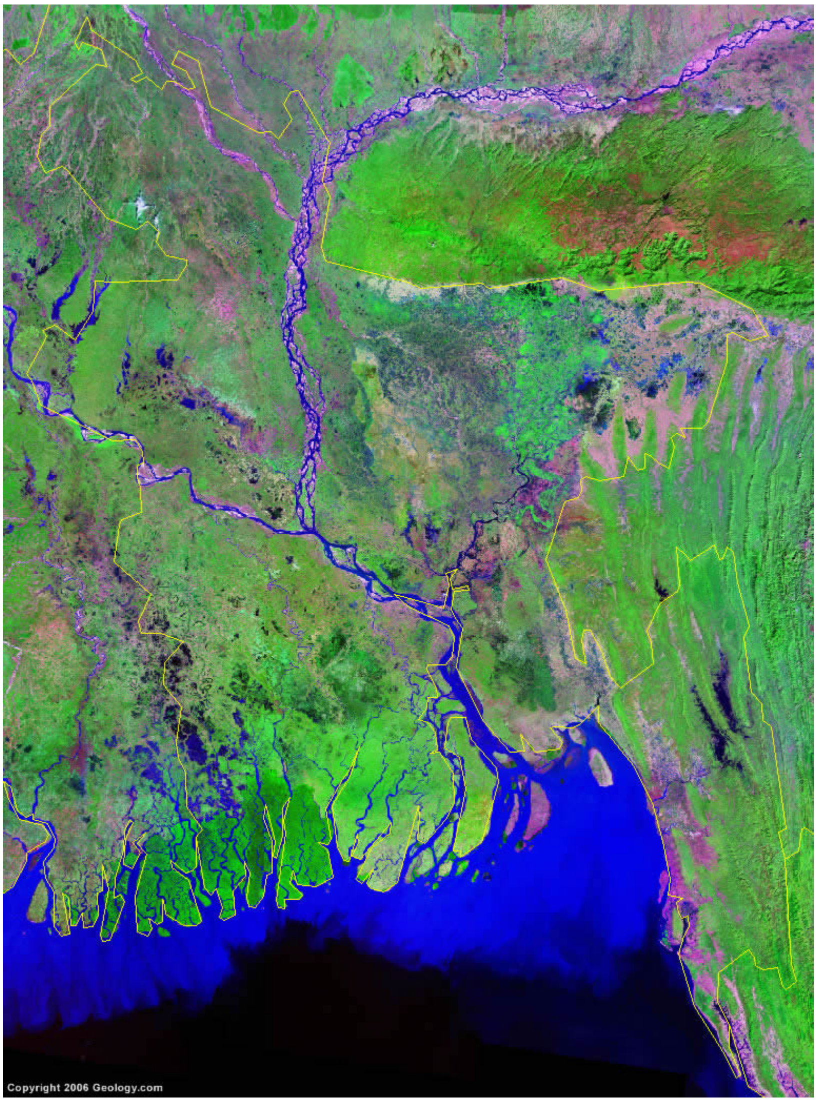

100% RENEWABLE ENERGY FOR BANGLADESH - *FINAL DRAFT*

Access to renewable energy for all within one generation

Prepared for:
Coastal Development Partnership (CDP)
Bread for the World
World Future Council

UTS Institute for Sustainable Futures

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ABOUT THE AUTHORS

The Institute for Sustainable Futures (ISF) was established by the University of Technology Sydney in 1996 to work with industry, government and the community to develop sustainable futures through research and consultancy. Our mission is to create change toward sustainable futures that protect and enhance the environment, human wellbeing and social equity. We seek to adopt an inter-disciplinary approach to our work and engage our partner organisations in a collaborative process that emphasises strategic decision-making.

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1 EXECUTIVE SUMMARY

Bangladesh needs to build up and expand its power generation system to increase the energy access rate to 100 per cent. Building new power plants – no matter what technology – will require new infrastructure, such as power grids, spatial planning, a stable policy framework and access to finance.
With decreased prices for solar photovoltaic and onshore wind in recent years, renewables have become an economic alternative to building new gas or coal power plants.

As a result, renewables achieved a global market share of over 60 per cent of all new build power plants since 2014. Bangladesh has significant solar resource and coastal areas are suitable for on- and offshore wind. Renewable generation costs are generally lower with increased solar radiation and wind speeds. However, constantly shifting policy frameworks often lead to high investment risks and therefore higher project development and installation costs for solar and wind projects relative to countries with more stable policy.

For this analysis, three scenarios have been calculated:

1) Reference case (“REF”)
2) Renewables 2.0°C (“2.0°C”)
3) Renewable 1.5°C (“1.5°C”)

The scenario-building process for all scenarios includes assumptions on policy stability, the role of future energy utilities, centralized fossil fuel-based power generation, population and GDP, firm capacity and future costs.

- **Policy stability:** This research assumes that Bangladesh will establish a secure and stable framework for the deployment of renewable power generation. Financing a gas power plant or a wind farm is quite similar. In both cases a power purchase agreement, which ensures a relatively stable price for a specific quantity of electricity, is required to finance the project. Daily spot market prices for electricity and/or renewable energy or carbon are not sufficient for long-term investment decisions for any kind of power plants with technical lifetimes of 20 years or longer.
- **Strengthened energy efficiency policies:** Existing policy settings, namely energy efficiency standards for electrical applications, buildings and vehicles, will need to be strengthened in order maximize cost-efficient use of renewable energy and achieve a high energy productivity by 2030.
- **Role of future energy utilities:** With ‘grid parity’ of rooftop solar PV under most current retail tariffs, this modelling assumes that the energy utilities of the future take up the challenge of increased local generation and develop new business models that focus on energy services, rather than just on selling kilowatt-hours.
- **Population and GDP:** The three scenarios are based on the same population and GDP assumptions. Projections of population growth are taken from the World Population Review 61 while the GDP projection are taken from Bangladesh’s Power System Master Plan 2016 which assumes long-term average growth of around 7 per cent per year over the scenario period, as documented in Section 4.1.3.
- **Firm capacity:** The scale of each technology deployed and the combinations of technologies in each of the three scenarios target a firm capacity. Firm capacity is the “proportion of the maximum possible power that can reliably contribute towards meeting peak power demand when needed.” Firm capacity is important to ensure a reliable and secure energy system. Note that variable renewables still have a firm capacity rating, and the combination of technology options increases the firm capacity of the portfolio of options (see also ‘security of energy supply’ point in the RE scenarios).
- **Cost assumptions:** The same cost assumptions are utilized across all three scenarios. As technology costs decline with deployment scale rather than time, the renewable energy cost reduction potential in both RENEWABLES cases may even be larger than in the REFERENCE case due to larger market sizes. The reverse is true for the fuel cost assumptions as all three scenarios are based on low fossil fuel price projections; while both RENEWABLES scenarios have a significant drop in demand, the REFERENCE case assumes increased demand that may lead to higher fuel costs. As such, the costs should be considered conservative.

The **REFERENCE** scenario (REF) reflects a continuation of current policies and is based on Bangladesh’s Government Power System Masterplan 2016. Energy statistics are taken from the International Energy Agency’s World Energy Balances of OECD Countries 2018 as well as from the Power Development Plan 2016 and statistics published by the government of Bangladesh.

Both the **RENEWABLES 2.0°C (“2.0°C”)** and the **RENEWABLES 1.5°C (“1.5°C”)** scenarios are built on a framework of targets and assumptions that strongly influence the development of individual technological and structural pathways for each sector. The main assumptions considered for this scenario-building process are detailed below.

- **Emissions reductions:** the main measures to meet CO_2 emission reductions in the 2.0°C and 1.5°C scenarios include strong improvements in energy efficiency resulting in doubling energy productivity over the next 10 to 15 years, and the dynamic expansion of renewable energy across all sectors.
- **Renewables industry growth:** dynamic growth in new capacities for renewable heat and power generation is assumed based on current knowledge about potential, costs and recent trends in renewable energy deployment. Communities will play a significant role in the expansion of renewables, particularly regarding project development, inclusion of local population and operation of regional and/or community owned renewable power projects.
- **Fossil fuel phase-out:** the operational lifetime for gas power plants is conservatively estimated to be 30 years. In both scenarios, coal power plants are phased out early on, followed by gas power plants.
- **Future power supply:** the capacity of large hydropower remains flat in Bangladesh over the entire scenario period, while the quantities of bioenergy grow within the nation's potential for sustainable biomass (see below). Wind power (on- and offshore) and solar photovoltaic are expected to be the main pillars of future power supply, complemented by contributions from bioenergy and gas power plants (fueled with synthetic-fuels/hydrogen after 2040 – see below). Solar PV figures combine both rooftop and utility scale PV plants including floating solar. The potential for offshore wind is significantly higher than onshore wind, thus most of the wind power under both RENEWABLES scenarios is offshore wind. Solar resources for concentrating solar power (CSP) are not sufficient and therefore not used.
- **Offshore wind:** Wind resources in Bangladesh are concentrated on the three coastal states Khulna, Barisal and Chittagong. The entire capacity in both RENEWABLES scenarios is concentrated there. Offshore wind parks are located up to 120 km offshore.
- **Security of energy supply:** the scenarios limit the share of variable power generation and maintain a sufficient share of controllable, secured capacity. Power generation from biomass and gas-fired back-up capacities and storage, are considered important for the security of supply in a future energy system, related to the output of firm capacity discussed above. Storage technologies play an increase role after 2030, while gas power plants will switched to synthetic full towards the end of the scenario period.
- **Sustainable biomass levels:** the sustainable level of biomass use for Bangladesh is assumed to be limited to 1000 PJ. Low-tech biomass use, such as in inefficient household wood-burners, are largely replaced in the RENEWABLES scenarios by state-of-the-art technologies, primarily highly efficient cogeneration plants. The remaining bio energy is assumed to be imported.
- **Electrification of transport:** efficiency savings in the transport sector are a result of fleet penetration with new highly efficient vehicles such as electric vehicles, but also assumed changes in mobility patterns and the implementation of efficiency measures for combustion engines. The scenarios assume limited use of biofuels for transportation given the limited supply of sustainable biofuels.
- **Hydrogen and synthetic fuels:** are generated by electrolysis using renewable electricity are introduced as a third renewable fuel in the transportation sector, complementary to biofuels, the direct use of renewable electricity and battery storage. Hydrogen generation can have high-energy losses; however, the limited potential of biofuels and mostly likely also battery storage for electric mobility mean it is necessary to have a third renewable option in the transport sector. Alternatively, this renewable hydrogen could be converted into synthetic methane and liquid fuels depending on economic benefits (storage costs versus additional losses) as well as technology and market development in the transport sector (combustion engines versus fuel cells). Due to the limited renewable energy potential of Bangladesh, it is assumed that hydrogen and synthetical fuels are imported.

The **RENEWABLES 2.0°C** scenario (2.0°C) is designed to meet Bangladesh's energy-related targets to achieve 100 per cent renewable electricity as soon as possible. The renewable energy trajectories for the initial years take the "Bangladesh Policy Road Map for Renewable energy" into account. This suggest that renewable energy markets in developing countries are projected to grow at a rate equal to the renewable energy markets of OECD countries. In addition, pathways for the deployment of renewable energy and efficiency measures reflect the technology trends of recent years and market estimations of the solar photovoltaic, wind industry and other innovative technologies. This scenario includes significant efforts to fully exploit the extensive potential for energy efficiency available through current best-practice technology. At the same time, various proven renewable energy sources are integrated – to a large extent for electricity generation, and to a lesser extent to produce synthetic fuels and hydrogen for heating (domestic, commercial and industrial) and transport.

The **RENEWABLES 1.5°C** scenario (1.5°C) takes a more ambitious approach to transforming Bangladesh's entire energy system towards 100 per cent renewable energy supply. The consumption pathways remain almost the same as in the RENEWABLES 2.0°C scenario, however under this scenario a much faster introduction of new technologies leads to a complete decarbonisation of energy for stationary energy (electricity), heating (including process heat for industry) and transportation. The latter requires a strong role for storage technologies such as batteries, synthetic fuels and hydrogen.

Bangladesh: Potential for utility scale solar photovoltaic and wind power

<u>Regional distribution of solar and wind resources:</u>
Bangladesh has almost 6,250 square kilometers of available land where 156 gigawatts of solar power can potentially be harvested through utility scale solar farms. To avoid conflicts with National Parks and other competing uses of land, only perennial cropland and open bushland land cover types were included in the analysis. Only utility scale solar photovoltaic is included in the analysis, as the solar resource is not sufficient for concentrated solar power (CSP) which requires highest direct normal irradiance. It is assumed that this suitable area will be used for utility-scale solar photovoltaic, 20 per cent of the total utility scale photovoltaic power plants are floating installations.

Regarding wind energy, Bangladesh has only a relative small amount of land available for utility scale **onshore wind power** generation, therefore offshore wind has been considered to a large extend as well. Potential exists to install at least 150 gigawatts of wind power (on- and offshore) from sites spread over 3,200 square kilometers across Bangladesh, mainly in the southern part of the country. This analysis considers only sides with wind speeds of 5 meters per second and above to plot optimal sites. Site selection is restricted to include only the following land cover types: bare soil, annual cropland, perennial cropland, grassland and ocean. Offshore water bodies within 50 to 120 kilometers of the coast were included in the analysis. This leads to an estimated offshore wind potential of 134 gigawatts and an onshore wind potential of around 16 gigawatts. This potential has been used entirely to maximize local electricity generation in Bangladesh.

Resource	Maximum installable generation capacity [GW]	Maximum recoverable electricity [TWh/year]	1.5°C in 2050: installed capacity [GW]	1.5°C in 2050: generation [TWh/year]
Wind – onshore	16	55	10	27
Wind – offshore	134	525	36	133
Wind - total	150	580	46	160
Solar Photovoltaics – roof top	35	40	35	
Solar Photovoltaics – utility scale	156	177	155	
Of which is floating PV	31	35	30	35
Solar Photovoltaic - total	191	217	188	211
Total	**341**	**797**	**234**	**371**

SOURCE: ISF mapping, January 2019, values are rounded

A 100% renewable energy supply for Bangladesh is feasible with an import rate – for bio energy and synthethic fuels – of about 25% (final energy) by 2050.

Key results – long term energy scenarios

<u>Development of energy demand:</u> Combining the projections on population development, GDP growth and energy intensity results in future development pathways; the **Reference** scenario, total final energy demand increases by 320% from the current 1000 PJ/a to 4200 PJ/a in 2050. In the 2.0°C scenario, final energy demand increases at a much lower rate by 250% compared to current consumption and is expected to reach 3500 PJ/a by 2050. The1.5°C scenario results in some additional reductions due to a higher share of electric cars.

Under both Renewable scenarios, due to economic growth, increasing living standards and electrification of the transport sector, overall electricity demand is expected to increase despite efficiency gains in all sectors (see Figure 14). Total electricity demand will rise from about 40 TWh/a to 380 TWh/a by 2050 in the 2.0°C scenario. Compared to the Reference scenario, efficiency measures in the industry, residential and service sectors avoid the generation of about 30 TWh/a.

This reduction can be achieved by introducing highly efficient electronic devices using the best available technology in all demand sectors. The transformation to a carbon free energy system in the 1.5°C scenario will further increase the electricity demand in 2050 up to 400 TWh/a. 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 60 TWh are used in 2050 for electric vehicles and rail transport in 2050 in the 1.5°C case.

Efficiency gains in the heating sector are even larger than in the electricity sector. Under both RENEWABLE scenarios, consumption equivalent to about 100 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 climatization’ 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.

Electricity generation, capacity and breakdown by technology: The renewable energy market grows dynamically and has an increasing share in the required electricity supply. This trend will more than compensate for the phasing out of fossil fuel-based power production in both Renewable scenarios. By 2050, 76% of the electricity produced in Bangladesh will come from renewable energy sources in the 2.0°C scenario. ‘New’ renewables – mainly wind and solar photovoltaics – will contribute 56% to the total electricity generation. Already by 2020 the share of renewable electricity production will be 2% and 33% by 2030. The installed capacity of renewables will reach about 30 GW in 2030 and 150 GW by 2050. A 100% electricity supply from renewable energy resources in the 1.5°C scenario leads to around 200 GW installed generation capacity in 2050.

Between 2020 and 2025, solar photovoltaic and wind overtake hydropower, currently the largest contributor to the growing renewable electricity market. The continuing growth of wind and PV will be complemented by electricity from solar thermal, geothermal and ocean energy. Renewable scenarios will lead to a high share of variable power generation sources (PV, wind and ocean) of already 12% to 23% by 2030 and 56% to 65% by 2050. Therefore, smart grids, demand side management (DSM), energy storage capacities and other options need to be expanded to increase the flexibility of the power system for grid integration, load balancing and a secure supply of electricity.

In contrast to the REF scenario which plans to build nuclear reactors with a total capacity of 7,000 MW, the 2.0°C scenario includes on the completion of one reactor block with a capacity of 600 MW which is currently under construction. The 1.5°C scenario assumes, that this current construction of the nuclear reactor will not be complete due to the substantial economic advantage of renewable power generation.

Future Costs of electricity generation: Both Renewable scenarios increase the future costs of electricity generation compared to the Reference scenario over the next ten years but lead to lower costs afterwards. However, this difference in full cost of generation will be less than 0.3 US$ cent/kWh in the 2.0°C and about 0.5 US$ cent/kWh in the Renewables 2 scenario. This cost estimation includes costs for storage. Possible additional costs for grid expansion requirements are not calculated as this was out of scope of this analysis. However, the significant increase of demand in Bangladesh under the Reference case as well as the two alternative scenarios indicate that grid expansion will be required in any case. Because of increasing prices for conventional fuels and the lower CO_2 intensity of electricity generation, electricity generation costs will become economically favorable after 2040 under the Renewable scenarios. By 2050, the cost will be 0.2 / 1.1 US$ cent/kWh, respectively, below those in the Reference case.

Future investments in the power sector: Around US$ 250 billion is required in investment for the 2.0°C scenario to become reality (including investments for replacement after the economic lifetime of the plants) - approximately US$ 6 billion per year, US$ 80 billion more than in the Reference scenario (US$ 170. billion). Investments for the Renewables 2 scenario sum up to US$ 310 billion until 2050, on average US$ 8 billion per year. Under the Reference scenario, the levels of investment in conventional power plants add up to almost 97% while approximately 3% would be invested in renewable energies and cogeneration until 2050.
Under the Renewable scenarios, however, Bangladesh would shift almost 86% / 89% of the entire investment towards renewables and cogeneration, respectively. By 2030, the fossil fuel share of power sector investment would be focused mainly on gas power plants. Because renewable energy has no fuel costs, the fuel cost savings in the 2.0°C scenario reach a total of US$ 140 billion up to 2050, US$ 4 billion per year. The total fuel cost savings therefore would cover 180% of the total additional investments compared to the Reference scenario. Fuel cost savings in the 1.5°C scenario are even higher and add up to US$ 200 billion, or US$ 5 billion per year. 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.

Cooking and industrial heat: Today, renewables meet around 51% of Bangladesh’s energy demand for heating, the main contribution coming from the use of traditional and predominantly unsustainable biomass. Dedicated support instruments are required to ensure a dynamic development for renewable technologies for buildings and renewable process heat production. In the 2.0°C scenario, renewables already provide 44% of Bangladesh’s total heat demand in 2030 and 81% in 2050.

- Energy efficiency measures help to reduce the currently growing energy demand for heating by 4 % in 2050 (relative to the Reference scenario), despite improving living standards and economic growth.
- In the industry sector solar collectors, geothermal energy (incl. heat pumps) as well as electricity and hydrogen from renewable sources are increasingly substituting for fossil fuel-fired systems.
- A shift from coal and oil to natural gas in the remaining conventional applications leads to a further reduction of CO_2 emissions.

Biomass remains the main contributor among renewable heating technologies, with increasing investments in highly efficient modern biomass technology. After 2030, a massive growth of solar collectors and a growing share of geothermal and environmental heat as well as heat from renewable hydrogen can further reduce the dependence on fossil fuels. The 1.5°C scenario results in a complete substitution of the remaining gas consumption by hydrogen generated from renewable electricity.

Future investments in the heating sector: Both Renewable energy scenarios would require a major revision of current investment strategies in heating technologies. Solar thermal, geothermal and heat pump technologies need an enormous increase in installations if these potentials are to be tapped for the heating sector. The use of biomass for heating purposes will shift from often traditional biomass today to modern, efficient and environmentally friendly heating technologies in both Renewable scenarios. 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 2.0°C scenario in total requires around US$ 290 billion to be invested in renewable heating technologies up to 2050 (including investments for replacement after the economic lifetime of the plants) - approximately US$ 7 billion per year. The 1.5ºC scenario assumes an equally ambitious expansion of renewable technologies resulting in an average investment of around US$ 8 billion per year, while the main strategy in the scenario is the substitution of the remaining natural gas amounts with electricity, hydrogen or other synthetic fuels.

Transport: A key target in Bangladesh is to develop the transport sector with local available and accepted technologies. Bangladesh has among the highest densities of rickshaws in Asia: About 2 million rickshaws, a majority is already or is in the process of conversion towards battery electric drives.
The 1.5°C scenario increases the use of electric rickshaws and tri-cycles significantly making them one of the backbones of the road transport systems. In addition, all urban regions will shift the transport system to a high degree towards to efficient rail, light rail and buses, especially in the expanding large metropolitan areas.

Along with rising prices for fossil fuels, these changes reduce the further growth in car sales projected under the Reference scenario. Due to population increase, GDP growth and higher living standards, energy demand from the transport sector is expected to increase in the Reference scenario by around 678% to 990 PJ/a in 2050. In the 2.0°C scenario, efficiency measures and modal shifts will save 44% (440 PJ/a) in 2050 compared to the Reference scenario.

Additional modal shifts and technology switches lead to even higher energy savings in the 1.5°C scenario of 41% (410 PJ/a) in 2050 compared to the Reference scenario. 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 5% of the transport sector's total energy demand in the 2.0°C, while in 2050 the share will be 15% (40% in the 1.5°C scenario). Bio- and other synthetic fuels generated using renewable electricity are complementary options to further increase the renewable share in the transport sector. However, due to the limited renewable electricity generation potential within the country, the use of hydrogen for transport has not been considered.

Primary energy: Under the 2.0°C scenario, primary energy demand will increase by 370% from today's 1230. PJ/a to around 5000. PJ/a. Compared to the Reference scenario, overall primary energy demand will be reduced by 17% in 2050 under the 2.0°C scenario (REF: around 6000. PJ in 2050). The 1.5°C scenario results in a primary energy consumption of around 4500 PJ in 2050 (incl. imports). The RENEWABLE scenarios aim to phase out coal and oil as fast as technically and economically possible by 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 33% in 2030 and 65% in 2050 in the 2.0°C and 100% in 2050 in the 1.5°C case (excluding non-energy consumption).

CO_2-emissions: Whilst Bangladesh`s CO_2 emissions will increase by a factor of 6 – from 67 million tons to over 400 million tons – between 2015 and 2050 under the REFERENCE scenario, both RENEWABLES scenarios will result in a moderate increase to 123 million tons with a population increase from 157 to 195 million people in the same period. As such, annual per capita emissions will remain at around 0.5 tons. While the power demand will increase by a factor of 10 in the 2.0ºC case, overall CO_2 emissions of the electricity sector will double. In the long run, efficiency gains and the increased use of renewable electricity in vehicles will also dramatically reduce emissions in the transport sector. With a 25 per cent share of CO_2, the transport sector will be the second largest source of emissions in 2050 in the 2.0°C scenario. The 1.5°C case will fully decarbonize the electricity sector, while the industry sector will be responsible for 1 million tons – mainly due to gas-based process heat generation. This represents 20% of the projected overall CO2 emissions of Bangladesh in 2050. The biggest CO2 emissions under the 1.5ºC case come from the transport sector with 8 million tons (46%) by 2050. A full decarbonisation of all sectors seems possible with increased import shares of renewable electricity and fuels. However more research is required to find alternative renewable energy supply options for the industry sector in Bangladesh.

Significant fuel cost savings refinances investment in renewables: Under the RENEWABLES case, the annual investment is estimated at $2.4 billion higher than in the REFERENCE case. However, the fuel cost saving would add up to $3.7 billion. Thus, required investment in renewables will be more than refinanced by fuel cost savings. With high uncertainties in both future investment costs for power generation equipment and fossil fuel prices, it seems certain, that the overall cost balance is economically beneficial for the 2.0°C case.
Under the 1.5°C case, the additional investment is estimated at around US$3.8 billion; compared to the REFERENCE case, the fuel cost saving would add up to $5.0 billion without the transport sector. Just as in the 2.0°C case, the 1.5°C case leads to fuel cost savings that will more than refinance the investment cost for renewable power generation.

Power system Analysis: Both RENEWABLE scenarios use Bangladesh's renewable energy resources to the maximum in order to reduce energy imports dependence and to utilize local resources. Bangladesh will significantly increase its power demand – under each power generation scenario. Thus, power grids will have to expand, and power generation will have to be increased by an order of magnitude.
A renewable energy dominated power generation requires a different infrastructural design then a fossil and nuclear power dominated future. To harvest Bangladesh's offshore wind and solar resources, the power grid needs to be able to transport large loads from the coast further north inland, while decentralized will shoulder a significant part of the residential sector. Offshore wind requires transmission lines to the load centers of Bangladesh.

The annual installation rates for solar PV installations must increase to around 5 GW between 2025 and 2035 and further increase to around 10 GW per year until 2050 in both RENEWABLES cases. By 2035, the installation rates for offshore wind must be around 1.6 GW in the 2.0C case and 2.8 GW in the 1.5ºC case. Offshore wind power plants have significant potential for all three coastal provinces of Bangladesh. Solar PV and offshore wind are the key renewable energy technologies to achieving the decarbonisation targets.

Most of dispatch power in 2050 will come from gas power which operate with hydrogen and / or synthetic fuels after 2045. The limited renewable energy resources of Bangladesh – with the current available technology – will not be able to supply all required renewable fuels and need to be imported. Further research is also required to specify locations of utility scale floating solar photovoltaic to optimize their distribution regarding supply and to reduce storage demand.

Further research requirements
The renewable power generation resources of Bangladesh can supply the country with reliable power generation, however, the unique geographical and meteorological circumstances require further adaption of the existing technologies such as:
- Floating storage devices to avoid battery damage in flooding situations
- Floating solar photovoltaic devices suitable for rivers and tidal waters

Bangladesh has the technical possibilities to implement new innovative technologies and to reduce it's future dependence on energy imports significantly.

2 INTRODUCTION AND SCOPE OF WORK

In 2018, the Coastal Development Partnership Bangladesh (CDP), the World Future Council (WFC) and Bread for the World (BftW) started a project in Bangladesh to develop a coherent strategy to implement 100 per cent Renewable Energy (RE) to help develop Bangladesh's National Determined Contribution (NDC) under the Paris Climate Agreement and to serve as an input for Poverty Reduction Goals. This project builds on the previous experience of the project partners in facilitating the deployment of Low Carbon Development (LCD) and renewable energy (RE) in Tanzania.

Through an inclusive and interactive approach engaging local stakeholders and key decision makers in the energy transformation and poverty reduction process, this project intends to:

- inspire stakeholders and build hands-on knowledge of how 100 per cent RE adds value to local economic development and community sustainability
- strengthen synergies, networks and platforms for multi-stakeholder dialogue and follow-up at the national level among government, parliamentary committees, policy-makers, civil society, trade unions, churches and media on LCD, poverty reduction and 100 per cent RE
- identify necessary legislation and policy reforms.

The proposed assignment aims to support the project by informing a policy framework on 100 per cent RE with the following aims:

1. **providing universal access to renewable energy**
2. **fully decarbonising Bangladesh's economy, and**
3. **boosting socio-economic development and reducing inequalities.**

To put Bangladesh on such a pathway, Bread for the World, the World Future Council and the Coastal Development Partnership (CDP) Bangladesh aims to analyse:

1. the technical RE potential of the country
2. the country's future energy demand given universal energy access
3. optimal RE expansion trajectories to achieve 100 per cent RE by 2030, 2040 and 2050.

Using the estimated costs and investment needed to realise different trajectories, and in a further step not within the scope of this study, CDP, World Future Council and Bread for the World will develop policy recommendations in a workshop based on the results of this analysis.

The Institute of Sustainable Futures (ISF) at the University of Technology Sydney has produced an economic and technical scenario model for transition towards a renewable energy system. The model describes Bangladesh's future energy system, including an assessment of technology pathways and cost implications of three future energy scenarios. The model used by ISF was created by the German Aerospace Agency and has previously been used to inform the German Government's 'Energiewende' and climate mitigation scenarios for the Intergovernmental Panel on Climate Change (IPCC).

The key results of the modelling are presented in Section 2, followed by methodology in Section 3, assumptions in Section 4 and detailed results and cost analysis in Section 5.

2.1 INTRODUCTION AND SCOPE OF WORK

The Coastal Development Project (CDP) provided the following terms of reference (ToR):

The study shall cover the following activities:

1. Mapping the current energy scenario of Bangladesh

The study shall develop a baseline of current status of energy usage in Bangladesh as well as the current energy sector priorities and policies.

2. Developing key assumptions for the 100% RE scenario involving multi-stakeholder groups

The study shall organize a workshop in Bangladesh involving CDP, Bread for the World, World Future Council and relevant Bangladeshi stakeholders to clarify key assumptions in the scenario calculations. The workshop will identify accepted assumptions by the stakeholders about future developments to calculate the scenario.

3. Analysing the RE (solar, wind, hydro, geothermal, biomass) potential of Bangladesh

The study shall analyse the potential of different RE technologies including solar photovoltaic (PV), concentrated solar power (CSP), on- and off-shore wind, small and medium scale hydro and bio energy in a very detailed way, for example in hourly or daily format. Besides a quantitative analysis, the study shall provide a specific geographical overview where which technology can be used.

4. Predicting the future energy demand in Bangladesh

Taking the goal of universal energy access into account, the study provides an estimation of future total energy demand of Bangladesh from 2018 until 2050, assuming that:

- Bangladesh moves towards becoming a middle-income country by 2021
- universal access to electricity and clean cooking solutions is reached by 2030
- the SDGs are reached by 2030
- there will be electrification of the transport sector
- more than half of the population will live in urban areas by 2040
- more green jobs will be created

5. Developing 100% RE Trajectories

The study shall develop 100% RE trajectories with a timespan from 2018 until 2050 in which 100% RE will be reached by 2030, 2040 and 2050. In addition, a business as usual trajectory is developed.

Each trajectory shall assume that:

- universal access to electricity and clean cooking solutions is reached by 2030
- the SDGs are reached by 2030
- the most economic technology is applied (given current estimations on innovation)
- Bangladesh economy is completely decarbonized latest by 2050

6. Estimated costs & investment needs

The study shall estimate investments needed to realize the trajectories, projecting capital flows and breaking down financial sources and components. The study shall also estimate the comparative cost of renewable energy production with regard to affordability and competitiveness with fossil fuel options. The study shall try to estimate the investments needed for each year to meet the 2030 trajectory.

7. Estimating socio-economic benefits of 100% RE

The study shall provide an estimation of the following socio-economic benefits under each trajectory:

- Economic inequality
- Access to electricity
- GDP per capita (and growth rates)
- Carbon emissions (and carbon intensity of GDP)
- Improved and reliable social services (education, health, transport, communication sectors)

8. Recommending 100% RE Implementation Options

The study shall provide recommendations about the implementation options (policy, institutional, technology and financing options) to realize the RE trajectories.

METHODOLOGY AND PROCESS OF THE STUDY

The study will be carried out by the faculty members of the University under the leadership of an expert Team Leader. The study team will decide on appropriate methods and tools for undertaking the study on the expected results. The Team Leader should share his/her approach ahead with the CDP, BftW and WFC.

3 GLOBAL ENERGY CONTEXT

Global energy markets are changing rapidly. Renewable power generation capacity saw its largest annual increase ever with an estimated 178 gigawatts added globally in 2018. New solar photovoltaic generating capacity alone was greater than additions in coal, natural gas and nuclear power combined[1]. In 2014, growth rates for coal use stalled globally for the first time, including in China, and this trend continued throughout 2015 and 2016[2]. In 2018, however, coal consumption grew again slightly, due to an increased use in China. Oil and coal prices are now at a record low, halting the development of most new coal and oil mining projects.

Renewable energy technologies have been developing rapidly since the beginning of the century, and they have emerged from niche markets to become mainstream. This section provides an overview of the development of renewable energy in the power, heating, and transport sectors up to the year of writing (2018). These developments will put the energy scenarios presented in the following chapters into a global context. The research and data in this Section are based on the REN21 Renewables 2018—Global Status Report Renewables.

3.1 GLOBAL TRENDS IN RENEWABLE ENERGY IN 2017

In 2017, ongoing trends continued: solar photovoltaics (PV) and wind power dominated the global market for new power plants, the price of renewable energy technologies continued to decline, and fossil fuel prices remained low. A new benchmark was reached, in that the new renewable capacity began to compete favourably with existing fossil fuel power plants in some markets. Electrification of the transport and heating sectors is gaining attention, and although the amount of electrification is currently small, the use of renewable technologies is expected to increase significantly over the next four to five years..

The growth in solar PV has been remarkable, nearly double that of second-ranking wind power, and the capacity of new solar PV is greater than the combined increases in the coal, gas, and nuclear capacities (FS-UNEP 2018)[22]. Storage is increasingly used in combination with variable renewables as battery costs decline, and solar PV plus storage has started to compete with gas peaking plants (Carroll 2018)[3]. However, bioenergy (including traditional biomass) remains the leading renewable energy source in the heating (buildings and industry) and transport sectors. Renewable energy's share of the total final energy consumption has increased only modestly in recent years, despite tremendous growth in the modern renewable energy sector. There are two main reasons for this:

One is that the growth in the overall energy demand (except for the drop in 2009 after the global economic recession) has counteracted the strong forward momentum of modern renewable energy technologies. The other is the declining share of traditional biomass, as people switch to other forms of energy. Traditional biomass makes up nearly half of all renewable energy used, and its use has increased at a rate lower than the growth in total energy consumption.

Since 2013, the global energy-related CO_2 emissions from fossil fuels have remained relatively flat. Early estimates based on preliminary data suggest that this changed in 2017, with global CO2 emissions growing by around 1.4% (REN21-GSR 2018)[4]. These increased emissions were primarily due to increased coal consumption in China, which grew by 3.7% in 2017 after a 3-year decline (ENERDATA 2018)[5]. This increased Chinese consumption, as well as steady growth of around 4% in India, is expected to lead to an upturn in global coal use, reversing the annual global decline observed from 2013 to 2016 (ENERDATA 2018)[5]. Renewable energy policies in India and China however, are substantial for renewable energies, especially wind power and solar photovoltaic. The coal increase was not due to the lack of renewable energy policies, but due to delayed infrastructural projects.

In contrast to the upturn in global coal use, in 2017, 26 countries joined the Powering Past Coal Alliance, which is committed to phasing-out coal power by 2030, with new pledges from Angola, Denmark, Italy, Mexico, New Zealand, and the United Kingdom (Carrington 2017)[6]. An increasing number of companies who owned,

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[1] REN21 (2018) *Renewables 2018 Global Status Report*, Paris, REN21 Secretariat. Available at: www.ren21.net/status-of-renewables/global-status-report/

[2] Li Junfeng, Director General at the National Climate Change Strategy Research and International Cooperation Centre: *The Guardian Interview*, 20th January 2016. Available at: www.theguardian.com/environment/2016/jan/19/chinas-coal-burning-in-significant-decline-figures-show

[3] Carroll (2018), Phil Carroll, "Are gas-fired peaking plants on the way out?" , (Missouri, USA, Finley Engineering 28 Feb 2018). http://finleyusa.com/industries/energy/whitepapers/are-gas-fired-peaking-plants-on-the-way-out/are-gas-fired-peaking-plants-on-the-way-out/

[4] REN21-GSR (2018), REN21; Renewables 2018 Global Status Report, Paris: REN21 Secretariat, ISBN 978-3-9818911-3-3, http://www.ren21.net/wp-content/uploads/2018/06/17-8652_GSR2018_FullReport_web_final_.pdf

[5] ENERDATA (2018), ENERDATA, Rise in global energy-related CO2 emissions in 2017, 29 January 2018, https://www.enerdata.net/publications/executive-briefing/global-increase-co2-emissions-2017.html

[6] Carrington (2017) Damian Carrington, "Political watershed' as 19 countries pledge to phase out coal", The Guardian, 16 Nov 2017 (Bonn). https://www.theguardian.com/environment/2017/nov/16/political-watershed-as-19-countries-pledge-to-phase-out-coal

developed or operated coal power plants have moved away from the coal business (Shearer 2017)[7]. Also, in 2017, 26 of 28 European Union member states signed an agreement to build no more coal-fired power plants from 2020 onwards, and the Port of Amsterdam, which currently handles 16 million tonnes of coal per year, announced plans to become coal-free by 2030 (Campbell 2017)[6].

The global oil price averaged USD 52.5 per barrel in 2017, equivalent to about half the record high prices that occurred between 2011 and 2014, although it was still almost double the prices from 1996 to 2005 (Statista 2018)[8]. Natural gas prices fell from 2013 to 2016, and early indicators suggest that prices remained low or decreased further in 2017 (BP 2017)[9]. Low fossil fuel prices have challenged renewable energy markets, especially in the heating and transport sectors (IEA-RE 2016)[10].

The value of direct global fossil fuel consumption subsidies in 2016 was estimated to be about USD 360 billion, a 15% reduction since 2015—but still more than 20% higher than the total renewable industry turnover in 2017 (IEA-WEB 2018)[11]. The value of fossil fuel subsidies also increases by an order of magnitude if externalities are considered (IMF 2015)[12]. Although the Group of Twenty (G20) reaffirmed their 2009 commitment to phasing-out inefficient fossil fuel subsidies in 2017, progress has been slow and there are calls from large investors, insurers, and civil society to both increase transparency and accelerate the process (G20-2017)[13]. The main problems identified include that the G20 has not defined 'inefficient subsidies'; there is no mandatory reporting; and there are no timelines for phase-out commitments (Asmelash 2017)[14].

At the global policy level, international climate negotiations have continued to influence energy markets. Following the 2015 Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC), a technical meeting on its implementation took place in Bonn, Germany, in November 2017 at the 23rd Conference of the Parties (COP23) (UNFCCC 2017)[15]. Although renewable energy figured prominently in a large proportion of the Nationally Determined Contributions (NDCs) that countries submitted in the lead-up to COP22 in 2016, the climate negotiations in 2017 were unable to resolve the question of how NDCs should be organized, delivered, and updated, leaving uncertainty about how national renewable energy commitments could be ramped up (Timberley 2017)[16].

Despite these uncertainties, an increasing number of communities, cities, and regions have introduced 100% renewable energy targets. The number of cities powered by at least 70% renewable electricity has more than doubled in 2 years, from 42 in 2015 to 101 in 2017. These cities now include Auckland, Brasilia, Nairobi, and Oslo (CDP-WEB 2018)[17]. By end 2018, 176 companies committed for 100% renewable energy target, among them are large cooperation's such as Ikea, Coca Cola and Apple[18].

Carbon pricing policies, which include carbon taxes and emission trading schemes, were in place in 64 jurisdictions around the world in 2017, up from 61 in 2016. In December 2017 (REN21-GSR 2018)[4], China launched the first phase of its long-awaited nationwide carbon emissions trading scheme, which will focus on the power sector. Carbon trading will be based in Shanghai and will include about 1,700 power companies emitting more than 3 billion tonnes of CO_2 annually (Xu and Mason 2017)[19]. For comparison, the emissions

7 Shearer (2017), Boom and Bust 2018, Tracking the Global Coal Pipeline, https://endcoal.org/global-coal-plant-tracker/reports/boom-bust-2018/

8 Statista (2018), Statista: "Average annual Brent crude oil price from 1976 to 2018 (in U.S. dollars per barrel)",https://www.statista.com/statistics/262860/uk-brent-crude-oil-price-changes-since-1976/ , updated 2018, Viewed 21 March 2018.; "Average annual OPEC crude oil price from 1960 to 2018 (in U.S. dollars per barrel)", https://www.statista.com/statistics/262858/change-in-opec-crude-oil-prices-since-1960/. viewed September 2018.

9 BP (2017), Average prices to 2016 from: BP Statistical Review of World Energy "Natural gas – 2016 in review", presentation, (BP,June 2017) https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review-2017/bp-statistical-review-of-world-energy-2017-natural-gas.pdf According to https://tradingeconomics.com/commodity/natural-gas, gas prices fell by 14% between 2 Jan 2017 and 1 January 2018 (viewed 21 March 2018)

10 IEA-RE (2016), International Energy Agency (IEA), MediumTerm Renewable Energy Market Report 2016 (Paris: 2016),Page 214 https://www.iea.org/newsroom/news/2016/october/mediumterm-renewable-energy-market-report-2016.html ;

11 IEA-WEB (2018) International Energy Agency (IEA),, Energy Subsidies; website, September 2018, https://www.iea.org/statistics/resources/energysubsidies/

12 IMF (2015), The International Monetary Fund (IMF) includes externalities in fossil fuel subsidies and arrives at US$5.3 trillion for 2015, 6.5% of the world's GDP; Damian Carrington, "Fossil fuels subsidized by $10m a minute, says IMF", The Guardian, 18 May 2015, https://www.theguardian.com/environment/2015/may/18/fossil-fuel-companies-getting-10m-a-minute-in-subsidies-says-imf,

13 G20 (2017), G20 reaffirm commitment to phasing out subsidies: G20. G20 Hamburg Climate and Energy Action Plan for Growth: Annex to G20 Leaders' Declaration. (Hamburg, Germany: 2017) Page 11 https://www.g20germany.de/Content/DE/_Anlagen/G7_G20/2017-g20-climate-and-energy-en.pdf?__blob=publicationFile&v=6;

14 Asmelash, H.B. (2017). "Phasing Out Fossil Fuel Subsidies in the G20: Progress, Challenges, and Ways Forward." (Geneva, Switzerland: International Centre for Trade and Sustainable Development, 2017), Page vii. https://www.ictsd.org/sites/default/files/research/phasing_out_fossil_fuel_subsidies_in_the_g20-henok_birhanu_asmelash.pdf

15 UNFCCC (2017), United Nation – Climate Change, UNFCCC – The Paris Agreement, website viewed 12th March 2018, http://unfccc.int/paris_agreement/items/9485.php; Jocelyn Timperley, COP23: Key outcomes agreed at the UN climate talks in Bonn, CarbonBrief, 19 November 2017, https://www.carbonbrief.org/cop23-key-outcomes-agreed-un-climate-talks-bonn

16 Timberley (2017), Jocelyn Timperley, COP23: Key outcomes agreed at the UN climate talks in Bonn, CarbonBrief, 19 November 2017, https://www.carbonbrief.org/cop23-key-outcomes-agreed-un-climate-talks-bonn

17 CDP-WEB (2018), Carbon Disclosure Project (CDP), "The World's Renewable Energy Cities" https://www.cdp.net/en/cities/world-renewable-energy-cities website, September 2018

18 100 Percent Renewable Pledges Do Not Equal Carbon-Free Power, Benjamin Storrow, E&E News on May 28, 2019 https://www.scientificamerican.com/article/100-percent-renewable-pledges-do-not-equal-carbon-free-power/

19 XU, Mason (2017), Muyu Xu, Josephine Mason, "China aims for emission trading scheme in big step vs. global warming", Reuters, 19 December 2017, , https://www.reuters.com/article/us-china-carbon/china-aims-for-emission-trading-scheme-in-big-step-vs-global-warming-idUSKBN1ED0R6

trading scheme of the European Union included around 1.7 billion tonnes of CO_2 in 2016 (EC 2017)[20]. Reforms to the European Union scheme were agreed upon at the end of 2017, which will reduce the number of emission certificates issued and accelerate the cancellation of surplus certificates (Agora 2018)[21].

The global investment in renewable energy in 2017 (excluding hydropower plants larger than 50 megawatts [MW]) was USD 280 billion (REN21-GSR 2018)[4], up by 2% from 2016, but 13% below the all-time high, which occurred in 2015. It is noteworthy that each dollar represents more capacity on the ground as prices per GW decrease. Nearly all the investment was in either solar PV (58%) or wind power (38%). Developing countries accounted for the largest share of investment for the third consecutive year, at 63% of the total investment. China alone accounted for 45% of global investment, with a 30% increase since 2016. The United States was next, with 14%, followed by Japan (5%) and India (4%). Investment remained steady or trended upwards in Latin America and the USA, but has been falling in Europe since about 2010, with a drop of 30% from 2016 to 2017 (UNEP-FS 2018)[22].

Pressure to diversify and stable growth in the renewables sector over the past decade has increased the interest of the fossil fuel industry in renewables. Large oil corporations more than doubled their acquisitions, project investments, and venture capital stakes in renewable energy in 2016 relative to those in 2015. This increased the investment in clean energy companies to USD 6.2 billion over the past 15 years, with more than 70% of deals involving solar PV or wind, and 16% involving biofuels (Bloomberg 2017). However, this is dwarfed by the spending of these companies on fossil fuels. One estimate is that renewables account for about 3% of the total annual spending (around USD 100 billion) by the world's five biggest oil companies (Schneyer and Bousso 2018)[23]. Bank finance for fossil fuels increased in 2017 by 11% relative to that in 2016, after a significant decline in 2016 (RAN 2018)[24].

In 2017, as in previous years, renewables saw the greatest increases in capacity in the power sector, whereas the growth of renewables in the heating, cooling, and transport sectors was comparatively slow. Sector coupling—the interconnection of power, heating, and transport, and particularly the electrification of heating and transport—is gaining increasing attention as a way to increase the uptake of renewables by the transport and thermal sectors. Sector coupling also allows the integration of large shares of variable renewable energy, although this is still at an early stage. For example, China is specifically encouraging the electrification of heating, manufacturing, and transport in high-renewable areas, including promoting the use of renewable electricity for heating to reduce the curtailment of wind, solar PV, and hydropower. Several USA states are examining options for electrification, specifically to increase the overall renewable energy share (NEEP 2017)[25].

3.1.1 TRENDS IN THE RENEWABLE POWER SECTOR

The capacity for generating renewable power saw its largest annual increase ever in 2017, with an estimated 178 GW of capacity added. The total global renewable power capacity increased by almost 9% relative to that in 2016. Solar PV additions reached a record high and represented about 55% of newly installed renewable power capacity in 2017. The increase in the solar PV capacity was greater than the combined net additions to the fossil fuel and nuclear capacities. For the first time, the installed solar PV capacity surpassed the global operating capacity of nuclear power. Wind and hydropower installations were in second and third positions, contributing about 29% and 11% of the increase in renewable generation capacity, respectively (REN21-GSR 2018)[4].

In 2017, renewables accounted for an estimated 70% of net additions to the global power-generating capacity, up from 63% in 2016 (REN21-GSR 2018)[4]. The cost-competitiveness of renewable power generation continued to improve. Wind power and solar PV are now competitive with the generation of new fossil fuel energy in many markets, and even with existing fossil fuel generation in some markets. The costs of bio-electricity, hydropower, and geothermal power projects commissioned in 2017 were mostly within the range of the cost of fossil-fuel-fired electricity generation. Offshore wind prices also fell significantly in 2017, as competitive tenders in

[20] EC (2017), European Commission, Report From The Commission To The European Parliament And The Council - Report on the functioning of the European carbon market, COM(2017) 693 final, (Brussels,Belgium 23 November 2017), page 23 Table 8 provides an overview to all verified emissions (in million tonnes CO2 equivalents), https://ec.europa.eu/commission/sites/beta-political/files/report-functioning-carbon-market_en.pdf

[21] Agora (2018), Agora Energiewende and Sandbag. The European Power Sector in 2017. State of Affairs and Review of Current Developments. (London, 2018) p.37. https://sandbag.org.uk/project/european-energy-transition-power-sector-2017/

[22] UNEP-FS (2018), Frankfurt School - UNEP Collaborating Centre for Climate & Sustainable Energy Finance (FS-UNEP) in co-operation with Bloomberg New Energy Finance. Global Trends in Renewable Energy Investment 2018 (Frankfurt, Germany: 2018). Pages 14, 15 & 26.

[23] Schneyer, Bousso (2018), Ernest Scheyder, Ron Bousso, "Peak Oil? Majors Aren't Buying Into The Threat From Renewables", Reuters, 8 November 2018. https://uk.reuters.com/article/us-oil-majors-strategy-insight/peak-oil-majors-arent-buying-into-the-threat-from-renewables-idUKKBN1D80GA

[24] RAN (2018), Overall finance went USD 126 billion in 2015, to USD 104 billion in 2016, to USD 115 billion in 2017, from: Rainforest Action Network, BankTrack, Sierra Club, and Oil Change International, Banking On Climate Change: Fossil Fuel Finance Report Card 2018, (2018). p. 3. https://www.ran.org/bankingonclimatechange2018

[25] NEEP (2017), Northeast Energy Efficiency Partnerships Northeastern Regional Assessment of Strategic Electrification: Summary Report. (Massachusetts, USA 2017), http://www.neep.org/reports/strategic-electrification-assessment; National Development and Reform Commission, National Energy Administration. Notice on publication of the "Measures for resolving curtailment of hydro, wind and PV power generation",

Germany, the UK, and the Netherlands resulted in bids that were competitive with new conventional power generation.

By the end of 2017, the countries with the greatest total installed renewable electric capacities were China, the USA, Brazil, Germany, and Canada. When only solar and wind capacities are considered, the top countries were China, the USA, and Germany, followed by Japan, India, and Italy, and then by Spain and the UK, which had about equal amounts of capacity by the year's end.

Seventeen countries have more than 90% renewable electricity, with the majority supplied almost completely by hydropower. However, three of these, Uruguay, Costa Rica, and Ethiopia, also have significant contributions from wind power (32%, 10%, and 7%, respectively) (REN21-GSR 2018)[4]. Increasing proportions of variable renewable electricity (VRE) must be integrated into electricity systems, and VRE penetration reached locally significant levels in 2017. The countries leading the way with wind and solar penetration are Denmark (52%), Uruguay (32%), and Cape Verde (31%), with another three countries at or above the 25% VRE penetration mark. Several countries and regions integrated much higher shares of VRE into their energy systems as instantaneous shares of the total demand for short periods during 2017, e.g., South Australia (more than 100% of load from wind power alone, and 44% of load from solar PV alone on another occasion), Germany (66% of load from wind and solar combined), Texas (54% of load from wind alone), and Ireland (60% of load from wind alone) (Parkinson 2017)[26].

Curtailment—the forced reduction of wind and solar generation—is an indicator of grid integration challenges. In six of the jurisdictions with the highest VRE penetration, the curtailment rates were low (0%–6%) in 2016 (Wynn 2018)[27]. Although curtailment initially tends to increase as the VRE share increases, some jurisdictions have successfully introduced measures, such as transmission upgrades, that have significantly reduced curtailment (Wynn 2018). Integration challenges have led to high curtailment rates in China, the world's largest wind and solar PV market (ECNS.CN 2018)[28]. These were reduced in 2017, with the average curtailment of wind power for the year at around 12%, down from 17% in 2016, and the average curtailment of solar PV was 6%–7%, down 4.3% relative to that in 2016 (Haugwitz 2018)[29].

The ongoing increase in the growth and geographic expansion of renewable energy was driven by the continued decline in the prices for renewable energy technologies (in particular, for solar PV and wind power), caused by the increasing power demand in some countries and by targeted renewable energy support mechanisms. Solar PV and onshore wind power are now competitive with new fossil fuel generation in an increasing number of locations, due in part to declines in system component prices and to improvements in generation efficiency. The bid prices for offshore wind power also dropped significantly in Europe during 2016 (FT 12.9.2017)[30].

Such declines in cost are particularly important in developing and emerging economies, and in isolated electric systems (such as on islands or in isolated rural communities) where electricity prices tend to be high (if they are not heavily subsidized), where there is a shortage of generation, and where renewable energy resources are particularly plentiful, making renewable electricity more competitive relative to other options. Many developing countries are racing to bring new power-generating capacities online to meet rapidly increasing electricity demands, often turning to renewable technologies (which may be grid-connected or off-grid) through policies such as tendering or feed-in tariffs, in order to achieve the desired growth quickly.

Approximately 1.06 billion people, most in sub-Saharan Africa, lived without electricity in 2016, 223 million fewer than in 2012 (IEA-WEO 2016[31]; IEA-EAO, 2017[32]). Distributed renewables for energy access (DREA) systems were serving an estimated 300 million people at the end of 2016, and they comprised about 6% of new

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26 Parkinson (2017), Giles Parkinson, "Wind Output Hits Record In July, Wind And Solar 59% In S.A.", Reneweconomy, 31 August 2017. http://reneweconomy.com.au/wind-output-hits-record-in-july-wind-and-solar-59-in-s-a-45242/ , Giles Parkinson, "Rooftop Solar Provides 48% Of South Australia Power, Pushing Grid Demand To Record Low", Reneweconomy, 18 September 2017, http://reneweconomy.com.au/rooftop-solar-provides-48-of-south-australia-power-pushing-grid-demand-to-record-low-47695/;

27 Wynn 2018, Power-Industry Transition, Here and Now: Wind and Solar won't break the grid: Nine Case Studies Cleveland, OH Institute for Energy Economics and Financial Analysis, 2018, pp 29

28 ECNS.CN (2018), ECNS.CN, People Daily Online, Wang Zihao,China's clean power waste continues to drop, 8th June 2017, viewed 13th March 2018, http://www.ecns.cn/2017/06-08/260610.shtml

29 Haugwitz (2018), 2017 data from: AECEA, "China 2017 – what a year with 53 GW of added solar PV! What's in for 2018!" Briefing Paper – China Solar PV development, January 2018, Frank Haugwitz, AECEA.

30 FT (12.9.2017), Financial Times, 12 September 2017, Natalie Thomas, Powerful turbines slash price of offshore wind farms, https://www.ft.com/content/28b0eb2e-96f1-11e7-a652-cde3f882dd7b

31 IEA-WEO (2016), 2014 total from IEA, "World Energy Outlook 2016 – Electricity Access Database", http://www.worldenergyoutlook.org/media/weowebsite/2015/WEO2016Electricity.xlsx, 2016;

32 IEA-EAO (2017) International Energy Agency, Energy Access Outlook 2017, Table 2.1, https://www.iea.org/publications/freepublications/publication/WEO2017SpecialReport_EnergyAccessOutlook.pdfhttp://www.iea.org/publications/freepublications/publication/WEO2017_Special_Report_Energy_Access_Outlook_ExecutiveSummary_English.pdf

electricity connections worldwide between 2012 and 2016 (IRENA-P 2017)[33]. In places where the electricity grid does not reach or is unreliable, DREA technologies provide a cost-effective option to improve energy access. For example, about 13% of the population of Bangladesh gained access to electricity through solar home systems (SHS), and more than 50% of the off-grid population in Kenya is served by DREA systems (Dahlberg 2018). Off-grid solar devices, such as solar lanterns and SHS, displayed annual growth rates of 60% between 2013 and 2017 (Dahlberg 2018)[34].

3.1.2 HEATING AND COOLING

Energy use for heating and cooling is estimated to have accounted for just over half of the total global final-energy consumption in 2017, with about half of that used for industrial process heat (IEA-RE 2017)[35]. Around 27% of this was supplied by renewables. The largest share of renewable heating was from traditional biomass, which continued to supply about 16.4% of the global heat demand, predominantly for cooking in the developing world (IEA-RE 2017)[35]. Renewable energy—excluding traditional biomass—supplied approximately 9% of the total global heat production in 2017, up from about 6% in 2008 (REN21-GSR 2018)[4].

Renewable heating and cooling receives much less attention than renewable power generation and has been identified as the ‘sleeping giant of energy policy’ for the past decade (IEA-Collier 2018)[36]. The use of modern renewable heat has increased at an average rate close to 3% per year since 2008, gradually increasing its share of heat supply, but it lags well behind the average annual increase of 17% in modern renewables for electricity (IEA-RE 2017)[35]. Renewable energy technologies for heating and cooling include a variety of solar thermal collectors for different temperature levels; geothermal and air-sourced heat pumps; bioenergy used in traditional combustion applications or converted to gaseous, liquid, or solid fuels and subsequently used for heat; and any type of renewable electricity used for heating. Heat may be supplied by on-site equipment or by a district heating network.

A wide range of temperature requirements exist, from temperatures of around 40–70°C for space and water heating in buildings, to steam at several hundred degrees Celsius for some industrial processes (Averfalk et al. 2017)[37] (USA-EPA 2017)[38]. The variety in renewable heating systems and applications is much greater than in the renewable power sector, which makes standardization to reduce costs by economies of scale more challenging and makes it difficult for policy makers to find effective mechanisms to increase the renewable share. Trends in the use of modern renewable energy for heating vary according to the technology, although the relative shares of the main renewable heat technologies have remained stable for the past few years. In 2017, bioenergy (excluding traditional biomass) accounted for the greatest share, providing an estimated 68% of renewable heat, followed by renewable electricity at 18%, solar thermal at around 7%, district heating at 4% (which was nearly all bioenergy), and geothermal at 2% (REN21-GSR 2018)[4]. Although additional bio-heat and solar thermal capacities were added in 2017, the growth in both markets continued to slow. The trends in direct geothermal heating are unclear.

Bioenergy systems provide individual heating in residential and medium-sized office buildings, either as stand-alone systems or in addition to an existing central heating system, and bioenergy also accounts for 95% of district heating (IEA-RE 2017)[35]. District heating systems are suitable for use in densely populated regions with an annual heating demand during ≥ 4 months of the year, such as in the northern part of China, Denmark, Germany, Japan, Poland, Russia, Sweden, the UK, and the northern United States (IRENA-RE-H 2017)[39]. However, district heating supplies a very small proportion of global heating needs. The majority of district heating systems are fuelled by either coal or gas, with the share of renewables ranging from 0%–42% (IRENA-RE-H 2017)[39]. Switching existing districting heating systems from fossil fuels to renewables has considerable potential (IRENA-RE-H 2017)[39]. Since the 1980s, Sweden has progressively switched from an almost entirely

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[33] IRENA-P (2017)Estimate of 300 million from International Renewable Energy Agency (IRENA), “2016 a record year for renewables, latest IRENA data reveals”, press release (Abu Dhabi: 30 March 2017), http://irena.org/newsroom/pressreleases/2017/Mar/2016-a-Record-Year-for-Renewables-Latest-IRENA-Data-Reveals;

[34] Dahlberg (2018), Dahlberg Advisors and Lighting Global, Off-Grid Solar Market Trends Report 2018 (Washington, DC: International Finance Corporation, 2018), p. 70, https://www.gogla.org/sites/default/files/resource_docs/2018_mtr_full_report_low-res_2018.01.15_final.pdf.

[35] IEA-RE (2017),International Energy Agency Renewables 2017. Analysis and Forecasts to 2022. (Paris, France: 2017), Page 121. http://www.iea.org/bookshop/761-Market_Report_Series:_Renewables_2017

[36] IEA- Collier (2018), Ute Collier ,Commentary: More policy attention is needed for renewable heat, ,(Paris, France: International Energy Agency, 25 January 2018), http://www.iea.org/newsroom/news/2018/january/commentary-more-policy-attention-is-needed-for-renewable-heat.html

[37] Averfalk, H., Werner, S. et al. (2017), Averfalk, H., Werner, S. et al. “Transformation Roadmap from High to Low Temperature District Heating Systems”. Annex XI final report. International Energy Agency Technology Collaboration on District Heating and Cooling including Combined Heat and Power (2017), page 5. http://www.iea-dhc.org/index.php?eID=tx_nawsecuredl&u=1440&g=3&t=1521974500&hash=312c2176feeabc6fcf75a735f3031f91e33940f1&file=fileadmin/documents/Annex_XI/IEA-DHC-Annex_XI_Transformation_Roadmap_Final_Report_April_30-2017.pdf ,

[38] USA-EPA (2017), United States of America, Environmental Protection Agency (EPA), Renewable Heating and Cooling, Renewable Industrial Process Heat, https://www.epa.gov/rhc/renewable-industrial-process-heat, updated 26 October 2017,

[39] IRENA-RE-H (2017), International Renewable Energy Agency (IRENA), Renewable Energy in District Heating and Cooling: A Sector Roadmap for REmap, , (Abu Dhabi, UAE 2017)page 17, table 2, http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Mar/IRENA_REmap_DHC_Report_2017.pdf

fossil-fuelled heating supply to systems supplied by 90% renewables and recycled heat (Brown 2018)[40]. District heating can combine different sources of heat, and can play a positive role in the integration of VRE through the use of electric heat pumps.

Solar thermal collector installations continued to decline globally in 2017, with a reduction of 3% (REN21-GSR 2018)[4] compared with 2016, but the markets in China and India remained strong. In Europe, hybrid systems, in which solar thermal systems are used in combination with gas-fired central heating or bioenergy, are becoming more common, with specialized companies offering standardized technology.

Electricity accounts for an estimated 6% of the total heating and cooling consumption in buildings and industry, with about half of that electricity estimated to be renewable (IEA-RE 2017)[35]. The further electrification of heating and cooling drew increasing attention in 2017, particularly in the United States and China. Residential solar PV systems are also increasingly connected to electricity-using heat pumps in buildings rather than feeding the energy into the public electricity grid, especially when feed-in tariffs for solar electricity are reduced or have been entirely phased out.

Space cooling accounts for about 2% (REN21-GSR 2018)[4] of the total world final energy consumption and is supplied almost entirely by electricity (IEA-RE 2017)[35]. Solar-based space-cooling systems are still in the minority compared with conventional air-conditioning systems.

3.1.3 TRANSPORT

The global energy demand for transport increased by an average of 2.1% between 2000 and 2016 and is responsible for approximately 29% of the final global energy use and 24% of GHG emissions (IEA-WEO 2017)[41]. The vast majority (92%) of global transport energy needs are met by oil, with small proportions met by biofuels (2.9%) and electricity (1.4%) (IEA-WEO 2017)[41].

There are three main entry points for renewable energy in the transport sector: the use of 100% liquid biofuels or biofuels blended with conventional fuels; natural gas vehicles and infrastructure (these can run on upgraded biogas); and the electrification of transport (if the electricity is itself renewable), which can be via batteries or hydrogen in fuel cells.

Biofuels (bioethanol and biodiesel) make by far the greatest contribution to renewable transport. The overall renewable share of road transport energy use was estimated to be 4.2% in 2016, with nearly all of that from biofuels (IEA-RE 2017)[35]. In 2017, global bioethanol production increased by 2.5% relative to that in 2016, with a slight decline in Brazil offset by increases in the USA, Europe, and China (IEA OIL 2018)[42]. Biodiesel production remained relatively stable in 2017, following a 9% increase in 2016 relative to 2015 (IEA OIL 2018)[42].

The technology for producing, purifying, and upgrading biogas for use in transport is relatively mature, and the numbers of natural gas vehicles (NGVs) and the associated infrastructure are increasing slowly but steadily internationally. Many countries have relatively well-developed NGV infrastructures, and NGVs provide a good entry point for biogas in the transport sector (IRENA-RV-2017)[43]. The largest producers of biogas for vehicle fuel in 2016 were Germany, Sweden, Switzerland, the UK, and the USA (IRENA-RV-2017)[43]. The main barriers to the further expansion of biogas for transport are economic, with supply costs of USD 0.22–1.55 per cubic metre (m^3), compared with natural gas prices, which are as low as USD 0.13 per m^3. However, the lack of consistent regulation and access to gas grids are also significant barriers (IRENA-RV-2017)[43].

Historically, the electrification of the transport sector has been limited to trains, light rail, and some buses. In 2017, there were signs that the entire sector would open to electrification. Fully electric passenger cars, scooters, and bicycles are rapidly becoming common-place, and prototypes for heavy-duty trucks, planes, and ships were released in 2017 (Hawkins 2017)[44].

The number of electric vehicles (EVs) on the road passed the 3 million mark in 2017 (Guardian 25.12.2017). Annual sales are still only a very small proportion of the global total (1%), but this is set to change. In 2017, partly influenced by the scandal over diesel emissions cheating, five countries announced their intention to ban sales of new diesel and petrol cars from 2030 (India, the Netherlands, and Slovenia) or 2040 (France and the

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[40] Brown, P (2018), Paul Brown, "District Heating Warms Cities Without Fossil Fuels ", Ecowatch, 15 January 2018, , , https://www.ecowatch.com/district-heating-energy-efficiency-2525685749.html

[41] IEA-WEO (2017), IEA, World Energy Outlook 2017 (Paris: 2017) p. 648. https://www.iea.org/weo2017/ ; GHG emissions share for 2015 from IEA, CO2 Emissions from Fuel Combustion 2017, (Paris: 2017) p. 12. http://www.iea.org/bookshop/757-CO2_Emissions_from_Fuel_Combustion_2017

[42] IEA OIL (2018), International Energy Agency: Analysis and Forecasts to 2023, (Paris, France: 2018), p.77 & p.134 http://www.oecd.org/publications/market-report-series-oil-25202707.htm

[43] IRENA-RV (2017),IRENA, Biogas for Road Vehicles Technology Brief (Abu Dhabi: March 2017), p. 2, http://www.irena.org/DocumentDownloads/Publications/IRENA_Biogas_for_Road_Vehicles_2017.pdf.

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UK) (Bloomberg 11.2017)[45]. The announcement of electric product lines by car manufacturers in 2017 was another breakthrough. However, the number of EVs on the road is dwarfed by the number of electric bikes. The global fleet was estimated to be around 200 million at the end of 2016, most of them in China, and 30% of bicycles sold in the Netherlands were e-bikes in 2017 (Wang 2017)[46]. Electric two- and three-wheel vehicles account for less than 0.5% of all transport energy use, but they account for most of the remaining renewable share after biofuels (IEA-RE 2017)[35].

Further electrification of the transport sector will potentially create a new market for renewable energy and ease the integration of variable renewable energy, if market and policy settings ensure that the charging patterns are effectively harmonized with the requirements of electricity systems. There are already examples of countries and cities supplying electricity for both heavy and light rail from renewable electricity, including the Netherlands (BI 2017), Delhi (Times of India 2017), and Santiago de Chile (CT 2017)[47].

Road transport accounts for 67% of global transport energy use, and two-thirds of that is used for passenger transport.

Aviation accounts for around 11% of the total energy used in transport (US-EIA-2017)[48]. In October 2016, the International Civil Aviation Organization (ICAO), a UN agency, announced a landmark agreement to mitigate GHG emissions in the aviation sector. By the end of 2017, 106 states representing 90.8% of global air traffic had settled on a global emissions reduction scheme (Guardian 6.10.2016)[49]. Together with technical and operational improvements, this agreement will support the production and use of sustainable aviation fuels, specifically drop-in fuels produced from biomass and different types of waste (ICAO 2018)[50]. In 2017, Norway announced a target of 100% electric short-haul flights by 2040 (Guardian 18.1.2018)[51].

Shipping consumes around 12% of the global energy used in transport (US-EIA-2017)[48] and is responsible for approximately 2.0% of global CO_2 emissions. There are multiple entry points for renewable energy: ships can incorporate wind (sails) and solar energy directly, and can use biofuels, synthetic fuels, or hydrogen produced with renewable electricity for propulsion. China saw the launch of the world’s first all-electric cargo ship in 2017, and in Sweden, two large ferries were converted from diesel to electricity in 2017 (China Daily 14.11.2017)[52]. In 2017, the International Maritime Organization’s (IMO’s) Marine Environment Protection Committee (MEPC) approved a roadmap (2017 to 2023) to develop a strategy for reducing GHG emissions from ships. The roadmap includes plans for an initial GHG strategy to be adopted in 2018 (IMO 2017)[53].

Rail accounts for around 1.9% of the total energy used in transport and is the most highly electrified transport sector. The share of rail transport powered by electricity was estimated to be 39% in 2015, up from 29% in 2005 (IEA-UIC 2017)[54]. Just over a third of the electricity (9% of rail energy) is estimated to be derived from renewable sources (IEA-UIC 2017). Some jurisdictions are opting to ensure that the proportion of energy from renewable sources in their transport sectors is well above the share of renewable energy in their power sectors. For example, the Dutch railway company NS announced that its target to power all electric trains with 100% renewable electricity was achieved ahead of schedule in 2017 (Caughill 2017)[55], and the New South Wales Government in Australia announced a renewable tender for the Sydney’s light rail system.

Following the historic Paris Climate Agreement in December 2015, the international community has focused increasing attention on the decarbonisation of the transport sector. At the climate conference in November 2017

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45 Bloomberg (11.2017) Anna Hirtenstein, “Global Electric Car Sales Jump 63 Percent”, Bloomberg, 21 November 2017, https://www.bloomberg.com/news/articles/2017-11-21/global-electric-car-sales-jump-63-percent-as-china-demand-surges,

46 Wang (2017) Brian Wang. “Electric bikes could grow from 200 million today to 2 billion in 2050”, Next Big Future, 27t April 2017. https://www.nextbigfuture.com/2017/04/electric-bikes-could-grow-from-200-million-today-to-2-billion-in-2050.html; Sales and Trends. “E-Bike Puts Dutch Market Back on Growth Track”. Bike Europe. 6 March 2018. http://www.bike-eu.com/sales-trends/nieuws/2018/3/e-bike-puts-dutch-market-back-on-growth-track-10133083

47 CT (2017) Chile’s Santiago Metro Will Meet 60% Of Its Energy Demand From Renewables”, Clean Technica, 8 July 2017. https://cleantechnica.com/2017/07/08/chiles-santiago-metro-will-meet-60-energy-demand-renewables/

48 US-EIA (2017) U.S. Energy Information Administration. International Energy Outlook 2017. Transportation sector passenger transport and energy consumption by region and mode: https://www.eia.gov/outlooks/aeo/data/browser/#/?id=50-IEO2017&region=0-0&cases=Reference&start=2010&end=2020&f=A&linechart=Reference-d082317.2-50-IEO2017&sourcekey=0

49 Guardian (6.10.2016) Oliver Milman. “First deal to curb aviation emissions agreed in landmark UN accord”, 6 October 2016, https://www.theguardian.com/environment/2016/oct/06/aviation-emissions-agreement-united-nations; ICAO Website, Environment, September 2018, https://www.icao.int/environmental-protection/Pages/ClimateChange_ActionPlan.aspx

50 ICAO (2018) ICAO Website, Environment, September 2018,https://www.icao.int/environmental-protection/GFAAF/Pages/default.aspx

51 Guardian (18.1.2018) The Guardian, Norway aims for all short-haul flights to be 100% electric by 2040, AFP, 18th January 2018, viewed 16th March 2018, https://www.theguardian.com/world/2018/jan/18/norway-aims-for-all-short-haul-flights-to-be-100-electric-by-2040

52 China Daily (14.11.2017) Qiu Quanlin, “Fully electric cargo ship launched in Guangzhou”, China Daily, 14 November 2017, http://www.chinadaily.com.cn/business/2017-11/14/content_34511312.htm.; ABB, “HH Ferries electrified by ABB win prestigious Baltic Sea Clean Maritime Award 2017”, press release (Zurich: 14 June 2017), http://new.abb.com/news/detail/1688/HH-ferries-electrified-by-ABB-win-prestigious-baltic-sea-clean-maritime-award-2017; Fred Lambert, “Two massive ferries are about to become the biggest all-electric ships in the world”, Electrek, 24 August 2017, https://electrek.co/2017/08/24/all-electric-ferries-abb/; Daniel Boffey,.

53 IMO (2017) International Maritime Organization (IMO) Website, September 2018, http://www.imo.org/en/MediaCentre/HotTopics/GHG/Pages/default.aspx

54 IEA-UIC (2017), IEA and International Union of Railways, Railway Handbook 2017, Energy Consumption and CO2 emissions, (Paris: 2017). P. 26, https://uic.org/IMG/pdf/handbook_iea-uic_2017_web2-2.pdf

55 Caughill (2017), Patrick Caughill “All Dutch Trains Now Run On 100% Wind Power”, Business Insider. 3 June 2017. http://uk.businessinsider.com/wind-power-trains-in-netherlands-2017-6?r=US&IR=T

in Bonn, Germany, a multi-stakeholder alliance launched the Transport Decarbonisation Alliance (UN-P 2018)[56]. France, the Netherlands, Portugal, Costa Rica, and the Paris Process on Mobility and Climate (PPMC) are members of the Alliance, which includes countries, cities, regions, and private-sector companies committed to ambitious action on transport and climate change (UN-P 2018)[56].

3.2 ACCESS TO ENERGY – 7TH SUSTAINABLE DEVELOPMENT GOAL

The growth of megacities and the slow process of providing access to energy services are closely related, and in many cases two sides of the same coin. Young people leave the rural areas for large cities due to the lack of professional opportunities, while access to energy is fundamental to sustain economic activities and alleviate poverty. For well over 1 billion people around the world, obtaining access to the energy required to meet very basic needs remains a daily struggle. In rural areas of many developing countries, as well as some urban slums and peri-urban areas, connection to central electric grids is economically prohibitive and may take decades to materialise, if at all (REN21-GSR 2016). Recent progress has been too slow to meet changing needs.

In 2013, the United Nations Development Programme (UNDP) launched the *Sustainable Energy for All* initiative to aid in accelerating the rate of increased energy access for the least developed countries. The first step in the process was to develop a central database in order to make previously dispersed information available to decision makers. The UNDP – in cooperation with a number of other energy advocacy organisations such as the IEA and REN21 – published the *Global Tracking Framework*[57] report, providing a statistical overview of the progress of energy access between 1990 and 2010. Information from these reports combined with new data from the *REN21 Global Status* report provides a clear picture of progress in this area.

3.3 ENERGY ACCESS PLANNING FOR DEVELOPING COUNTRIES

Between 1990 and 2010, an additional 1.7 billion people worldwide gained the benefits of electrification, while 1.6 billion people secured access to generally less polluting non-solid fuels. Furthermore, the successful implementation of energy efficiency measures led to a significant reduction in energy intensity. As a result, economic growth and the growth of energy demand began to disconnect. This is a significant change that avoided 2,300 exajoules of new energy supply over the past 20 years; in other words, without these measures the global energy demand would have been 25 per cent higher during that period. In addition, renewable energy supplied a cumulative global total of more than 1,000 exajoules between 1990 and 2010, comparable to the combined total energy consumption of China and France over the same period (UNDP 2013).

Unfortunately, the rapid demographic and economic growth over the last decades has to some extent diluted the impact of these advances. Between 1990 and 2010:

- the proportion of the world's population with access to electricity and non-solid fuels grew 1.2 per cent and 1.1 per cent respectively each year
- renewable energy supply grew by around 2 per cent per annum
- energy demand grew by 1.5 per cent per annum.

As a result, the global renewable energy share increased from 16.6 per cent in 1990 to 18 per cent in 2010 (UNDP 2013) – an average of only 0.07 per cent per year. The majority of successful electrification in the past took place in urban areas, close to cities where the electrification rate was twice as high as in remote areas. Even with this significant expansion, however, electrification only just kept pace with rapid urbanisation in the same period so that the overall urban electrification rate remained relatively stable, growing from 94 to 95 per cent across the period (UNDP 2013).

Improvements to indoor cooking with open fires mainly in rural areas are an important factor in increasing public health, particularly in developing nations. Globally, almost two million deaths each year from pneumonia, chronic lung disease and lung cancer are associated with exposure to indoor air pollution resulting from cooking with biomass and coal; 99 per cent of these deaths occur in developing countries. Almost half the global population (45 per cent) still rely on solid fuels for household use with dramatic impacts on health, particularly for children and women. Some 44 per cent of these deaths occur in children; of the adult deaths, 60 per cent occur in women in developing countries (UNDP 2013).

56 UN-P (2018), United Nations, Press release, New Transport Decarbonisation Alliance for Faster Climate Action, 11th November 2018, https://cop23.unfccc.int/news/new-transport-decarbonisation-alliance-for-faster-climate-action

57 UNDP 2013: The Energy Access Situation in Developing Countries: A Review Focusing on the Least Developed Countries and Sub-Saharan Africa, May 2013 http://www.undp.org/content/undp/en/home/librarypage/environment-energy/sustainable_energy/SEFA-resources/global-tracking-framework.html

Status quo: Access to energy services

Currently, approximately 1.5 billion people in developing countries lack access to electricity and around 3 billion people rely on solid fuels for cooking. More than every second person without access to electricity lives in Sub-Saharan Africa. The entire African continent has a total installed capacity of approximately 150 gigawatts – equal to one-seventh of Europe's power plant capacity – and consumes about the same amount of electricity as Germany, while Africa's population is 12 times larger.

In (South) East Asia and the Pacific, less than 200 million people lack electricity access, but almost 1.1 billion people rely on solid fuels for cooking (UNDP 2013). Figure 1 and Figure 2 provide an overview of the key statistics.

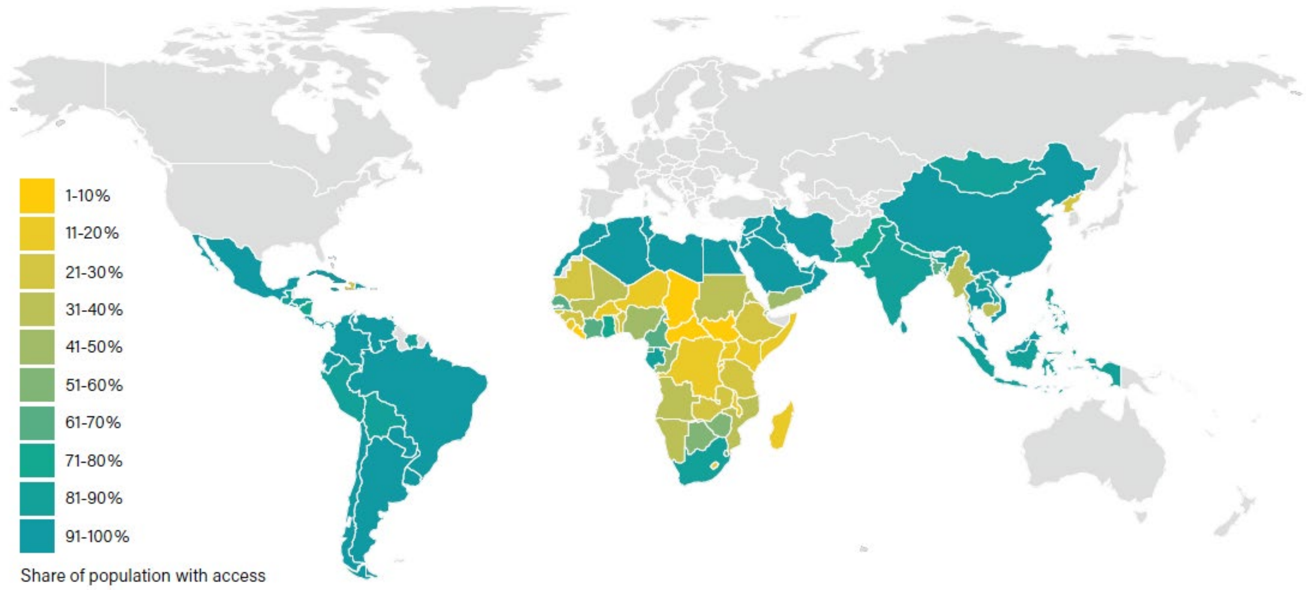


Figure 1: Access to clean cooking facilities in developing countries, 2014 (REN21-GSR 2017)

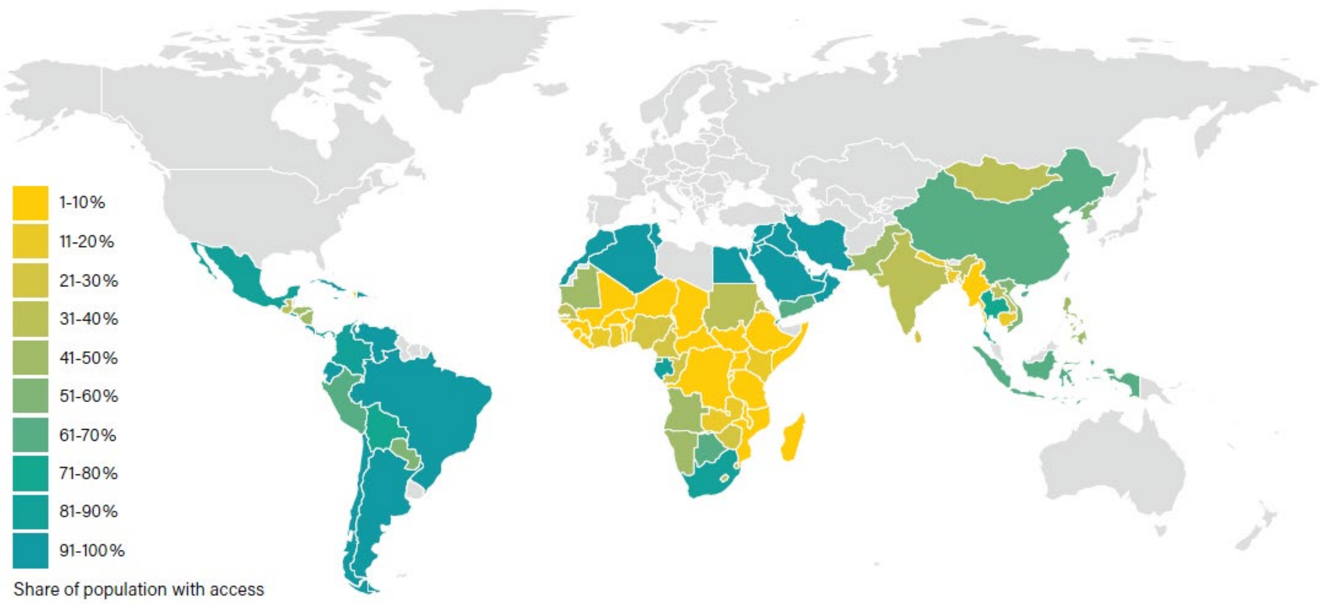


Figure 2: Status quo: Distributed renewable energy technologies for energy access

Distributed renewable energy (DRE) systems need to provide electricity for lighting, communication and small businesses, as well as energy for residential heating and process heat for applications such as in the agricultural sector and cooking. DRE systems can serve as a complement to centralised energy generation systems, or as a substitute (REN21-GSR 2016). These technologies and systems must operate reliably and with low maintenance requirements over many years, with multiple proven benefits including:

- improved health through the displacement of indoor air pollution
- reduced greenhouse gas emissions
- enabling of small business activities
- increased security, for example, via street lighting at night
- enhanced communications and facilitation of greater quality and availability of education through access to affordable lighting.

Table 1: Examples of Distributed Renewable Energy Use for Productive Energy Services (REN21-GSR2016)

ENERGY SERVICE	INCOME-GENERATING VALUE	RENEWABLE ENERGY TECHNOLOGIES
Irrigation	Better crop yields, higher-value crops, greater reliability of irrigation systems, enabling of crop growth during periods when market prices are higher	Wind, solar PV, biomass, micro-hydro
Illumination	Reading, extension of operating hours	Wind, solar PV, biomass, micro-hydro, geothermal
Grinding, milling, husking	Creation of value-added products from raw agricultural commodities	Wind, solar PV, biomass, micro-hydro
Drying, smoking (preserving with process heat)	Creation of value-added products, preservation of products that enables sale in higher-value markets	Biomass, solar heat, geothermal
Expelling	Production of refined oil from seeds	Biomass, solar heat
Transport	Reaching new markets	Biomass (biodiesel)
TV, radio, computer, Internet, telephone	Support of entertainment businesses, education, access to market news, co-ordination with suppliers and distributors	Wind, solar PV, biomass, micro-hydro, geothermal
Battery charging	Wide range of services for end-users (e.g., phone charging business)	Wind, solar PV, biomass, micro-hydro, geothermal
Refrigeration	Selling cooled products, increasing the durability of products	Wind, solar PV, biomass, micro-hydro

There are three main categories of energy access technology designs. The choice depends on a variety of different factors, one of them being the geographical situation. Furthermore, system designs also serve different business concepts and each of these models has advantages and drawbacks. Standalone, isolated devices and systems for power generation at the household level as well as for heating, cooking and production use mini or micro grid systems to supply whole communities with grid-based electrification, where the grid is extended beyond urban and peri-urban areas (REN21-GSR 2016).

Energy access market development: Power

According to the most recently available data, an estimated 26 million households (or 100 million people) worldwide are served through DRE systems (REN21-GSR 2016).

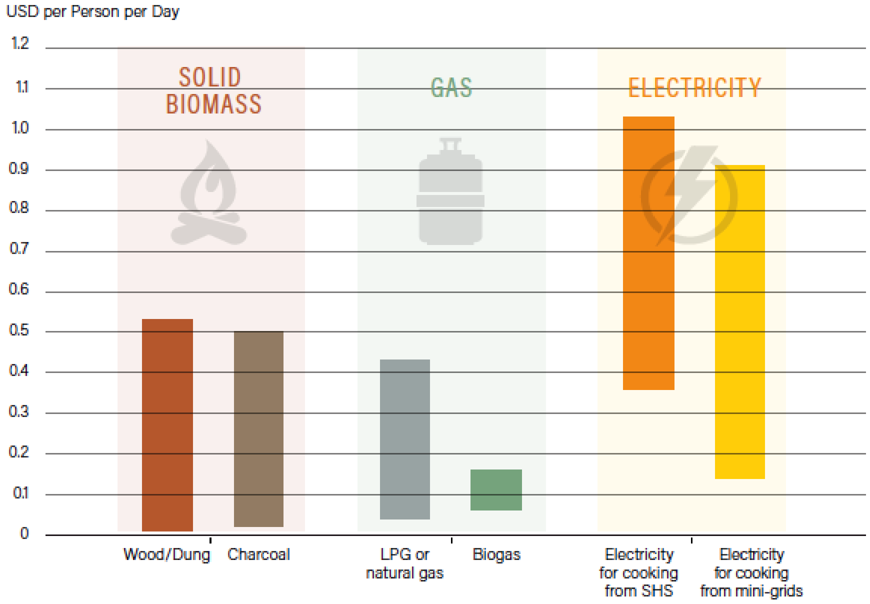
- 20 million households with solar home systems.
- 5 million households with renewables-based mini grids (mainly micro-hydro).
- 0.8 million households supplied by small-scale wind turbines.

Markets for DRE systems continue to grow rapidly, with some countries already experiencing comparatively high market penetration.

Cooking with firewood, gas or electricity

A variety of technologies can provide cooking services in different capacities, with corresponding variances in performance and cost. Wood, charcoal and dung are still widely used around the world as fuels for cooking; dung is a major cooking fuel for about 185 million people. A number of substitutes already exist, including improved and cost-efficient biomass cook stoves, biogas cook stoves and electric hot plates powered by SHS or mini grids. While electric cooking has reduced the consumption of firewood and/or charcoal by between 10 per cent and 40 per cent, biogas stoves – which are more widely used – offer a reduction in consumption levels of between 66 and 80 per cent (REN21-GSR 2017). Electric cooking costs are expected to decrease in line with reducing electricity generation costs for decentralised renewables, in particular solar photovoltaic (WFC-2019)[58].

Figure 3: Costs of various cooking technologies (REN21 GSR 2017)



[58] WFC (2019) - Beyond the fire – How to achieve electric cooking, Toby D. Couture (E3 Analytics), Dr. David Jacobs (IET – International Energy Transition GmbH, Eco Matser, Harry Clements (Hivos), Anna Skowron (WFC), World Future Council, Germany, May 2019

4 METHODOLOGY AND ASSUMPTIONS

4.1 THE ROLE OF SCENARIOS IN ENERGY POLICIES

Increasing the access to energy in developing countries requires thorough planning based on comprehensive information on all aspects of the energy sector. Scenarios are necessary to describe possible future development paths, giving decision-makers a broad overview of the implications of various options. A scenario is by no means a prognosis of what will happen, but an "if-then" analysis that provides decision-makers with an indication of how they can shape the future energy system.

Three scenarios have been developed to show possible pathways for Bangladesh's future energy supply system:

- REFERENCE scenario based on Bangladesh's Power System Master Plan 2016 and reflecting a continuation of the status quo. (for more details see 5.5)
- RENEWABLES 2.0ºC scenario focused on renewable energy in the stationary power sector while the transport and industry sectors remain dependent on fossil fuels (for more details see 5.5.)
- RENEWABLES 1.5ºC scenario for a fully decarbonised power sector by 2030 and a fully renewable energy supply system – including for the transport and industry sectors – by 2050 (for more details see 5.5.)

Changes to energy markets require long term decision-making because of the potential changes in required infrastructure are not dependent on short term market developments. Without long-term planning for infrastructure the power market cannot function optimally. Grid modifications and the rollout of smart metering infrastructure, for example, require several years to implement. These technologies form the basis for the energy market and enable energy trading. Energy scenarios show the effects of different policies and inform about possible costs and benefits as well as required infrastructure such as power grids.

This report specifically looks at possibilities to increase energy access for all citizens from the current 75 per cent (2015: 69% in rural and 94% in urban areas) to 100 per cent within just over a decade. The Institute for Sustainable Futures of the University of Technology Sydney has developed the methodology to simulate a bottom-up electrification from mini grids towards an interconnected national power grid on the basis of three energy models.

4.2 MODELLING OVERVIEW

The [*R]E24/7 energy access* pathway methodology was developed by the Institute for Sustainable Futures (ISF) at the University of Technology Sydney (UTS) and based on the long-term energy scenario model of the Institute for Thermodynamics of German Aero Space Centre (DLR), energy models developed for various UTS/ISF surveys and the [R]E24/7 model. The following section explains the methodology and provides an overview of the required input parameter, basic functions and calculated outputs.

The entire modelling uses four modules:

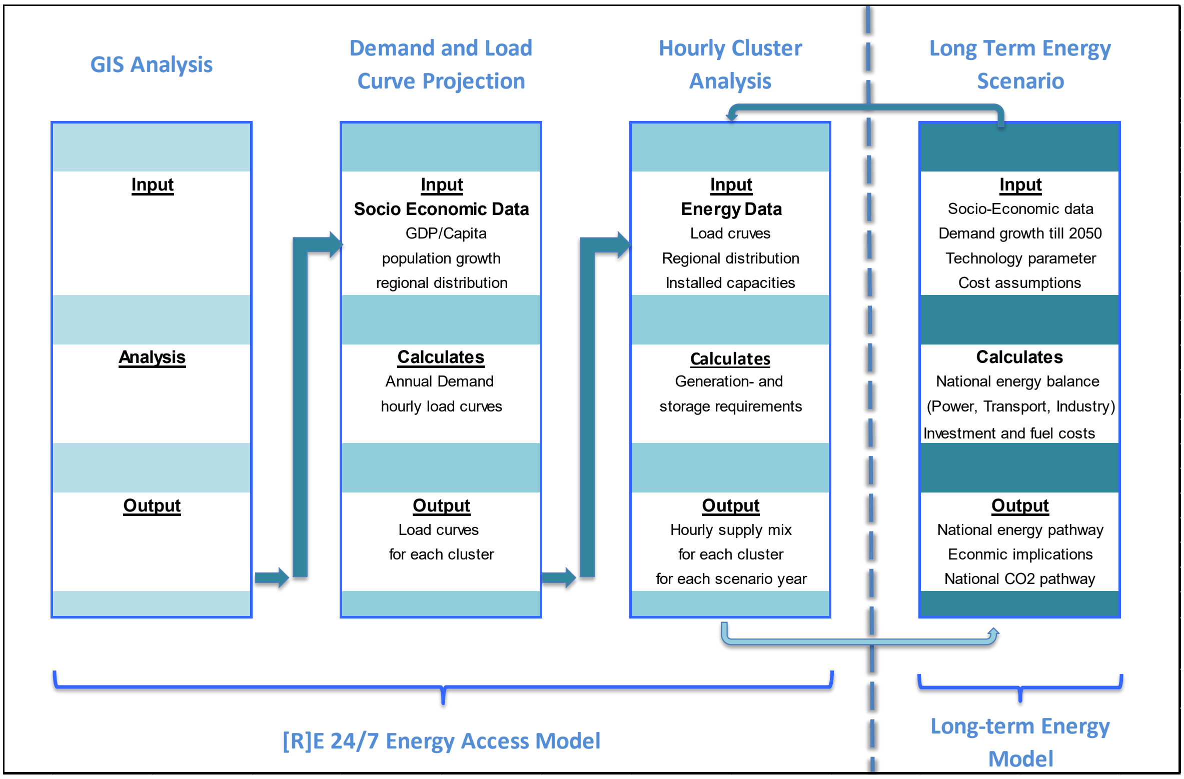
I. GIS analysis:
   a. for a regional analysis in regard to population, renewable energy resource and infrastructure
   b. to define the cluster break down.

II. Long-term energy scenario:
   a. for a long-term energy development pathway
   b. to develop detailed national energy plans including cost- and carbon emissions analysis.

III. Demand and load curve projection:
   a. for detailed demand development analysis
   b. to develop hourly load profiles for full years (8760 hours).

IV. Hourly cluster analysis for one year:
   a. for detailed supply analysis
   b. to develop detailed regional energy access and/or energy development plans.

Figure 4: Overview – Modelling concept



4.3 [R]E 24/7 - GIS MAPPING TOOL

The primary purpose of geographic information system (GIS) mapping is to ascertain the renewable energy resources (primarily solar and wind) available in Bangladesh. It also contributes to a regional analysis of geographic and demographic parameters as well as available infrastructure that could be leveraged in developing the scenarios.

For this project, the mapping has been undertaken with the computer software '*QGIS*'. *QGIS* is a cross-platform, free and open-source desktop GIS application that supports viewing, editing and analysis of geospatial data. It analyses and edits spatial information in addition to composing and exporting graphical maps and has been used to allocate solar and wind resources as well as for demand projection for each calculated region. Population density, access to electricity via the central power grid or mini grids and the distribution of wealth, or the economic development projections, are key parameters for the region-specific analysis of Bangladesh's future energy situation.

Open source data and maps from various sources are used to visualise the country and its regions and districts. The regions and districts are divided as per the energy cluster concept based on transmission levels (described in detail, further in this section). Further demographic data related to population and poverty, as well as infrastructure for centralised transmission networks, power plants and decentralised mini grids, installations, etc., are also plotted on the map.

Table 2: [R]E 24/7 - GIS-mapping – data sources

Data	Source
Regions	Bangladesh Bureau of Statistics (BBS)
Land use/land cover	World Food Programme
Population Density	WorldPop. 2017
Power plants	World Resources Institute
Solar irradiance	SolarGIS
Transmission lines and network	NREL
Wind speed	Vaisala

Wind speed data in metres per second at different levels was obtained from ESMAP under the World Bank. For this analysis, wind speed at a height of 80 meters was used to determine the electricity generation potential. Wind speeds are categorised and mapped within the range of 6 to 12 metres per second to gain an understanding of the potential of generation across the country, with speeds under 6 metres per second ignored in order to plot optimal sites. Land cover types were constrained to bare soil, annual cropland, perennial cropland, grassland and ocean, and offshore water bodies (ocean) within 50-120 kilometres of the coast were included in the analysis. As such, it accounts for both onshore and offshore generation potential.

Similarly, solar irradiance data was sourced from ESMAP, World Bank. The average yearly DNI (Direct Normal Insolation/Irradiation) values range from 1 to 5 MWh/m^2 per year, and data categorised by DNI was mapped to estimate the potential of solar photovoltaic in Bangladesh. In order to avoid conflict with competing uses of land, only land cover types of bare soil, perennial cropland and open bushland were included in the analysis.

The area of land available for potential solar and wind power generation was calculated at a national and cluster level using the ellipsoidal area tool in the *QGIS* processing toolbox. Intersects were created between the transmission level layers and the solar/wind utility vector layers to break down the total land area available cluster wise. A correction was put in place for sites that intersected the cluster boundaries and were part of two transmission levels. This input feeds into the calculations for the Energy Access Model as described below.

4.4 LONG-TERM SCENARIO MODELLING

Historically, heating, electricity and mobility have been quite separate in terms of their energy sources, requiring different infrastructure and therefore planning – electricity for stationary power, petrol and diesel for mobility and onsite heat for buildings and industrial processes. Things are changing, however, with increasing electricity projected for use in heating and mobility, such as via electric vehicles. As such, it is important to take an integrated approach across heat, mobility and electricity/stationary power when developing future energy system scenarios, as this model does.

The long-term modelling approach used in this research is the development of target-orientated scenarios. In this approach, a target is set, and technical scenarios are developed to meet this target and then compared to a reference case. The scenarios are based on detailed input data sets that consider defined targets, renewable and fossil fuel energy potential and specific parameters for power, heat and fuel generation in the energy systems. The data sets are then fed into the LT-[R]E 24/7 which is based on DLR model that uses MESAP/PlaNet software, an accounting framework for the calculation of the complete energy system balance to 2050. The simulation model PlaNet that includes MESAP, an energy and environmental planning package (MESAP, 2008) created to assist long-term strategic planning at a national, regional or local level. PlaNet consists of two independent modules:

1. a flow calculation module, balancing energy supply and demand annually, and
2. a cost calculation module for the calculation of the corresponding generation and fuel costs.

The LT-[R]E 24/7 model uses the same methodology as PlaNet - a flow calculation which uses a set of linear equations that can be solved sequentially. Please note that this is not a dispatch model, such as the [R]E 24/7 power sector model used to calculate a further regional and hourly power, or a technical grid simulation (including frequency stability) such as DIgSILENT's PowerFactory, which is out of the scope of this analysis.

The LT-[R]E 24/7 model is a bottom-up integrated energy balance model. Different modelling approaches each have their benefits and drawbacks; this model is particularly good at helping policy makers and analysts understand the relationships between different energy demand types in an economy – across all sectors and over a longer time period, usually 30 to 40 years.

In a simulation model, the user specifies the drivers of energy consumption, including forecast population growth, GDP and energy intensities.

Specific energy intensities are assumed for:

- electricity consumption per person
- the industrial heat demand to GDP ratio
- demand for energy services, such as useful heat
- different transport modes.

For both heat and electricity production, the model distinguishes between different technologies characterised by their primary energy source, efficiency and costs. Examples include biomass or gas burners, heat pumps, solar thermal and geothermal technologies, and several power generation technologies such as PV, wind, biomass, gas, coal, nuclear, combined heat and power.

For each technology, the market share with respect to total heat or electricity production is specified according to a range of assumptions including targets, potential costs and societal, structural and economic barriers.

The main outputs of the model are:

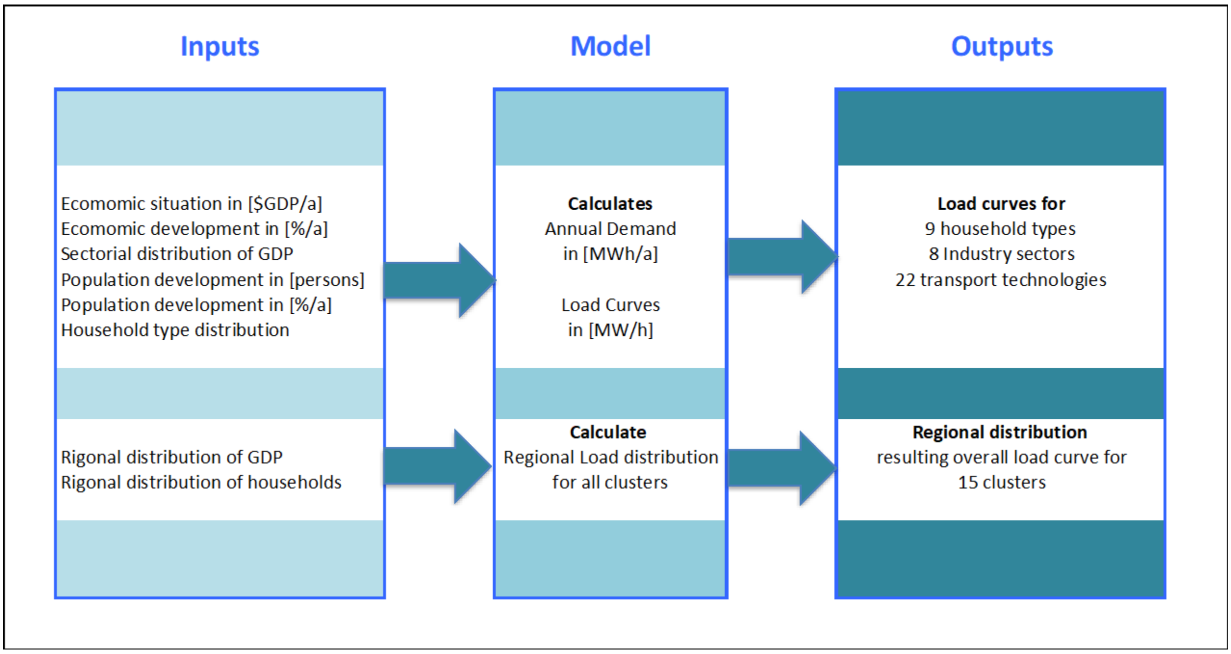
- final and primary energy demand, broken down by fuel, technology and sectors of the economy as defined by the International Energy Agency (IEA) – industry, power generation, transport and other (buildings, forestry and fisheries)[59]
- results broken down by the three main types of energy demand – electricity, heating and mobility (transport); specifically, the required energy, technology deployment and financial investment for each of these energy demand types
- total energy budget, being the total cost of energy for the whole energy system
- energy-related greenhouse gas emissions over the projection period.

[59] Note these industry sectors correspond to IEA energy statistics input into the model.

4.5 [R]E 24/7 – POWER ANALYSIS

Energy demand projection and load curve calculation are an important factor, especially for energy supply concepts with high shares of variable renewable power generation, in calculating supply security and required dispatch and storage capacities. The detailed bottom-up projection of increased access to energy on the basis of used applications, demand patterns and household types allows a detailed demand forecast. Infrastructure needs such as power grids in combination with storage facilities require an in-depth knowledge of local loads and generation capacities.

Figure 5: Overview – energy demand and load curve calculation module



4.5.1 ENERGY DEMAND PROJECTION AND LOAD CURVE CALCULATION

The [R]E24/7 Energy Access model calculates future power demand development and the resulting possible load curves. Actual load curves – particularly in developing countries with low access to energy rates – do not yet exist and must be calculated based on a set of assumptions. The model generates load curves and resulting annual power demands for three different consumer groups/sectors:

- households
- industry and business, and
- transport.

While each sector has its specific consumer groups and applications, the same set of parameters are used to calculate load curves:

- electrical applications in use
- demand pattern (24hours)
- efficiency progress (base year 2015) for 2020 until 2050, in 5-year steps.

Methodology: Load curve calculation for households

The model differentiates 9 household groups with various degrees of electrification and equipment:

- Rural – phase 1: Minimal electrification stage
- Rural – phase 2: White goods are introduced and increase the overall demand
- Rural – phase 3: Full equipped western standard household with electrical cooking and air conditioning and vehicle(s).
- Urban single: household with minimal equipment
- Urban shared Flat: 3-5 persons share one apartment in the centre of larger cities. Full equipped western household, but without vehicles.
- Urban – Family 1: 2 adults 2-3 children – middle income
- Urban – Family 2: 2 adults more than 3 children and/or higher income
- Suburbia 1: average family, middle income, full equipment high transport demand due to extensive commuting
- Suburbia 2: High income household, fully equipped, extreme high transport demand due to high end vehicles and extensive commuting.

The following electrical equipment and applications can be selected from a drop-down menu:

- Lighting: 4 different light bulb types
- Cooking: 10 different cooking stoves (2+4-burner, electricity, gas, firewood)
- Entertainment: 3 different computer, TV and radio types
- White goods: 2 different efficiency each for washing machines, dryer, fridge, freezer
- Climatisation: 2 different efficiency levels each for fan, air-conditioning
- Water heating: a selection of direct electric, heat pump and solar

For details about the household demand projections and categories developed for the Bangladesh analysis see section 5.1.8

Load curve calculation for business and industry

The industrial sector is clustered in 8 groups based on widely used statistical categories:

- Agriculture
- Manufacturer
- Mining
- Iron and steel
- Cement industry
- Construction industry
- Chemical industry
- Service and trade

For each sector are between 2 and 6 different efficiency levels available. The data is taken from international statistical publications [IEA (2016)[60], IRENA (2016)[61], DLR (2012)[62]].

[60] IEA (2016), World Energy Balances, 2016
[61] Report citation IRENA (2016), REmap: Roadmap for a Renewable Energy Future, 2016 Edition. International Renewable Energy Agency (IRENA), Abu Dhabi, www.irena.org/remap
[62] DLR et. al. (2012) Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global Schlussbericht BMU - FKZ 03MAP146 (DLR), (IWES), (IFNE), 29 March 2012

Load curve calculation for transport

The transport sector is divided into individual, public and freight, with the following technologies:

Individual transport

- two-wheeled: bicycle, e-bike, scooter, e-scooter
- combustion engines: small, medium and large (SUV) car
- electric vehicles: small, medium, large fuel cell

Public Transport

- light rail (electric)
- rail (electric)
- rail (diesel)
- mini-bus (diesel)
- mini-bus (electric)
- large bus (diesel)
- large bus electric/fuel cell

Freight transport

- battery electric transport (medium size)
- fuel cell/electric transport (large)
- diesel transport (medium)
- diesel transport (large)

The various vehicles can be assigned to the analysed sectors of households, industry and trade.

Load curve generation via demand pattern

The energy intensities for various industry sectors; small- and medium businesses and transport technologies are derived from the long-term model (see 4.4) and further broken down by hour. Heavy industry sectors are assumed to require baseload, while public- and individual transport are expected to need baseload with demand reduction from midnight until 5am. The development of household profiles is based on interviews with local households in Bangladesh about typical demand patterns. with the specific times for meals and their preparation, average equipment features, etc., used for the calculation of possible load curves.

4.5.2 THE [R]E24/7 DISPATCH MODULE

Though the dispatch module for the [R]E24/7 energy access model has been developed specifically for developing countries, integral parts have been taken from the model developed for analysis of generation and storage needs for a micro grid on Kangaroo Island (Dunstan, Fattal, James, & Teske, 2016) and Australian Storage Requirements (ACOLA)[63]. The key objective of the modelling is to calculate the theoretical generation and storage requirements for energy adequacy for each cluster and for the whole survey region.

In 2018/2019 the [R]E 24/7 power analysis model was further developed for a global energy scenario model (Teske et. al. 2019)[64].

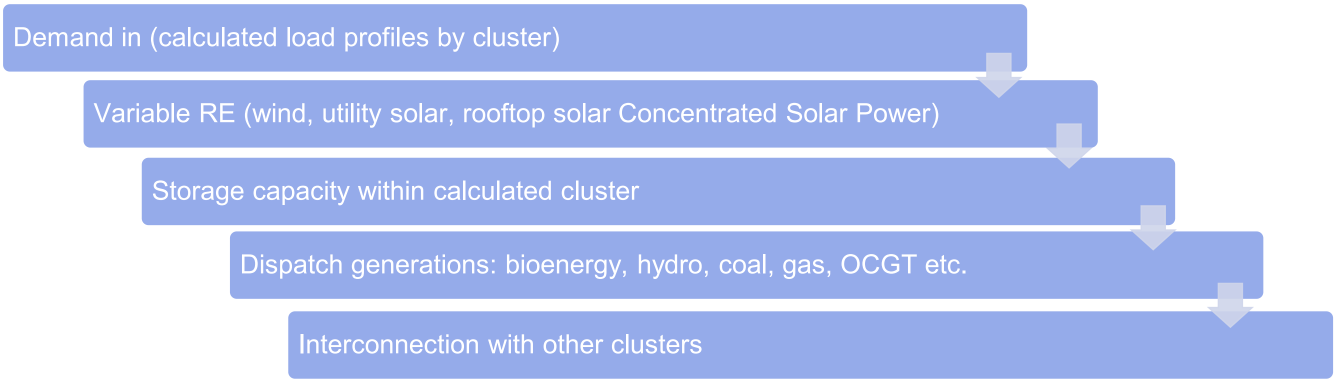
Figure 6 provides an overview of the dispatch calculation process. The dispatch order can be changed in regard to the order of renewables and the dispatch power plant, as well as the order of the generation categories: variable, dispatch generation and storage. Key inputs include the generation capacities by type, demand projections and load curves for each cluster, interconnection with other clusters and meteorological data to calculate solar and wind power generation in hourly resolutions. Installed capacities are derived from the long-

[63] Rutovitz, J., James, G., Teske S., Mpofu, S., Usher, J, Morris, T., and Alexander, D. 2017. Storage Requirements for Reliable Electricity in Australia. Report prepared by the Institute for Sustainable Futures for the Australian Council of Learned Academies (ACOLA)

[64] Teske et. al. 2019, Achieving the Paris Climate Agreement Goals – 2019 Global and Regional 100% Renewable Energy Scenarios with Non-energy GHG Pathways for +1.5°C and +2°C, Springer Nature, Open Access, ISBN 9783030058432 (online) 9783030058425 (print), February 2019

term projections described in 4.4, while the resulting annual generation in megawatt hours is calculated on the basis of meteorological data (in case of solar and wind) or dispatch requirements.

Figure 6: Dispatch order within one cluster



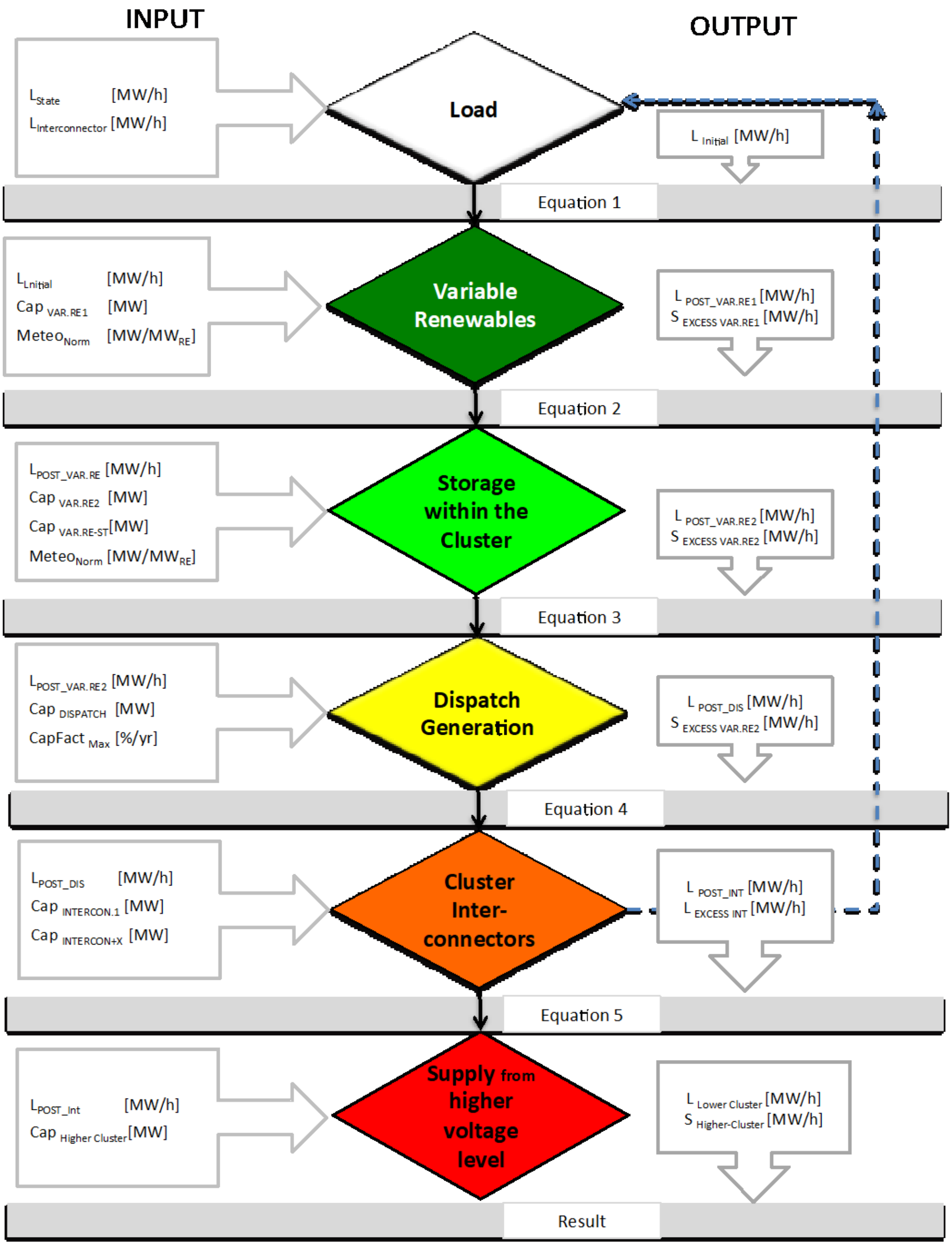
While the MESAP/PlaNet based RE24/7 mode (Teske 2015)[65] simulates power flows across multiple voltage levels including the high voltage transmission level, the present model iteration does not include different voltage levels. The interconnections of clusters are limited to directly connected and/or neighbouring regions in regard to voltage levels.

[65] Teske, S (2015), Thesis, 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, chapter 2, University Flensburg, Germany

Overview: input and output – [R]E 24/7 energy dispatch model

Figure 7 provides an overview of the input and output parameter and dispatch order. While the model allows a change in the dispatch order, the 100 per cent renewable energy analysis always follows the same dispatch logic. The model identifies excess renewable production, defined as potential wind and solar photovoltaic generation greater than the actual hourly demand in MW during a specific hour. In order to avoid curtailment, the surplus renewable electricity must be stored in some form of electric storage technology or exported to a different cluster. Within the model, excess renewable production accumulates through the dispatch order. If storage is present, it will charge the storage within the limits of the input capacity. If no storage is included, this potential excess renewable production is reported as 'potential curtailment' (pre-storage). It has been assumed that a certain amount of behind-the-meter consumer batteries will be installed, independent of system requirements.

Figure 7: Overview: input, output and dispatch order



4.6 EMPLOYMENT ANALYSIS

The methodology outlined in this section comprises of two dimensions: the total employment in the energy sector and the occupational breakdown. The methodology for analysing the total employment in the energy sector was first developed in 2009 for the Greenpeace Energy [R]evolution study (see Rutovitz et al., 2015; Rutovitz and Atherton, 2009). This methodology has been updated for a global energy scenario project by UTS-ISF, in partnership with the German Aerospace Centre (DLR), Institute for Engineering Thermodynamics, Department of Systems Analysis and Technology Assessment (STB), and funded by the Leonardo DiCaprio Foundation (Teske, 2019) and the German Greenpeace Foundation (Greenpeace Umweltstiftung).

4.6.1 TOTAL EMPLOYMENT IN THE ENERGY SECTOR

4.6.1.1 Overview of methodology

This study projects the total employment in the energy sector against two scenarios: A 2.0°C Scenario for 100% renewable energy and a reference case 5.0°C Scenario.
Employment is projected for each of scenarios from 2015 until 2050 for Bangladesh. The calculations are based on a series of employment multipliers and the projections for energy use and capacity. Only direct employment is included, namely jobs in construction, manufacturing, operations and maintenance, and fuel supply associated with electricity generation and direct heat provision. An overview of the total employment methodology is given in Figure 8.

Figure 8: Total employment calculation: methodological overview

Manufacturing (for local use)	=	MW installed per year in region	x	Manufacturing employment factor	X	Regional job multiplier for year	x	% local manufacturing
Manufacturing (for export)	=	MW exported per year	x	Manufacturing employment factor	X	Regional job multiplier for year		
Construction	=	MW installed per year	x	Construction employment factor	X	Regional job multiplier for year		
Operation and Maintenance	=	Cumulative capacity	x	O&M employment factor	X	Regional job multiplier for year		
Fuel supply (nuclear)	=	Electricity generation	x	Fuel employment factor	X	Regional job multiplier for year		
Fuel supply (coal, gas and biomass)	=	Primary energy demand plus exports	x	Fuel employment factor (always regional for coal)	X	Regional job multiplier for year	x	% of local production
Heat supply	=	MW installed per year	x	Employment factor for heat	X	Regional job multiplier for year		

Jobs in region = Manufacturing + Construction + Operation and maintenance (O&M) + Fuel + Heat

Employment factors at 2020, 2030 or 2050 = 2015 employment factor x Technology decline factor [number of years after 2015]

The main inputs for the quantitative employment calculations are outlined below.

4.6.1.2 For each scenario (2.0°C and 5.0°C):

- the electrical and heating capacity that will be installed each year for each technology;
- the primary energy demand for coal, gas, and biomass fuels in the electricity and heating sectors;
- the amount of electricity generated per year from nuclear power, oil, and diesel.

4.6.1.3 For each technology:

- ‘employment factors’, or the number of jobs per unit of capacity, separated into manufacturing, construction, operation, and maintenance, and per unit of primary energy for fuel supply;
- for the 2020, 2030, and 2050 calculations, a ‘decline factor’ for each technology, which reduces the employment factors by a certain percentage per year. This reflects the fact that employment per unit decreases as technology efficiencies improve.

4.6.1.4 For Bangladesh – in comparison to OECD:

- the percentage of local manufacturing and domestic fuel production in each region, to calculate the proportions of jobs in manufacturing and fuel production that occur in the region;
- the percentage of world trade in coal and gas fuels, and traded renewable components that originates in each region.
- a ‘regional job multiplier’, which indicates how labour-intensive the economic activity is in that region compared with the OECD, is used to adjust the OECD employment factors because local data was not available.
- a set of ‘decline factors’ for each technology, based on the projected costs for that region in the Reference Scenario.

The figures for the increase in electrical capacity and energy use from each scenario are multiplied by the employment factors for each of the technologies, and then adjusted for regional labour intensity and the proportion of fuel or manufacturing that occurs locally.

A range of data sources were used for the model inputs, including the International Energy Agency, US Energy Information Administration, BP Statistical Review of World Energy, US National Renewable Energy Laboratory, International Labour Organization, World Bank, industry associations, national statistics, company reports, academic literature, and the UTS-ISF’s own research.

These calculations only take into account direct employment; for example, the construction team required to build a new wind farm. They do not include indirect employment; for example, the extra services provided in a town to accommodate the construction team.

The calculations do not include jobs in energy efficiency because this is beyond the scope of this project. The large number of assumptions required to make these calculations means that employment numbers are only estimates, especially for regions where few data exist. However, within the limits of data availability, the figures presented are representative of employment levels under the given scenarios.

4.6.1.5 Employment factors

Employment factors were used to calculate the number of jobs required per unit of electrical or heating capacity, or per unit of fuel. The employment factors differ depending on whether they involve manufacturing, construction, operation and maintenance, or fuel supply. Information about these factors usually comes from OECD countries because that is where most data are collected, although local data were used wherever possible. For job calculations in non-OECD regions, regional adjustments were made when a local factor was not available. The employment factor for India is used for Bangladesh in our calculations, the factor is shown in Table 3.

Table 3: Summary of employment factors

	Construction/ installation	Manufacturing	Operations & maintenance	Fuel – Primary energy demand
	Job years/ MW	Job years/ MW	Jobs/MW	
Coal	11.4	5.1	0.14	Regional
Gas	1.8	2.9	0.14	Regional
Nuclear	11.8	1.3	0.6	0.001 jobs per GWh final energy demand
Biomass	14.0	2.9	1.5	29.9 Jobs/PJ
Hydro-large	7.5	3.9	0.2	
Hydro-small	15.8	11.1	4.9	
Wind onshore	3.0	3.4	0.3	
Wind offshore	6.5	13.6	0.15	
PV	13.0	6.7	0.7	
Geothermal	6.8	3.9	0.4	
Solar thermal	8.9	4.0	0.7	
Ocean	10.3	10.3	0.6	
Geothermal – heat	6.9 jobs/ MW (construction and manufacturing)			
Solar – heat	8.4 jobs/ MW (construction and manufacturing)			
Nuclear decommissioning	0.95 jobs per MW decommissioned			
Combined heat and power	CHP technologies use the factor for the technology, i.e. coal, gas, biomass, geothermal, etc., increased by a factor of 1.5 for O&M only.			

4.6.1.6 Coal fuel supply:

The employment factors for coal are particularly important to have at the regional level, because employment per tonne varies significantly across the world regions and because coal plays a significant role in energy production in many countries. In Australia and the USA, coal is extracted at an average rate of more than 9000 tonnes per person per year, whereas in Europe, the average coal miner is responsible for less than 1000 tonnes per year. China has relatively low per capita productivity at present, with 650 tonnes per worker per year, but the annual increases in productivity are very high. India and Eurasia have significantly increased their productivity since a similar analysis was performed in 2015. Local data were also used for gas extraction in every region except India, the Middle East, and Non-OECD-Asia. The calculation of coal and gas employment per petajoule (PJ) drew on data from national statistics and company reports, combined with production figures from the BP Statistical Review of World Energy 2018 (BP-SR 2018) or other sources. Data were collected for as many major coal-producing countries as possible, and coverage was obtained for 90% of the world coal production.

Table 4: Employment factors used for coal fuel supply (mining and associated jobs)

	Employment factor Jobs per PJ	Tonnes per person per year (coal equivalent)
World average	36.2	943
India (and Bangladesh)	33.6	1 016

4.6.1.7 Regional adjustments

The employment factors used in this model for energy technologies other than coal mining were usually for OECD regions, which are typically wealthier than other regions. A regional multiplier was applied to make the jobs per MW more realistic for other parts of the world. In developing countries, there are generally more jobs per unit of electricity because those countries have more labour-intensive practices. The multipliers change over the study period, consistent with the projections for GDP per worker. This reflects the fact that as prosperity increases, labour intensity tends to fall. The multipliers are shown in Table 3.

Table 5: Regional multipliers used for the quantitative calculation of employment

	2015	2020	2030	2040	2050
OECD (North America, Europe, Pacific)	1.0	1.0	1.0	1.0	1.0
Latin America	3.4	3.4	3.4	3.1	2.8
Africa	5.7	5.7	5.5	5.2	4.8
Middle East	1.4	1.5	1.4	1.4	1.2
Eastern Europe/Eurasia	2.4	2.4	2.2	2.0	1.8
India (+ Bangladesh)	7.0	5.5	3.7	2.7	2.2
Developing Asia	6.1	5.2	4.1	3.5	3.1
China	2.6	2.2	1.6	1.3	1.2

Source: Derived from ILO (2013) Key Indicators of the Labour Market, eighth edition software, with growth in GDP per capita derived from IEA World Energy Outlook 2018 and World Bank data.

5 SCENARIO ASSUMPTIONS

5.1 BANGLADESH COUNTRY OVERVIEW

The country overview is based on research by the Coastal Development Partnership (CDP) and the World Future Council (WFC).

5.1.1 POLITICAL CONTEXT

Bangladesh is a single state under a presidential parliamentary democratic system. The parliament of Bangladesh is based in Dhaka. The current parliament is the 11th of Bangladesh with 350 members. Political power since independence in 1971 has remained highly centralised around inherited political leadership positions. Extensive power and responsibility to control development directions has been in the hands of a few local elites, controlling the lowest tiers (Union Parishad) to the highest tiers (national parliaments). Bangladesh is currently embarked on its seventh 5-year plan (2016-2020)[66] and its Perspectives Plan (2010-2021)[67]. Underlying the Perspectives Plan is Bangladesh's Vision 2021 which aims to turn Bangladesh into a middle-income country by 2021 – the 50th anniversary of the country's independence. The Perspectives Plan is a roadmap for this vision constituting the country's sustainable development agenda. It aims to develop Bangladesh into a resourceful and modern, resilient economy through efficient use of information and communication technology which has been described by the Prime Minister as turning Bangladesh into a "Digital Bangladesh". To do so, the Vision's targets are to: 1) become a participatory democracy; 2) to have an efficient, accountable, transparent and decentralised system of governance; 3) to become a poverty-free middle-income country; 4) to have a nation of healthy citizens; 5) to develop a skilled and creative human resource; 6) to become a globally integrated regional economic and commercial hub; 7) to be environmentally sustainable; and 8) to be a more inclusive and equitable society. These eight goals were identified after a one-year long activism of Bangladesh's civil society throughout 2006, when local level dialogues were held across the country[68]. In order to achieve these goals, the Vision 2021 and the Perspective Plan identified the following priority areas[69]:

- Ensuring broad-based growth and food security;
- Addressing globalization and regional cooperation;
- Providing energy security and development and welfare;
- Establishing a knowledge based society;
- Building a sound infrastructure;
- Ensuring effective governance;
- Mitigating the impacts of climate change;
- Creating a caring society;
- Promoting innovation under a "Digital Bangladesh".

5.1.2 POPULATION DEVELOPMENT

Bangladesh is a densely populated country in South Asia, bordering Burma, India, Nepal and Bhutan. Bangladesh has an estimated 2019 population of 168.07 million, up from the 2013 estimate of 156.5 million. This makes Bangladesh the 8th most populous country in the world.[70]

Through the 1960s and 1970s, the birth rate in Bangladesh was among the highest in the world but that started to slow down considerably in the 1980s. The fertility rate is now at 2.4 children born per woman. Bangladesh has a fairly young population with 34% aged 15 and younger and just 5% aged 65 and older.[70]

It has a population density of 1139 persons per km^2[6], 12% of the total population lives in 20 cities – half of that urban population lives in Dhaka. Over 80 per cent of the population living in rural areas[71]. Projections for population and economic growth are important factors in energy scenario-building because they affect the size

[66] http://www.lged.gov.bd/UploadedDocument/UnitPublication/1/361/7th_FYP_18_02_2016.pdf
[67] https://bangladesh.gov.bd/sites/default/files/files/bangladesh.gov.bd/page/6dca6a2a_9857_4656_bce6_139584b7f160/Perspective-Plan-of-Bangladesh.pdf
[68] *https://cpd.org.bd/bangladesh-vision-2021/*
[69] https://bangladesh.gov.bd/sites/default/files/files/bangladesh.gov.bd/page/6dca6a2a_9857_4656_bce6_139584b7f160/Perspective-Plan-of-Bangladesh.pdf
[70] World Population Review (2019) http://worldpopulationreview.com/countries/bangladesh-population/
[71] Calculated with data from World Population Review (2019) http://worldpopulationreview.com/countries/bangladesh-population

and composition of energy demand, both directly and through their impact on economic growth and development. World Bank projections detail expected population development (see Table 3).

5.1.3 ECONOMIC CONTEXT

Despite being among the five fastest growing economies of the world[72], Bangladesh is one of the world's poorest economies in terms of per capita income, averaging US$ 1750 per year[73] – equivalent to less than 15 per cent of the global average. Although its per capita income is between low income countries (US$ 785) and lower middle-income countries (US$ 2,192) according to the World Bank definition and database (World Bank 2019). The Bangladeshi economy has been identified by Goldman Sachs as one of the "Next Eleven" economies globally (Buckley 2016)[74]. The annual GDP growth was stable over 5% since 2004 increasing to around 6.5% to 7% per year since 2015 (World Bank 2019).

The sustained economic expansion has resulted in increased demand for infrastructure to support continued growth in industry and in services such as telecommunications, transport and energy. Bangladesh's economy is transitioning away from its historic reliance on the agriculture sector[75], with the industrial sector set to grow at 9-10% annually while service sector growth is forecasted at a still robust 6% annually (Buckley 2016)[10]. This increasing share of the economy by the Industrial sector has implications for the electricity sector, both in regard to the overall energy demand – both for heat and electricity – as well as for higher electric loads which requires infrastructural changes (power lines).

Table 6: Bangladesh's population and GDP projections

	t	2015	2020	2025	2030	2035	2040	2045	2050
GDP	[billion $/a]	195	261	373	533	723	936	1,161	1,221
GDP/Person	[$/capita]	1,232	1,561	2,122	2,886	3,726	4,705	5,836	6,232
Population	[million]	158	167	175	184	194	199	199	196
		2015-2050	**2015-2020**	**2020-2025**	**2025-2030**	**2030-2035**	**2035-2040**	**2040-2045**	**2045-2050**
Economic growth	[%/a]	0	6.0%	7.4%	7.4%	6.3%	5.3%	4.4%	1.0%
Population growth	[%/a]		1.1%	1.0%	1.0%	1.0%	0.5%	0.0%	-0.3%

The population and GDP shown in Table 3 are based on projections of the Bangladesh government which have been used for the Power System Master Plan 2016 (PSMP 2016)[95.]

5.1.4 SOCIAL CONTEXT

According to the Sustainable & Renewable Energy Development Authority (SREDA), Power Division within the Ministry of Power, Energy, & Mineral Resources of the Government of the Peoples Republic of Bangladesh, poverty in Bangladesh is widespread, but has declined considerably. Yet, Bangladesh still remains in the "Low Human Development" category of the global Human Development Index (HDI), ranking 136th out of 189 countries[76]. In 2015, about 25 percent of the population lived below the national poverty line, down from 32 percent in 2010 and 49 percent in 2000. Despite this considerable improvement, Bangladesh still has substantially higher poverty rates (in terms of purchasing power parity, or PPP) than other countries in the South Asia region. Bangladesh had a poverty rate of 43.3 percent in 2010 (in terms of purchasing power parity, or PPP), while the regional average was just 24.5 percent. According to the UN Human Development Index 2018, more than two-fifth (41.1%) of Bangladesh's population is living with multidimensional poverty and nearly one-sixth (16.2%) lives with severe multidimensional poverty[77]. The incidence of poverty in Bangladesh is highest in the Rangpur and Barisal administrative divisions and northern Dhaka. According to BBS Census of Slum Areas and Floating Population 2014, the number of slums has increased by 366% and the number of slum dwellers

[72] http://www.worldbank.org/en/news/feature/2019/04/04/bangladesh-development-update-regulatory-predictability-can-sustain-high-growth
[73] https://data.worldbank.org/country/bangladesh
[74] Buckley et. al (2016) Bangladesh Electricity Transition: A Diverse, Secure and Deflationary Way Forward, Institute for Energy Economics and Financial Analysis (IEEFA), November 2018, Tim Buckley, Simon Nicholas and Sara Jane Ahmed
[75] Yet, the agricultural sector, despite contributing only around 17% to the country's GDP, engages around 48% of the labour force of the country.
[76] http://hdr.undp.org/en/countries/profiles/BGD
[77] http://hdr.undp.org/en/composite/MPI

doubled, more than 2.2 million people live in slums[78]. Each year, around half a million people migrate from climate vulnerable areas to Dhaka, increasing the number of slums further[79].

The participation of women in economic activities is very limited, due to their responsibilities in their households (fetching water, collecting biomass or fuel wood etc.), lack of ownership of land and missing opportunities for employment, due to socio-cultural practices. Female labour force participation is around 34% - as compared to 82% for men. In addition, women only earn roughly half of what their male counterparts earn. These differences put an additional burden on women-headed households in poverty-stricken urban areas. Entrepreneurship is limited to men and only a quarter of women have their own bank account, making them virtually dependent on their husbands.

Nationwide, 74 percent of the population has access to electricity (up from only about 20 percent in 1990). Electrification rates are highest in urban areas, where only about one percent lack access to electricity. In rural areas, 34 percent do not have electricity. Electrification rates have improved in recent years because of rapid acceleration of grid connection to rural areas, coupled with the installation of solar home systems—since 2003, about 3.8 million solar home systems have been installed, benefiting around 20 million people (SREP IP 2015)[80].

5.1.5 ENVIRONMENTAL CONTEXT

Bangladesh will be among the most affected countries in South Asia by an expected 2°C rise in the world's average temperatures in the next decades, with rising sea levels and more extreme heat[81].
Despite the insignificant share of past and current greenhouse gas emissions, Bangladesh has been trying to adopt a sustainable, low-carbon development pathway since 2009 and further with Vision 2021. In spite of the globally comparatively low emissions, Bangladesh is one of the countries which is most vulnerable to climate change and ranks 6th, according to the Global Climate Risk Index 2016[82]. The country will suffer an annual loss of 2% of GDP by 2050 (ADB, 2014)[83], due to the adverse effects of climate change. Surface prone to such climate catastrophes – char land, flash flood prone land, coastal tidal regions, hilly areas etc. – constitute around 41% of the country's land. Climate occurrences such as flooding, droughts, cyclones and fluctuations in temperature and rainfall are frequent. Indeed, a severe cyclone strikes the country every three years[84], one-fifth of the country is flooded annually and extreme floods even swallow up to two-thirds of the country[85]. This forces poor rural households to migrate to urban areas. In fact, 26,000 people lose their land due to flooding and related soil erosion every year[86]. In 2010, nearly 0.6 million people were displaced by natural disasters in Bangladesh[87]. By 2050, sea level rise could displace as many as 20 million people in Bangladesh[88]. The southern region of Bangladesh may lose 40% of productive land if 65cm sea level rise happen by the 2080[89]. In Bangladesh, the salinity affected area has increased by 3.5% during 2000-2009 period[90] (Ahsan, 2010). Within a decade (from 2000 to 2009), saline water intrusion increased up to 15 km north of the coast and reached up to 160 km inland in the dry season due to low flow from upstream rivers[91]. The area exposed to high salinity (>5 ppt) will increase around 24% by 2050[92] and the population exposed to high salinity (>5 ppt) will be around 14 million in 2050[93]. Between 1970 and 2010, river salinity has increased from 2 to 10 times[94].

[78] http://www.bbs.gov.bd/WebTestApplication/userfiles/Image/Slum/FloatingPopulation2014.pdf.
[79] https://www.dhakatribune.com/opinion/op-ed/2019/02/28/the-impacts-of-migration
[80] SREP IP (2015) Investment Plan for Bangladesh, Government of the People's Republic of Bangladesh; Sustainable and Renewable Development Authority (SREDA); Power Division; Ministry of Power, Energy & Mineral Resources; www.sreda.gov; Ref No: 27.02.0000.000.24.002.14-501, October 2015
[81] World Bank, 2013: Warming Climate to Hit Bangladesh Hard with Sea Level Rise, More Floods and Cyclones
[82] Sönke Kreft, David Eckstein, Lukas Dorsch & Livia Fischer, 2015: Global Climate Risk Index 2016; Who Suffers Most from Extreme Weather Events? Weather-related Loss Events in 2014 and 1995 to 2014. Germanwatch, www.germanwatch.org/en/cri
[83] http://www.adb.org/news/bangladesh-could-see-climate-change-losses-reach-over-9-gdp-report
[84] Ahammad, R.; Nandy, P.; Husnain, P., 2013: Unlocking ecosystem-based adaptation opportunities in coastal Bangladesh. J. Coast. Conserv. 17, 833–840.
[85] Minar, M.H., M. Belal Hossain and M.D. Shamsuddin, 2013: Climate Change and Coastal Zone of Bangladesh: Vulnerability, Resilience and Adaptability, Middle-East Journal of Scientific Research 13 (1): 114-120, 2013.
[86] http://www.ipsnews.net/2014/10/bangladeshi-char-dwellers-in-search-of-higher-ground/
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[88] World Bank, 2010: Economics of Adaptation to Climate Change: Bangladesh, the World Bank, Dhaka.
[89] Rahman M. A., Rahman S., 2015: Natural and traditional defense mechanisms to reduce climate risks in coastal zones of Bangladesh, Weather and Climate Extremes Volume 7, March 2015, Pages 84–95.
[90] Ahsan, M., 2010: Saline Soils of Bangladesh, SRMAF Project, Soil Resource Development Institute (SRDI), Ministry of Agriculture; Government of the People's Republic of Bangladesh.
[91] SRDI 2010: Saline Soils of Bangladesh; Soil Resources Development Institute (SRDI), Ministry of Agriculture: Dhaka, Bangladesh.
[92] CEGIS and DoE, 2011: Final report on programmes containing measures to facilitate adaptation to climate change of the second national communication project of Bangladesh. Dhaka, Department of Environment.
[93] CEGIS, 2006: Impact of Sea Level Rise on The Land use Suitability and Adaptation Options, Component of SEMP. Center for Environmental and Geographic Information Services, Dhaka.
[94] Hossain MS, Dearing JA, Rahman MM, Salehin M, 2015: Recent changes in ecosystem services and human wellbeing in the coastal zone. Reg Environ Change 1–15. doi:10.1007/s10113- 014-0748-z

5.2 POWER SYSTEM MASTER PLAN – 2016

Bangladesh has published a Power System Master Plan (PSMP) in 2016. The following section documents this master plan and is taken from the original executive summary (PSMP 2016)[95]:

The Power System Master Plan (PSMP) 2016, sponsored by Japan International Cooperation Agency (JICA), aims at assisting Bangladesh in formulating an extensive energy and power development plan up to the year 2041, covering energy balance, power balance, and tariff strategies.

Bangladesh has an aspiration to become a high-income country by 2041. The development of energy and power infrastructure therefore pursues not only the quantity but also the quality to realize the long-term economic development.

Since Bangladesh is facing to the depletion of domestic gas supply, various issues such as sustainable development harmonizing with economic optimization, improvement of power quality for the forthcoming high-tech industries, and the discipline of operation and maintenance (O&M) for power plants need to be addressed holistically.

Furthermore, energy subsidy is also a tough challenge, because there's always a concern that drastic increase of fuel and electricity prices may trigger another negative effect on the national economy. A meticulous analysis is required to find the best pathway to attain the sustainability of the energy and power sectors in balancing with the economic growth. The new PSMP study covers all the aforementioned challenges comprehensively, and come up with feasible proposals and action plans for Bangladesh to implement.

The People's Republic of Bangladesh (hereinafter "Bangladesh") mainly depends on Domestic Natural Gas. The Government of Bangladesh formulated the Power System Master Plan 2010 (PSMP2010) targeting, among others, for a long-term energy diversification due to the foreseen decrease in the production volume of Natural Gas. However, energy development is not on track compared with the PSMP2010 plan, because various assumptions about expected sources for base load energy have subsequently changed. In particular, a review is needed reflecting namely exponential increasing of oil based rental power plants and development constraints of domestic primary energy.

Currently, many of power plants in Bangladesh cannot generate electricity as specified in terms of power, thermal efficiency etc. for each unit. Daily shortage of power does not allow to stop facilities and to undertake periodical maintenance in a planned way. Legal framework does not stipulate preventive maintenance works as an obligation for plant owner. Low financial soundness of public generating companies due to low electricity tariff does not permit to purchase in advance necessary spare parts. In order to secure a stable electricity supply, we need to find out solutions to all of these issues and to establish a comprehensive institutional framework. Moreover, hydro power generation studies (on small scale hydropower plants of 30 kW ～ 5MW and a pumped storage power plant as a regulator between demand and supply) have become an urgent issue through the government's renewable energy promotion policy.

Based on the aid policy of the Government of Japan for Bangladesh, the Japan International Cooperation Agency (JICA) is considering the power sector as one of priority areas assisting Bangladesh not only by Yen Loans to the construction of power plants (gas combined cycle, super-critical using import coal and hydropower), transmission and distribution lines and development of renewable energy but also by Technical Assistance such as the master plan for energy efficiency.

JICA is thus supporting the entire power and energy sector. It was under such circumstances that JICA decided to undertake the Power System Master Plan 2016 (PSMP2016) in order to grasp middle to long term development issues and risks and to formulate a comprehensive and result-oriented aid strategy for the energy sector by examining effective approaches for each issue. After the start of this survey, however, the Government of Bangladesh announced, in its new policy "Vision 2041", an important target of becoming one of the developed nations by 2041.

Consequently, for the power and energy sector which receives quite dominant development budget, it has become newly necessary to secure the consistency between the economic development strategy of the country toward joining the developed countries and the master plan of the power and energy sector (PSMP). With such consistency only, JICA will be able to make the best use of the result of this survey as basic information for the future cooperation.

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[95] PSMP (2016) - Power System Master Plan 2016, Summary, Supported by Japan International Cooperation Agency (JICA); Tokyo Electric Power Services Co., Ltd.; Tokyo Electric Power Company Holdings, Inc. Power Division; Ministry of Power, Energy and Mineral Resources; Government of the People's Republic of Bangladesh; September 2016

To study consistency between an economic growth strategy and PSMP, an additional survey on estimated changes of the industrial structure that will be brought by the coming strategy and a precise forecast of future demand of primary energy and corresponding supply policy must be added to this survey, since the power sector is one of the largest sectors which consume primary energy. It was therefore decided to estimate in this survey the most rational and probable demand and supply scenarios of primary energy for other sectors than power sector such as fertilizer, industry, commerce and transportation.

Moreover, the power sector will be required to cope with the changes of industrial structure in line with the economic growth as expected in order for Bangladesh to join the developed nations. Specifically, improvement of the quality of electricity is indispensable given the view of the government that sophistication of industries is generally essential for the nation to become one of the developed countries.

After the commencement of this survey, Bangladesh started considering also a specific plan to expand power import from neighbouring countries such as India, Bhutan and Nepal. Usually, international cooperation in power system is oriented toward direct cooperation by means of alternate current and, to do so, quality of electricity is required to be equivalent or better than that of counterpart countries. It is therefore necessary for the promotion of international cooperation to improve the quality of electricity. Since this issue will be a concern to the entire power sector in revising PSMP, it was also decided to add to this survey collection of additional basic information and examination of feasible measures responding to the specific needs of quality improvement.

Therefore, the collection and analysis of the information on the plan for the supply and demand for primary energy sources and the needs for the improvement of the quality of power supply were included in this survey that had consisted of the revision of power development plan and the studies on the institutional reform for the improvement of O&M and the introduction of hydropower generation.

This inclusion of the new survey subject enabled the formulation of a new master plan that covers not only the power sector but also the energy sector comprehensively and describes the interface between the two sectors. The new master plan is the output of the first joint survey of the two divisions in the Ministry of Power, Energy and Mineral Resources (MoPEMR), Power Division and Energy Division, and this survey is expected to serve as a good precedent of the cooperation between them in the implementation of policies in the power and energy sectors.

This master plan provided the basis for the reference case described in section 5.7.

5.2.1 ECONOMIC DEVELOPMENT PROJECTIONS FOR POWER SYSTEM MASTER PLAN

Table 7 and Figure 9 compares the actual performance of GDP growth rate with the projected growth rate in PSMP 2010 and the target of GDP growth rate in the Sixth Five-Year Plan that was set forth by the GOB in 2011. During the period of the Sixth Five-Year Plan, Bangladesh achieved annual average of 6.3% growth rate. This was higher than the actual growth rate in each of the past five-year plans (1st-5th) and the result implies that the country started taking a path of rapid economic growth (PSMP 2016)[95].

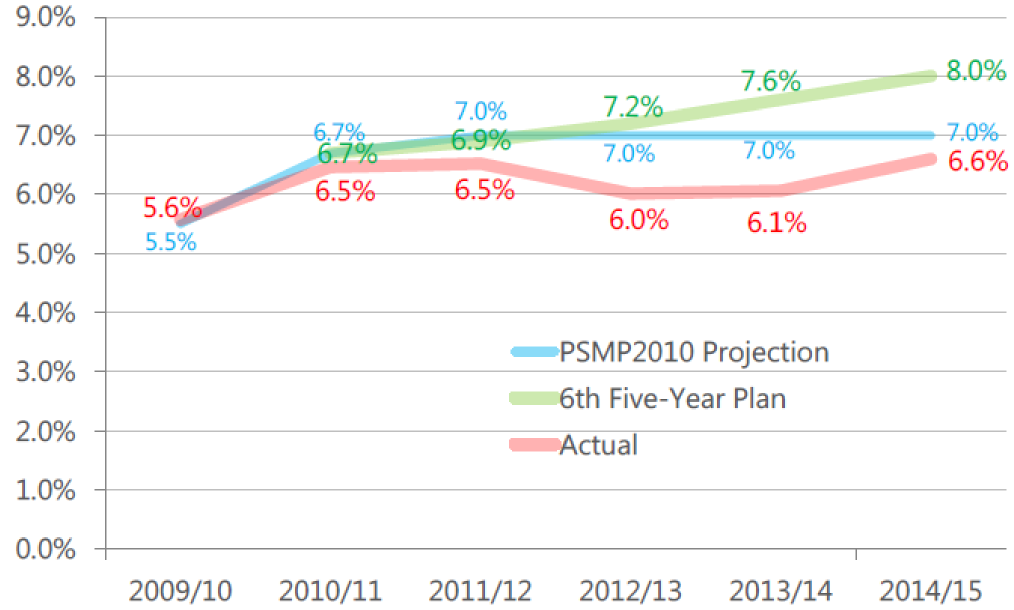
However, the economic growth rate still underperformed the target of the Sixth Five-Year Plan (average 7.3% growth) every year and the gap were widened in the later years. The actual growth rate was also lower than the projection of PSMP2010 that expected the Bangladesh economy to attain 7% growth. The main factor of this gap is supposed to be the delay of economic reforms for inducing further economic growth. The country may not be able to fully reap the opportunity of economic development and the growth rate may continue underperforming the government's expectation unless economic policies to promote the development are in place as planned (PSMP 2016)[95].

Table 7: Bangladesh - PSMP2010 Review (Economic Development)

Financial Year	GDP Growth Rate (real price)		
	PSMP 2010 Projection	6th Five-Year Plan	Actual
	[%]	[%]	[%]
2009/10	5.5%	-	5.6%
2010/11	6.7%	6.7%	6.5%
2011/12	7.0%	6.9%	6.5%
2012/13	7.0%	7.2%	6.0%
2013/14	7.0%	7.6%	6.1%

2014/15	7.0%	8.0%	6.6%
Average	6.9%	7.3%	6.3%

Figure 9: Bangladesh – PSMP 2016 – GDP Growth Rate (real)



Source: JICA Survey Team

5.2.2 ENERGY DEMAND – STATUS QUO

Bangladesh's national energy demand is based on residential needs – about half of 2015 needs – and commercial, industrial and transport demand. (PSMP 2016)[95]. Bangladesh's per capita electricity consumption is very low – 310 kWh per year in 2014, compared to East Asia and Pacific average consumption of 3677 kWh per year, and the 2,500 kWh per annum global average consumption (WORLDBANK 2019)[96].

5.2.3 ENERGY DEMAND – FUTURE PROJECTIONS

Government plan until 2041

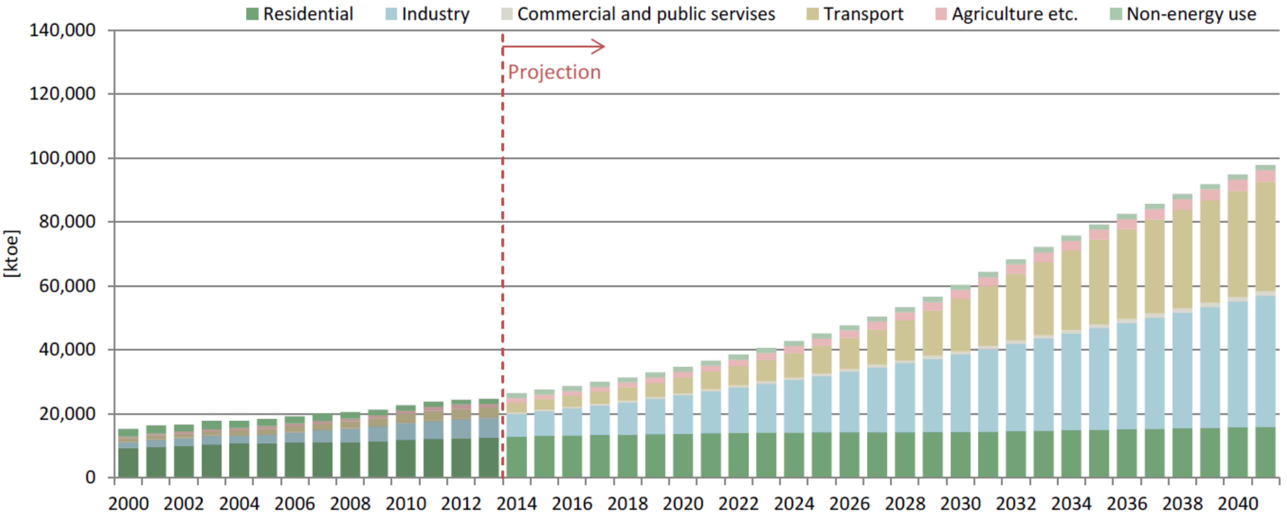
The *Bangladesh Power System Masterplan 2016* identified a energy demand development based on economic growth projection (see Table 3), by sector until 2041. Final energy consumption outlook and the sectoral breakdown in the BAU scenario. The demand development in Figure 10would increase from 1,400 PJ in 2015 to around 2,800 PJ/a (67,000 ktoe) in 2030 and about 5,000 PJ/a (120,000 ktoe) in 2040.

The PSMP expects a rapid advancement of industrialization in Bangladesh with a shift in the industrial sector from labor-intensive industries like *ready-made-garment* (RMG) to energy-intensive industries. As a result, energy consumption in the industrial sector would increase rapidly. Furthermore, the PSMP suggests that the transport sector grows parallel with per capita GDP leading to increase private vehicle ownership from the middle of the 2020s onward. This would lead to a transport energy consumption significantly exceeding that of the residential sector.

Energy demand growth is estimated to be slower with the Bangladesh "Energy Efficiency and Conservation Master Plan up to 2030" (EECMP) which has been formulated in March 2015, supported by JICA. With efficiency measure identified in the EECMP the demand in the PSMP 2016 Energy Efficiency Scenario would increase to 2,500 PJ/a (60 Mtoe) in 2030 and 3,750 PJ/a (90 Mtoe) in 2050. Figure 10 shows the projection of final energy consumption under the PSMP Energy Efficiency Scenario which is the basis for the REFERENCE case calculated in our analysis (Chapter 6)

[96] WORLDBANK (2019) World Bank Database 2019 - https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC?locations=IN-PK-BD-LK-NP-AF&name_desc=true

Figure 10: Bangladesh - Projection of Final Energy Consumption (Energy Efficiency Scenario)



Source: JICA Survey Team

5.2.4 ENERGY SUPPLY - STATUS QUO

Supply is dominated by natural gas (over 50%) followed biofuel and waste (approx. 25%) mainly for cooking and oil (around 17%). Coal and renewable electricity supply less than 5% of Bangladesh's national primary energy (PSMP 2016)[95].

Gas:

Gas Production from the current domestic gas fields in 2015 was 962.7 PJ/a (2,500 mmscfd[97]) and reached a peak production of 1040 PJ/a (2,700 mmscfd) in 2017, then start to decline. However, Gas demand in Bangladesh forecasts a significant increase in the future. The demand and supply gap must be filled by gas (LNG) imports. First LNG supply will be introduced in 2019 at the rate of 192.5 PJ/a (500 mmscfd), which corresponds to 17% of gas demand. This percentage is forecast to increase to 40% in 2023, 50% in 2028, and 70% in 2041 (PSMP 2016)[95].

Coal:

Bangladesh currently has only one coal mine with a production volume of 680,000 tons in 2015 (PSMP 2016)[95].

The REFERENCE case requires to expand local production as well as increased import of coal. Both cases require a significant investment in new coal infrastructure and to build up local know-how.

Oil:

Bangladesh's current oil annual demand is around 5 million tons, and the self-sufficiency rate is only at 5%. The REFERENCE case would lead to drastic oil demand growth: 6 times higher in 2041 than in 2016 (average growth rate 7.4% p.a.), even under the "Energy Efficient and Conservation Scenario".

According to the PSMP 2016, Bangladesh has several plans to extend or newly develop oil refineries; however, if the oil demand grows as projected, oil imports will be mandatory to meet the demand and keep increasing.

[97] mmscfd: million standard cubic feet per day

5.2.5 ENERGY SUPPLY – FUTURE PROJECTIONS

The PSMP 2016 projects five different supply scenarios, all of them are dominated by fossil fuels while the share of gas, oil and coal varies. For the development of the REFENCE case (see chapter 6) the PSMP 2016 primary energy supply *SCENARIO 3* has been chosen.

Table 8: Bangladesh – Projection of Primary Energy Supply – PSMP 2016, SCENARIO 3

Primary Energy Sources	2014			2041			Annual growth rate (2014-41)
	[PJ/a]	[ktoe]	share	[PJ/a]	[ktoe]	share	
Natural Gas	868	20,726	56%	2,100	50,149	38%	3.3%/a
Oil (incl. crude oil and refined products)	262	6,263	17%	1,346	32,153	25%	6.2%/a
Coal	57	1,361	4%	1,100	26,273	20%	12.7%/a
Nuclear	-	-	-	500	11,942	9%	-
Renewable (excl. bio energy)	2	36	0%	8	197	0%	6.5%/a
Bio energy & Waste	354	8,449	23%	171	4,086	3%	-2.7%/a
Import (Power)	16	377	1%	252	6,027	5%	10.8%/a
Total	**1,544**	**36,888**	**100%**	**5,477**	**130,827**	**100%**	**4.8%/a**

5.2.6 POWER SECTOR – STATUS QUO

The pervious Power System Management Plan – published in 2010 (PSMP2010) suggested an increase of 10,000 MW power generation capacity, actual addition where at 8,000 MW which is about 80% of the plan, because of delayed power plant construction which had been planned and necessary infrastructure such as ports - essential to stable fuel imports supplied via marine tanker - have not been established.

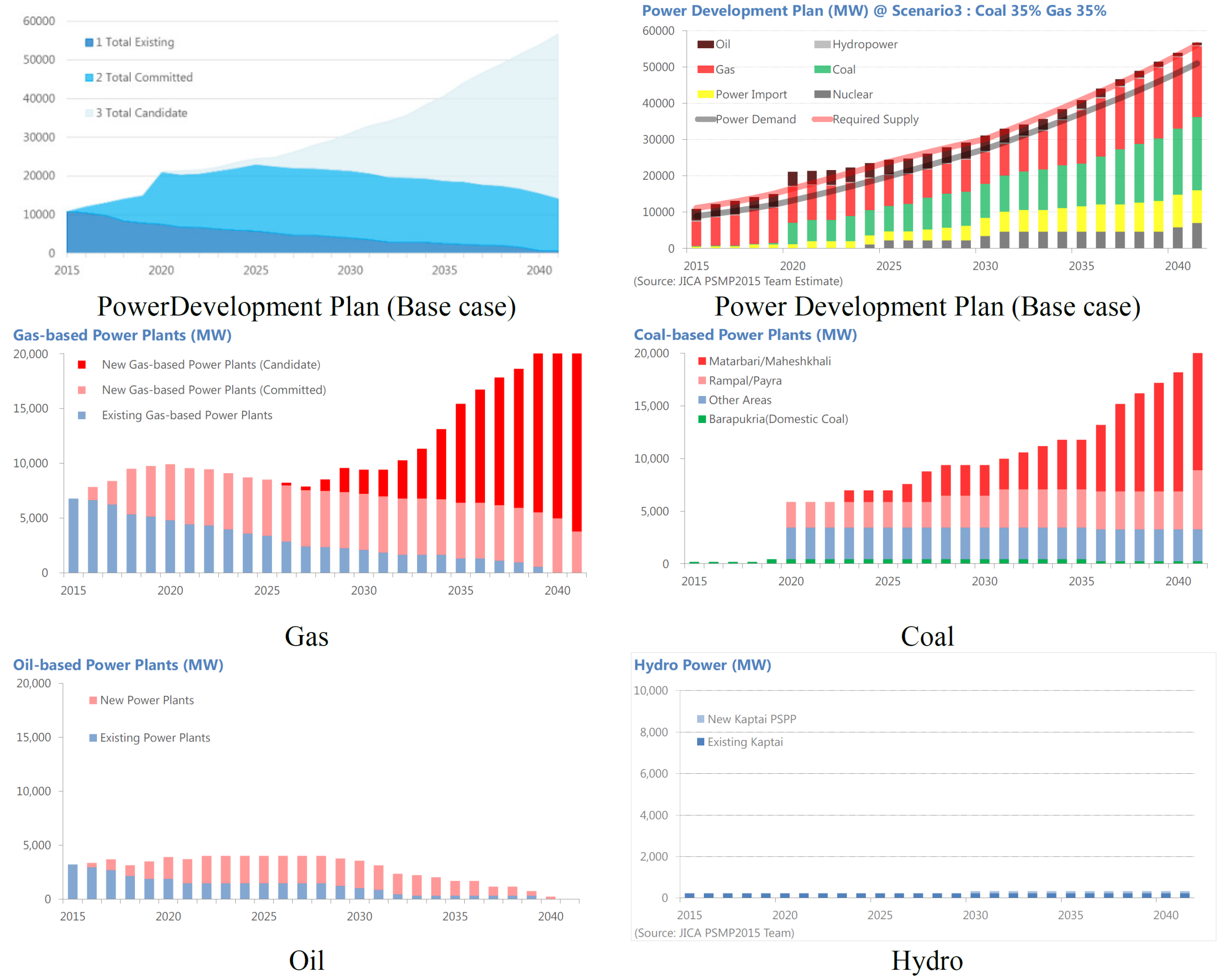
The current Power System Management Plan of Bangladesh will lead to a total dependence on technology and fuel imports and will leave the energy industry dependent on world market development with little or no possibilities to influence energy costs in the future. Local renewable energy resources are largely ignored in the PSMP 2016 and a detailed analysis of the renewable energy potential is lacking.

The possibility to tap into Bangladesh's solar photovoltaic resources as well as the relative high offshore wind potential are left untouched. Decentralized power generation and offshore wind which could provide employment to the rapidly declining gas industry are not considered.

5.2.7 POWER SECTOR – FUTURE PROJECTIONS

The PSMP 2016 identifies short- and medium-term power development plans which consider the current and possible load demands, fuel supply as well as existing infrastructure for fuel supply, power generation and electricity transport. This includes possible retirement needs for energy infrastructure – especially power plants – which reach the end of their technical lifetime. The specific data is documented in the "Data Collection Survey on Integrated Development for Southern Chittagong Region" (Southern Chittagong MP Survey)
Long- and "ultra-long" term plans (till 2035 and beyond 2040) are covered under the PSMP 2016 to some extend as well. Figure 11 shows "SCENARIO 3" of the PSMP 2016 which is the basis for the REFERENCE case (Chapter 6)

Figure 11: Bangladesh – Development of power generation capacities under SCENARUIO 3 of the PSMP 2016



The PSMP 2016 relies to 70% on fossil fuel-based power generation – 35% gas and 35% coal – while the remaining supply is covered to a large extend by imports and six new nuclear power plants. The power supply of Bangladesh under SCENARIO 3 will almost entirely be dependent on foreign resources (coal and gas), foreign technology know-how (nuclear) and foreign electricity infrastructure (power lines from India). Indigenous renewable energy resources will continue to play a minor role. Furthermore, the PSMP 2016 states that Bangladesh has only a very limited potential.

5.2.8 ENERGY ACCESS SCENARIO

The ENERGY ACCESS SCENARIO (EAS) is a bottom up electricity demand analysis which has been used for the RENEWABLES 2.0ºC and RENEWABLES 1.5ºC case. The EAS aims to increase access to energy – especially electricity – for all by 2050 while increasing the electrification and comfort standard to the level of industrialized countries. The growing economy requires a reliable power supply for small and medium businesses (SME's), industry and the transport sector. It is assumed that households will use modern and energy-efficient applications according to the highest efficiency standards to slow down the power demand growth, and to allow the parallel expansion of energy infrastructure and the construction of renewable power plants. The electrification will be organized from the 'bottom up' in a new and innovative approach developed by UTS/ISF:

3-Step–Solar-Swarm Grid (3SG) expansion – from pico-grid via micro-grid to transmission grids.

According to government statistics, 74 percent of Bangladesh's population has access to electricity (up from only about 20 percent in 1990). Electrification rates are highest in urban areas, where only about one percent lack access to electricity. In rural areas, 34 percent do not have electricity. Electrification rates have improved in recent years because of rapid acceleration of grid connection to rural areas, coupled with the installation of solar home systems—since 2003, about 3.8 million solar home systems have been installed, benefiting about 20 million people (SREP 2015)[80]. The authors of this analysis define “access to energy” as a reliable access to energy services 24 hours a day, 365 days a year.

Solar home systems (SHS) provide enough electricity to power bright efficient LED lights, radios, mobile phones, TVs, DC fridges and a variety of further household and consumer appliances. However, this development is not currently coordinated with the national grid expansion plans of the Bangladesh government.

It is important for Bangladesh to develop a technical and economic concept along with a real test case, to interconnect SHS to a micro grid in a first step and, in a second step, several micro grids to a distribution power grid, equal to those in industrialized countries.

As a third and final step, distribution grids will be interconnected to a transmission grid.

The industry will continue to expand on-site power generation (auto-produce) for their own supply – wherever possible with cogeneration plants – and as dispatch power plants for balancing high shares of grid-connected utility-scale solar PV and wind. Fuel will move from natural gas to biogas and/or hydrogen and synthetic fuels after 2030.

5.2.8.1 Energy access – household demand

The analysis of current and future development of the electricity demand for Bangladesh’s households was done from the second half of 2018 onwards under the leadership of the Coastal Development Partnership (CDP) Bangladesh in cooperation with the World Future Council (Germany) and Bread for the World (Germany). The future development of the household demand has been discussed during a multiple stakeholder workshop with representatives from Bangladesh’s academia, civil society and government in Dhaka/Bangladesh in March 2019. Table 9 shows the current electricity demand and used electrical appliances of households in Bangladesh 2019. This survey formed the basis for the demand development projection for electricity for the residential sector until 2050 for both RENEWABLES cases. The 11 categories have been further reduced to 8 household types to fit the [R]E 24/7 model.

Table 9: Bangladesh – Results of household electricity demand survey from January 2019

Household (HH) Category	Number of Rooms	Monthly Income (BDT)		Average electricity use (kWh/month)
1. Very Low Income Rural Household	1 (60%) 2 (40%)	<8000	2 Incandescent Bulbs (40W), 1 Ceiling/Table Fan, 1 button mobile	<20
2. Very Low Income Urban Household	1 (80%) 2 (20%)	<10000	2 CFL bulbs, 1 Ceiling/Table Fan, 2 button mobiles, 1 rechargeable light, Rice Cooker (10%),	<40
3. Low Income Rural Household	2 (70%) 3 (30%)	10000-16000	3 60W-Incandescent Bulbs (80%HH), 2 CFL bulbs & 1 LED bulb (20%HH), 2 Ceiling Fans, 1 Table Fan, 3 button mobiles, 1 rechargeable light (80%), Rice Cooker (30%), Small Submersible Water Pump (30%), Color CRT TV (95%), Electric Kettle (15%)	41-75
4. Low Income Urban Household	1	10000-16000	2 CFL bulbs, 1 Ceiling Fan, 1 Rechargeable Table Fan, 2 button mobiles, 1 rechargeable light, Rice Cooker (50%), TV (50% Color CRT), small refrigerator (20%), Mosquito Bat, Electric Kettle (30% HH), induction cooker (20%)	76-100
5. Lower Middle Income Rural Household	2	16001-26000	2 Incandescent Bulbs (60W), 2 CFL bulbs & 1 LED back-up bulb, 2 Ceiling/Table Fans, 2 button mobiles, 1 rechargeable light, Rice Cooker (60%), Color CRT TV (70%), Electric Kettle (30% HH), Submersible Water Pump (60%), small refrigerator (10%)	76-100
6. Lower Middle Income Urban Household	1 (60%) 2 (40%)	16001-26000	2 CFL bulbs, 1 Ceiling Fan, 1 Rechargeable Table Fan, 2 mobiles (1 smart, 1 button), 1 rechargeable light, Rice Cooker (70%), TV (50% Color CRT, 20% LCD), small refrigerator (50%), Mosquito Bat, Electric Kettle (50% HH), induction cooker (30%), power bank (50%)	101-200
7. Middle Income Rural Household	3	26001-40000	3 Incandescent Bulbs, 2 CFL bulbs & 1 LED bulb (6-12W), 2 Ceiling Fans, 1 Table Fan, 3 mobiles (2 smart, 1 button), Mosquito Bat, 1 rechargeable light, Rice Cooker, Submersible Water Pump, TV (80% Color CRT), Standard LCD/LED TV (20%), Electric Kettle (40% HH), Refrigerator (40%), Portable Room Heater (20%), power bank (80%), induction cooker (60%),	101-200
8. Middle Income Urban Household	3-4	26001-40000	3 CFL bulbs & 1 LED bulb (6-12W), 2 Ceiling Fans, 1 Table Fan, 3 mobiles (1 smart, 2 button), 1 rechargeable light, Rice Cooker (60%), Submersible Water Pump (80%), TV (50% Color CRT, 30% LCD/LED), Electric Kettle (50% HH), refrigerator (70%), induction cooker (40%, Wi-Fi/internet modem (60%), IPS (60%), power bank (70%)	201-300
9. Upper Middle Income Rural Household	4	40001-65000	3 Incandescent Bulbs, 2 CFL bulbs, 2 tube lights, 1 LED bulb, Refrigerator (<20CFT), Submersible Water Pump, Iron (20%HH), Irrigation Pump (40% HH), Electric Kettle (40% HH), Electric Vehicle (40%), Laptop (10%), 3 mobiles (2 smart, 1 button), Mosquito Bat, Wi-Fi/internet modem (10%),1 rechargeable table fan, LCD TV (50%), Color CRT TV (50%),	201-400
10. Upper Middle-Income Urban Apartment Household	4	40001-65000	4 CFL bulbs, 4 tube lights, 2 LED back-up bulbs, 4 Ceiling Fans, 1 table fan, 1 normal fridge, 1 deep fridge, TV (50% Color CRT), Standard LCD/LED TV (50%), Electric Iron, Rice cooker, Blender, Electric Oven (50%), Microwave Oven (30%), large water pump, induction cooker, 1 Split AC (20%), 1 laptop, 4 mobiles (3 smart, 1 button), Mosquito bat, IPS (30%), Electric Kettle, Hair Dryer/Blower, Hair straightener, Rechargeable Electric Shaver, Electric Egg Bitter, 1 power bank, 1 rechargeable light, 1 rechargeable table fan, Washing machine (30%), Wi-Fi/internet modem (60%), Water Heater/Geyser (40%), Exhaust fan, Toaster/Sandwich maker (30%), Electric Sewing machine (30%), Room Heater (10%), DVD Player (20%), Tablet (30%), Video Game console (20%), Stereo sound system (40%), Vacuum Cleaner (20%), Portable Cooling Fan (25%), Portable Room Heater (20%), Cooker hood (30%), Electric Frying Pan (10%), Bread maker (10%), Coffee Maker (10%), Table Lamp (30%), Digital Picture Frame (10%), Printer (10%), Aquarium, Calling Bell, UPS, Voltage Stabilizer, Water Heater	301-600
11. High Income Urban Household	6-12	>65000	20 CFL bulbs, 4 LED tube lights, 4 Bedside lamps, 2 Table Lamps, 10 Ceiling Fans, Washing Machine (80%), Electric Clothes Dryer (40%), Electric Toothbrush, Air Purifier, Vacuum Cleaner (big), 4 smart phones, 2 A/C (80%), 2 large Refrigerators (>20 CFT), 2 laptops, Water Heater/Geyser, Microwave Oven, Electric Iron (steam), Rice cooker, Blender, Electric Exercise Equipment (20%), Exhaust fan, Toaster/ Sandwich maker, Electric Kettle, Hair Dryer/Blower, Hair Curler, Hair straightener, Rechargeable Electric Shaver, IPS (80%), Dehumidifier, Wi-Fi Internet Router, Gaming Computer/laptop/ Video Game console, 1 Tablet, Surround Stereo sound system (50%), 2 Large (43"-61") LED/Plasma TVs, Lawn Mower (20%), Submersible Water Pump, Sauna (2%), Cooker hood (70%), Dishwasher (50%), Dish Dryer (20%), Electric Frying Pan (40%), Bread maker (50%), Electric BBQ Grill (20%), Induction Cooker, Coffee Maker, Chandelier (20%), Electric Insect Killer (60%), Digital Picture Frame (40%), Printer (70%) Aquarium, Calling Bell, UPS, Voltage Stabilizer	>600

For the electricity demand development until 2050, the following categories have been used:

Table 10: Household types used in both RENEWABLE cases and assumed annual electricity demand

Household type	Bangladesh survey	Average annual electricity demand
Rural - Phase 1	- Very low income rural household - Low income rural household	490 kWh/a
Rural - Phase 2	- Lower middle income rural household	1,100 kWh/a
Rural - Phase 3	- Upper middle income rural household	4,000 kWh/a
Urban – Single	- Very low income urban household	450 kWh/a
Urban/Shared App.	- Lower middle income urban household	845 kWh/a
Urban - Family 1	- Middle income households (urban and rural)	1,600 kWh
Urban - Family 2	- Upper middle income urban household	2,500 kWh/a
Suburbia 1	- High income rural household	3,200 kWh
Suburbia 2	- High income urban household	4,400 kWh/a

The electric applications for each of the nine household types will gradually increase from those with very basic needs, such as light and mobile phone charging, to a household standard matching that of industrialized countries. To phase out unsustainable biomass for cooking, a direct leap from cook stoves to electrical cooking is assumed. The third phase of a rural household includes an electric oven, fridge, a washing machine, air-conditioner and entertainment technologies and aims to provide the same level of comfort as households in urban areas in industrialized countries. An adjusted level of comfort for households in the city and in rural areas aims to prevent residents – especially young people – from leaving their homeland and moving into big cities. Rapidly expanding cities proved problematic as infrastructure for transport and energy supply and the requirements of residential apartment buildings cannot match the demand, often leading social tensions.

According to the most recent data published by Bangladesh Bureau of Statistics (BBS) published in December 2016, on average 85 per cent of Bangladesh's households have access to electricity. However, the percentage varies significantly between urban households (94.1 per cent) and rural households (68.5 per cent)[98].

However, the majority of households had an annual per capita demand around or under 100kWh per year. The analysis presented in this report assumes more electrical applications leading to higher annual power demands per household. The following tables (Table 11 till Table 18) show the most recent available statistical data about the situation of electricity and energy supply and demand of households in Bangladesh. This data has been used as an input for the future electricity demand projection.

Table 11: Bangladesh energy access statistic

Indicators	2017	2016	2015	2014	2013
Population (in million)	162.7	160.8	158.9	156.8	154.7
Rate of Population Growth	1.34	1.36	1.37	1.37	1.37
Population Density (per sq. km)	1103	1090	1077	1063	1049
Access to Electricity as Source of Light (%)	85.3	81.2	77.9	67.8	66.9
Access to Solar as Source of Light (%)	5.8	5.6	5.4		
Use Kerosene as Source of Light (%)	8.8	13.0	16.3	31.4	32.3
Source: Report on Bangladesh Sample Vital Statistics 2017, Bangladesh Bureau of Statistics (BBS)					

[98] http://bbs.portal.gov.bd/sites/default/files/files/bbs.portal.gov.bd/page/a1d32f13_8553_44f1_92e6_8ff80a4ff82e/Bangladesh%20%20Statistics-2017.pdf

Table 12: Bangladesh Electricity connections in percent.

Electricity Connections in the Households (%)	Rural	Urban	Both Rural & Urban	
Name of the Divisions			Solar	No Connection
Barisal	62.7	0.1	16.9	16.5
Chittagong	56.3	22.6	7.4	7.6
Dhaka	57.6	24.9	5.4	7.8
Khulna	86.4	0.6	4.8	7.1
Mymensingh	61.3	16.5	5.8	14.9
Rajshahi	69.3	18.2	3.1	8.7
Rangpur	61.5	15.6	5.7	17.3
Sylhet	66.8	11.7	12.7	9.0
National	64.7	14.5	7.6	11.0
Source: Bangladesh Bureau of Statistics (BBS), 2017: Report on the Opinion Survey on Power Supply 2016-17				

Table 13: Population with access to electricity in Bangladesh

Access to electricity in Bangladesh (% of population)								
2014			**2015**			**2016**		
Urban	**Rural**	**Total**	**Urban**	**Rural**	**Total**	**Urban**	**Rural**	**Total**
90.7	51.4	62.4	92.5	55.53	68.2	94.1	68.85	75.92
Source: https://data.worldbank.org/indicator/EG.ELC.ACCS.UR.ZS?locations=BD								

Table 14: Access to electricity for households in Bangladesh

	2016			**2010**		
	Total	**Rural**	**Urban**	**Total**	**Rural**	**Urban**
Access to electricity to households (%)	75.92	68.85	94.01	55.26	42.49	90.10
Source: BBS, 2017: Preliminary Report on Household Income and Expenditure Survey 2016, Bangladesh Bureau of Statistics (BBS), Statistics and Informatics Division (SID), Ministry of Planning, Government of The People's Republic of Bangladesh, October, 2017						

Table 15: Energy use by household type and region

Household Characteristics	**Residence**			**Division**						
	Total	Rural	Urban	Barishal	Chattogram	Dhaka	Khulna	Rajshahi	Rangpur	Sylhet
Sources of light										
Electricity	85.3	78.6	93.5	83.3	84.4	88.4	89.6	82.8	78.7	88.1
Kerosene	8.8	12.0	4.9	5.6	7.4	6.7	6.3	13.1	16.5	6.4
Solar	5.8	9.3	1.5	10.9	8.2	4.8	3.9	4.0	4.7	5.3
Others	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.0	0.1
Source of cooking fuel										
Straw/Leaf	30.2	44.3	12.8	25.7	27.0	28.1	26.6	52.0	34.9	12.7
Husk	3.5	3.3	3.7	3.4	3.0	2.4	4.4	6.6	2.7	2.5
Jute stick/wood/ bamboo	41.3	45.3	36.4	53.3	40.3	31.8	53.8	26.3	49.3	47.7
Kerosene	0.3	0.3	0.4	0.3	0.2	0.4	0.3	0.3	0.4	0.3
Electricity	1.0	0.2	2.0	0.6	0.6	0.5	1.1	1.3	2.9	0.3
Gas	23.1	5.9	44.2	16.1	28.3	36.5	12.4	12.6	9.8	35.8
Others	0.6	0.8	0.5	0.5	0.6	0.4	1.4	1.0	0.1	0.6
Source: BBS, 2017: Report on Bangladesh Sample Vital Statistics 2017, Bangladesh Bureau of Statistics (BBS)										

Table 16: Household use of electricity for cooking

Region	Average	Summer	Winter
Barisal	8.0	8.7	7.2
Chittagong	13.8	14.9	12.7
Dhaka	12.1	8.8	15.8
Khulna	21.4	16.8	26.0
Mymensingh	7.1	8.0	6.1
Rajshahi	13.3	14.6	11.9
Rangpur	14.5	11.0	17.4
Sylhet	6.5	5.9	7.0
National	**12.1**	11.1	13.1
Source: Bangladesh Bureau of Statistics (BBS), 2017: Report on the Opinion Survey on Power Supply 2016-17			

Table 17: Household sizes by (geographic) region

Household Category	Barishal	Chattogram	Dhaka	Khulna	Rajshahi	Rangpur	Sylhet	Total
1	2.4	1.9	3.3	3.1	4.0	4.1	1.9	**3.0**
2	9.5	8.5	13.2	11.7	12.6	10.3	7.2	**10.8**
3	20.6	17.6	21.1	23.8	23.9	21.2	15.2	**20.7**
4	29.6	26.1	27.3	30.5	30.2	30.9	23.1	**28.2**
5	19.9	20.5	18.1	17.1	16.1	18.3	19.6	**18.4**
6	9.9	12.0	9.0	7.8	7.1	8.4	13.5	**9.5**
7	4.4	6.2	4.0	2.9	2.9	3.5	8.2	**4.5**
8	2.2	3.5	2.2	1.6	1.6	1.7	5.3	**2.8**
9	0.6	1.6	0.7	0.7	0.7	0.8	2.3	**1.0**
10+	0.9	2.1	1.0	0.8	0.9	0.9	3.7	**1.4**
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	**100.0**
Average	**4.2**	**4.6**	**4.1**	**4.0**	**3.9**	**4.1**	**5.0**	**4.2**
Source: Report on Bangladesh Sample Vital Statistics 2017, Bangladesh Bureau of Statistics (BBS)								

Rural Consumption pattern: Bangladesh Rural Electrification Board with its 80 Palli Bidyut Samities has connected 23.6 million consumers (77.2% of the total electricity consumers). Among the Bangladesh Rural Electrification Board consumer, **90% domestic/residential**, 1.0% irrigation, 6.4% commercial, 0.7% industrial, and 1.3% Charitable. Around 75,000 villages are electrified[99].

Urban Consumption Pattern: The power distribution companies (Bangladesh Power Development Board, the Dhaka Power Distribution Company, Dhaka Electric Supply Company and the West Zone Power Distribution Company) serving urban centers. The Dhaka area under the distribution of Dhaka Electric Supply Company Ltd. (DESCO) is the largest single distribution territory consuming about 50 percent of the total electricity sold in Bangladesh. The total area is around 400 square kilometers. 56,266 new connections were added in DESCO during the FY 2017-18.

Among the 880,505 customers of DESCO, 90% are residential, 7% commercial and 1% industrial. However, in terms of power consumption, residential customers consume 54%, Industrial customers consumes 24%, and commercial customers consume 19%[100].

The development of the country-wide share of various household types is presented in Table 18. The electrification starts with basic household types such as rural phase 1, urban family 1 and suburbia 1 and moves to better equipped households. Thus, the share of fully-equipped households grows constantly while the basic households increase in the first years and decrease towards the end of the modelling period. By 2050, most households have a medium to high comfort equipment degree.

The authors of this report have deliberately chosen a higher standard for Bangladesh's households to close the gap between households in industrialized countries and developing countries and achieve greater equity.

Table 18: Household types – development of shares countrywide

House hold type	Country wide share [%] (rounded)			
	2020	2030	2040	2050
No access to electricity	10.00%	5.00%	3.00%	0%
Rural - Phase 1	50.0%	45.0%	35.0%	20.0%
Rural - Phase 2	13.0%	12.0%	10.0%	20.0%
Rural - Phase 3	5.0%	6.0%	10.0%	15.0%
Urban – Single	5.0%	8.0%	10.0%	10.0%
Urban/Shared App.	5.0%	8.0%	10.0%	10.0%
Urban - Family 1	7.0%	10.0%	10.0%	10.0%
Urban - Family 2	2.0%	2.0%	4.0%	5.0%
Suburbia 1	1.5%	2.0%	4.0%	5.0%
Suburbia 2	1.5%	2.0%	4.0%	5.0%
Total				

Source: CDP, REB, DESCO and UTS/ISF research

[99] REB, 2018; Annual Report 2017-18, Bangladesh Rural electrification Board.
[100] DESCO Annual report 2018

5.2.9 ENERGY ACCESS –INDUSTRY AND BUSINESS DEMAND

Analysis of Bangladesh's economic development is based on the 2015 GDP breakdown, and assumes that the overall structure of the economy does not change and that all sectors grow at equal rates to GDP over the entire modelling period. Table 19 shows the assumed breakdown of GDP by sub-category. While the GDP shares for industry, services and agricultural for Bangladesh are available (CIA 2019)[101], sub-categories for specific industries are not available and have been assumed to calibrate the bottom up energy demand model with current energy demand document in the IEA Energy Balances statistic (IEA (2019)[102].T

Table 19: Development of GPD shares by industry sector across all regions in Bangladesh

Industry	27.5%
Manufacturer	5.0%
Mining	2.0%
Iron + Steel	2.5%
Cement	2.0%
Construction	15.0%
Chemical	1.0 %
Services	54%
Food/Trade	12.5%
Tourism	5.0%
Office	36.5%
Agriculture	18.5%
Agriculture	18.5%

[101] CIA (2019): CIA-Factbook + http://statisticstimes.com/economy/countries-by-gdp-sector-composition.php
[102] IEA (2019): World Energy balances – IEA database

5.3 TECHNOLOGY- AND FUEL COST PROJECTIONS

All cost projection in this analysis are based on a recent publication from Teske et. al. (2019)[103]. The entire section 5.2 is based on chapter 5 of this book, written by Dr. Thomas Pregger, Dr. Sonja Simon and Dr. Tobias Naegler of the German Aerospace Center / DLR. The parameterization of the models requires many assumptions about the development of the characteristics of technologies, such as specific investment and fuel costs. Therefore, because long-term projections are highly uncertain, we must define plausible and transparent assumptions based on background information and up-to-date statistical and technical information.

The speed of an energy system transition also depends on overcoming economic barriers. These largely relate to the relationships between the costs of renewable technologies and their fossil and nuclear counterparts. For our scenarios, the projection of these costs is vital in making valid comparisons of energy systems. However, there have been significant limitations to these projections in the past in relation to investment and fuel costs.
In addition, efficiency measures also generate costs which are usually difficult to determine depending on technical, structural and economic boundary conditions. In the context of this study, we have therefore assumed uniform average costs of 3 cent per avoided kWh of electricity consumption in our cost accounting.

During the last decade, fossil fuel prices have seen huge fluctuations. Figure 12 shows oil prices since 1997. After extremely high oil prices in 2012, we are currently in a low-price phase. Gas prices saw similar development (IEA 2017)[104]. Therefore, fossil fuel price projections have also seen considerable variations (IEA 2017[104]; IEA 2013[105]) and have had a considerable influence on scenario results ever since.

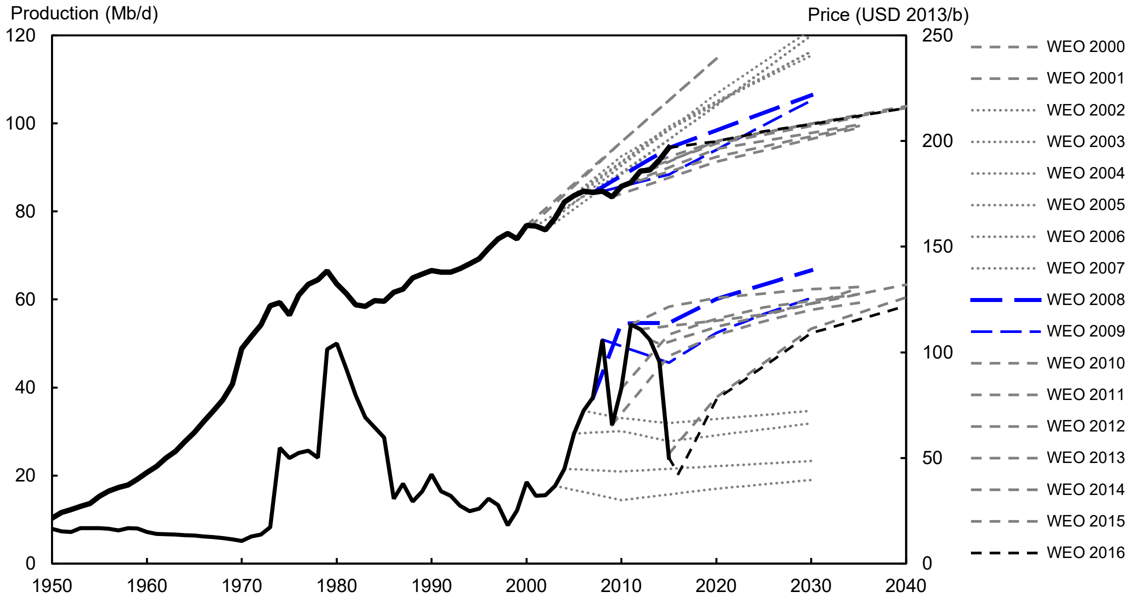


Figure 12: Historic development and projections of oil prices (bottom lines) and historical world oil production and projections (top lines) by the IEA according to Wachtmeister et al. (2018)

Although in the past, oil-exporting countries provided the best oil price projections, institutional price projections have become increasingly accurate, with the International Energy Agency (IEA) leading the way in 2018 (Roland Berger 2018)[106]. An evaluation of the oil price projections of the IEA since 2000 by Wachtmeister et al. (2018)[107] showed that price projections have varied significantly over time. Whereas the IEA's oil production projections seem comparatively accurate, oil price projections showed errors of 40%–60%, even when made for only 10 years ahead. Between 2007 and 2017, the IEA price projections for 2030 varied from $70 to $140 per barrel, providing significant uncertainty regarding future costs in the scenarios. Despite this limitation, the IEA provides a comprehensive set of price projections. Therefore, we based our scenario assumptions on these projections, as described below.

[103] Teske (2019), Achieving the Paris Climate Agreement Goals – Global and Regional 100% Renewable Energy Scenarios with Non-energy GHG Pathways for +1.5°C and +2.0°C, ISBN 978-3-030-05842-5, Springer, Switzerland 2019

[104] IEA (2017): IEA (2017) World Energy Outlook 2017. International Energy Agency, Organization for Economic Co-operation and Development, Paris

[105] IEA 2013: IEA (2013) World Energy Outlook 2013. International Energy Agency, Organization for Economic Co-operation and Development, Paris

[106] Roland Berger (2018) 2018 oil price forecast: who predicts best? Roland Berger study of oil price forecasts. https://www.rolandberger.com/en/Publications/pub_oil_price_forecast_2015.html. Accessed 10.9.2018 2018

[107] Wachtmeister H, Henke P, Höök M (2018) Oil projections in retrospect: Revisions, accuracy and current uncertainty. Applied Energy 220:138-153. doi:https://doi.org/10.1016/j.apenergy.2018.03.013

However, because most renewable energy technologies provide energy without fuel costs, the projections of investment costs become more important than fuel cost projections, and this limits the impact of errors in the fuel price projections. It is only for biomass that the cost of feedstock remains a crucial economic factor for renewables. Today, these costs range from negative costs for waste wood (based on credit for the waste disposal costs avoided), through inexpensive residual materials, to comparatively expensive energy crops. Because bioenergy holds significant market shares in all sectors in many regions, a detailed assessment of future price projections is provided below.

Investment cost projections also pose challenges for scenario development. Available short-term projections of investment costs depend largely on the data available for existing and planned projects. Learning curves are most commonly used to assess the future development of investment costs as a function of their future installations and markets (McDonald and Schrattenholzer 2001[108]; Rubin et al. 2015[109]). Therefore, the reliability of cost projections largely depends on the uncertainty of future markets and the availability of historical data. Fossil fuel technologies provide a large cost data set featuring well-established markets and large annual installations. They are also mature technologies, where many cost reduction potentials have already been exploited.

For renewable technologies, the picture is more mixed. For example, hydro power is, like fossil fuels, well established and provides reliable data on investment costs. Other technologies, such as PV and wind, are currently experiencing tremendous developments in installation and cost reduction. Solar PV and wind are the focus of cost monitoring, and considerable data are already available on existing projects. However, their future markets are not easily predicted, as can be seen from the evolution of IEA market projections over recent years in the World Energy Outlook series (compare for example IEA 2007, IEA 2014, and IEA 2017). For PV and wind, small differences in cost assumptions will lead to large deviations in the overall costs, and cost assumptions must be made with special care.

Furthermore, many technologies feature only comparably small markets, such as geothermal, modern bioenergy applications, and CSP, for which costs are still high and for which future markets are insecure. The cost reduction potential is correspondingly high for these technologies. This is also true for technologies that might become important in a transformed energy system but are not yet widely available. Hydrogen production, ocean power, and synthetic fuels might deliver important technology options in the long term after 2040, but their cost reduction potential cannot be assessed with any certainty today.

Thus, cost assumptions are a crucial factor in evaluating scenarios. Because costs are an external input into the model and are not internally calculated, we assume the same progressive cost developments for all scenarios. In the next sections, we present a detailed overview of our assumptions for power and renewable heat technologies, including the investment and fuel costs, and the potential CO_2 costs in the scenarios.

5.3.1 POWER AND CHP TECHNOLOGIES

The focus of cost calculations in our scenario modelling is the power sector. We compared the specific investment costs estimated in previous studies (Teske et al. 2015)[110], which were based on a variety of studies, including the European Commission-funded NEEDS project (NEEDS 2009), projections from the European Renewable Energy Council (Zervos et al. 2010)[111], investment cost projections by the IEA (IEA 2014), and current cost assumptions by IRENA and IEA (IEA 2016c). We found that investment costs generally converged, except for PVs. Therefore, for consistency reasons, the investment costs and operation and maintenance costs for the power sector are based primarily on the investment costs within WEO 2016 (IEA 2016c) up to 2040, including their regional disaggregation. We extended the projections until 2050 based on the trends in the preceding decade.

For renewable power production, we used investment costs from the 450-ppm scenario from IEA 2016c. For technologies not distinguished in the IEA report (such as geothermal CHP), we used cost assumptions based on our own research, from (Teske et al. 2015). As the cost assumptions for PV systems by the IEA do not

108 McDonald A, Schrattenholzer L (2001) Learning rates for energy technologies. Energy Policy 29 (4):255-261. doi:https://doi.org/10.1016/S0301-4215(00)00122-1

109 Rubin ES, Azevedo IML, Jaramillo P, Yeh S (2015) A review of learning rates for electricity supply technologies. Energy Policy 86:198-218. doi:https://doi.org/10.1016/j.enpol.2015.06.011

110 Teske S, Sawyer S, Schäfer O, Pregger T, Simon S, Naegler T, Schmid S, Özdemir ED, Pagenkopf J, Kleiner F, Rutovitz J, Dominish E, Downes J, Ackermann T, Brown T, Boxer S, Baitelo R, Rodrigues LA (2015) Energy [R]evolution - A sustainable world energy outlook 2015. Greenpeace International

111 Zervos A, Lins C, Muth J (2010) RE-thinking 2050: a 100% renewable energy vision for the European Union. European Renewable Energy Council (EREC)

reflect recent cost reductions, we based our assumptions on a more recent analysis by Steurer et al. (2018)[112], which projects lower investment costs for PV in 2050 than does the IEA.

The costs for onshore and offshore wind in Europe were adapted from the same source, to reflect more recent data. The cost assumptions for hydrogen production come from our own analysis in the Plan DelyKaD project (Michalski et al. 2017)[113]. Table 20 summarizes the cost trends for power technologies derived from the assumptions discussed above for OECD Europe. It is important to note that the cost reductions are, in reality, not a function of time, but of cumulative capacity (production of units), so dynamic market development is required to achieve a significant reduction in specific investment costs. Therefore, overall, we might underestimate the costs of renewables in the reference scenario compared with both RENEWABLES Scenarios.

However, our approach is conservative when we compare the reference scenario with RENEWABLES Scenarios. The cost assumptions for the other nine regions are in the same range but differ slightly for different renewable energy technologies. Fossil fuel power plants have a limited potential for cost reductions because they are at an advanced stage of technology and market development. Gas and oil plants are relatively cheap, at around $670/kW and $822/kW, respectively. CHP applications and coal plants are more expensive, ranging between $2 000/kW and $2 500/kW. The IEA sees some cost reduction potential for expensive nuclear plants, tending towards $4 500/kW by 2050, whereas gas might even increase in cost.

In contrast, several renewable technologies have seen considerable cost reductions over the last decade. This is expected to continue if renewables are deployed extensively. Fuel cells are expected to outpace other CHP technologies, with a cost reduction potential of more than 75% (from currently high costs). Hydro power and biomass remain stable in terms of costs. Tremendous cost reductions are still expected for solar energy and offshore wind, even though they have experienced significant reductions already. Although CSP might deliver dispatchable power at half its current cost in 2050, variable PV costs could drop to 35% of today’s costs. Offshore wind could see cost reductions of over 30%, whereas the cost reduction potential for onshore wind seems to have been exploited already to a large extent.

112 Steurer M, Brand H, Blesl M, Borggrefe F, Fahl U, Fuchs A-L, Gils HC, Hufendiek K, Münkel A, Rosenberg M, Scheben H, Scheel O, Scheele R, Schick C, Schmidt M, Wetzel M, Wiesmeth M (2018) Energiesystemanalyse Baden-Württemberg: Datenanhang zu techoökonomischen Kenndaten. Ministerium für Umwelt Klima und Energiewirtschaft Baden-Württemberg, STrise: Universität Stuttgart, Deutsches Zentrum für Luft- und Raumfahrt, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, Stuttgart

113 Michalski J, Bünger U, Crotogino F, Donadei S, Schneider G-S, Pregger T, Cao K-K, Heide D (2017) Hydrogen generation by electrolysis and storage in salt caverns: Potentials, economics and systems aspects with regard to the German energy transition. International Journal of Hydrogen Energy 42 (19):13427-13443. doi:https://doi.org/10.1016/j.ijhydene.2017.02.102

Table 20: Investment cost assumptions for power generation plants (in $2015/kW) until 2050

Investment costs power generation plants in Europe						
		2015	2020	2030	2040	2050
CHP Coal	$/kW	2 500	2 500	2 500	2 500	2 500
CHP Gas	$/kW	1 000	1 000	1 000	1 000	1 000
CHP Lignite	$/kW	2 500	2 500	2 500	2 500	2 500
CHP Oil	$/kW	1 310	1 290	1 240	1 180	1 130
Coal power plant	$/kW	2 000	2 000	2 000	2 000	2 000
Diesel generator	$/kW	900	900	900	900	900
Gas power plant	$/kW	670	500	500	500	670
Lignite power plant	$/kW	2 200	2 200	2 200	2 200	2 200
Nuclear power plant	$/kW	6 600	6 000	5 100	4 500	4 500
Oil power plant	$/kW	950	930	890	860	820
CHP Biomass	$/kW	2 550	2 500	2 450	2 350	2 250
CHP Fuel cell	$/kW	5 000	5 000	2 500	2 500	1 120
CHP Geothermal	$/kW	13 200	11 190	8 890	7 460	6 460
Biomass power plant	$/kW	2 400	2 350	2 300	2 200	2 110
Geothermal power plant	$/kW	12 340	2 800	2 650	2 500	2 400
Hydro power plant	$/kW	2 650	2 650	2 650	2 650	2 650
Ocean energy power plant	$/kW	6 950	6 650	4 400	3 100	2 110
PV power plant	$/kW	1 300	980	730	560	470
CSP power plant	$/kW	5 700	5 000	3 700	3 050	2 740
Wind turbine offshore	$/kW	4 000	3 690	3 190	2 830	2 610
Wind turbine onshore	$/kW	1 640	1 580	1 510	1 450	1 400
Hydrogen production	$/kW	1 380	1 220	920	700	570

*Costs for a system with solar multiple of two and thermal storage for eight hours of turbine operation
**Values apply to both run-of-the-river and reservoir hydro power

In the RENEWABLES Scenarios, hydrogen is introduced as a substitute for natural gas, with a significant share after 2030. Hydrogen is assumed to be produced by electrolysis. With electrolysers just emerging on larger scale on the markets, they have considerable cost reduction potential. Based on the Plan-DelyKaD studies (Michalski et al. 2017), we assume that costs could decrease to $570/kW in the long term.

5.3.2 HEATING TECHNOLOGIES

Assessing the costs in the heating sector is even more ambitious than in the power sector. Costs for new installations differ significantly between regions and are interlinked with construction costs and industry processes, which are not addressed in this study. Moreover, no data are available to allow the comprehensive calculation of the costs for existing heating appliances in all regions. Therefore, we concentrate on the additional costs resulting from new renewable applications in the heating sector.

Our cost assumptions are based on a previous survey of renewable heating technologies in Europe, which focused on solar collectors, geothermal, heat pumps, and biomass applications. Biomass and simple heating systems in the residential sector are already mature. However, more-sophisticated technologies, which can provide higher shares of heat demand from renewable sources, are still under development and rather expensive. Market barriers will slow the further implementation and cost reduction of renewable heating systems, especially for heating networks. Nevertheless, significant learning rates can be expected if renewable heating is increasingly implemented, as projected in both RENEWABLES cases

Table 21 presents the investment cost assumptions for heating technologies for OECD Europe, disaggregated by sector. Geothermal heating displays the same high costs in all sectors. In Europe, deep geothermal applications are being developed for heating purposes at investment costs ranging from €500/kW $_{thermal}$ (shallow) to €3000/kW $_{thermal}$ (deep), with the costs strongly dependent on the drilling depth. The cost reduction potential is assumed to be around 30% by 2050.

Heat pumps typically provide hot water or space heat for heating systems with relatively low supply temperatures, or they supplement other heating technologies. Therefore, they are currently mainly used for small-scale residential applications. Costs currently cover a large band-width and are expected to decrease by only 20% to $1450/kW by 2050.

For biomass and solar collectors, we assume the appropriate differences between the sectors. 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 on an MW scale. Investment costs show similar variations: simple log-wood stoves can be obtained from $100/kW, but more sophisticated automated heating systems that cover the whole heat demand of a building are significantly more expensive. Log-wood or pellet boilers range from $500–1 300/kW. Large biomass heating systems are assumed to reach their cheapest costs in 2050 at around $480/kW for industry. For all sectors, we assume a cost reduction of 20% by 2050. In contrast, solar collectors for households are comparatively simple and will become cheap at $680/kW by 2050. The costs of simple solar collectors for swimming pools might have been optimized already, whereas their integration in large systems is neither technologically nor economically mature. For larger applications, especially in heat grid systems, the collectors are large and more sophisticated. Because there is not yet a mass market for such grid-connected solar systems, we assume there will be a cost reduction potential until 2050.

Table 21: Specific investment cost assumptions (in $2015) for heating technologies in the scenarios until 2050

Investment costs heat generation plants in OECD Europe							
			2015	**2020**	**2030**	**2040**	**2050**
Geothermal		$/kW	2 390	2 270	2 030	1 800	1 590
Heat pumps		$/kW	1 790	1 740	1 640	1 540	1 450
Biomass heat plants		$/kW	600	580	550	510	480
Residential biomass stoves	industrialized countries	$/kW	840	810	760	720	680
Residential biomass stoves	developing countries	$/kW	110	110	110	110	110
Solar collectors	industry	$/kW	850	820	730	650	550
	in heat grids	$/kW	970	970	970	970	970
	residential	$/kW	1 060	1 010	910	800	680

5.3.3 FUEL COST PROJECTIONS

Fossil Fuels

Although fossil fuel price projections have seen considerable variations, as described above, we based our fuel price assumptions up to 2040 on the WEO 2017 (IEA 2017). Beyond 2040, we extrapolated from the price developments between 2035 and 2040. Even though these price projections are highly speculative, they provide a set of prices consistent to our investment assumptions. Fuel prices for nuclear energy are based on the values in the Energy [R]evolution report 2015 (Teske et al. 2015)[110], corrected by the cumulative inflation rate for the Eurozone of 1.82% between 2012 and 2015.

Table 22: Development projections for fossil fuel prices in $2015 (IEA 2017)

Development projections for fossil fuel prices							
All Scenarios			**2015**	**2020**	**2030**	**2040**	**2050**
Oil		$/GJ	8.5	12.3	21.5	24.2	35.1
Gas		$/GJ	9.8	10.0	10.7	10.9	11.8
Coal		$/GJ	3.2	3.5	4.3	4.5	5.3
Nuclear		$/GJ	1.1	1.2	1.5	1.8	2.1

5.3.4 BIOMASS PRICES

Biomass prices depend on the quality of the biomass (residues or energy crops) and the regional supply and demand. The variability is large. Lamers et al. (2015)[114] found a price range of €4–4.8/GJ for forest residues in Europe in 2020, whereas agricultural products might cost €8.5–12/GJ. Lamers et al.[114] modelled a range for wood pellets from €6/GJ in Malaysia to 8.8€/GJ in Brazil. IRENA modelled a cost supply curve on a global level for 2030, ranging from $3/GJ for a potential of 35 EJ/yr up to $8–10/GJ for a potential up to 90–100 EJ/yr (IRENA 2014) (and up to $17/GJ for an potential extending to 147 EJ).

[114] Lamers P, Hoefnagels R, Junginger M, Hamelinck C, Faaij A (2015) Global solid biomass trade for energy by 2020: an assessment of potential import streams and supply costs to North-West Europe under different sustainability constraints. GCB Bioenergy 7 (4):618–634. doi:https:// doi.org/10.1111/gcbb.12162

5.4 RENEWABLE ENERGY POTENTIAL

Bangladesh has a mostly untapped potential for renewable energy sources, and the only resource significantly in use is biomass. Additionally, solar photovoltaic has excellent potential and is particularly feasible in rural areas. Biomass resources are mostly exploited in traditional but unsustainable ways, though there exists a greater potential of organic waste generated by the agricultural sector. Solar energy is abundant, with initial efforts being undertaken to exploit this resource through both off-grid and grid-connected solutions. Wind resources have been assessed with promising results in the three coast states Khulna, Barisal and Chittagong. However, wind energy is currently not used in Bangladesh. The US based National Renewable Energy Laboratory (NREL) published a detailed survey about Bangladesh's wind energy potential in 2018 (NREL 2018)[115].

Wind energy

Based on the available information, Bangladesh has moderate wind resources, located in the coastal areas. Wind resource assessments indicate that areas in Khulna, Barisal and Chittagong) have adequate wind speed for grid-scale electricity generation. Small-scale off-grid wind turbines along the coastline and in the islands also hold great potential in Bangladesh, where areas of onshore wind power potential cover only a fraction of the country.

Onshore Wind

Currently, Bangladesh has only 2.9 MW onshore wind turbines installed. However, the government announced plans for 150 MW new wind capacities in three locations (50 MW each) in March 2019[116]. Most of the potential is in the three coastal provinces. The overall wind resources on land are – compared to other countries – relatively small and the average annual wind speed drops with the distance to the coast. Table 23 shows to what extend the mapped potential has been utilized in the most ambitious scenario while Table 26 identifies the total potential estimated under land use restrictions with a minimum annual wind speed of 5 m/s. For Bangladesh, wind turbines optimized for low wind speed are required, usually used in inland locations.

Offshore Wind

Bangladesh has a significant offshore wind potential. This analysis uses offshore wind as a backbone for the renewable power generation in Bangladesh. Further research is required to locate the exact offshore wind areas both in regard to the available wind resource as well as the offshore wind power grid capacities. The declining offshore gas sector can benefit from increased offshore wind deployment as workers and parts of the infrastructure can be re-used (e.g. ships, supply equipment). Further research is needed to develop the R&D requirements for building up Bangladesh's offshore renewable energy industry.

Solar energy

Bangladesh enjoys average annual solar radiation levels of between 4 and 6.5 kWh/m^2 per day. The solar radiation is not suitable for concentrated solar power due to cloud conditions (CSP need clear sky with direct sunlight). There are around 4 million off grid solar home systems (SHS) in place. Increasing consumer electricity prices in Bangladesh could provide an opportunity for RE sources to compete with conventional energy sources. Current electricity prices from diesel or furnace oil-based plants cost around Tk 14-18/kWh (USD 17-21 cents/kW)[117]. The total capacity of all installed solar photovoltaic systems in Bangladesh adds up to 326 MW (PV-M 2019)[118].

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[115] Assessing the Wind Energy Potential in Bangladesh
Enabling Win d Energy Development With Data Products; Mark Jacobson, Caroline Draxl, Tony Jimenez, and Barbara O'Neill; National Renewable Energy Laboratory; Taj Capozzola, Harness Energy; Jared A. Lee, Francois Vandenberghe, and Sue Ellen Haupt, National Center for Atmospheric Research; Technical Report NREL/TP-5 007 1077; September 2018; https://www.nrel.gov/docs/fy18osti/71077.pdf

[116] Dhaka Times, 20th March 2019, *Three wind power plants with 150MW capacity by 2021*, https://www.dhakatribune.com/business/2019/03/20/three-wind-power-plants-with-150mw-capacity-by-2021

[117] SUNTRACE, Economics and Finance / Electricity Markets / Solar Energy / Bangladesh Country Report 2018, Suntrace GmbH, Hamburg, Germany; https://suntrace.de/fileadmin/user_upload/Suntrace_Solar_Market_Brief_Bangladesh.pdf

[118] PV-M 2019, PV-Magazine, *Bangladesh to complete 7.4 MW of solar capacity in April*, Syful Islam, 20th March 2019; https://www.pv-magazine.com/2019/03/20/bangladesh-to-complete-7-4-mw-of-solar-capacity-in-april/

Main challenge for utility scale solar photovoltaic is the availability of land.

In order to use Bangladesh's utility scale solar photovoltaic as efficient as possible, further research is required in regard to the breakdown the utility scale photovoltaic potential into ground mounted solar PV, agricultural solar PV and floating solar PV:

- Utility scale solar PV: Large scale solar PV generators need space. Space is limited in Bangladesh due to extremely high population density. Therefore, space for solar should be utilized as efficient as possible and multiple use options should be considered.
    - Agricultural solar photovoltaic solar PV is a new development which combines agricultural food production technics and solar PV equipment. The solar generator is mounted above the field – in some cases several meters high – in order to leave. enough space for harvesting and to ensure access of light
    - Requirements for R&D for floating solar in flooding regions and rivers with changing currents: Floating solar is a fairly new form of solar PV. Standardized floating devices are used for mounting solar panels in utility scale projects usually designed for ground mounting systems. While current projects are designed for lakes and water reservoirs, Bangladesh would need floating solar PV suitable for floating rivers, possibly in combination with housing.

Table 23: Bangladesh: Required areas for three types of renewable energy technologies under the most ambitious 1.5°C scenario.

Technology		Unit	2020	2030	2040	2050	Percentage of landmass of Bangladesh (for 2050)
PV	Total installed capacity	GW	0.4	23.1	104.2	126.7	0.5%
	Specific nominal capacity	kW/m^2	0.15	0.16	0.17	0.17	
	Area	km^2	3	144	613	745	
Wind onshore	Total installed capacity	GW	0	0.9	3.7	9.6	1%
	Average capacity	MW	3.00	3.50	5.00	7.00	
	Number of plants	#	0	257	740	1,371	
	Specific nominal capacity	MW/km^2	4	5	5	7	
	Area	km^2	0	180	740	1,371	
Wind offshore	Total installed capacity	GW	0	2.5	14.4	36.3	2.5%
	Average capacity	MW	6.00	7.50	8.50	9.00	
	Number of plants	#	0	333	1,694	4,033	
	Specific nominal capacity	MW/km^2	7	8	9	10	
	Area	km^2	0	313	1,600	3,630	

Bio energy

The country has considerable biomass resources from agricultural residues. The Sustainable & Renewable Energy Development Authority estimated a bio energy potential of 285 MW[80] with an annual generation of 1,800 GWh/a which seems extremely conservative.

Table 24: Bangladesh – Bio energy potential

Technology	Resource	Capacity [MW]	Annual Generation [GWh/a]
Biomass	Rice husk	275	1800
Biogas	Animal waste	10	40

Source: SREP 2015

The total bio energy potential for Bangladesh is estimated with 1000 PJ/a (Huda et. al 2013)[119]. The 2.0°C uses 1,500 PJ/a and 1.5°C uses 2,100 PJ/a – the additional bio energy is assumed to be imported.

Hydropower

The only existing hydropower plants in Bangladesh are the 230 MW Kaptai Hydropower Plant and a 10 kW Micro-hydropower plant in Bamerchara. A 2014 study by Stream Tech (a US-based engineering firm) for the Ministry of Power, Energy and Mineral Resources identified potential hydropower sites at different locations along the Sangu, Matamuhuri, and Bakkhali Rivers, as well as the Banshkhali Eco-park stream. The technical assessment only includes the sites from this study because other studies on potential hydropower sites were either outdated or provided inadequate information for a technical assessment.

The technical assessment consisted of an estimate of the generation potential at each site. Topographic analysis was performed using GIS-based Digital Elevation Model (DEM) data to determine the available gross hydraulic head at each site. A hydrologic model was developed to simulate the river flows at the selected sites over a 15-year period based on observed stream flow data (2003-2012) from the Bangladesh Water Development Board (BWDB).

Hydropower has limited potential in Bangladesh due to concerns about land use and flooding. The construction of the Kaptai dam in 1961 displaced about 100,000 people from the Chittagong Hills Tracts due to flooding caused by the dam's reservoir (SREP 2015)[80].

5.4.1 ASSUMPTIONS FOR HYDROGEN AND SYNFUEL PRODUCTION

In both RENEWABLES cases, hydrogen and sustainable synthetic fuels are introduced as a substitute for natural gas and make up a significant share of transport fuels after 2030. Hydrogen is assumed to be produced via electrolysis, resulting in an additional electricity demand supplied by extra renewable power production capacity, predominantly from wind, PV and CSP.[120] Renewable hydrogen and synthetic fuels are essential for a variety of sectors.

- For the industry sector, hydrogen serves as an additional renewable fuel option for high-temperature applications, supplementing biomass in industrial processes, whenever direct use of renewable electricity is not applicable.
- The transport sector also increasingly relies on hydrogen as a renewable fuel, where battery-supported electric vehicles reach their limitations and where limited biomass potential restricts the extension of biofuel use. However, future hydrogen applications may not be sufficient to replace all fossil fuel demand, especially in aviation, heavy duty vehicles and navigation. The RENEWABLES 2 study introduces synthetic hydrocarbons from renewable hydrogen, electricity and biogenic/atmospheric CO_2. These synthetic fuels are introduced after 2030 and provide for the remaining fossil fuel demand that cannot be met by biofuels due to limited potential.

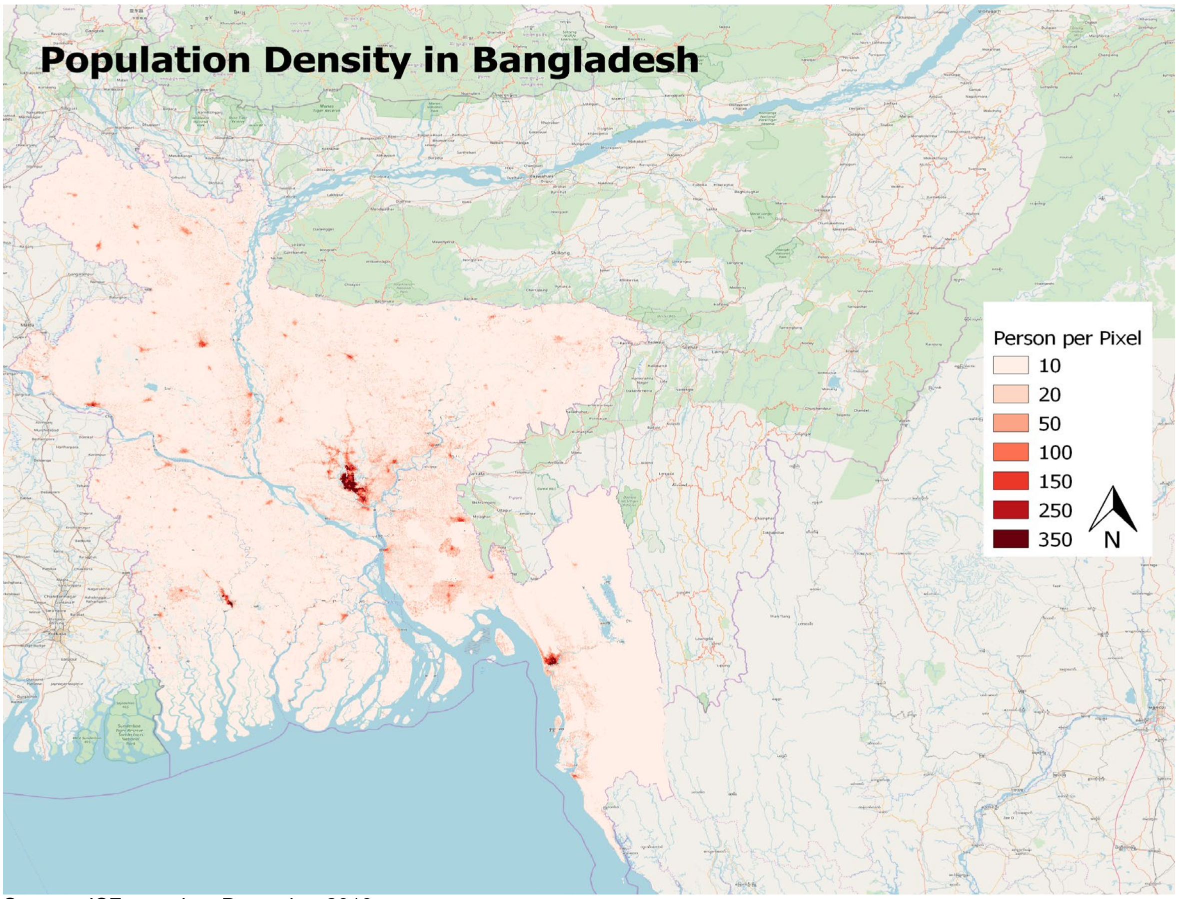
[119] Huda et. al. 2013 - Biomass energy in Bangladesh: Current status and prospects
A.S.N. Huda; S. Mekhilef (Department of Electrical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia) and A. Ahsan (Department of Civil Engineering and Institute of Advanced Technology, University Putra Malaysia, 3400 UPM Serdang, Selangor, Malaysi), Elsevier, Renewable and Sustainable Energy Review 30 (2014) 504-517, November 2013

5.5 BANGLADESH – ASSUMPTIONS BY REGION

The regional distribution of demand and supply is based on interviews with experts in Bangladesh and the results of mapping analysis with QGIS (see 4.2) as input data for the [R]E 24/7 energy access analysis. This section provides an overview of the key mapping results.

Distribution of population and power grid
The regional breakdown used for the energy model and the distribution of Bangladesh's populations is shown in Figure 13. Bangladesh has one of the highest population densities in the world, thus available land is scarce. The highest population density is in and around Dhaka, the capital of Bangladesh with over 1600 people per square kilometer. The lowest population densities are in the two coastal states Khulna und Barisal and in the north-eastern province of Sylhet.

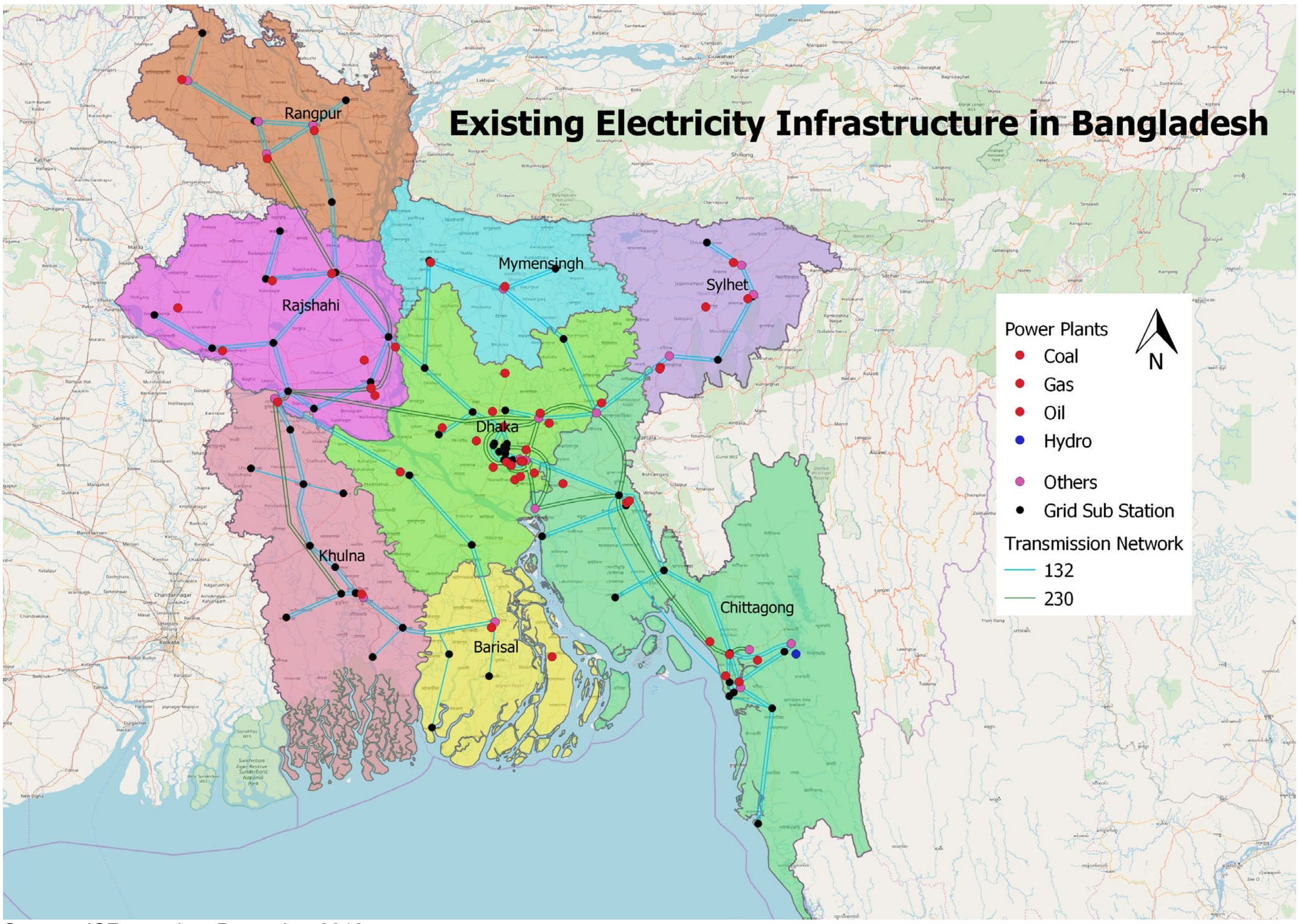
Figure 13: Distribution of population in relation to existing power grid and mini grids



Source: ISF mapping, December 2019

Figure 14 shows the different types of grids and power stations in the country. The dots mark grid connected power plants t- GIS based data about existing mini grids is not available for Bangladesh. Different colors highlight the fuel source, ranging from fossil fuel-based coal and oil plants to alternative fuel-based solar, biomass and wind power plants.

Figure 14: Existing electricity infrastructure by type



Source: ISF mapping, December 2018

5.6 OVERVIEW – LONG TERM SCENARIO

Bangladesh needs to build up and expand its power generation system in order to increase the energy access rate to 100 per cent. Building new power plants – no matter what the technology – will require new infrastructure, such as power grids, spatial planning, a stable policy framework and access to finance.

With decreased prices for solar photovoltaic and onshore wind in recent years, renewables have become an economic alternative to building new gas power plants. As a result, renewables achieved a global market share of over 60 per cent of all new build power plants since 2014. Bangladesh has significant solar resource and coastal areas are suitable for on- and offshore wind. Renewable generation costs are generally lower with increased solar radiation and wind speeds. However, constantly shifting policy frameworks often lead to high investment risks and therefore higher project development and installation costs for solar and wind projects relative to countries with more stable policy.

The scenario-building process for all scenarios includes assumptions on policy stability, the role of future energy utilities, centralised fossil fuel-based power generation, population and GDP, firm capacity and future costs.

- **Policy stability:** This research assumes that Bangladesh will establish a secure and stable framework for the deployment of renewable power generation. In essence, financing a gas power plant or a wind farm is quite similar. In both cases a power purchase agreement, which ensures a relatively stable price for a specific quantity of electricity, is required to finance the project. Daily spot market prices for electricity and/or renewable energy or carbon are not sufficient for long-term investment decisions for any kind of power plants with technical lifetimes of 20 years or longer.
- **Strengthened energy efficiency policies:** Existing policy settings, namely energy efficiency standards for electrical applications, buildings and vehicles, will need to be strengthened in order maximise cost-efficient use of renewable energy and achieve a high energy productivity by 2030.
- **Role of future energy utilities:** With 'grid parity' of rooftop solar PV under most current retail tariffs, this modelling assumes that the energy utilities of the future take up the challenge of increased local generation and develop new business models that focus on energy services, rather than just on selling kilowatt-hours.
- **Population and GDP:** The three scenarios are based on the same population and GDP assumptions. Projections of population growth are taken from the *World Population Review* [70] while the GDP projection are taken from Bangladesh's Power System Master Plan 2016 which assumes long-term average growth of around 7 per cent per year over the scenario period, as documented in Section 4.1.3.
- **Firm capacity:** The scale of each technology deployed and the combinations of technologies in each of the three scenarios target a firm capacity. Firm capacity is the "proportion of the maximum possible power that can reliably contribute towards meeting peak power demand when needed."[121] Firm capacity is important to ensure a reliable and secure energy system. Note that variable renewables still have a firm capacity rating, and the combination of technology options increases the firm capacity of the portfolio of options (see also 'security of energy supply' point in the RE scenarios).
- **Cost assumptions:** The same cost assumptions are utilised across all three scenarios. As technology costs decline with deployment scale rather than time, the renewable energy cost reduction potential in both RENEWABLES cases may even be larger than in the REFERENCE case due to larger market sizes. The reverse is true for the fuel cost assumptions as all three scenarios are based on low fossil fuel price projections; while both RENEWABLES scenarios have a significant drop in demand, the REFERENCE case assumes increased demand that may lead to higher fuel costs. As such, the costs should be considered conservative. The cost assumptions are documented in section 4.1.4.

[121] http://igrid.net.au/resources/downloads/project4/D-CODE_User_Manual.pdf

5.6.1 THE REFERENCE SCENARIO

The REFERENCE scenario (REF) reflects a continuation of current policies and is based on Bangladesh's Government *Power System Masterplan 2016* (5.2.3). Energy statistics are taken from the International Energy Agency's *World Energy Balances of OECD Countries 2018*[122] as well as other sources documented in Sections 5.2.2 to 5.2.1.

5.6.2 ASSUMPTIONS FOR BOTH RENEWABLES SCENARIOS

Both the RENEWABLES 2.0°C ("2.0°C") and the RENEWABLES 1.5°C ("1.5°C") scenarios are built on a framework of targets and assumptions that strongly influence the development of individual technological and structural pathways for each sector. The main assumptions considered for this scenario-building process are detailed below.

- **Emissions reductions:** the main measures to meet CO_2 emission reductions in the 2.0°C and 1.5°C scenarios include strong improvements in energy efficiency resulting in doubling energy productivity over the next 10 to 15 years, and the dynamic expansion of renewable energy across all sectors.
- **Renewables industry growth**: dynamic growth in new capacities for renewable heat and power generation is assumed based on current knowledge about potential, costs and recent trends in renewable energy deployment (see energy potentials discussed in Section 4. and 5). Communities will play a significant role in the expansion of renewables, particularly regarding project development, inclusion of local population and operation of regional and/or community owned renewable power projects.
- **Fossil fuel phase-out:** the operational lifetime for gas power plants is conservatively estimated to be 30 years. In both scenarios, coal power plants are phased out early on, followed by gas power plants**.**
- **Future power supply:** the capacity of large hydropower remains flat in Bangladesh over the entire scenario period, while the quantities of bioenergy grow within the nation's potential for sustainable biomass (see below). Wind power (on- and offshore) and solar photovoltaic are expected to be the main pillars of future power supply, complemented by contributions from bioenergy and gas power plants (fueled with synthetic-fuels/hydrogen after 2040 – see below). Solar PV figures combine both rooftop and utility scale PV plants including floating solar. The potential for offshore wind is significantly higher than onshore wind, thus the majority of the wind power under both RENEWABLES scenarios is offshore wind.
- **Offshore wind:** Wind resources in Bangladesh are concentrated on the three coastal states Khulna, Barisal and Chittagong. The entire capacity in both RENEWABLES scenarios is concentrated there. Offshore wind parks are located up to 120 km offshore.
- **Security of energy supply:** the scenarios limit the share of variable power generation and maintain a sufficient share of controllable, secured capacity. Power generation from biomass and gas-fired back-up capacities and storage, are considered important for the security of supply in a future energy system, related to the output of firm capacity discussed above. Storage technologies play an increase role after 2030, while gas power plants will switched to synthetic full towards the end of the scenario period.
- **Sustainable biomass levels:** the sustainable level of biomass use for Bangladesh is assumed to be limited to 1000 PJ. Low-tech biomass use, such as in inefficient household wood-burners, are largely replaced in the RENEWABLES scenarios by state-of-the-art technologies, primarily highly efficient cogeneration plants. **The remaining bio energy is assumed to be imported.**
- **Electrification of transport**: efficiency savings in the transport sector are a result of fleet penetration with new highly efficient vehicles such as electric vehicles, but also assumed changes in mobility patterns and the implementation of efficiency measures for combustion engines. The scenarios assume limited use of biofuels for transportation given the limited supply of sustainable biofuels.
- **Hydrogen and synthetic fuels:** hydrogen and synthetic fuels generated by electrolysis using renewable electricity are introduced as a third renewable fuel in the transportation sector, complementary to biofuels, the direct use of renewable electricity and battery storage. Hydrogen generation can have high-energy losses; however, the limited potential of biofuels and mostly likely also battery storage for electric mobility mean it is necessary to have a third renewable option in the transport sector. Alternatively, this renewable hydrogen could be converted into synthetic methane and liquid fuels depending on economic benefits (storage costs versus additional losses) as well as technology and market development in the transport sector (combustion engines versus fuel cells). Due to the limited renewable energy potential of Bangladesh, it is assumed that hydrogen and synthetic fuels are imported.

[122] International Energy Agency, 2019, *World Energy Balances of OECD Countries 2018.* Available at: https://www.iea.org/statistics/relateddatabases/energybalancesofoecdcountries/

5.6.3 THE RENEWABLES 2.0°C SCENARIO

The RENEWABLES 2.0°C scenario (2.0°C) is designed to meet Bangladesh's energy-related targets to achieve 100 per cent renewable energy as soon as possible, as outlined in section 5.1. The energy efficiency projections for each sector are calculated as documented in section 4.4.
The renewable energy trajectories for the initial years take the "Bangladesh Policy Road Map for Renewable energy" (Basu 2015) [123] into account. This suggests that renewable energy markets in developing countries are projected to grow at a rate equal to the renewable energy markets of OECD countries.

In addition, pathways for the deployment of renewable energy and efficiency measures reflect the technology trends of recent years and market estimations of the solar photovoltaic, wind industry and other innovative technologies. This scenario includes significant efforts to fully exploit the extensive potential for energy efficiency available through current best-practice technology. At the same time, various proven renewable energy sources are integrated – to a large extent for electricity generation, and also to a lesser extent for the production of synthetic fuels and hydrogen for heating (domestic, commercial and industrial) and transport.

5.6.4 THE RENEWABLES 1.5°C SCENARIO

The RENEWABLES 1.5°C scenario (1.5°C) takes a more ambitious approach to transforming Bangladesh's entire energy system towards 100 per cent renewable energy supply. The consumption pathways remain almost the same as in the RENEWABLES scenario, however under this scenario a much faster introduction of new technologies leads to a complete decarbonisation of energy for stationary energy (electricity), heating (including process heat for industry) and transportation. The latter requires a strong role for storage technologies such as batteries, synthetic fuels and hydrogen.
The resulting final energy demand for transportation is lower compared to the RENEWABLES 2.0°C scenario based on the assumptions that:

- Future vehicles and particularly electric vehicles will be more efficient and
- There will be greater improvement in the public transport system

The RENEWABLES 1.5°C scenario increases the share of electric and fuel cell vehicles. This scenario also relies on greater production of synthetic fuels from renewable electricity for use in the transport and industry sectors. Renewable hydrogen is converted into synthetic hydrocarbons that replace the remaining fossil fuels, particularly in heavy-duty vehicles and air transportation – albeit with low overall efficiency of the synthetic fuels system. Note that since renewable synthetic fuels require (gas) pipeline infrastructure, this technology is not widely applied for Bangladesh's energy access plan due to relatively high costs in the early development stages. It is assumed that synthetic fuels and hydrogen will not enter Bangladesh's energy system before 2040; to compensate for the high energy losses associated with the production of synthetic fuels, it requires more fundamental infrastructure changes that seems too costly for a developing country as this stage. In the heating sector, mainly heat for industry, electricity and hydrogen play a larger role in replacing remaining fossil fuels. In the power sector, natural gas is also replaced by hydrogen. Therefore, electricity generation increases significantly in this scenario, assuming power from renewable energy sources to be the main 'primary energy' of the future.

The RENEWABLES 1.5°C scenario also models a shift in the heat sector towards increased direct use of electricity because of the enormous and diverse potential for renewable power and the limited availability of renewable fuels for high-temperature process heat in industry. Increased implementation of district heating infrastructure (interconnection of buildings in Central Business Districts) and geothermal heat pumps for office buildings and shopping centers in larger cities is assumed, leading to a growth in electricity demand that partly offsets the efficiency savings in these sectors. A rapid expansion of solar and geothermal heating systems is also assumed.

The increasing shares of variable renewable power generation, principally by wind farms and photovoltaics, will require the implementation of smart grids and a fast interconnection of micro and mini grids with regional distribution networks, storage and other load balancing capacities. Other infrastructure requirements include the increasing role of on-site renewable process heat generation for industries and mining and the generation and distribution of synthetic fuels. The RENEWABLES 1.5°C scenario therefore assumes that such infrastructure projects will be implemented in all parts of Bangladesh without serious societal, financial or political barriers. Scenarios by no means claim to predict the future; they provide a useful tool to describe and compare potential development pathways from the broad range of possible 'futures'. The RENEWABLES 1.5°C scenario was

[123] Basu (2015) Sumedha Basu, South Asia Policy Coordinator and Mukul Sharma, South Asia Director Climate Parliament, Dr. Rudolf Rechsteiner, advisor, Bangladesh Policy Road Map for Reneable Energy, Dhaka/London/Delhi/Basel, May 2015; published in May 2017.

designed to indicate the efforts and actions required to achieve the ambitious objective of a 100 per cent renewable energy system and to illustrate the options available to change our energy supply system into one that is truly sustainable. They may serve as a reliable basis for further analyses of possible concepts and actions needed to implement pathways for Results.

The following results are from both the long-term scenario model (LT) as well as the [R]E 24/7 model described in chapter 3. The models are not directly connected, and as such the results for power generation can vary by +/- 5 per cent because of differing modelling methodologies. The [R]E 24/7 model calculates hourly generation profiles with a chosen dispatch order, which influences capacity factors, whereas the long-term model calculates annual accounting totals with assumed capacity factors. As a result, dispatch power plants may be calculated with higher capacity factors.

5.7 BANGLADESH – ENERGY PATHWAY UNTIL 2050

In this section we outline the key results across a range of areas, both in terms of the impacts and the costs of the different scenarios. Firstly, we consider stationary energy, focusing on electricity generation, capacity and breakdown by technology. We then examine energy supply for heating with a focus on industrial heat supply, followed by a consideration of the impacts and costs of the different scenarios on transport and the development of CO_2 emissions. The section ends with an examination of the final costs, outlining the required energy budget.

To understand the results, it is first necessary to clarify the metrics used. Two of the main metrics used in the energy industry to analyze energy are primary energy consumption and final energy demand. Final energy demand "is a measure of the energy that is delivered to energy end users in the economy to undertake activities as diverse as manufacturing, movement of people and goods, essential services and other day-to-day energy requirements of living."[124] Primary energy consumption is defined as the "direct energy use at the source, or supply to users without transformation, of crude energy; that is, energy that has not been subjected to any conversion or transformation process."[125]

Primary energy statistics often make the renewables share appear lower than other forms of energy. For example, IEA's 2010 statistics listed the global primary energy share for nuclear energy as 6 per cent and hydropower at 2 per cent, however both technologies produced the same amount of power generation in terawatt hours. This is because nuclear power is a thermal process with an average efficiency of around 30 per cent – thus the input of uranium (the primary energy resource) is therefore three times higher than the final energy (3:1), while hydropower, which does not involve a thermal process is calculated as final energy, is equal to primary energy (1:1).

[124] http://www.seai.ie/Energy-Data-Portal/Frequently-Asked-Questions/Energy_Use_FAQ/
[125] https://stats.oecd.org/glossary/detail.asp?ID=2112

5.7.1 BANGLADESH FINAL ENERGY DEMAND

Combining the projections on population development, GDP growth and energy intensity results in future development pathways for Bangladesh's final energy demand. These are shown in Figure 15 for the Reference and Renewable scenarios. Under the Reference scenario, total final energy demand increases by 320% from the current 1000 PJ/a to 4200 PJ/a in 2050. In the 2.0°C scenario, final energy demand increases at a much lower rate by 250% compared to current consumption and is expected to reach 3500 PJ/a by 2050. The 1.5°C scenario results in some additional reductions due to a higher share of electric cars.

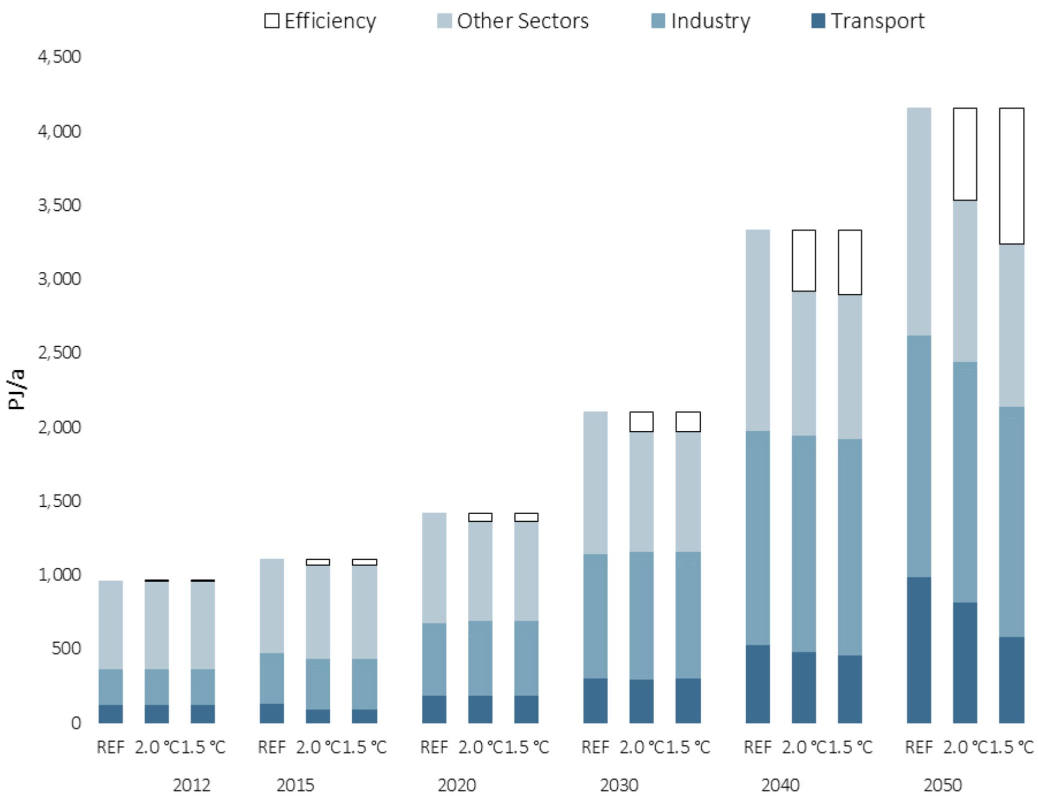
Under both Renewable scenarios, due to economic growth, increasing living standards and electrification of the transport sector, overall electricity demand is expected to increase despite efficiency gains in all sectors (see Figure 15). Total electricity demand will rise from about 40 TWh/a to 380 TWh/a by 2050 in the Renewables 2.0°C scenario. Compared to the Reference scenario, efficiency measures in the industry, residential and service sectors avoid the generation of about 30 TWh/a.

This reduction can be achieved in particular by introducing highly efficient electronic devices using the best available technology in all demand sectors. The transformation to a carbon free energy system in the 1.5°C scenario will further increase the electricity demand in 2050 up to 400 TWh/a. 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 60 TWh are used in 2050 for electric vehicles and rail transport in 2050 in the 1.5°C.

Efficiency gains in the heating sector are even larger than in the electricity sector. Under both RENEWABLE scenarios, consumption equivalent to about 100 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 climatization' 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 15: Projection of total final energy demand by sector

(excluding non-energy use and heat from CHP auto producers)



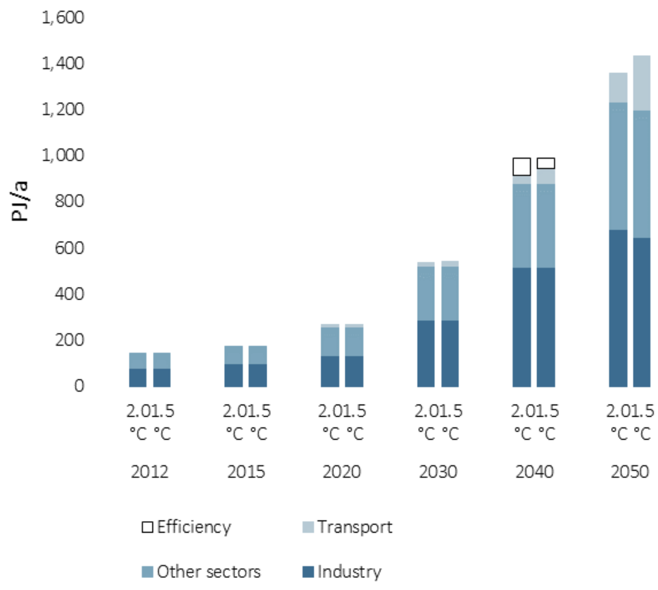


Figure 16: Development of electricity demand by sector in both RENEWABLES scenarios

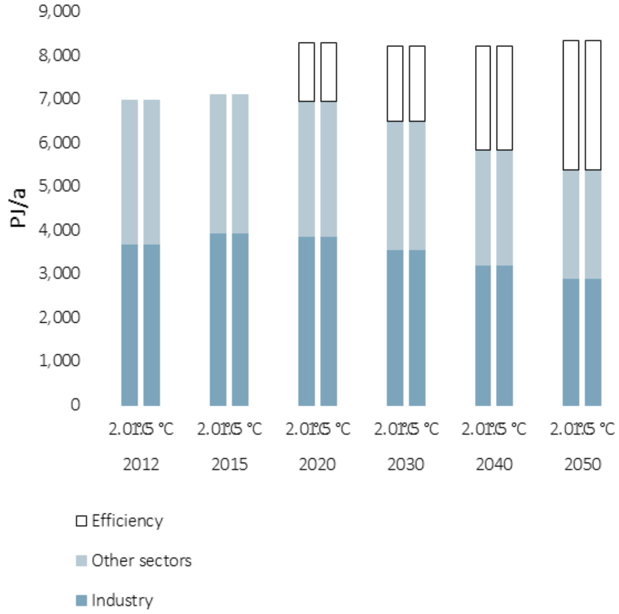


Figure 17: Development of the final energy demand for transport by sector in the RENEWABLES scenarios

5.7.2 ELECTRICITY GENERATION

5.7.2.1 Electricity generation, capacity and breakdown by technology

The renewable energy market grows dynamically and has an increasing share in the required electricity supply. This trend will more than compensate for the phasing out of fossil fuel-based power production in both Renewable scenarios. By 2050, 76% of the electricity produced in Bangladesh will come from renewable energy sources in the 2.0°C scenario. 'New' renewables – mainly wind and solar photovoltaic electricity – will contribute 56% to the total electricity generation. Already by 2020 the share of renewable electricity production will be 2% and 33% by 2030. The installed capacity of renewables will reach about 30 GW in 2030 and 150 GW by 2050. A 100% electricity supply from renewable energy resources in the 1.5°C scenario leads to around 200 GW installed generation capacity in 2050.

Figure 18: Breakdown of electricity generation by technology

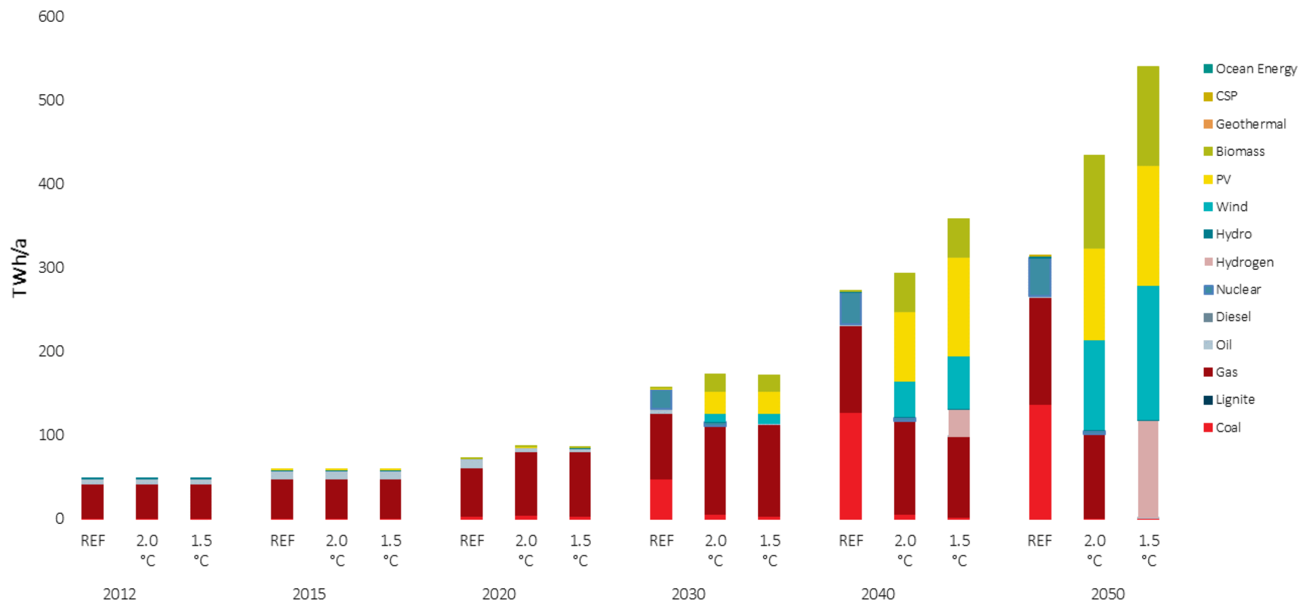


Table 25 shows the comparative evolution of the different renewable technologies in Bangladesh over time. Until 2040 hydro will remain the main renewable power source. By 2020 wind and PV overtake biomass, currently the second largest contributor to the growing renewable market. After 2020, the continuing growth of wind and PV will be complemented by electricity from solar thermal, geothermal and ocean energy. Renewable scenarios will lead to a high share of variable power generation sources (wind and photovoltaics) of already 12% to 23% by 2030 and 56% to 65% by 2050. Therefore, smart grids, demand side management (DSM), energy storage capacities and other options need to be expanded to increase the flexibility of the power system for grid integration, load balancing and a secure supply of electricity. In contrast to the REF scenario which plans to build nuclear reactors with a total capacity of 7,000 MW, the 2.0°C scenario includes on the completion of one reactor block with a capacity of 600 MW which is currently under construction. The 1.5°C scenario assumes, that this current construction of the nuclear reactor will not be complete due to the substantial economic advantage of renewable power generation.

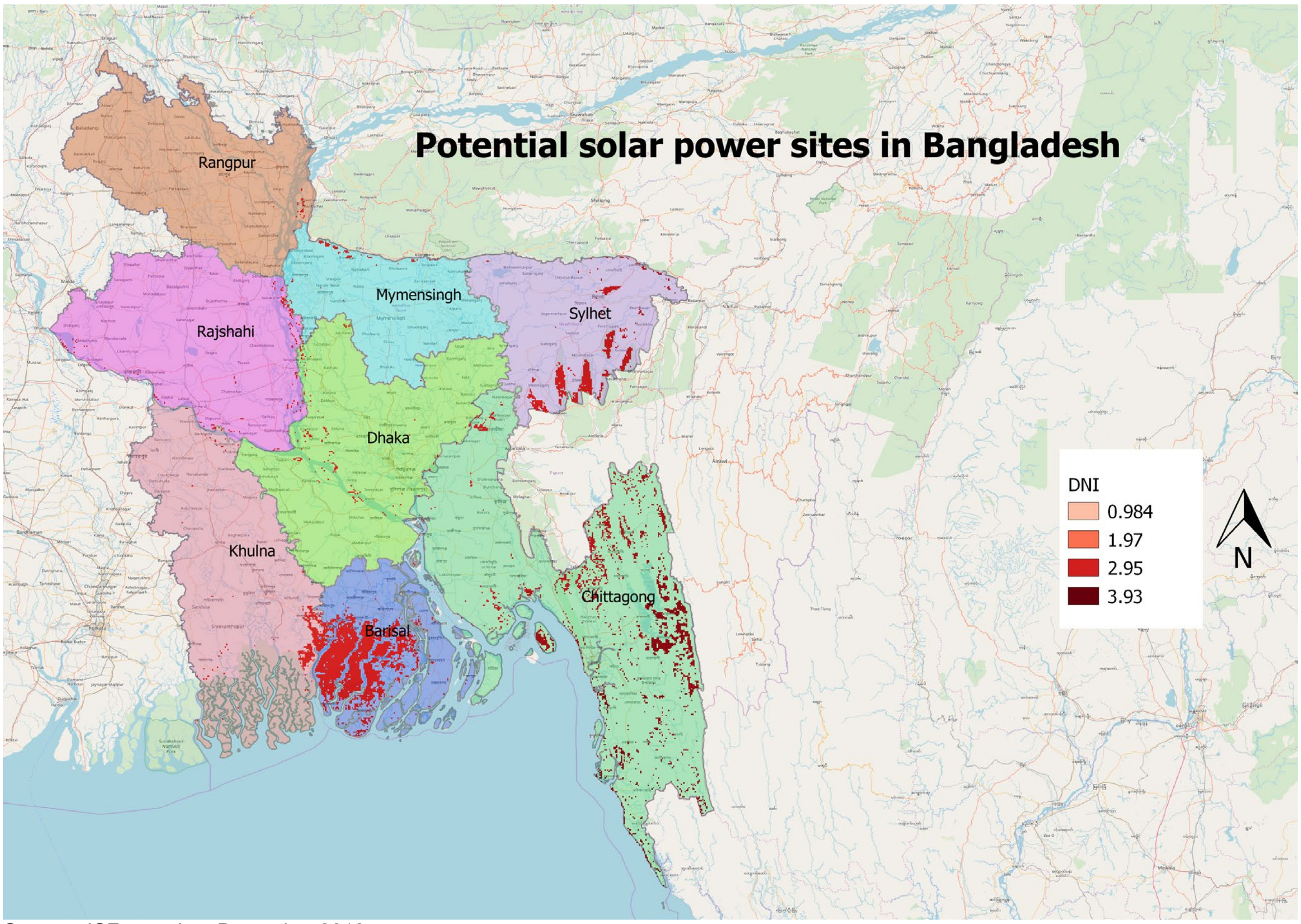
Table 25: Projection of renewable electricity generation capacity

In GW		2015	2020	2030	2040	2050
Hydro	REF	0.230	0.242	0.358	0.530	0.780
	2.0 °C	0.230	0.238	0.263	0.445	0.491
	1.5 °C	0.230	0.238	0.263	0.445	0.491
Biomass	REF	0.000	0.001	0.002	0.002	0.003
	2.0 °C	0.000	0.088	3.610	8.207	21.511
	1.5 °C	0.000	0.090	3.621	8.252	24.724
Wind	REF	0.003	0.003	0.005	0.007	0.010
	2.0 °C	0.003	0.010	2.871	12.312	31.203
	1.5 °C	0.003	0.010	3.423	18.137	45.906
PV	REF	0.100	0.105	0.156	0.230	0.336
	2.0 °C	0.100	0.428	23.084	73.603	96.470
	1.5 °C	0.100	0.428	23.084	104.199	126.694
Total	REF	0.333	0.351	0.520	0.769	1.130
	2.0 °C	0.333	0.763	29.828	94.567	149.676
	1.5 °C	0.333	0.765	30.391	131.033	197.815

5.7.2.2 Regional distribution of solar and wind resources

Bangladesh has almost 6,250 square kilometers of available land where 156 gigawatts of solar power can potentially be harvested through utility scale solar farms. To avoid conflicts with National Parks and other competing uses of land, only perennial cropland and open bushland land cover types were included in the analysis. Only utility scale solar photovoltaic is included in the analysis, as the solar resource is not sufficient for concentrated solar power (CSP) which requires highest direct normal irradiance. In Figure 19 it is assumed that this suitable area will be used for utility-scale solar photovoltaic, 20 per cent of the total utility scale photovoltaic power plants are floating installations. Figure 19 shows the distribution of potential sites that are ideal for setting up utility scale solar plants.

Figure 19 : Solar energy generation potential in Bangladesh

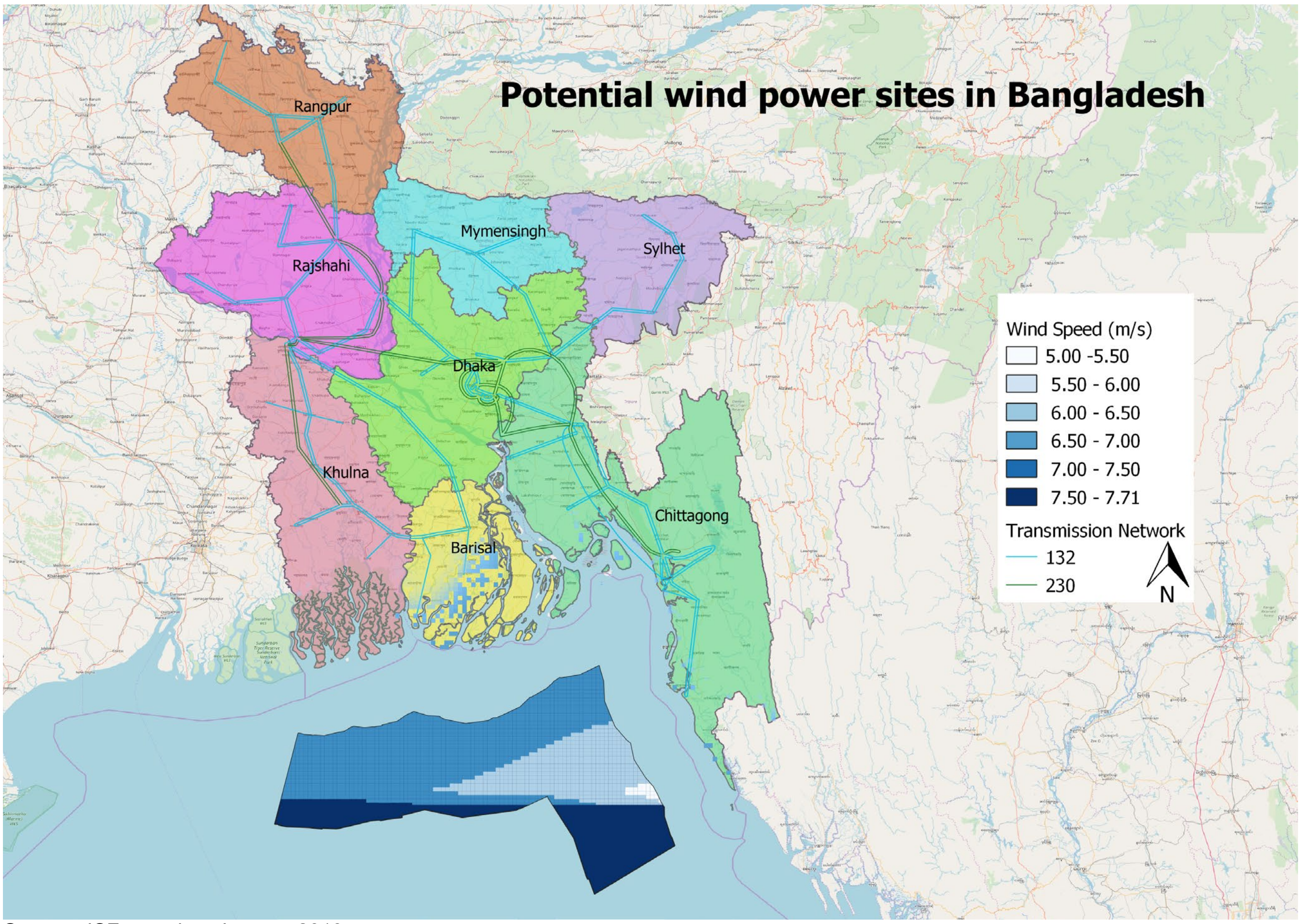


Source: ISF mapping, December 2018

The distribution of potential sites for optimal wind power generation is shown in Figure 20. The map highlights the only a relative small amount of land is available for utility scale onshore wind power generation, therefore offshore wind has been considered to a large extend as well.

Potential exists to install at least 16 gigawatts of onshore wind power from sites spread over 3,200square kilometers across Bangladesh, mainly in the southern part of the country. This analysis considers only sides with wind speeds of 5 meters per second and above to plot optimal sites. Site selection is restricted to include only the following land cover types: bare soil, annual cropland, perennial cropland, grassland and ocean. Offshore water bodies within 50 to 120 kilometers of the coast were included in the analysis. This leads to an estimated offshore wind potential of 134 gigawatts and an onshore wind potential of around 16 gigawatts. The onshore wind potential has been used to a large extent in order to maximize local electricity generation in Bangladesh.

Figure 20 : On- and offshore wind energy generation potential in Bangladesh



Source: ISF mapping, January 2019

Table 26: Renewable energy potential – results from QGIS mapping

Resource	Maximum installable generation capacity [GW]	Maximum recoverable electricity [TWh/year]	1.5°C in 2050: installed capacity [GW]	1.5°C in 2050: generation [TWh/year]
Wind – onshore	16	55	10	27
Wind – offshore	134	525	36	133
Wind - total	150	580	46	160
Solar Photovoltaics – roof top	35	40	35	
Solar Photovoltaics – utility scale	156	177	155	
Of which is floating PV	31	35	30	35
Solar Photovoltaic - total	191	217	188	211
Total	**239**	**380**	**234**	**371**

SOURCE: ISF mapping, January 2019, values are rounded

5.7.3 ENERGY SUPPLY FOR COOKING AND INDUSTRIAL PROCESSHEAT

Today, renewables meet around 51% of Bangladesh'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. In the 2.0°C scenario, renewables already provide 44% of Bangladesh's total heat demand in 2030 and 81% in 2050.

- Energy efficiency measures help to reduce the currently growing energy demand for heating by 4 % in 2050 (relative to the Reference scenario), despite improving living standards and economic growth.
- In the industry sector solar collectors, geothermal energy (mainly heat pumps) as well as electricity and hydrogen from renewable sources are increasingly substituting for fossil fuel-fired systems.
- A shift from coal and oil to natural gas in the remaining conventional applications leads to a further reduction of CO_2 emissions.

Figure 21: Projection of heat supply by energy carrier (REF, 2.0°C and 1.5°C)

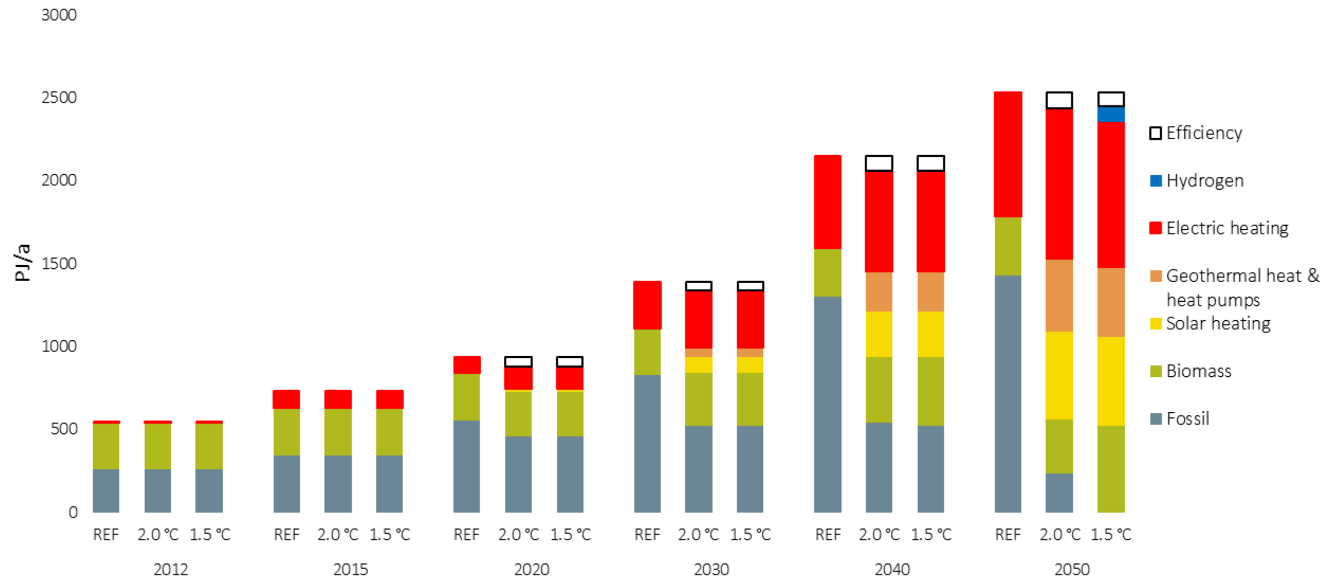


Table 27: Projection of renewable heat supply (cooking and process heat)

in PJ/a		2015	2020	2030	2040	2050
Biomass	REF	282	282	281	293	357
	2.0 °C	277	273	320	397	331
	1.5 °C	277	273	320	412	514
Solar heating	REF	0	0	0	0	0
	2.0 °C	0	8	95	271	528
	1.5 °C	0	8	95	272	5328
Geothermal heat & heat pumps	REF	0	0	0	0	0
	2.0 °C	0	5	58	243	437
	1.5 °C	0	5	58	243	425
Hydrogen	REF	0	0	0	0	0
	2.0 °C	0	0	0	1	2
	1.5 °C	0	0	0	1	97
Total	REF	282	282	281	293	357
	2.0 °C	277	286	472	911	1,297
	1.5 °C	277	286	472	928	1,573

Table 28 shows the development of different renewable technologies for cooking and industrial process heat in Bangladesh over time. Biomass remains the main contributor, with increasing investments in highly efficient modern biomass technology. After 2030, a massive growth of solar collectors and a growing share of geothermal and environmental heat as well as heat from renewable hydrogen can further reduce the dependence on fossil fuels. The 1.5°C scenario results in a complete substitution of the remaining gas consumption by hydrogen generated from renewable electricity.

Table 28: Installed capacities for renewable heat generation

in GW		2020	2030	2040	2050
Biomass	REF	70	69	69	79
	2.0 °C	67	70	72	32
	1.5 °C	67	70	74	52
Geothermal	REF	0	0	0	0
	2.0 °C	0	2	10	19
	1.5 °C	0	2	10	18
Solar heating	REF	0	0	0	0
	2.0 °C	2	19	62	138
	1.5 °C	2	19	62	138
Heat pumps	REF	0	0	0	0
	2.0 °C	1	6	23	44
	1.5 °C	1	6	23	43
Total	REF	70	69	69	79
	2.0 °C	71	98	167	232
	1.5 °C	71	98	169	251

5.7.4 TRANSPORT

A key target in Bangladesh is to develop the transport sector with local available and accepted technologies. Bangladesh has among the highest densities of rickshaws in Asia: About 2 million rickshaws, a majority is already or is in the process of conversion towards battery electric drives.
The 1.5°C scenario increases the use of electric rickshaws and tri-cycles significantly making them one of the backbones of the road transport systems. In addition, all urban regions will shift the transport system to a high degree towards efficient rail, light rail and buses, especially in the expanding large metropolitan areas.

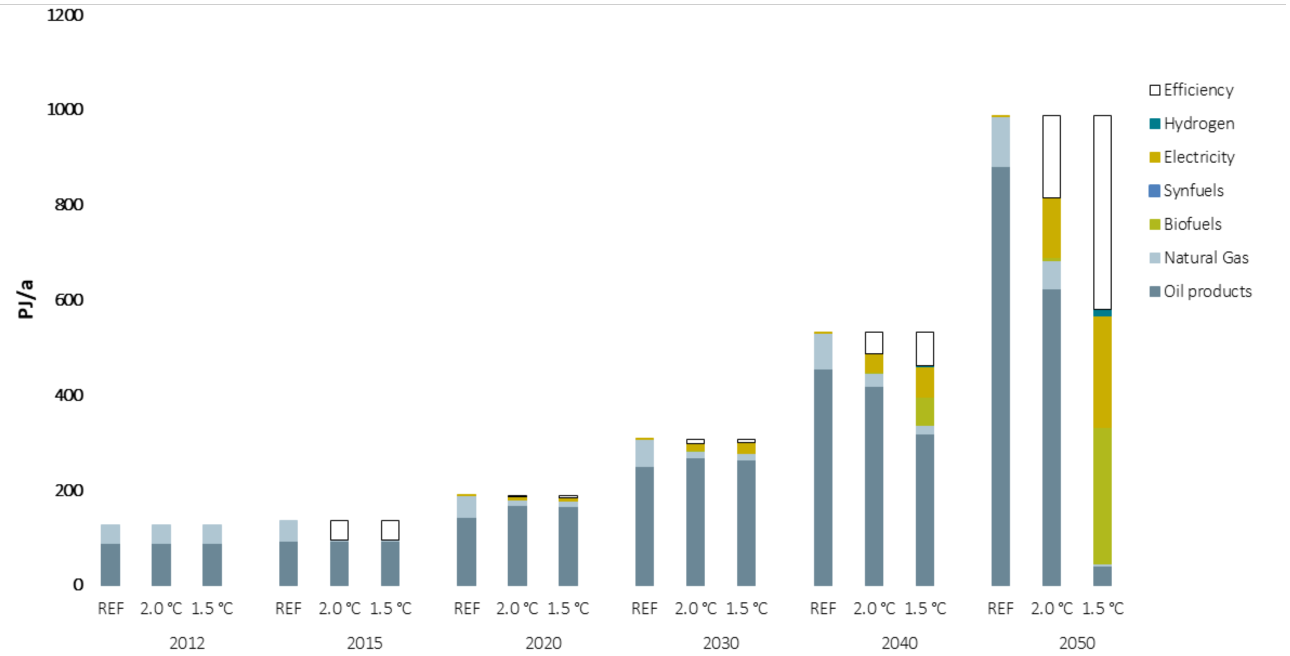
Along with rising prices for fossil fuels, these changes reduce the further growth in car sales projected under the Reference scenario. Due to population increase, GDP growth and higher living standards, energy demand from the transport sector is expected to increase in the Reference scenario by around 678% to 990 PJ/a in 2050. In the 2.0°C scenario, efficiency measures and modal shifts will save 44% (440 PJ/a) in 2050 compared to the Reference scenario.

Additional modal shifts and technology switches lead to even higher energy savings in the 1.5°C scenario of 41% (410 PJ/a) in 2050 compared to the Reference scenario. 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 5% of the transport sector's total energy demand in the 2.0°C, while in 2050 the share will be 15% (40% in the 1.5°C scenario). Bio- and other synthetic fuels generated using renewable electricity are complementary options to further increase the renewable share in the transport sector. However, due to the limited renewable electricity generation potential within the country, the use of hydrogen for transport is limited to imported fuels.

Table 29: Projection of transport energy demand by mode

in PJ/a		2015	2020	2030	2040	2050
Rail	REF	12	12	13	13	14
	2.0 °C	12	13	13	13	13
	1.5 °C	12	13	26	45	67
Road	REF	103	135	247	463	909
	2.0 °C	99	131	236	419	737
	1.5 °C	99	129	226	363	441
Domestic navigation	REF	17	17	20	24	30
	2.0 °C	16	17	20	24	30
	1.5 °C	16	17	20	24	30
Total	REF	132	165	280	501	952
	2.0 °C	127	161	270	456	780
	1.5 °C	127	159	272	432	538

Figure 22: Final energy consumption transport under the scenarios

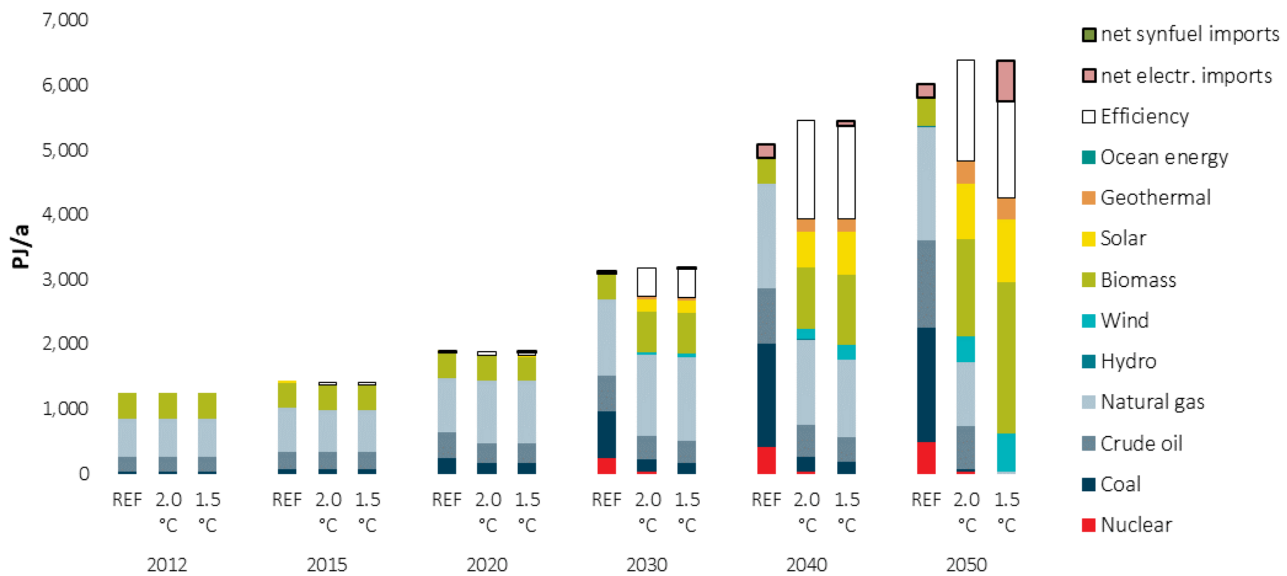


5.7.5 PRIMARY ENERGY CONSUMPTION

Considering the assumptions discussed above, the resulting primary energy consumption under both RENEWABLES and the reference cases is shown in Figure 23. Under the 2.0°C scenario, primary energy demand will increase by 370% from today's 1230. PJ/a to around 5000. PJ/a. Compared to the Reference scenario, overall primary energy demand will be reduced by 17% in 2050 under the 2.0°C scenario (REF: around 6000. PJ in 2050). The 1.5°C scenario results in a primary energy consumption of around 4500 PJ in 2050 (incl. imports).

The RENEWABLE scenarios aim to phase out coal and oil as fast as technically and economically possible by expansion of renewable energies and a fast introduction of very efficient vehicle concepts e.g. plug-in hybrids and electric rickshaws in the transport sector to replace oil-based combustion engines. This leads to an overall renewable primary energy share of 33% in 2030 and 65% in 2050 in the 2.0°C and 100% in 2050 in the 1.5°C case (excl. non-energy consumption).

Figure 23: Projection of total primary energy demand by energy carrier (incl. electricity imports balance)

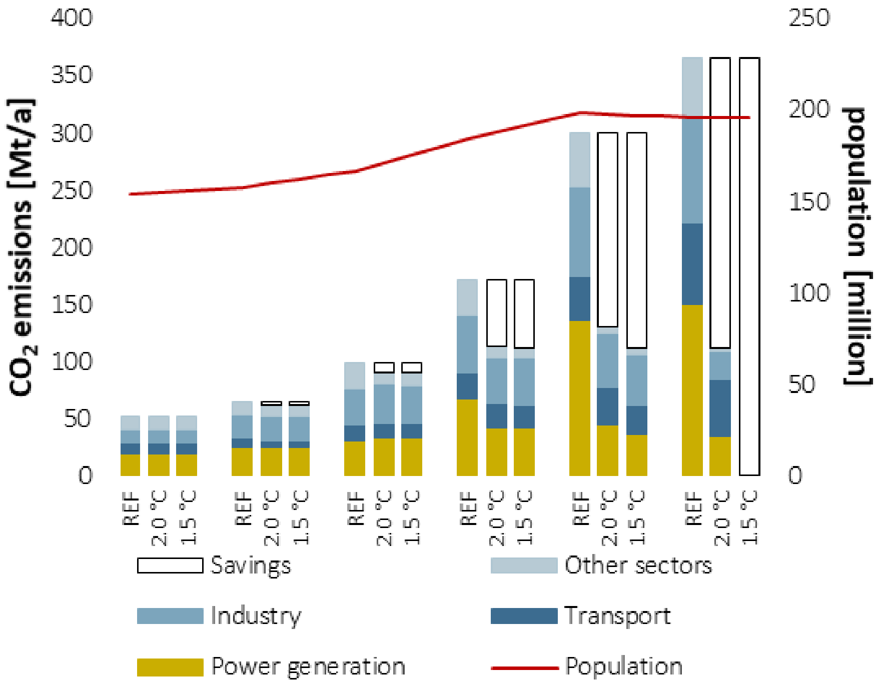


5.7.6 CO_2 EMISSIONS TRAJECTORIES

Whilst Bangladesh`s CO_2 emissions will increase by a factor of 6 – from 67 million tons to over 400 million tons – between 2015 and 2050 under the REFERENCE scenario, both RENEWABLES scenarios will result in a moderate increase to 123 million tons with a population increase from 157 to 195 million people in the same period. As such, annual per capita emissions will remain at around 0.5 tons. While the power demand will increase by a factor of 10 in the 2.0°C case, overall CO_2 emissions of the electricity sector will double. In the long run, efficiency gains and the increased use of renewable electricity in vehicles will also dramatically reduce emissions in the transport sector. With a 25 per cent share of CO_2, the transport sector will be the second largest source of emissions in 2050 in the 2.0°C scenario.

The 1.5°C case will fully decarbonize by 2050. In 2040, will the electricity sector 36 million tons CO_2, just like the industry sector with equally high carbon emissions – mainly due to gas-based process heat generation. Thes two sectors combined represent 65% of the projected overall CO_2 emissions of Bangladesh in 2040. The third biggest CO_2 emissions under the 1.5°C case in 2040 will be the transport sector with 25 million tons (46%) by 2040. A full decarbonisation of all sectors is feasible with increased imported renewable energy (bio energy and synthetic fuels).

Figure 24: Development of CO2 emissions by sector under the RENEWABLES scenarios ('Efficiency' = reduction compared to the REFERENCE scenario)



5.7.7 COST ANALYSIS

5.7.7.1 Future costs of electricity generation

Figure 25 shows that the introduction of renewable technologies under both Renewable scenarios increases the future costs of electricity generation compared to the Reference scenario until 2030. This difference in full cost of generation will be less than 0.3 US$ cent/kWh in the 2.0°C and about 0.5 US$ cent/kWh in the 1.5°C scenario. This cost estimation excludes costs for storage. Possible additional costs for grid expansion requirements are not calculated as this was out of scope of this analysis. However, the significant increase of demand in Bangladesh under the reference case as well as the two alternative scenarios indicate that grid expansion will be require in any case. Because of increasing prices for conventional fuels and the lower CO_2 intensity of electricity generation, electricity generation costs will become economically favorable after 2040 under the Renewable scenarios. By 2050, the cost will be 0.2 / 1.1 US$ cent/kWh, respectively, below those in the Reference case. Figure 26 shows the future generation costs under the assumption of a relative low carbon price starting in 2030 with $10 per ton of CO2 increasing to $30 (2040) and $50 in 2050. The highest decarbonisation scenario is the most favorable one in both cases.

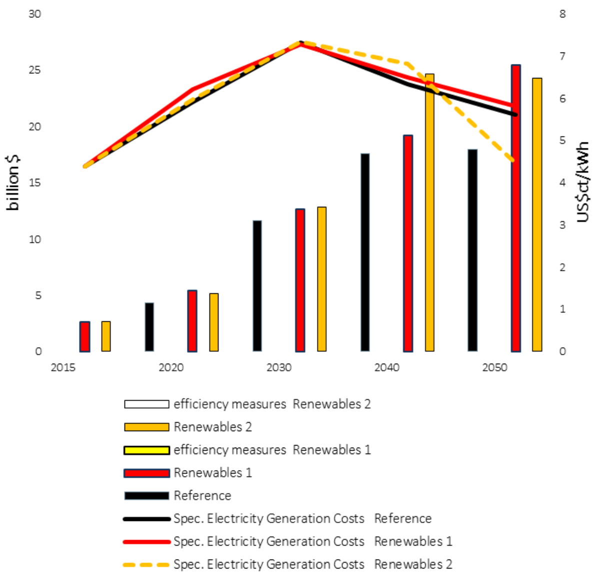


Figure 25: Development of total electricity supply costs and of specific electricity generation costs in the scenarios – with no carbon costs

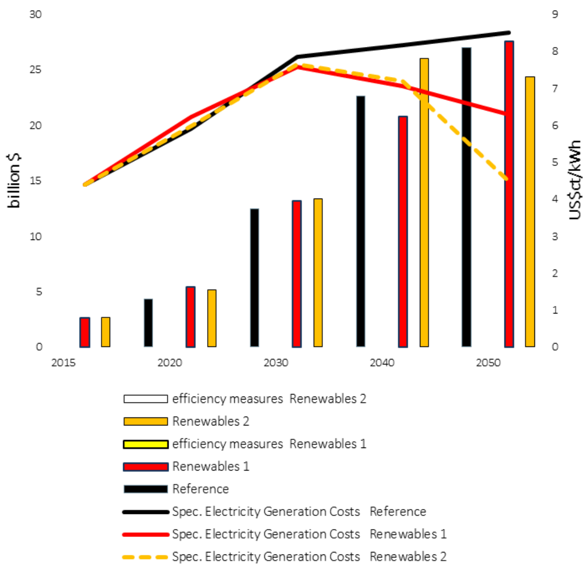


Figure 26: Development of total electricity supply costs and of specific electricity generation costs in the scenarios –including carbon costs

5.7.7.2 Future investments in the power sector

Around US$ 250 billion is required in investment for the 2.0°C scenario to become reality (including investments for replacement after the economic lifetime of the plants) - approximately US$ 6 billion per year, US$ 80 billion more than in the Reference scenario (US$ 170. billion). Investments for the Renewables 2 scenario sum up to US$ 310 billion until 2050, on average US$ 8 billion per year. Under the Reference scenario, the levels of investment in conventional power plants add up to almost 97% while approximately 3% would be invested in renewable energies and cogeneration until 2050.
Under the Renewable scenarios, however, Bangladesh would shift almost 84% (2.0°C case) respectively 88% (1.5°C) of the entire investment towards renewables and cogeneration, respectively. By 2030, the fossil fuel share of power sector investment would be focused mainly on gas power plants.

Because renewable energy has no fuel costs, the fuel cost savings in the 2.0°C scenario reach a total of US$ 140 billion up to 2050, US$ 4 billion per year. The total fuel cost savings therefore would cover 180% of the total additional investments compared to the Reference scenario. Fuel cost savings in the 1.5°C scenario are even higher and add up to US$ 200 billion, or US$ 5 billion per year. 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.

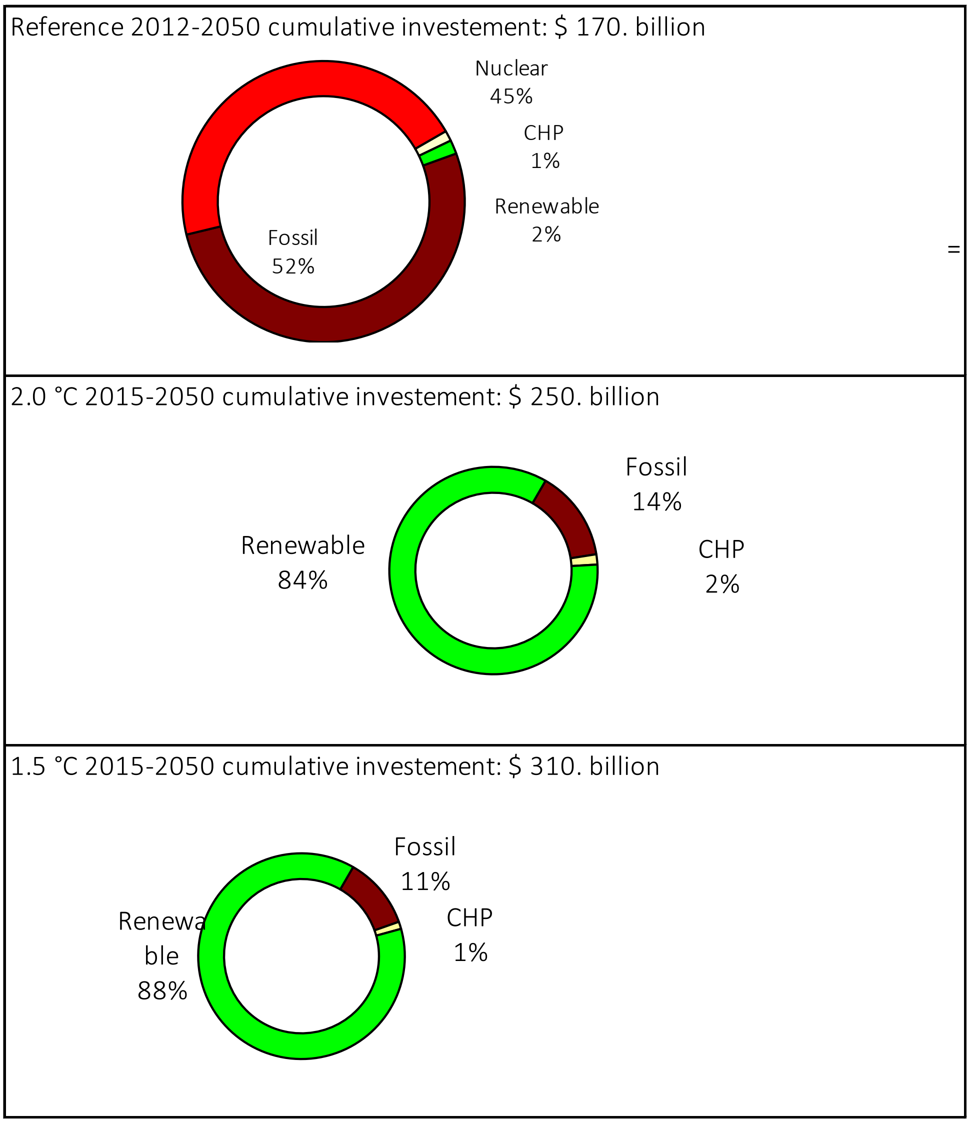


Figure 27: Cumulative investment in power generation under the RENEWABLES scenarios and the REFERENCE scenario

5.7.7.3 Future investments in the heating sector

Also, in the heating sector the Renewable energy scenarios would require a major revision of current investment strategies in heating technologies. Solar thermal, geothermal and heat pump technologies need an enormous increase in installations if these potentials are to be tapped for the heating sector. The use of biomass for heating purposes will shift from often traditional biomass today to modern, efficient and environmentally friendly heating technologies in both Renewable scenarios.

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 2.0°C scenario in total requires around US$ 290 billion to be invested in renewable heating technologies up to 2050 (including investments for replacement after the economic lifetime of the plants) - approximately US$ 7 billion per year. The 1.5°C scenario assumes an equally ambitious expansion of renewable technologies resulting in an average investment of around US$ 8 billion per year, while the main strategy in the scenario is the substitution of the remaining natural gas amounts with electricity, hydrogen or other synthetic fuels.

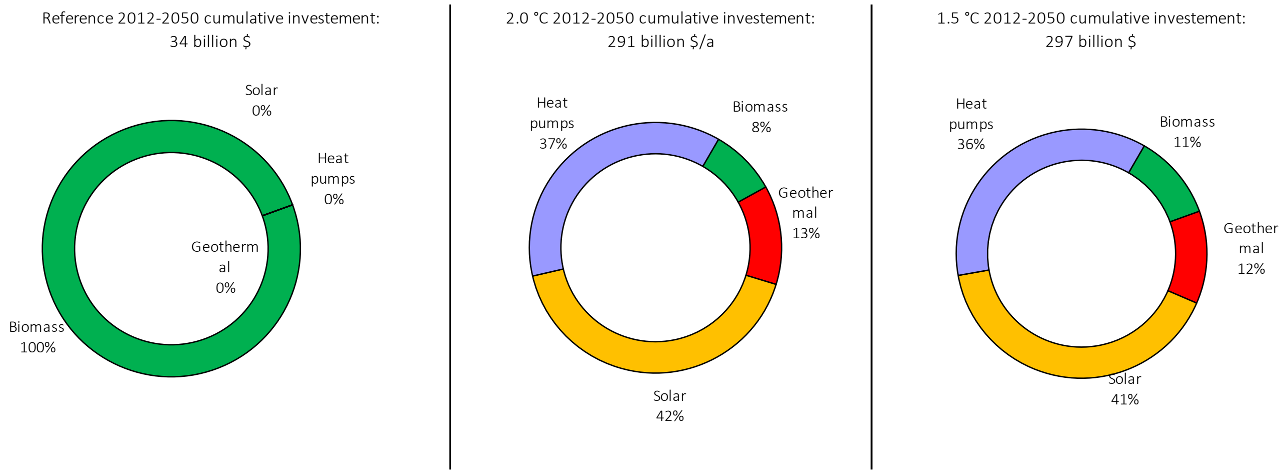


Figure 28: Cumulative investment in the heating technologies (generation) under the RENEWABLES scenarios and the REFERENCE scenario

5.7.8 INVESTMENT AND FUEL COST SAVINGS

Under the RENEWABLES case, the additional annual investment is estimated at $2.4 billion; compared to REFERENCE case, the fuel cost saving would add up to $3.7 billion. Thus, required additional investment cost will be more than refinanced by fuel cost savings. With high uncertainties in both future investment costs for power generation equipment and fossil fuel prices, it seems certain, that the overall cost balance is economically beneficial for the 2.0°C case.

Table 30: Accumulated investment costs for electricity generation and fuel cost savings under the RENEWABLES scenario compared to the REFERENCE scenario (REF minus 2.0°C)

ACCUMULATED INVESTMENT COSTS Difference Reference minus 2.0 °C		2012-2020	2021-2030	2031-2040	2041-2050	2012-2050	2012 - 2050 average per year
conventional (fossil + nuclear	billion $	0.2	38.4	47.0	30.1	115.7	3.0
renewables (incl. CHP)	billion $	0.1	-36.8	-71.8	-100.4	-208.8	-5.4
total	billion $	0.3	1.7	-24.8	-70.3	-93.2	-2.4
ACCUMULATED FUEL COST SAVINGS							
Savings cumulative Renewables 1 versus Reference							
fuel oil	billion $	2.5	15.0	8.2	5.3	30.9	0.8
gas	billion $	-4.4	-29.1	-5.9	14.2	-25.2	-0.6
hard coal	billion $	0.0	10.5	41.9	66.6	118.9	3.0
lignite	billion $	0.0	0.0	0.0	0.0	0.0	0.0
nuclear energy	billion $	0.0	2.1	6.1	10.6	18.8	0.5
total	billion $	-2.0	-1.6	50.2	96.7	143.4	3.7

Table 31: Accumulated investment costs for heat generation under the 2.0°C scenario compared to the REFERENCE scenario

ACCUMULATED INVESTMENT COSTS Difference Reference minus 2.0 °C		2012-2020	2021-2030	2031-2040	2041-250	2012-2050	2012 - 2050 average per year
renewable	billion $	-6.8	23.1	83.4	156.8	256.5	6.6

Under the 1.5°C case, the additional investment is estimated at around US$3.8 billion; compared to the REFERENCE case, the fuel cost saving would add up to $5.0 billion without the transport sector. Just as in the 2.0°C case, the 1.5°C case leads to fuel cost savings that will more than refinance the investment cost for renewable power generation.

Table 32: Accumulated investment costs for electricity generation and fuel cost savings under the 1.5°C scenario compared to the REFERENCE scenario (REF minus 1.5°C)

ACCUMULATED INVESTMENT COSTS Difference Reference minus 1.5 °C		2012-2020	2021-2030	2031-2040	2041-2050	2012-2050	2012 - 2050 average per year
conventional (fossil + nuclear	billion $	2.5	42.7	49.2	31.1	125.5	3.2
renewables (incl. CHP)	billion $	0.1	-38.4	-108.4	-126.0	-272.7	-7.0
total	billion $	2.6	4.3	-59.2	-94.9	-147.2	-3.8
ACCUMULATED FUEL COST SAVINGS							
Savings cumulative 1.5 °C versus Reference							
fuel oil	billion $	2.5	14.9	8.1	5.3	30.9	0.8
gas	billion $	-4.4	-32.4	-5.1	62.6	20.7	0.5
hard coal	billion $	0.0	11.6	43.4	67.5	122.5	3.1
lignite	billion $	0.0	0.0	0.0	0.0	0.0	0.0
nuclear energy	billion $	0.0	2.7	7.0	11.7	21.3	0.5
total	billion $	-1.9	-3.2	53.4	147.0	195.3	5.0

Table 33: Accumulated investment costs for heat generation under the 1.5°C scenario compared to the REFERENCE scenario

ACCUMULATED INVESTMENT COSTS Difference 1.5 °C minus Reference		2012-2020	2021-2030	2031-2040	2041-250	2012-2050	2012 - 2050 average per year
renewable	billion $	-6.8	20.5	84.4	164.9	263.0	6.7

5.8 BANGLADESH POWER SECTOR ANALYSIS

This section summarizes the results of the hourly simulation of the long-term scenario projections of section 5.7. The [R]E 24/7model calculates demand and supply by cluster.

5.8.1 BANGLADESH: POWER SECTOR ANALYSIS

The electricity market in Bangladesh is in dynamic development. The government of Bangladesh is making great efforts to increase the reliability of the power supply and at the same time, developing universal access to electric power. In 2015, about 74 percent had access to electricity, up from 20 per cent in 1990 (SREP IP 2015)[80]. In 2016, the Government of Bangladesh launched the *Power System Master Plan 2016*, which covers the period from 2016 to 2041. The Power System Master Plan (PSMP) 2016 is sponsored by Japan International Cooperation Agency (JICA) and aims to "[…] a*ssisting the Bangladesh in formulating an extensive energy and power development plan up to the year 2041, covering energy balance, power balance, and tariff strategies.*"
Furthermore, the Bangladesh government declared its intention to "[…] *develop the country in order to become one of the advanced countries by 2041 as the key goal of VISION2041. To achieve the VISION, this master plan defines the intended goal and "five key viewpoints" that are to be kept in mind by all the members who are involved in the realization of the goal."*
The five key view points in the PSMP 2016 are:

1. Enhancement of imported energy infrastructure and its flexible operation
2. Efficient development and utilization of domestic natural resources (gas and coal)
3. Construction of a robust, high-quality power network
4. Maximization of green energy and promotion of its introduction
5. Improvement of human resources and mechanisms related to the stable supply of energy

This analysis took those key points in the centre of the scenario development for both RENEWABLES cases but focuses on renewable and sustainable local resources and avoids limited and unsustainable resources coal, oil and gas as much as possible. Foreign technologies – such as nuclear power – are not considered to avoid high economic and logistical dependencies to foreign countries for Bangladesh future generations.

5.8.1.1 Bangladesh: development of power plant capacities

The PSMP 2016 for Bangladesh would lead to a high dependence of imported fuels and technologies. By 2040, the power plant capacities for gas and coal would increase to around 15 to 18 GW each - depending on the scenario, while six nuclear reactors with a capacity of 1,200 MW each would have to be installed. This section provides an overview about the development of the power sector under two renewable and energy efficiency-based scenarios. The 2.0°C case will lead to a renewable energy share of 59 per cent by 2040 and 76 per cent by 2050, while the 1.5°C case will lead to 69 percent (2040) and 95% (2050).

Table 34: Bangladesh: average annual change in installed power plant capacity

Power Generation: average annual change of installed capacity [GW/a]	2015-2025		2026-2035		2036-2050	
	2.0°C	1.5°C	2.0°C	1.5°C	2.0°C	1.5°C
Hard coal	0.134	-0.019	-0.008	-0.028	-0.092	-0.040
Lignite	0.000	0.000	0.000	0.000	0.000	0.000
Gas	0.606	0.579	0.247	0.283	-0.453	-0.170
Hydrogen-Gas	0.000	0.001	0.000	0.002	0.000	4.475
Oil/Diesel	-0.783	-0.329	-0.004	-0.004	-0.004	-0.004
Nuclear	0.075	0.000	0.000	0.000	0.000	0.000
Biomass	0.353	0.441	0.226	0.255	1.406	1.487
Hydro	0.003	0.003	0.022	0.022	0.006	0.006
Wind (Onshore)	0.031	0.114	0.311	0.340	0.508	0.550
Wind (Offshore)	0.005	0.313	0.299	0.394	1.661	2.755
PV (roof top)	0.483	2.124	4.937	6.167	2.410	3.479
PV (utility scale)	0.161	0.708	1.646	2.056	0.803	1.160
Geothermal	0.000	0.000	0.000	0.000	0.000	0.000
Solar thermal power plants	0.000	0.000	0.000	0.000	0.000	0.000
Ocean energy	0.000	0.000	0.000	0.000	0.000	0.000

The annual installation rates for solar PV installations must increase to around 5 GW between 2025 and 2035 and further increase to around 10 GW per year —the PV market size in Japan in 2017 - until 2050 in both RENEWABLES cases. By 2035, the installation rates for offshore wind must be around 1.6 GW in the 2.0°C case and 2.8 GW in the 1.5°C case. Offshore wind power plants have significant potential for all three coastal provinces of Bangladesh. Solar PV and offshore wind are the key renewable energy technologies to achieving the decarbonisation targets.

5.8.1.2 Bangladesh: utilization of power-generation capacities

The division of Bangladesh into eight sub-regions is intended to reflect the main provinces and it is assumed that interconnection will increase to 15% in 2030 and 20% in 2050. Both scenarios aim for an even distribution of variable power plant capacities across all regions of Bangladesh. By 2030, the variable power generation will reach 20% in most regions, whereas dispatchable renewables will supply between 25% and 35% of the demand by 2030.

Table 35: Bangladesh: power system shares by technology group

Bangladesh: Power Generation Structure and interconnection		2.0°C			1.5°C		
		Variable RE	Dispatch RE	Dispatch Fossil	Variable RE	Dispatch RE	Dispatch Fossil
Rangpur	2015	0%	3%	96%	0%	3%	96%
	2030	24%	18%	58%	24%	18%	58%
	2050	34%	29%	38%	48%	31%	21%
Rajshahi	2015	0%	3%	96%			
	2030	34%	25%	42%	28%	19%	53%
	2050	49%	41%	10%	50%	30%	21%
Mymensingh	2015	0%	3%	96%	0%	3%	96%
	2030	23%	17%	60%	23%	17%	60%
	2050	34%	33%	33%	47%	31%	22%
Dhaka	2015	0%	3%	96%			
	2030	31%	24%	44%	25%	18%	57%
	2050	46%	43%	11%	48%	31%	22%
Khulna	2015	0%	3%	96%	0%	3%	96%
	2030	44%	21%	35%	32%	20%	48%
	2050	81%	16%	3%	62%	25%	13%
Barisal	2015	0%	3%	96%			
	2030	54%	19%	28%	34%	20%	46%
	2050	92%	7%	1%	66%	24%	10%
Chittagong	2015	0%	3%	96%	0%	3%	96%
	2030	33%	18%	48%	30%	18%	52%
	2050	61%	26%	13%	60%	24%	16%
Sylhet	2015	0%	3%	96%			
	2030	51%	38%	11%	26%	19%	56%
	2050	53%	45%	2%	49%	30%	21%
Average	2015	0%	3%	96%	0%	3%	96%
	2030	37%	23%	41%	28%	19%	54%
	2050	56%	30%	14%	54%	28%	18%

Bangladesh's average capacity factors for the entire power plant fleet remain at around 35% over the entire modelling period, as the calculation results in Table 36 show. The low calculated capacity factor for 2015 is due to installed gas power plant capacities which haven't generated electricity yet. Contributions from limited dispatchable fossil power plants will remain low until 2030 and indicate that only those coal power plants will produce electricity which have been under construction in 2018. However, coal will be phased out by 2050 in both RENEWABLES cases.

Table 36: Bangladesh: capacity factors by generation type

Utilization of Variable and Dispatchable power generation:		2015	2020	2020	2030	2030	2040	2040	2050	2050
Bangladesh			2.0°C	1.5°C	2.0°C	1.5°C	2.0°C	1.5°C	2.0°C	1.5°C
Capacity Factor - average	[%/a]	**35%**	**35%**	**36%**	**25%**	**32%**	**30%**	**30%**	**28%**	**35%**
Limited dispatchable: Fossil and nuclear	[%/a]	34%	34%	53%	23%	59%	30%	29%	14%	34%
Limited dispatchable: Renewable	[%/a]	0%	0%	0%	0%	0%	0%	0%	0%	0%
Dispatchable: Fossil	[%/a]	40%	40%	28%	20%	40%	38%	32%	40%	40%
Dispatchable: Renewable	[%/a]	89%	89%	79%	66%	42%	66%	68%	70%	89%
Variable: Renewable	[%/a]	14%	14%	18%	14%	20%	14%	18%	14%	14%

5.8.1.3 Bangladesh: development of load, generation, and residual load

Table 37 shows that Bangladesh's load is predicted to double or triple in all eight sub-regions between 2020 and 2030. Under both RENEWABLES cases, additional interconnection between regions will increase—beyond the assumed 20% of maximum load interconnection—but may only be required for the coastal regions towards the centre of Bangladesh due to high shares of offshore wind. However, for the 1.5°C case, interconnections must increase above capacities calculated for 2.0°C due to higher wind shares.

Table 37: Bangladesh: load, generation, and residual load development

Power Generation Structure		2.0°C				1.5°C			
		Max Demand	Max Generation	Max Residual Load	Max Load Development (Base year 2020)	Max Demand	Max Generation	Max Residual Load	Max Load Development (Base year 2020)
		[GW]	[GW]	[GW]	[%]	[GW]	[GW]	[GW]	[%]
Rangpur	2020	1.0	10.0	0.1	100%	1.0	1.6	0.1	100%
	2030	2.3	12.1	0.1	229%	2.3	3.5	0.1	234%
	2050	6.5	13.1	0.1	649%	7.1	11.9	3.0	710%
Rajshahi	2020	1.3	0.6	0.6	100%	1.3	2.2	0.1	100%
	2030	2.7	3.2	1.2	211%	2.7	4.2	0.1	216%
	2050	7.6	11.8	3.7	596%	8.3	15.8	2.9	653%
Mymensingh	2020	0.7	1.8	0.0	100%	0.7	1.2	0.0	100%
	2030	1.8	3.5	0.1	247%	1.8	2.6	0.2	252%
	2050	5.6	7.0	2.1	770%	6.1	8.6	3.0	830%
Dhaka	2020	3.3	1.8	1.5	100%	3.3	5.7	0.2	100%
	2030	7.7	8.0	3.8	232%	7.8	10.7	0.3	237%
	2050	24.5	30.3	14.5	741%	26.5	40.1	12.6	799%
Khulna	2020	1.1	0.6	0.5	100%	1.1	1.9	0.1	100%
	2030	2.2	2.8	0.8	204%	2.2	3.7	0.1	209%
	2050	5.9	15.8	2.4	551%	6.5	14.1	1.8	608%
Barisal	2020	0.7	0.6	0.1	100%	0.7	1.1	0.0	100%
	2030	1.3	1.9	0.4	186%	1.3	2.3	0.1	190%
	2050	3.2	13.2	1.1	464%	3.6	8.6	0.7	510%
Chittagong	2020	1.8	2.4	0.1	100%	1.8	3.2	0.1	100%
	2030	4.2	6.7	0.1	229%	4.3	6.7	0.1	234%
	2050	12.3	22.1	4.8	671%	13.5	25.2	5.3	731%
Sylhet	2020	0.6	0.0	0.6	100%	0.6	1.1	0.0	100%
	2030	0.8	1.6	1.1	138%	0.1	2.3	0.0	15%
	2050	2.4	5.9	2.5	420%	1.8	7.8	1.8	316%

The load in the northern regions Rangpur and Mymensingh, the central region Dhaka and the southern province Chittagong increases by factor 5 to 7, while the north-eastern province Sylhet has the lowest increase by factor 4. The lower the maximum residual load – the difference between the demand and generation load – the higher the generation concentration. Dhaka for example has a load of 25 GW in 2050 under the RENEWABLES 1 case, the maximum regional generation gap was 14.5 GW. In contrast, Barisal was almost any time able to supply the local load to a large extend, maximum generation gap was only1.1 GW in our calculation.

In comparison to the PSMP 2016, the development of peak load across Bangladesh in both RENEWABLES cases are similar. While the PSMP 2016 calculates a peak load 20 GW for 2025 and around 27 GW by 2030, the peak load in both RENEWABLE cases increases to 23 GW by 2030.

Table 38 shows the storage and dispatch requirements under both RENEWABLE scenarios. All the regions remain within the maximum curtailment target of 10%. Charging capacities are moderate compared with other world regions. Compared to all other world regions, hydrogen dispatch utilization is very low due to a relatively moderate increase in the gas and hydrogen capacities in Bangladesh.

Table 38: Bangladesh: storage and dispatch service requirements

Storage and Dispatch		2.0°C		1.5°C	
Bangladesh		Required to avoid curtailment	Utilization Battery -through-put-	Required to avoid curtailment	Utilization Battery -through-put-
		[GWh/a]	[GWh/a]	[GWh/a]	[GWh/a]
Rangpur	2020	0	0	0	0
	2030	0	0	0	0
	2050	982	6	3,079	793
Rajshahi	2020	0	0	0	0
	2030	24	11	16	0
	2050	2,679	1,017	6,225	1178
Mymensingh	2020	0	0	0	0
	2030	0	0	0	0
	2050	180	232	1,300	514
Dhaka	2020	0	0	0	0
	2030	1	1	0	0
	2050	1,499	1,486	7,534	2576
Khulna	2020	0	0	0	0
	2030	104	23	26	0
	2050	10,223	702	8,140	820
Barisal	2020	0	0	0	0
	2030	259	17	56	0
	2050	15,642	241	6,068	308
Chittagong	2020	0	0	0	0
	2030	12	0	4	0
	2050	6,511	1,446	10,770	1746
Sylhet	2020	0	0	0	0
	2030	3	2	1	0
	2050	941	463	2,531	562
Total	2020	0	0	0	0
	2030	403	55	104	1
	2050	38,657	5,593	45,647	8497

5.9 EMPLOYMENT ANALYSIS

The 2.0°C scenario results in more energy sector jobs in Bangladesh at every stage of the projection.

- There are 0.9 million energy sector jobs in the 2.0°C in 2020, and 0.3 million in the REF scenario.
- In 2030, there are 1 million jobs in the 2.0C scenario, and 0.2 million in the 5.0C scenario.
- In 2050, there are 1.1 million jobs in the 2.0C scenario and 0.1 million in the 5.0C scenario.

"

Figure 28 shows the change in job numbers under both scenarios for each technology between 2015 and 2030. Jobs in the 5.0C Scenario drop to -7% below 2015 levels by 2020 and then remain quite stable to 2030.

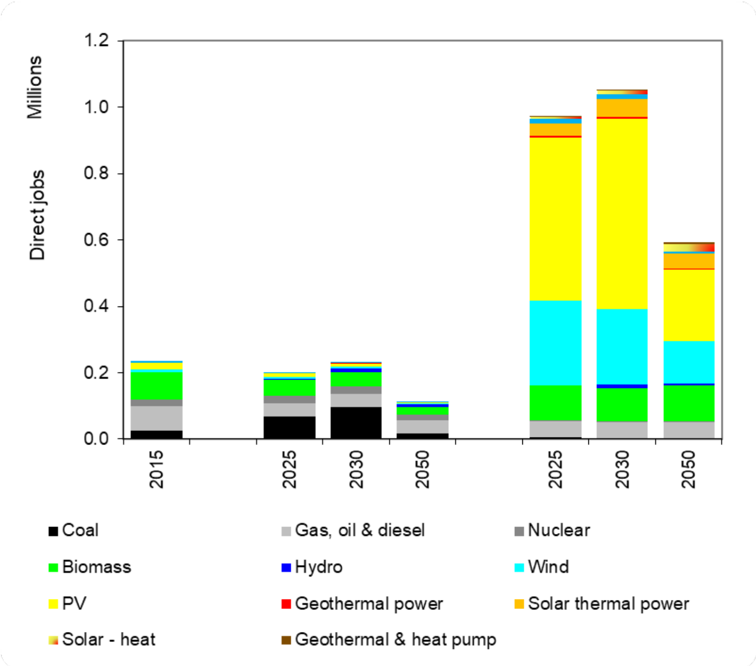


Figure 29: Employment development under the RENEWABLES scenarios and REFERENCE scenario

Strong growth in renewable energy leads to an increase of 268% in total energy sector jobs in the 2.0°C scenario by 2020. By 2030, energy jobs are more than double 2015 levels. Renewable energy accounts for 95% at 2030, with PV having the greatest share (55%), followed by biomass, wind, and solar heating.

Table 39: Bangladesh's total employment (thousand jobs) in the REFERENCE and 2.0°C scenarios

Bangladesh		5.0C			2.0C		
Thousand jobs	2015	2025	2030	2050	2025	2030	2050
Coal	27	69	97	18	6	4	3
Gas, oil & diesel	73	37	39	38	49	47	49
Nuclear	20	23	24	16	2	2	1
Renewable	114	69	70	39	916	1,000	539
Total jobs	234	199	230	111	972	1,052	593
Construction and installation	53	55	77	5	167	230	89
Manufacturing	66	39	50	10	648	650	292
Operations and maintenance	14	23	25	32	45	69	137
Fuel supply (domestic)	101	82	77	64	112	104	46
Coal and gas export	-	-	-	-	-	-	-
Total jobs (thousands)	234	199	230	111	972	1,052	593

5.10 CONSLUSION [R]E 24/7 MODELLING

Both RENEWABLE scenarios use Bangladesh's renewable energy resources to the maximum in order to reduce energy imports dependence and to utilize local resources. Bangladesh will significantly increase its power demand – under each power generation scenario. Thus, power grids will have to expand, and power generation will have to be increased by an order of magnitude.

A renewable energy dominated power generation requires a different infrastructural design then a fossil and nuclear power dominated future. In order to harvest Bangladesh's offshore wind and solar resources, the power grid needs to be able to transport large loads from the coast further north inland, while decentralized will shoulder a significant part of the residential sector. Offshore wind requires transmission lines to the load centres of Bangladesh.

The majority of dispatch power in 2050 will come from gas power which operate with hydrogen and / or synthetic fuels after 2045. The limited renewable energy resources of Bangladesh – with the current available technology – will not be able to supply all required renewable fuels and need to be imported. More research is required to assess how existing gas pipelines in Bangladesh can be converted to renewable fuels pipelines. Further research is also required to specify locations of utility scale floating solar photovoltaic to optimize their distribution regarding supply and to reduce storage demand.

The renewable power generation resources of Bangladesh can supply the country with reliable power generation, however, the unique geographical and meteorological circumstances require further adaption of the existing technologies such as:

- Floating storage devices to avoid battery damage in flooding situations
- Floating solar photovoltaic devices suitable for rivers and tidal waters

Bangladesh has the technical possibilities to implement new innovative technologies and to reduce its future dependence on energy imports significantly.

APPENDIX

The following tables set out the costs for power generation for the range of technologies used in the modelling. These are based on up-to-date data and current market developments, as described in section 3.3.3. The specific investment costs in $/kW are detailed in Table 40 and ongoing operation and maintenance costs in $/kW/year are shown in Table 41.

Table 40: Specific investment costs for power generation

in $/kW		2015	2020	2030	2040	2050
Power plants	Biomass and waste power plant	3,145	2,969	2,867	2,750	2,691
	Coal power plant	1,411	1,390	1,356	1,321	1,287
	Diesel generator	907	907	907	907	907
	Gas power plant	769	751	715	679	644
	Geothermal power plant	12,579	9,507	6,509	5,409	4,652
	Hydro large	3,466	3,573	3,734	3,869	3,987
	Hydro small	3,466	3,573	3,734	3,869	3,987
	Lignite power plant	1,645	1,609	1,575	1,540	1,507
	Nuclear power plant	6,615	6,615	6,615	6,615	6,615
	Ocean energy power plant	4,710	3,364	2,340	1,943	1,730
	Oil power plant	967	948	910	872	834
	PV power plant	1,817	1,682	1,305	1,059	1,079
	Solar thermal power plant	5,787	4,705	3,799	3,595	3,479
	Wind turbine offshore	5,631	3,876	3,072	2,775	2,386
	Wind turbine onshore	1,519	1,316	1,305	1,312	1,371
Hydrogen production	Electrolysis	893	844	746	746	746
CHP for Power Generation and Industry	CHP Biomass and waste	5,150	4,505	3,934	3,626	3,445
	CHP Coal	1,950	1,919	1,872	1,824	1,777
	CHP Fuel cell	1,726	1,346	1,214	1,155	1,141
	CHP Gas	1,038	995	974	954	933
	CHP Geothermal	13,456	11,409	9,068	7,606	6,582
	CHP Lignite	1,950	1,919	1,872	1,824	1,777
	CHP Oil	1,340	1,312	1,259	1,205	1,153
Buildings / Other Small Scale	CHP Biomass and waste	2,545	2,486	2,443	2,418	2,391
	CHP Coal	1,949	1,919	1,872	1,824	1,777
	CHP Fuel cell	1,726	1,346	1,214	1,155	1,141
	CHP Gas	965	911	804	790	775
	CHP Geothermal	13,456	11,409	9,068	7,606	6,582
	CHP Lignite	1,950	1,919	1,872	1,824	1,777
	CHP Oil	1,339	1,312	1,259	1,205	1,153

Table 41: Operation and maintenance costs for power generation technologies

in $/kW/a		2015	2020	2030	2040	2050
Power plants	Biomass and waste power plant	189.1	178.3	172.0	165.5	162.2
	Coal power plant	30.8	29.7	29.7	29.7	29.7
	Diesel generator	112.6	112.6	112.6	112.6	112.6
	Gas power plant	23.7	22.1	20.6	18.6	17.8
	Geothermal power plant	548.6	426.6	324.4	302.9	286.7
	Hydro large	139.0	143.3	149.2	155.0	159.4
	Hydro small	139.0	143.3	149.2	155.0	159.4
	Lignite power plant	27.1	26.5	25.9	25.4	24.9
	Nuclear power plant	162.0	162.0	162.0	162.0	162.0
	Ocean energy power plant	188.7	134.7	93.0	78.2	69.0
	Oil power plant	22.4	21.7	20.3	18.8	17.4
	PV power plant	38.7	21.9	15.4	14.7	15.4
	Solar thermal power plant	350.9	270.0	233.8	215.0	196.4
	Wind turbine offshore	209.5	164.5	133.6	126.6	108.9
	Wind turbine onshore	56.5	55.9	56.8	59.8	62.6
Hydrogen production	Electrolysis	17.9	16.8	14.6	14.6	14.6
CHP for Power Generation	CHP Biomass and waste	361.3	315.9	275.0	254.5	241.3
	CHP Coal	68.7	67.3	65.8	64.4	62.9
	CHP Gas	42.4	39.5	39.5	38.0	38.0
	CHP Geothermal	487.1	409.5	342.3	298.4	272.1
	CHP Lignite	81.9	80.4	77.5	76.1	73.1
	CHP Oil	48.3	46.8	43.9	42.4	41.0
CHP for Industry	CHP Biomass and waste	93.6	83.4	74.6	68.7	62.9
	CHP Coal	68.7	67.3	65.8	64.4	62.9
	CHP Fuel cell	86.3	67.3	61.4	58.5	57.0
	CHP Gas	42.4	39.5	39.5	38.0	38.0
	CHP Geothermal	239.9	231.1	222.3	220.9	219.4
	CHP Lignite	81.9	80.4	77.5	76.1	73.1
	CHP Oil	48.3	46.8	43.9	42.4	41.0
CHP for Buildings / Other Small Scale	CHP Biomass and waste	101.7	99.5	98.0	96.5	95.1
	CHP Coal	68.0	67.3	65.8	64.4	62.9
	CHP Fuel cell	86.3	67.3	61.4	58.5	57.0
	CHP Gas	38.8	36.6	32.2	32.2	30.7
	CHP Geothermal	239.9	231.1	222.3	220.9	219.4
	CHP Lignite	81.9	80.4	77.5	76.1	73.1

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Electricity generation [TWh/a]	2012	2015	2020	2030	2040	2050
Power plants	49	58	71	153	268	309
- Hard coal (& non-renewable waste)	1	0	3	47	126	136
- Lignite	0	0	0	0	0	0
- Gas	41	48	57	77	102	124
of which from H2	0	0	0	0	0	0
- Oil	6	10	10	5	1	1
- Diesel	0	0	0	0	0	0
- Nuclear	0	0	0	23	38	46
- Biomass (& renewable waste)	0	0	0	0	0	0
- Hydro	1	1	1	1	1	2
- Wind	0	0	0	0	0	0
of which wind offshore	0	0	0	0	0	0
- PV	0	0	0	0	0	0
- Geothermal	0	0	0	0	0	0
- Solar thermal power plants	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0
Combined heat and power plants	0	0	1	3	4	6
- Hard coal (& non-renewable waste)	0	0	0	1	1	1
- Lignite	0	0	0	0	0	0
- Gas	0	0	1	2	3	4
of which from H2	0	0	0	0	0	0
- Oil	0	0	0	0	0	0
- Biomass (& renewable waste)	0	0	0	0	0	0
- Geothermal	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0
CHP by producer						
- Main activity producers	0	0	0	0	0	1
- Autoproducers	0	0	1	3	4	5
Total generation	49	58	72	156	272	314
- Fossil	48	58	72	132	233	266
- Hard coal (& non-renewable waste)	1	0	4	48	127	137
- Lignite	0	0	0	0	0	0
- Gas	41	48	58	79	105	127
- Oil	6	10	10	5	2	1
- Diesel	0	0	0	0	0	0
- Nuclear	0	0	0	23	38	46
- Hydrogen	0	0	0	0	0	0
- of which renewable H2	0	0	0	0	0	0
- Renewables (w/o renewable hydrogen)	1	1	1	1	2	2
- Hydro	1	1	1	1	1	2
- Wind	0	0	0	0	0	0
- PV	0	0	0	0	0	0
- Biomass (& renewable waste)	0	0	0	0	0	0
- Geothermal	0	0	0	0	0	0
- Solar thermal power plants	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0
Distribution losses	6	7	9	20	39	45
Own consumption electricity	3	3	5	7	14	14
Electricity for hydrogen production	0	0	0	0	0	0
Electricity for synfuel production	0	0	0	0	0	0
Final energy consumption (electricity)	40	49	60	136	274	311
Variable RES (PV, Wind, Ocean)	0	0	0	0	0	0
Share of variable RES	0%	0%	0%	0%	0%	0%
RES share (domestic generation)	2%	1%	1%	1%	1%	1%

Transport - Final Energy [PJ/a]	2012	2015	2020	2030	2040	2050
road	99	107	135	247	463	909
- fossil fuels	61	65	96	197	392	809
- biofuels	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0
- natural gas	38	42	39	50	70	98
- hydrogen	0	0	0	0	0	0
- electricity	0	0	0	0	1	2
rail	12	12	12	13	13	14
- fossil fuels	12	12	12	13	13	14
- biofuels	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0
- electricity	0	0	0	0	0	0
navigation	16	17	17	20	24	30
- fossil fuels	16	17	17	20	24	30
- biofuels	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0
aviation	0	0	0	0	0	0
- fossil fuels	0	0	0	0	0	0
- biofuels	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0
total (incl. pipelines)	127	136	173	288	508	958
- fossil fuels	89	94	125	230	430	853
- biofuels (incl. biogas)	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0
- natural gas	38	42	47	57	77	104
- hydrogen	0	0	0	0	0	0
- electricity	0	0	0	0	1	2
total RES	0	0	0	0	0	0
RES share	0%	0%	0%	0%	0%	0%

Heat supply and air conditioning [PJ/a]	2012	2015	2020	2030	2040	2050
District heating plants	0	0	110	134	180	203
- Fossil fuels	0	0	110	134	180	203
- Biomass	0	0	0	0	0	0
- Solar collectors	0	0	0	0	0	0
- Geothermal	0	0	0	0	0	0
Heat from CHP 1)	0	0	3	9	14	25
- Fossil fuels	0	0	3	9	14	25
- Biomass	0	0	0	0	0	0
- Geothermal	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0
Direct heating (incl. traditional cooking)	542	731	827	1,245	1,958	2,307
- Fossil fuels	265	349	445	688	1,107	1,201
- Biomass	277	282	282	281	293	357
- Solar collectors	0	0	0	0	0	0
- Geothermal	0	0	0	0	0	0
- Heat pumps 2)	0	0	0	0	0	0
- Electric direct heating	0	100	100	276	557	748
- Hydrogen	0	0	0	0	0	0
Total heat supply3)	542	731	940	1,387	2,151	2,534
- Fossil fuels	265	349	558	830	1,301	1,429
- Biomass	277	282	282	281	293	357
- Solar collectors	0	0	0	0	0	0
- Geothermal	0	0	0	0	0	0
- Heat pumps 2)	0	0	0	0	0	0
- Electric direct heating	0	100	100	276	557	748
- Hydrogen	0	0	0	0	0	0
RES share (including RES electricity)	51%	39%	30%	20%	14%	14%

Installed Capacity [GW]	2012	2015	2020	2030	2040	2050
Total generation	12	20	21	30	43	50
- Fossil	12	20	21	26	37	42
- Hard coal (& non-renewable waste)	0	0	1	9	18	20
- Lignite	0	0	0	0	0	0
- Gas (w/o H2)	9	14	14	14	17	21
- Oil	2	6	6	3	1	1
- Diesel	0	0	0	0	0	0
- Nuclear	0	0	0	4	6	7
- Hydrogen (fuel cells, gas power plants	0	0	0	0	0	0
- Renewables	0	0	0	1	1	1
- Hydro	0	0	0	0	1	1
- Wind	0	0	0	0	0	0
of which wind offshore	0	0	0	0	0	0
- PV	0	0	0	0	0	0
- Biomass (& renewable waste)	0	0	0	0	0	0
- Geothermal	0	0	0	0	0	0
- Solar thermal power plants	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0
Variable RES (PV, Wind, Ocean)	0	0	0	0	0	0
Share of variable RES	0%	1%	1%	1%	1%	1%
RES share (domestic generation)	4%	2%	2%	2%	2%	2%

Final Energy Demand [PJ/a]	2012	2015	2020	2030	2040	2050
Total (incl. non-energy use)	1,025	1,167	1,447	2,182	3,437	4,291
Total energy use 1)	962	1,109	1,418	2,105	3,332	4,158
Transport	127	136	190	308	532	988
- Oil products	89	94	143	250	454	882
- Natural gas	38	43	47	57	77	104
- Biofuels	0	0	0	0	0	0
- Synfuels	0	0	0	0	0	0
- Electricity	0	0	0	0	1	2
RES electricity	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0
RES share Transport	0%	0%	0%	0%	0%	0%
Industry	242	342	487	839	1,446	1,637
- Electricity	80	97	100	270	557	630
RES electricity	1	1	1	2	3	5
- Public district heat	0	0	110	135	181	205
RES district heat	0	0	0	0	0	0
- Hard coal & lignite	28	84	87	172	339	383
- Oil products	7	15	19	35	63	72
- Gas	127	146	170	228	306	347
- Solar	0	0	0	0	0	0
- Biomass	0	0	0	0	0	0
- Geothermal	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0
RES share Industry	1%	0%	0%	0%	0%	0%
Other Sectors	593	631	741	957	1,355	1,533
- Electricity	65	78	114	221	430	487
RES electricity	1	1	1	2	3	4
- Public district heat	0	0	0	0	0	0
RES district heat	0	0	0	0	0	0
- Hard coal & lignite	0	0	0	0	0	0
- Oil products	64	52	104	165	275	312
- Gas	97	126	147	197	275	310
- Solar	0	0	0	0	0	0
- Biomass	367	376	376	375	375	425
- Geothermal	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0
RES share Other Sectors	62%	60%	51%	39%	28%	28%
Total RES	369	378	378	378	381	433
RES share	38%	34%	27%	18%	11%	10%
Non energy use	63	58	30	78	104	133
- Oil	5	4	2	5	6	8
- Gas	58	54	28	73	98	125
- Coal	0	0	0	0	0	0

Energy-Releated CO2 Emissions [Million tons/a]	2012	2015	2020	2030	2040	2050
Condensation power plants	20	24	31	68	136	150
- Hard coal (& non-renewable waste)	1	0	3	37	98	106
- Lignite	0	0	0	0	0	0
- Gas	14	17	21	28	37	43
- Oil + Diesel	5	7	8	4	1	1
Combined heat and power plants	0	0	1	2	3	4
- Hard coal (& non-renewable waste)	0	0	0	1	1	2
- Lignite	0	0	0	0	0	0
- Gas	0	0	0	1	1	2
- Oil	0	0	0	0	0	0
CO2 emissions power and CHP plants	20	24	32	70	138	154
- Hard coal (& non-renewable waste)	1	0	3	38	99	108
- Lignite	0	0	0	0	0	0
- Gas	14	17	21	29	38	45
- Oil + Diesel	5	7	8	4	1	1
CO2 intensity (g/kWh)	0	0	0	0	0	0
without credit for CHP heat	0	0	0	0	0	0
- CO2 intensity fossil electr. generation	409	419	441	531	594	577
- CO2 intensity total electr. generation	403	414	437	449	508	489
CO2 emissions by sector	51	65	98	171	300	366
- % of 1990 emissions (Mill t)	257%	324%	492%	855%	1500%	1832%
- Industry 1)	10	17	25	39	64	73
- Other sectors 1)	10	11	22	31	47	53
- Transport	9	9	13	22	38	72
- Power generation 2)	20	24	31	68	136	150
- Other conversion 3)	3	3	7	10	15	18
Population (Mill.)	154	158	167	184	198	196
CO2 emissions per capita (t/capita)	0	0	1	1	2	2

Primary Energy Demand [PJ/a]	2012	2015	2020	2030	2040	2050
Total	1,233	1,416	1,876	3,100	4,887	5,817
- Fossil	863	1,026	1,486	2,455	4,081	4,873
- Hard coal (& non-renewable waste)	37	87	244	729	1,609	1,771
- Lignite	0	0	0	0	0	0
- Natural gas	597	691	841	1,185	1,614	1,747
- Crude oil	229	248	401	541	859	1,354
- Nuclear	0	0	0	251	411	497
- Renewables	370	390	390	393	395	448
- Hydro	3	2	2	3	5	7
- Wind	0	0	0	0	0	0
- Solar	0	1	0	1	1	1
- Biomass (& renewable waste)	367	387	387	389	389	439
- Geothermal	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0
- of which non-energy use	63	58	30	78	104	133
Total RES	370	390	390	393	396	449
RES share (excluding non energy use)	32%	29%	21%	13%	8%	8%
RES share	30%	28%	21%	12%	7%	7%

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Electricity generation [TWh/a]	2012	2015	2020	2030	2040	2050
Power plants	49	58	86	170	290	428
- Hard coal (& non-renewable waste)	1	0	4	6	6	0
- Lignite	0	0	0	0	0	0
- Gas	41	48	76	104	109	99
of which from H2	0	0	0	0	0	0
- Oil	6	10	4	0	0	0
- Diesel	0	0	0	0	0	0
- Nuclear	0	0	0	4	4	4
- Biomass (& renewable waste)	0	0	0	19	44	107
- Hydro	1	1	1	1	1	1
- Wind	0	0	0	9	42	107
of which wind offshore	0	0	0	7	33	82
- PV	0	0	0	27	83	109
- Geothermal	0	0	0	0	0	0
- Solar thermal power plants	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0
Combined heat and power plants	0	0	1	3	4	6
- Hard coal (& non-renewable waste)	0	0	0	0	0	1
- Lignite	0	0	0	0	0	0
- Gas	0	0	1	2	2	1
of which from H2	0	0	0	0	0	0
- Oil	0	0	0	0	0	0
- Biomass (& renewable waste)	0	0	0	1	2	3
- Geothermal	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0
CHP by producer						
- Main activity producers	0	0	0	0	0	1
- Autoproducers	0	0	1	3	4	5
Total generation	49	58	87	173	294	434
- Fossil	48	58	85	112	117	101
- Hard coal (& non-renewable waste)	1	0	4	6	6	1
- Lignite	0	0	0	0	0	0
- Gas	41	48	77	105	111	100
- Oil	6	10	4	0	0	0
- Diesel	0	0	0	0	0	0
- Nuclear	0	0	0	4	4	4
- Hydrogen	0	0	0	0	0	0
- of which renewable H2	0	0	0	0	0	0
- Renewables (w/o renewable hydrogen)	1	1	2	57	172	328
- Hydro	1	1	1	1	1	1
- Wind	0	0	0	9	42	107
- PV	0	0	0	27	83	109
- Biomass (& renewable waste)	0	0	0	20	46	111
- Geothermal	0	0	0	0	0	0
- Solar thermal power plants	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0
Distribution losses	6	7	11	21	37	54
Own consumption electricity	3	3	3	2	2	2
Electricity for hydrogen production	0	0	0	0	0	1
Electricity for synfuel production	0	0	0	0	0	0
Final energy consumption (electricity)	40	49	73	149	255	377
Variable RES (PV, Wind, Ocean)	0	0	0	36	126	216
Share of variable RES	0%	0%	1%	21%	43%	50%
RES share (domestic generation)	2%	1%	2%	33%	59%	76%

Transport - Final Energy [PJ/a]	2012	2015	2020	2030	2040	2050
road	99	102	131	237	419	738
- fossil fuels	61	100	128	223	367	562
- biofuels	0	0	0	2	4	8
- synfuels	0	0	0	0	0	0
- natural gas	38	1	2	6	20	53
- hydrogen	0	0	0	0	0	0
- electricity	0	0	0	5	29	116
rail	12	12	13	13	13	13
- fossil fuels	12	12	5	5	4	3
- biofuels	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0
- electricity	0	0	7	8	9	9
navigation	16	16	17	20	24	30
- fossil fuels	16	16	17	20	24	30
- biofuels	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0
aviation	0	0	0	0	0	0
- fossil fuels	0	0	0	0	0	0
- biofuels	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0
total (incl. pipelines)	127	130	179	286	472	795
- fossil fuels	89	129	151	248	395	595
- biofuels (incl. biogas)	0	0	0	2	4	8
- synfuels	0	0	0	0	0	0
- natural gas	38	1	11	15	27	60
- hydrogen	0	0	0	0	0	0
- electricity	0	0	7	13	38	125
total RES	0	0	1	6	26	102
RES share	0%	0%	0%	2%	5%	13%

Heat supply and air conditioning [PJ/a]	2012	2015	2020	2030	2040	2050
District heating plants	0	0	0	51	154	233
- Fossil fuels	0	0	0	28	54	65
- Biomass	0	0	0	16	52	77
- Solar collectors	0	0	0	5	34	61
- Geothermal	0	0	0	2	14	30
Heat from CHP 1)	0	0	3	9	16	36
- Fossil fuels	0	0	3	4	3	0
- Biomass	0	0	0	5	13	35
- Geothermal	0	0	0	0	0	0
- Hydrogen	0	0	0	0	1	2
Direct heating	542	731	874	1,276	1,888	2,169
- Fossil fuels	265	349	456	491	488	171
- Biomass	277	282	273	298	331	219
- Solar collectors	0	0	8	90	237	467
- Geothermal	0	0	0	16	82	155
- Heat pumps 2)	0	0	5	40	147	252
- Electric direct heating	0	100	133	341	603	906
- Hydrogen	0	0	0	0	0	0
Total heat supply3)	542	731	877	1,336	2,059	2,438
- Fossil fuels	265	349	459	523	544	236
- Biomass	277	282	273	320	397	331
- Solar collectors	0	0	8	95	271	528
- Geothermal	0	0	0	18	96	185
- Heat pumps 2)	0	0	5	40	147	252
- Electric direct heating 2)	0	100	133	341	603	906
- Hydrogen	0	0	0	0	1	2
RES share (including RES electricity)	51%	39%	33%	44%	61%	81%
electricity consumption heat pumps (TWh/a)	0.0	0.0	0.2	6.5	24.0	34.4

Installed Capacity [GW]	2012	2015	2020	2030	2040	2050
Total generation	12	20	18	51	117	166
- Fossil	12	20	17	21	22	15
- Hard coal (& non-renewable waste)	0	0	1	1	1	0
- Lignite	0	0	0	0	0	0
- Gas (w/o H2)	9	14	14	19	20	15
- Oil	2	6	3	0	0	0
- Diesel	0	0	0	0	0	0
- Nuclear	0	0	0	1	1	1
- Hydrogen (fuel cells, gas power plants,	0	0	0	0	0	0
- Renewables	0	0	1	30	95	150
- Hydro	0	0	0	0	0	0
- Wind	0	0	0	3	12	31
of which wind offshore	0	0	0	2	9	22
- PV	0	0	0	23	74	96
- Biomass (& renewable waste)	0	0	0	4	8	22
- Geothermal	0	0	0	0	0	0
- Solar thermal power plants	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0
Variable RES (PV, Wind, Ocean)	0	0	0	26	86	128
Share of variable RES	0%	1%	2%	51%	74%	77%
RES share (domestic generation)	4%	2%	4%	58%	81%	90%

Final Energy Demand [PJ/a]	2012	2015	2020	2030	2040	2050
Total (incl. non-energy use)	1,024	1,125	1,411	2,010	2,958	3,573
Total energy use 1)	961	1,067	1,365	1,970	2,920	3,536
Transport	127	94	187	298	488	816
- Oil products	89	94	168	269	419	624
- Natural gas	38	1	10	14	26	59
- Biofuels	0	0	0	2	4	8
- Synfuels	0	0	0	0	0	0
- Electricity	0	0	7	13	38	125
RES electricity	0	0	0	4	22	95
- Hydrogen	0	0	0	0	0	0
RES share Transport	0%	0%	0%	2%	5%	13%
Industry	241	341	505	863	1,462	1,628
- Electricity	80	97	136	288	515	679
RES electricity	1	1	2	95	302	514
- Public district heat	0	0	0	8	68	77
RES district heat	0	0	0	1	25	50
- Hard coal & lignite	28	84	140	126	169	18
- Oil products	6	14	21	29	33	0
- Gas	127	146	207	287	294	163
- Solar	0	0	0	41	116	186
- Biomass	0	0	0	52	122	258
- Geothermal	0	0	1	33	145	248
- Hydrogen	0	0	0	0	0	0
RES share Industry	1%	0%	1%	26%	49%	77%
Other Sectors	593	631	673	810	970	1,092
- Electricity	65	78	124	233	364	553
RES electricity	1	1	2	77	214	419
- Public district heat	0	0	0	43	84	153
RES district heat	0	0	0	32	72	136
- Hard coal & lignite	0	0	1	0	0	0
- Oil products	64	52	52	38	13	5
- Gas	97	126	122	89	42	0
- Solar	0	0	8	49	121	281
- Biomass	367	376	364	345	301	3
- Geothermal	0	0	3	12	44	96
- Hydrogen	0	0	0	0	0	0
RES share Other Sectors	62%	60%	56%	64%	77%	86%
Total RES	369	378	381	742	1,489	2,293
RES share	38%	35%	28%	38%	51%	65%
Non energy use	63	58	46	40	38	37
- Oil	5	4	3	3	3	2
- Gas	58	54	43	37	35	34
- Coal	0	0	0	0	0	0

Energy-Releated CO2 Emissions [Million tons/a]	2012	2015	2020	2030	2040	2050
Condensation power plants	20	24	34	42	44	35
- Hard coal (& non-renewable waste)	1	0	3	5	5	0
- Lignite	0	0	0	0	0	0
- Gas	14	17	27	37	39	35
- Oil + Diesel	5	7	3	0	0	0
Combined heat and power plants	0	0	0	1	1	2
- Hard coal (& non-renewable waste)	0	0	0	0	0	1
- Lignite	0	0	0	0	0	0
- Gas	0	0	0	1	1	0
- Oil	0	0	0	0	0	0
CO2 emissions power and CHP plants	20	24	34	43	45	37
- Hard coal (& non-renewable waste)	1	0	3	5	5	2
- Lignite	0	0	0	0	0	0
- Gas	14	17	28	38	40	35
- Oil & diesel	5	7	3	0	0	0
CO2 intensity (g/kWh)	0	0	0	0	0	0
without credit for CHP heat	0	0	0	0	0	0
- CO2 intensity fossil electr. generation	409	419	401	387	386	360
- CO2 intensity total electr. generation	409	419	401	387	386	360
CO2 emissions by sector	51	62	91	113	131	112
- % of 1990 emissions (Mill t)	257%	311%	455%	566%	653%	558%
- Industry 1)	10	17	27	32	37	14
- Other sectors 1)	10	11	11	9	6	3
- Transport	9	7	13	21	33	50
- Power generation 2)	20	24	34	42	44	35
- Other conversion 3)	3	3	7	9	11	10
Population (Mill.)	154	158	167	184	198	196
CO2 emissions per capita (t/capita)	0	0	1	1	1	1

Primary Energy Demand [PJ/a]	2012	2015	2020	2030	2040	2050
Total	1,233	1,373	1,836	2,748	3,930	4,836
- Fossil	863	984	1,449	1,809	2,038	1,691
- Hard coal (& non-renewable waste)	37	87	175	190	230	36
- Lignite	0	0	1	0	0	0
- Natural gas	597	648	963	1,256	1,316	994
- Crude oil	229	248	310	363	492	661
- Nuclear	0	0	0	43	43	43
- Renewables	370	390	386	897	1,849	3,102
- Hydro	3	2	2	2	4	4
- Wind	0	0	0	34	152	385
- Solar	0	1	10	185	537	860
- Biomass (& renewable waste)	367	387	371	631	966	1,509
- Geothermal	0	0	3	44	190	343
- Ocean energy	0	0	0	0	0	0
- of which non-energy use	63	58	46	40	38	37
Total RES	370	390	386	897	1,849	3,102
RES share (excluding non energy use)	32%	30%	22%	33%	48%	65%
RES share	30%	28%	21%	33%	47%	64%

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Electricity generation [TWh/a]	2012	2015	2020	2025	2030	2040	2050
Power plants	49	58	85	131	170	355	544
- Hard coal (& non-renewable waste)	1	0	3	4	3	2	0
- Lignite	0	0	0	0	0	0	0
- Gas	41	48	76	104	109	126	116
of which from H2	0	0	0	0	0	32	116
- Oil	6	10	4	0	0	0	0
- Diesel	0	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0	0
- Biomass (& renewable waste)	0	0	0	15	19	44	123
- Hydro	1	1	1	1	1	1	1
- Wind	0	0	0	1	11	63	160
of which wind offshore	0	0	0	0	9	53	133
- PV	0	0	0	6	27	118	143
- Geothermal	0	0	0	0	0	0	0
- Solar thermal power plants	0	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0	0
Combined heat and power plants	0	0	1	2	3	4	6
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas	0	0	1	1	2	2	0
of which from H2	0	0	0	0	0	0	0
- Oil	0	0	0	0	0	0	0
- Biomass (& renewable waste)	0	0	0	1	1	2	5
- Geothermal	0	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0	0
CHP by producer							
- Main activity producers	0	0	0	0	0	0	1
- Autoproducers	0	0	1	2	3	4	5
Total generation	49	58	86	133	173	359	550
- Fossil	48	58	85	110	114	99	0
- Hard coal (& non-renewable waste)	1	0	4	5	3	3	0
- Lignite	0	0	0	0	0	0	0
- Gas	41	48	77	105	110	96	0
- Oil	6	10	4	0	0	0	0
- Diesel	0	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	32	116
- of which renewable H2	0	0	0	0	0	20	116
- Renewables (w/o renewable hydrogen)	1	1	2	24	59	228	434
- Hydro	1	1	1	1	1	1	1
- Wind	0	0	0	1	11	63	160
- PV	0	0	0	6	27	118	143
- Biomass (& renewable waste)	0	0	0	16	20	46	129
- Geothermal	0	0	0	0	0	0	0
- Solar thermal power plants	0	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0	0
Distribution losses	6	7	11	17	22	38	58
Own consumption electricity	3	3	3	3	2	2	2
Electricity for hydrogen production	0	0	0	0	0	78	260
Electricity for synfuel production	0	0	0	0	0	0	0
Final energy consumption (electricity)	40	49	74	117	151	263	405
Variable RES (PV, Wind, Ocean)	0	0	0	7	38	181	304
Share of variable RES	0%	0%	1%	5%	22%	50%	55%
RES share (domestic generation)	2%	1%	2%	18%	34%	69%	100%

Transport - Final Energy [PJ/a]	2012	2015	2020	2025	2030	2040	2050
road	99	102	129	172	227	369	472
- fossil fuels	61	100	126	165	213	270	0
- biofuels	0	0	0	1	2	50	279
- synfuels	0	0	0	0	0	0	0
- natural gas	38	1	2	4	6	12	0
- hydrogen	0	0	0	0	0	0	0
- electricity	0	0	0	2	6	36	193
rail	12	12	13	18	26	45	67
- fossil fuels	12	12	5	7	9	15	0
- biofuels	0	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0	0
- electricity	0	0	8	11	16	30	67
navigation	16	16	17	19	20	24	30
- fossil fuels	16	16	17	19	20	16	0
- biofuels	0	0	0	0	0	8	30
- synfuels	0	0	0	0	0	0	0
aviation	0	0	0	0	0	0	0
- fossil fuels	0	0	0	0	0	0	0
- biofuels	0	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0	0
total (incl. pipelines)	127	130	177	226	290	454	571
- fossil fuels	89	129	149	190	243	302	0
- biofuels (incl. biogas)	0	0	0	1	2	58	308
- synfuels	0	0	0	0	0	0	0
- natural gas	38	1	11	12	15	20	1
- hydrogen	0	0	0	0	0	0	0
- electricity	0	0	8	13	22	66	260
total RES	0	0	1	4	10	104	568
RES share	#DIV/0!	0%	0%	2%	3%	23%	100%

Heat supply and air conditioning [PJ/a]	2012	2015	2020	2025	2030	2040	2050
District heating plants	0	0	0	32	51	155	232
- Fossil fuels	0	0	0	20	28	33	0
- Biomass	0	0	0	12	16	74	125
- Solar collectors	0	0	0	0	5	34	77
- Geothermal	0	0	0	0	2	14	30
Heat from CHP 1)	0	0	2	6	7	11	17
- Fossil fuels	0	0	2	2	4	4	0
- Biomass	0	0	0	4	3	6	17
- Geothermal	0	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	1	2
Direct heating	542	731	875	1,077	1,277	1,893	2,106
- Fossil fuels	265	349	456	478	492	489	0
- Biomass	277	282	273	282	299	332	371
- Solar collectors	0	0	8	37	90	238	461
- Geothermal	0	0	0	6	16	82	147
- Heat pumps 2)	0	0	5	17	40	147	247
- Electric direct heating	0	100	133	257	341	605	879
- Hydrogen	0	0	0	0	0	0	95
Total heat supply3)	542	731	877	1,115	1,336	2,059	2,453
- Fossil fuels	265	349	458	500	524	526	0
- Biomass	277	282	273	297	318	412	514
- Solar collectors	0	0	8	37	95	272	538
- Geothermal	0	0	0	6	18	96	178
- Heat pumps 2)	0	0	5	17	40	147	247
- Electric direct heating	0	100	133	257	341	605	879
- Hydrogen	0	0	0	0	0	1	97
RES share (including RES electricity)	51%	39%	33%	36%	44%	65%	100%
electricity consumption heat pumps (TWh/a)	0.0	0.0	0.2	3.1	6.5	24.0	32.7

Installed Capacity [GW]	2012	2015	2020	2030	2040	2050
Total generation	12	20	18	50	159	270
- Fossil	12	20	17	19	21	18
- Hard coal (& non-renewable waste)	0	0	1	1	0	0
- Lignite	0	0	0	0	0	0
- Gas (w/o H2)	9	14	14	19	20	18
- Oil	2	6	3	0	0	0
- Diesel	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0
- Hydrogen (fuel cells, gas power plants,	0	0	0	0	7	54
- Renewables	0	0	1	30	131	198
- Hydro	0	0	0	0	0	0
- Wind	0	0	0	3	18	46
of which wind offshore	0	0	0	3	14	36
- PV	0	0	0	23	104	127
- Biomass (& renewable waste)	0	0	0	4	8	25
- Geothermal	0	0	0	0	0	0
- Solar thermal power plants	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0
Variable RES (PV, Wind, Ocean)	0	0	0	27	122	173
Share of variable RES	0%	1%	2%	53%	77%	64%
RES share (domestic generation)	4%	2%	4%	61%	83%	73%

Final Energy Demand [PJ/a]	2012	2015	2020	2030	2040	2050
Total (incl. non-energy use)	1,024	1,125	1,410	2,016	2,939	3,281
Total energy use 1)	961	1,067	1,363	1,975	2,901	3,244
Transport	127	94	185	301	463	576
- Oil products	89	94	166	263	318	0
- Natural gas/biogas	38	1	10	14	19	0
- Biofuels	0	0	0	2	58	308
- Synfuels	0	0	0	0	0	0
- Electricity	0	0	8	22	65	253
RES electricity	0	0	0	8	45	253
- Hydrogen	0	0	0	0	2	15
RES share Transport	0%	0%	0%	3%	23%	100%
Industry	241	341	506	864	1,466	1,572
- Electricity	80	97	136	289	516	648
RES electricity	1	1	3	98	357	648
- Public district heat	0	0	0	8	69	74
RES district heat	0	0	0	1	25	74
- Hard coal & lignite	28	84	140	126	169	0
- Oil products	6	14	21	29	33	0
- Gas	127	146	207	287	295	0
- Solar	0	0	0	41	117	177
- Biomass	0	0	0	52	122	439
- Geothermal	0	0	1	33	146	236
- Hydrogen	0	0	0	0	0	0
RES share Industry	1%	0%	1%	26%	52%	100%
Other Sectors	593	631	673	811	972	1,096
- Electricity	65	78	124	233	364	556
RES electricity	1	1	2	80	252	556
- Public district heat	0	0	0	44	84	155
RES district heat	0	0	0	32	72	155
- Hard coal & lignite	0	0	1	0	0	0
- Oil products	64	52	52	38	13	0
- Gas	97	126	122	89	43	0
- Solar	0	0	8	49	121	284
- Biomass	367	376	364	346	302	4
- Geothermal	0	0	3	12	45	97
- Hydrogen	0	0	0	0	0	0
RES share Other Sectors	62%	60%	56%	64%	81%	100%
Total RES	369	378	381	752	1,663	3,244
RES share	38%	35%	28%	38%	57%	100%
Non energy use	63	58	46	40	38	37
- Oil	5	4	3	3	3	2
- Gas	58	54	43	37	35	34
- Coal	0	0	0	0	0	0

Energy-Releated CO2 Emissions [Million tons/a]	2012	2015	2020	2030	2040	2050
Condensation power plants	20	24	33	42	36	0
- Hard coal (& non-renewable waste)	1	0	3	2	2	0
- Lignite	0	0	0	0	0	0
- Gas	14	17	27	39	34	0
- Oil + Diesel	5	7	3	0	0	0
Combined heat and power plants	0	0	0	1	1	0
- Hard coal (& non-renewable waste)	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0
- Gas	0	0	0	1	1	0
- Oil	0	0	0	0	0	0
CO2 emissions power and CHP plants	20	24	34	43	37	0
- Hard coal (& non-renewable waste)	1	0	3	3	2	0
- Lignite	0	0	0	0	0	0
- Gas	14	17	28	40	35	0
- Oil & diesel	5	7	3	0	0	0
CO2 intensity (g/kWh)	0	0	0	0	0	0
without credit for CHP heat	0	0	0	0	0	0
- CO2 intensity fossil electr. generation	409	419	396	381	318	1
- CO2 intensity total electr. generation	409	419	396	381	318	1
CO2 emissions by sector	51	62	90	112	112	0
- % of 1990 emissions (Mill t)	257%	311%	452%	562%	559%	2%
- Industry 1)	10	17	27	32	36	0
- Other sectors 1)	10	11	11	9	5	0
- Transport	9	7	13	21	25	0
- Power generation 2)	20	24	33	42	36	0
- Other conversion 3)	3	3	7	9	9	0
Population (Mill.)	154	158	167	184	198	196
CO2 emissions per capita (t/capita)	0	0	1	1	1	0

Primary Energy Demand [PJ/a]	2012	2015	2020	2030	2040	2050
Total	1,233	1,373	1,829	2,718	3,928	4,269
- Fossil	863	984	1,443	1,814	1,766	41
- Hard coal (& non-renewable waste)	37	87	171	164	194	0
- Lignite	0	0	1	0	0	0
- Natural gas	597	648	963	1,293	1,186	37
- Crude oil	229	248	308	357	386	3
- Nuclear	0	0	0	0	0	0
- Renewables	370	390	386	905	2,162	4,229
- Hydro	3	2	2	2	4	4
- Wind	0	0	0	41	228	577
- Solar	0	1	10	185	663	978
- Biomass (& renewable waste)	367	387	371	632	1,077	2,337
- Geothermal	0	0	3	44	190	333
- Ocean energy	0	0	0	0	0	0
- of which non-energy use	63	58	46	40	38	41
Total RES	370	390	386	905	2,162	4,229
RES share (excluding non energy use)	31.6%	29.6%	21.7%	33.8%	55.6%	100.0%
RES share	30.0%	28.4%	21.0%	33.1%	54.0%	86.3%

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