GLOBAL ENERGY SYSTEM BASED ON 100% RENEWABLE ENERGY
Power, Heat, Transport and Desalination Sectors

Executive Summary (English)

Study by

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Executive Summary

Climate change is impacting every continent on Earth at increasing intervals. The detrimental impacts of climate change are projected to get much worse at a temperature rise of 2°C above pre-industrial levels. Limiting global warming to 1.5°C by mid-century could reduce the exposure to both climate-related risks and the corresponding susceptibility to economic burdens. Rapid and fundamental change is required across all carbon emitting sectors of the global economy, most particularly in the energy sector, which is the primary contributor to greenhouse gas (GHG) emissions. There is an urgent need for the global community to collectively pursue a pathway towards net zero GHG emissions by launching a rapid transition of the energy sector. There are still many countries and regions that have yet to initiate plans which will align their short-term actions and long-term energy goals with the degree of ambition that is required to realise the objectives of the Paris Agreement.

This research study undertaken by Finland’s LUT University (LUT) and the Energy Watch Group (EWG) presents a first of its kind technology-rich, multi-sectoral, multi-regional and cost-optimal global energy transition pathway. Led by Dr. Christian Breyer, a group of 14 of the world’s leading energy transition scientists conducted the study over a period of four and a half years. Using LUT’s state-of-the-art energy transition modelling simulation, full hourly geo-spatial resolutions were used to compute the cost-optimal mix of technologies based on local available renewable energy sources. The research conducted in this study provides cost optimised simulations of energy systems for 145 global regions, the study has been aggregated into nine major world regions. The study is a techno-economic blueprint demonstrating the least-cost and feasible energy mix with the transitioning of the global power, heat, transport and desalination sectors to net zero GHG emissions by 2050.

The study showcases that a global 100% renewable energy system can be achieved with zero GHG emissions before 2050 and more cost-effectively than the current fossil fuel and nuclear-based energy system. Solar photovoltaics (PV) and wind energy emerge as the new workhorses of the future global energy system. Solar PV emerges as the most prominent electricity supply source accounting for approximately 69% of the total energy supply by 2050, complemented by wind energy at 18%, hydropower at 3% and bioenergy at 6%. This translates to a total installed capacity of approximately 63,400 gigawatts of solar PV and 8,000 gigawatts of wind energy across the world by 2050. PV prosumers will drive a more decentralised energy transition across the different regions of the world, contributing to approximately 19% of electricity generation. Low-cost renewable energy supply enables electrification across the power, heat, transport and desalination sectors. A 100% renewable energy system is more efficient and cost competitive than the current fossil fuel and nuclear power based system.
Energy Demand

A fundamental shift in the energy sector is shaping the energy transition, which is currently predominantly based on fossil fuels. As indicated in Figure ES-1, electrification across the energy sector, comprising of power, heat, transport and desalination results in a primary energy share of 90% renewable electricity by 2050 and zero fossil fuels. This is a complete shift from the primary energy supply of the 2015 energy system, which depended primarily on fossil fuels (89%) and just 4% electricity from renewables.

125,000 TWh in 2015 to nearly 105,000 TWh by 2035 and increases to over 150,000 TWh by 2050.

By comparison, current practices and low electrification would result in a primary energy demand of nearly 300,000 TWh by 2050 (see Figure ES-2). This massive gain in energy efficiency is primarily due to the high level of electrification of around 90% of primary energy demand, and will save nearly 150,000 TWh compared to the continuation of current practices with low shares of electrification.

Figure ES-1: Shares of main fuels in the total primary energy demand globally, in 2015 and 2050.

Figure ES-2: Sectoral final energy demand through the transition (left) and primary energy demand with high electrification and low electrification through the transition (right).
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Primary Energy Supply

As the primary energy supply increasingly shifts toward electricity, correspondingly, the share of renewable energy increases from around 10% in 2015 to 100% by 2050. Solar PV and wind energy emerge as the most prominent electricity supply sources with approximately 76% and 20%, respectively, of the total primary electricity supply by 2050 across the power, heat, transport and desalination sectors (see Figure ES-3). Solar PV is comprised of prosumer rooftop PV, fixed-tilted and single-axis tracking PV power plants. Additionally, hydropower contributes to around 3%, biomass 6%, and geothermal energy 2% and a further 2% by other renewables contribute to the lowest cost energy mix in 2050.

![Figure ES-3: Shares of primary energy supply in 2015 and 2050.](image)

Heat Supply

The heat supply shifts from being dominated by 85% fossil fuels in 2015, towards 100% renewable energy sourcing in 2050. Heat pumps play a significant role accounting for an approximate 44% share, followed by direct electric heating at 26%, and biomass-based heat accounting for 12% of the mix (see Figure ES-4). Additionally, renewables-based gas provides around 12% of heat supply in 2050. Gas as a fuel shifts from extracted fossil fuels towards synthetically produced gas by renewable electricity along with biomethane throughout the transition.

![Figure ES-4: Shares of heat supply in 2015 and 2050.](image)
Energy Storage

Energy storage plays a critical role in the transition of the global energy system toward 100% renewables. A combination of both electricity and heat storage technologies cover the energy demand throughout the transition period (see Figure ES-5). Energy storage covers about 23% of the electricity demand and about 26% of heat demand in 2050.

Figure ES-5: Energy Storage through the transition from 2015 to 2050 for electricity demand (left) and heat demand (right).

Synthetic Fuel Production

A critical aspect to enabling a 100% renewable energy system is the production of synthetic fuels. Fuel conversion technologies such as Fischer-Tropsch, water electrolysis, methanation, and others supply renewables-based fuels through the energy transition. Along with sustainably produced biofuels, such as jatropha plantations on degraded land, electrification, and renewables-based synthetic fuels, ensure a 100% renewable energy-based transport sector across the different regions of the world. The corresponding capacities of fuel production technologies are phased-in predominantly beyond 2035 (see Figure ES-6).

Heat management plays a vital role in efficiently producing synthetic fuels. Recovered heat can provide a high share of the energy needed for CO₂ direct air capture, which in turn provides carbon from the atmosphere for the production of synthetic fuels. Utilisation of recovered heat and excess heat are vital for a cost optimal energy transition in the transport sector. This occurs significantly beyond 2035 (see Figure ES-6).

Figure ES-6: Installed capacities of fuel conversion technologies (left) and heat management (right) through the energy transition from 2015 to 2050.
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Energy Costs and Investments

A shift to a 100% renewable energy sourced system results in a stable levelised cost of energy across the different regions of the world throughout the transition. The levelised cost of energy for a fully sustainable global energy system remains stable in the range of 50-57 €/MWh throughout the transition from 2015 to 2050 (see Figure ES-7). A trend develops where the levelised cost of energy shares become increasingly dominated by capital costs, as fuel costs lose significance through the transition period. There could be increased energy diversification and local self-reliance across the different regions of the world by 2050.

Investments in the energy sector increase through the transition and are well spread across a range of technologies with major investments for solar PV, wind energy, batteries, heat pumps, and synthetic fuel conversion (see Figure ES-7). Investments are also well distributed across the three major sectors of power, heat and transport through 2050.

![Figure ES-7: Levelised cost of energy (left) and investments in five-year intervals (right) through the energy transition from 2015 to 2050.](image)

Emissions Reduction

The most important result of the global energy transition is that GHG emissions can be reduced from nearly 30,000 mega tonnes CO\(_2\) equivalent (MtCO\(_2\)eq) in 2015 to zero by 2050 (see Figure ES-8).

The remaining cumulative GHG emissions of around 422 gigatonnes CO\(_2\) equivalent (GtCO\(_2\)eq) are in adherence to the ambitious goals of the Paris Agreement of limiting temperature rise to 1.5°C.

![Figure ES-8: Sectoral GHG emissions (left) jobs created by different energy resources (right) through the energy transition from 2015 to 2050.](image)
**Job Creation**

Approximately 35 million direct energy jobs are created over the transition in the power sector across the different regions of the world (see Figure ES-8). Jobs shift from the fossil fuel sectors toward renewable energy and storage sectors, with solar PV and batteries providing the majority of energy jobs by 2050. Jobs lost in the fossil fuel sectors are more than compensated with an additional 15 million jobs being created by 2050.

**Policy Recommendations**

To achieve a 100% renewable energy system, ambitious targets must be set and supported by stable, long-term, and reliable policies. Policy frameworks will need to be locally adapted to regional conditions and environments on the basis of subsidiarity. The energy transition can be spurred by:

- Feed-in policies, such as tariffs, guarantee a minimum price per unit of electricity. They stimulate local and regional, private and public, small- and medium-scale investments.
- Tendering procedures that are recommended for utility-scale projects with capacities above 40 MW. For projects below 40 MW of capacity, feed-in tariffs should apply to encourage distributed generation.
- Tax exemptions, direct subsidies, and legal privileges for renewable energy technologies.
- Introduction of carbon, methane, and radioactivity taxes.
- Regulation, mandates, and infrastructure planning that encourage heightened efficiency in buildings, lighting, electric appliances, electronic devices, and other energy loads.
- Co-generation (particularly bioenergy and power-to-gas) with full heat recovery.
- Levelling the playing field of energy supply through the removal of subsidies and by pricing negative externalities.
- An essential scaling-up of both public and private funding.
- Consistency of financial support from local, national, and regional governments.
- Divestment, investment, and setting up of new and innovative financing schemes.
- Creating stakeholder engagement across sectors to inclusively identify and take advantage of opportunities and eliminate barriers throughout the energy transition.
- Cooperative funding and share-based models combined with open and accessible online tools to monitor public expenditures (e.g. participatory budgeting schemes).

→ *Further sectoral and regional results of this global energy transition are presented in the report.*