incl. electr. and synfuel import	**60**	**131**	**203**	**276**	**358**	**415**	**461**	**544**
RES share excl. non energy use	**7.2%**	**12.1%**	**19.1%**	**26.6%**	**36.4%**	**45.6%**	**55.8%**	**80.1%**
Total incl. net elec. and synfuel import	**1160**	**1247**	**1213**	**1184**	**1123**	**1047**	**956**	**807**
of which non-energy use	140	158	152	147	141	136	131	128
'Efficiency' savings (compared to Ref.)	0	23	133	208	312	424	543	716

Annex 13. Final energy demand in PJ/a under Energy [R]evolution scenario

	2014	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-energy use)	**852**	**913**	**906**	**892**	**850**	**796**	**726**	**665**
Total energy use[a]	**712**	**755**	**754**	**745**	**709**	**660**	**595**	**537**
Transport	**172**	**170**	**170**	**166**	**160**	**148**	**133**	**126**
Oil products	148	143	136	119	103	79	49	18
Natural gas	20	18	16	14	12	11	9	7
Biofuels	0	4	10	18	19	18	22	28
Synfuels	0	0	0	0	0	0	0	0
Electricity	5	5	8	14	22	35	44	60
RES electricity	0	0	2	5	11	21	31	55
Hydrogen	0	0	0	1	3	5	9	12
RES share Transport	**0.1%**	**2.5%**	**6.9%**	**14.2%**	**19.5%**	**28.6%**	**44.6%**	**75.1%**
Industry	**189**	**181**	**183**	**183**	**174**	**160**	**145**	**127**
Electricity	46	47	50	54	56	58	59	57
RES electricity	0	3	10	19	27	34	42	52
Public district heat	63	67	64	64	61	56	50	45
RES district heat	5	14	20	21	26	28	27	30
Hard coal and lignite	21	0	0	0	0	0	0	0
Oil products	8	5	8	5	3	2	1	0
Gas	50	53	49	43	30	18	8	1
Solar	0	0	1	3	6	8	8	9
Biomass	2	8	10	14	16	15	14	9
Geothermal	0	0	0	1	2	3	3	3
Hydrogen	0	0	0	0	0	1	1	2
RES share Industry	**4.1%**	**13.9%**	**22.9%**	**31.2%**	**44.9%**	**55.5%**	**65.7%**	**83.1%**
Other Sectors	**351**	**403**	**400**	**395**	**375**	**352**	**317**	**284**
Electricity	58	65	73	86	104	109	107	103
RES electricity	0	4	15	30	50	65	76	95
Public district heat	150	163	152	150	138	124	107	91
RES district heat	13	33	47	49	60	62	58	60
Hard coal and lignite	8	3	0	0	0	0	0	0
Oil products	38	26	15	9	5	2	1	0
Gas	70	101	108	86	55	41	22	13
Solar	0	1	3	9	14	19	24	26
Biomass	28	43	46	48	45	42	38	31
Geothermal	0	1	3	7	12	16	18	20
Hydrogen	0	0	0	0	0	0	0	0
RES share Other Sectors	**11.7%**	**20.4%**	**28.4%**	**36.1%**	**48.7%**	**57.7%**	**67.2%**	**81.7%**
Total RES	**49**	**112**	**167**	**223**	**292**	**334**	**368**	**432**
RES share	**6.8%**	**14.8%**	**22.2%**	**30.0%**	**41.2%**	**50.6%**	**61.8%**	**80.5%**
Non energy use	**140**	**158**	**152**	**147**	**141**	**136**	**131**	**128**
Oil	82	86	76	68	60	52	46	41
Gas	58	71	75	78	80	83	84	86
Coal	1	1	1	1	1	1	1	1

Note: a — excluding heat produced by CHP autoproducers.

Annex 14. Final energy consumption in transport in PJ/a under Energy [R]evolution scenario

	2014	2020	2025	2030	2035	2040	2045	2050
Road:	**139**	**137**	**139**	**136**	**131**	**121**	**108**	**103**
fossil fuels	138	133	126	110	95	71	43	15
biofuels	0	3	9	16	17	16	18	22
synfuels	0	0	0	0	0	0	0	0
natural gas	0	0	0	0	1	1	1	1
hydrogen	0	0	0	1	3	5	9	12
electricity	1	1	4	9	16	29	37	53
Rail:	**13**	**14**	**14**	**15**	**15**	**15**	**15**	**14**
fossil fuels	9	9	9	8	8	7	5	3
biofuels	0	0	0	2	2	3	4	5
synfuels	0	0	0	0	0	0	0	0
electricity	4	4	4	5	5	5	6	6
Navigation:	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Aviation:	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
fossil fuels	1	1	1	1	1	1	1	1
biofuels	0	0	0	0	0	0	0	0
synfuels	0	0	0	0	0	0	0	0
Total (incl. pipelines):	**172**	**170**	**170**	**166**	**160**	**148**	**133**	**126**
fossil fuels	148	143	136	119	103	79	49	18
biofuels (incl. biogas)	0	4	10	18	19	18	22	28
synfuels	0	0	0	0	0	0	0	0
natural gas	20	18	16	14	12	11	9	7
hydrogen	0	0	0	1	3	5	9	12
electricity	5	5	8	14	22	35	44	60
Total RES	**0**	**4**	**12**	**24**	**31**	**42**	**59**	**94**
RES share	**0.1%**	**2.5%**	**6.9%**	**14.2%**	**19.5%**	**28.6%**	**44.6%**	**75.1%**

Annex 15. CO_2 emissions in mln t/a under Energy [R]evolution scenario

	2014	2020	2025	2030	2035	2040	2045	2050
Condensation power plants	**6**	**5**	**6**	**6**	**6**	**4**	**3**	**1**
Gas	6	5	6	6	6	4	3	1
Oil	0	0	0	0	0	0	0	0
Diesel	0	0	0	0	0	0	0	0
Combined heat and power plants	**16**	**15**	**11**	**10**	**9**	**8**	**7**	**4**
Gas	16	15	11	10	9	8	7	4
Oil	0	0	0	0	0	0	0	0
CO_2 emissions of power and CHP plants	**22**	**21**	**17**	**16**	**14**	**12**	**10**	**5**
Gas	22	20	17	16	14	12	10	5
Oil and diesel	0	0	0	0	0	0	0	0
CO_2 intensity (g/kWh)								
without credit for CHP heat								
CO_2 intensity fossil electr. generation	651	653	596	590	573	582	611	753
CO_2 intensity total electr. generation	647	502	382	303	231	175	122	60
CO_2 emissions by sector	**55**	**50**	**44**	**39**	**31**	**24**	**16**	**8**
% of 1990 emissions (102 mln t)	54%	49%	43%	38%	31%	23%	16%	7%
Industry[a]	7	8	7	5	4	3	2	1
Other sectors[a]	8	8	7	6	3	2	1	1
Transport	11	10	10	9	7	6	4	1
Power generation[b]	20	16	14	13	12	10	8	4
Other conversion[c]	10	8	7	6	4	3	2	0
Population (mln)	9.5	9.4	9.2	9.0	8.7	8.5	8.3	8.1
CO_2 emissions per capita (t/capita)	**5.8**	**5.3**	**4.8**	**4.3**	**3.6**	**2.8**	**2.0**	**0.9**
'Efficiency' savings (compared to Ref.)	0	5	9	17	27	36	45	55

Notes:
a — incl. CHP autoproducers;
b — incl. CHP public;
c — district heating, refineries, coal transformation, gas transport.

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The study “Energy [R]evolution: a Sustainable Belarus Energy Outlook” was carried out in 2016 – 2018 with the support of the Heinrich Boell Foundation and in collaboration with civil society organisations, scientists and independent experts in Belarus. The report presents modelling results of the scenario on the transition of Belarus to the energy system with a high share of renewable energy and briefly describes policy decisions and technologies that can be used today to implement the Energy [R]evolution scenario.

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