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GLOBAL ENERGY SYSTEM BASED ON 100% RENEWABLE ENERGY – POWER SECTOR

Study by

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KEY FINDINGS

A global transition to 100% renewable electricity is feasible at every hour throughout the year and more cost effective than the existing system, which is largely based on fossil fuels and nuclear energy. Energy transition is no longer a question of technical feasibility or economic viability, but of political will.

- Existing renewable energy potential and technologies, including storage can generate sufficient and secure power to cover the entire global electricity demand by 2050[1]. The world population is expected to grow from 7.3 to 9.7 billion. The global electricity demand for the power sector is set to increase from 24,310 TWh in 2015 to around 48,800 TWh by 2050.

- Total levelised cost of electricity (LCOE) on a global average for 100% renewable electricity in 2050 is 52 €/MWh (including curtailment, storage and some grid costs), compared to 70 €/MWh in 2015.

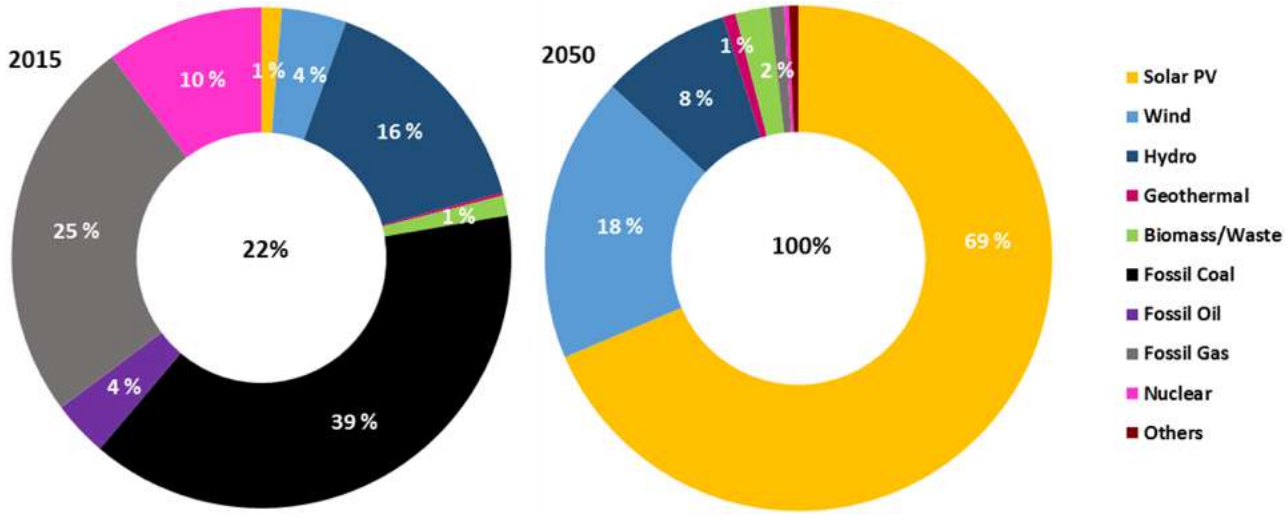
Solar PV and battery storage drive most of the 100% renewable electricity supply due to a significant decline in costs during the transition.

- Due to rapidly falling costs, solar PV and battery storage increasingly drive most of the electricity system, with solar PV reaching some 69%, wind energy 18%, hydropower 8% and bioenergy 2% of the total electricity mix in 2050 globally.

- Wind energy increases to 32% by 2030. Beyond 2030 solar PV becomes more competitive. Solar PV supply share increases from 37% in 2030 to about 69% in 2050.

- Batteries are the key supporting technology for solar PV. Storage output covers 31% of the total demand in 2050, 95% of which is covered by batteries alone. Battery storage provides mainly short-term (diurnal) storage, and renewable energy based gas provides seasonal storage.

Figure 1: Electricity generation from renewables in 2015 and 2050. In 2050, nuclear power still accounts for negligible 0.3% of the total electricity generation, due to the end of its assumed technical life, but could be phased out earlier



100% renewables bring GHG emissions in the electricity sector down to zero, drastically reduce total losses in power generation and create 36 million jobs by 2050

- Global greenhouse gas emissions significantly reduce from about 11 GtCO2eq in 2015 to zero emissions by 2050 or earlier, as the total LCOE of the power system declines.

- The global energy transition to a 100% renewable electricity system creates 36 million jobs by 2050 in comparison to 19 million jobs in the 2015 electricity system. Operation and maintenance jobs increase from 20% of the total direct energy jobs in 2015 to 48% of the total jobs in 2050 that implies more stable employment chances and economic growth globally.

- The total losses in a 100% renewable electricity system are around 26% of the total electricity demand, compared to the current system in which about 58% of the primary energy input is lost

1 *The simulations of the global power sector in this study were made until 2050. Yet, with favorable political frameworks, the transition to 100% renewable energy can be realized earlier than 2050.*

EXECUTIVE SUMMARY

The landmark Paris Agreement adopted in December 2015 has sent a historical signal: over 190 countries in the world have recognized the need for urgent climate action. If we are to keep the global temperature rise under 1.5˚C, the transition to a 100% renewable global energy system, which is already underway in many communities, cities and countries, should be dramatically accelerated. As costs of solar, wind energy and battery storage keep falling, and emerging markets lead in investments in renewables, a global electricity system based on 100% renewables is no longer a long-term vision, but a tangible reality. The challenge is reaching a maximum synergy between various renewable energy resources and technologies across different regions of the world.

Modelling a Global Transition towards a 100% Renewable Power System

Lappeenranta University of Technology (LUT) on behalf of the Energy Watch Group has simulated a global transition to 100% renewable energy in the power sector by 2050. However, the transition can be realised earlier than 2050 under favourable political conditions. The first of its kind modelling, developed by LUT, computes the cost-optimal mix of technologies based on locally available renewable energy sources for the world structured in 145 regions and calculates the most cost-effective energy transition pathway for electricity supply on an hourly resolution for an entire reference year. The global energy transition scenario is carried out in 5-year time periods from 2015 until 2050. The results are aggregated into nine major regions of the world: Europe, Eurasia, MENA, Sub-Saharan Africa, SAARC, Northeast Asia, Southeast Asia, North America and South America.

A global transition to

100% RENEWABLE ELECTRICITY

is feasible at every hour throughout the year and is more cost-effective than the existing system

Transition to a 100% Renewable Power System

The study shows that a global transition to 100% renewable electricity is feasible at every hour throughout the year and is more cost-effective than the existing system, which is largely based on fossil fuels and nuclear energy.

Total levelised cost of electricity (LCOE) on a global average for 100% renewable electricity in 2050 is 52 €/MWh (including curtailment, storage and some grid costs), compared to the total LCOE of 70 €/MWh in 2015.

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The share of renewable energy sources in the global electricity supply mix increases from 22% in 2015 to 100% in 2050, with solar PV and wind emerging as the most prominent energy sources. At the same time, the shares of fossil fuels and nuclear energy in power generation continually decrease. By 2050, fossil fuel and nuclear energy are phased-out, as their generation costs become increasingly uncompetitive.

Due to rapidly falling costs, solar PV and battery storage increasingly drive most of the electricity system. Wind energy increases to 32% by 2030 and beyond 2030 solar PV becomes even more competitive. The solar PV share increases from 37% in 2030 to 69% in 2050. Solar PV emerges as the least cost energy source through the transition in almost all regions of the world. In 2050, solar PV reaches 69%, wind energy 18%, hydropower 8% and bioenergy 2% of the total electricity mix globally (see Figure ES-1).

In MENA, Sub-Saharan Africa, SAARC, Northeast Asia and Southeast Asia, mainly solar PV and batteries drive the power system in 2050. Meanwhile, Eurasia, Europe and North America rely substantially on wind energy to power their systems, mainly due to strong seasonal variations. South America benefits from rich resources leading to electricity generated largely from a combination of wind, solar PV and hydropower.

The various power generation sources and storage technologies considered in the energy transition with their corresponding installed capacities in different regions around the world in the years 2015, 2030 and 2050 are indicated in Table ES-1. In 2050, there are still coal power plant capacities in cold reserve (also strategic reserve), but they do not generate any electricity. Gas turbines only use renewable energy based fuels. Most of the nuclear power plants are phased out by 2050 but still contribute a negligible share of 0.3% to the total electricity generation, due to the end of their assumed technical life, but they could be phased-out earlier. This share could be compensated by generation and storage of other renewable energy capacities for no relevant extra cost and utilisation of curtailed electricity. In 2050, renewable electricity generation covers 119% of final electricity demand, which accounts for balancing losses due to grids, storage and curtailment.

Figure ES-1: Share of electricity generation from renewable sources in 2015 and 2050. Gas capacities in 2050 only use renewable based gas. In 2050, nuclear power still accounts for a negligible 0.3% of the total electricity generation, due to the end of its assumed technical life, but could be phased out earlier.

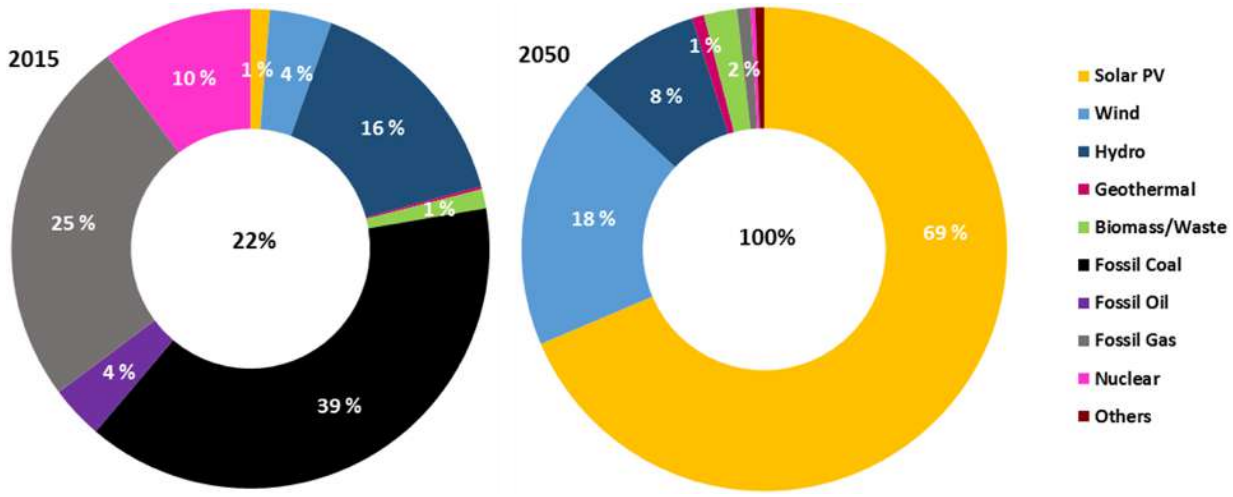


Table ES-1: Installed capacities of power and storage technologies across the major regions for the global energy transition in the representative years 2015, 2030 and 2050. Abbreviations: MENA – Middle East and North Africa, SSA – Sub-Saharan Africa, SAARC – South Asian Association for Regional Cooperation, NE-Asia – Northeast Asia, SE-Asia – Southeast Asia, N-Am – North America, S-Am – South America.

2015

Technology	Unit	Europe	Eurasia	MENA	SSA	SAARC	NE-Asia	SE-Asia	N-Am	S-Am	Global
PV utility-scale	GW	49	0	1	1	6	52	2	2	16	131
PV rooftop	GW	54	0	0	0	0	28	5	0	12	100
Wind	GW	135	0	2	1	24	118	5	78	8	372
Hydropower	GW	192	73	19	19	54	294	53	174	151	1028
Bioenergy	GW	56	0	0	0	7	13	8	23	13	120
Geothermal	GW	2	0	0	0	0	1	4	5	1	13
Gas Turbine	GW	274	156	239	25	63	251	108	606	67	1789
Coal PP	GW	234	67	7	43	163	942	80	348	10	1896
Nuclear PP	GW	138	24	1	2	6	80	0	114	3	368
Other generation	GW	58	9	78	10	16	103	17	68	27	386
Battery	GWh	0	2	0	0	0	0	0	0	0	2
Gas	GWh	0	0	0	0	0	0	0	0	0	0
Pumped Hydro	GWh	48	4	1	2	4	56	4	16	0	135
Other storage	GWh	0	0	0	0	0	0	0	0	0	0

2030

PV utility-scale	GW	281	94	377	180	717	1241	501	562	172	4124
PV rooftop	GW	590	13	52	48	273	880	221	634	145	2856
Wind	GW	487	208	240	71	172	1209	71	789	45	3293
Hydropower	GW	214	84	22	33	69	391	67	198	164	1242
Bioenergy	GW	254	12	10	4	61	77	51	67	63	598
Geothermal	GW	5	10	5	2	5	4	14	20	0	67
Gas Turbine	GW	318	201	468	96	170	354	171	876	81	2733
Coal PP	GW	72	12	5	26	142	902	60	66	8	1293
Nuclear PP	GW	58	10	1	0	6	63	0	43	1	182
Other generation	GW	6	1	25	7	5	21	7	8	15	94
Battery	GWh	1088	27	658	426	1930	2467	1234	1690	413	9934
Gas	GWh	68267	4694	977	466	2224	8194	4004	9899	3338	102062
Pumped Hydro	GWh	88	4	2	3	44	98	8	17	0	264
Other storage	GWh	47	1	68	22	20	1210	52	232	38	1691

2050

PV utility-scale	GW	688	218	1021	926	2593	5046	1733	1245	452	13921
PV rooftop	GW	1268	134	386	373	1137	2371	685	1302	383	8038
Wind	GW	560	267	237	78	200	921	80	766	44	3154
Hydropower	GW	224	91	22	40	70	394	69	202	169	1282
Bioenergy	GW	293	14	12	8	64	85	63	72	52	664
Geothermal	GW	6	12	6	2	5	5	14	18	0	67
Gas Turbine	GW	225	177	338	104	148	383	121	539	42	2077
Coal PP	GW	20	4	1	5	96	568	32	23	5	754
Nuclear PP	GW	2	2	1	0	3	18	0	0	0	26
Other generation	GW	6	0	52	4	12	5	14	3	1	98
Battery	GWh	3569	463	3593	3238	9191	15707	5288	5218	1590	47858
Gas	GWh	217330	49338	92575	54013	90806	185428	80533	222194	9681	1001898
Pumped Hydro	GWh	88	4	2	3	44	98	8	17	0	265
Other storage	GWh	466	69	729	263	498	589	829	248	53	3745

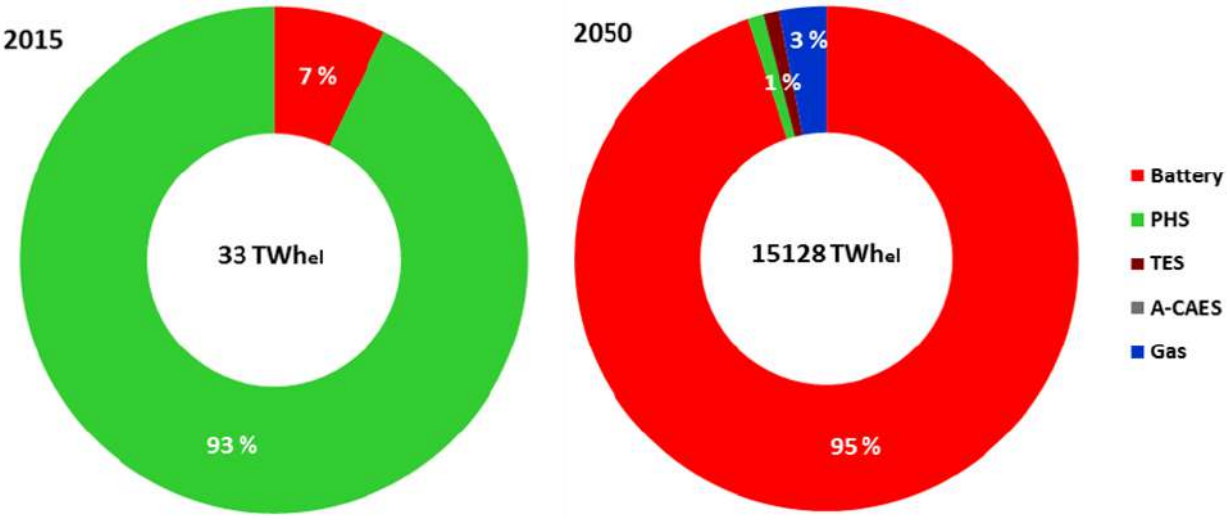
STORAGE

Storage technologies play a critical role in enabling a secure global power supply fully based on renewable energy. The results show that storage technologies increase from a mere 33 TWhel in 2015 to a substantial 15 128 TWhel in 2050. Batteries emerge as the critical storage technology in the global power mix, providing a major share of the output (almost 95%) by 2050 (see Figure ES-2).

The results indicate that with the arrival of cost-efficient storage, and as battery costs continue to decline dramatically, renewable power deployment will be further complemented.

Further price compression is expected as battery electric vehicles become more widespread and battery production ramps up.

Figure ES-2: Share of storage technologies in the overall output in 2015 and 2050. Gas storage in 2050 is based entirely on renewable resources.



Costs and investments

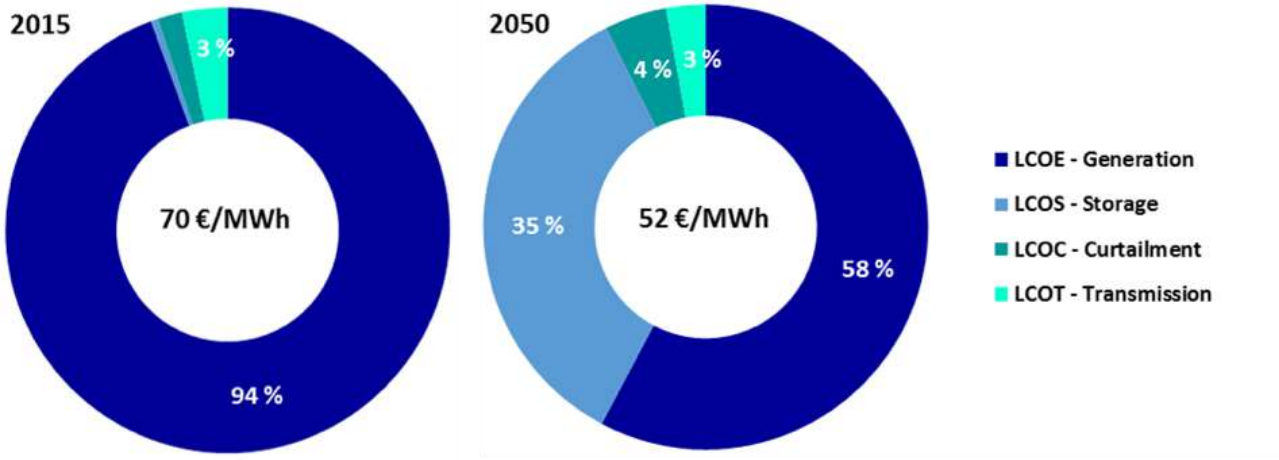
As increasing shares of power capacity are added globally, renewable energy sources on a levelised cost of electricity basis (LCOE) become the least cost power generation source. The global average energy system LCOE gradually declines from 70 €/MWh in 2015 to 52 €/MWh in 2050, with solar PV emerging as the least expensive source of power generation (see Figure ES-3).

Cost of **100%** renewable electricity in 2050 is **52 €/MWH** vs. **70 €/MWH** IN 2015

Figure ES-3 displays different shares of generation, storage, curtailment and transmission in the total LCOE, and indicates a decrease in the share of generation costs. This implies that power generation costs will be extremely low in a 100% renewable electricity system.

The results further imply an average annual investment requirement of 608 b€ globally during the energy transition period from 2015 to 2050, with higher investment requirements of 699 b€ per annum during 2020 to 2035 and then onwards less and stable investment needs of 488 b€ per annum from 2035 to 2050.

Figure ES-3: Total LCOE of global power supply in 2015 and 2050.

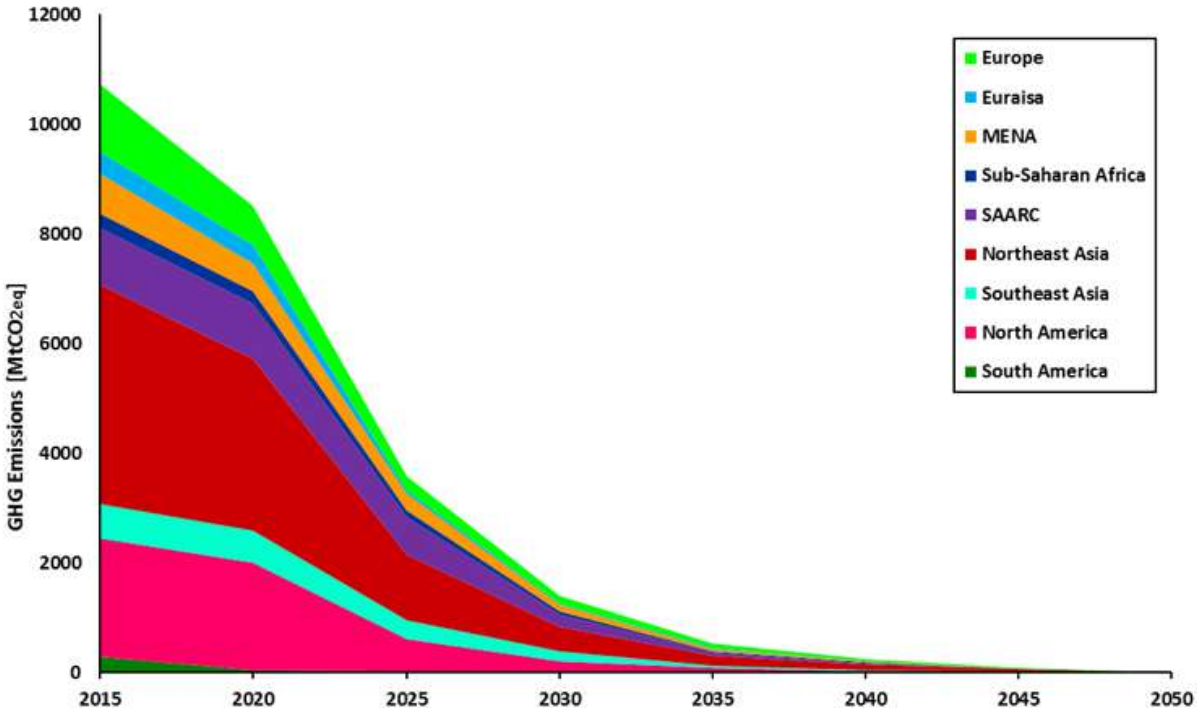


Socio-economic benefits

Development of renewable energy has emerged as a true multi-beneficial phenomenon, which enables climate change mitigation, drives economic growth, creates local value based on technology development, production, installation and maintenance, helps to increase energy access in a timely manner, and to reduce resource conflicts in water-stressed regions of the world.

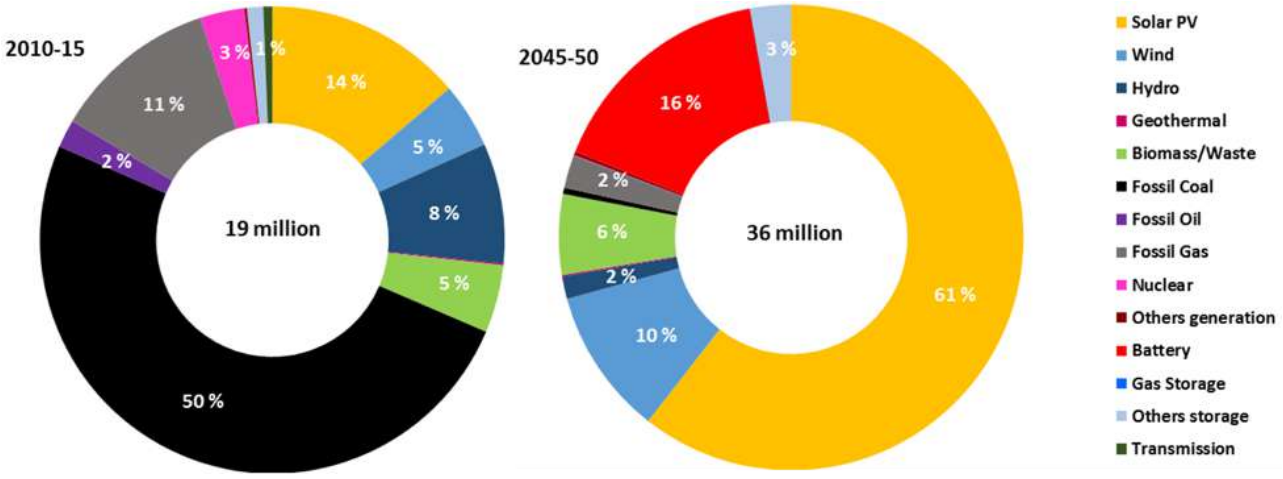
The results of the study indicate that greenhouse gas emissions in the global power sector can be reduced from about 11 GtCO2eq in 2015 to zero by 2050, with deep decarbonisation already by 2030 for many regions of the world (see Figure ES-4).

Figure ES-4: Decline in greenhouse gas (GHG) emissions during the energy transition from 2015 to 2050 from the power sector in different regions around the world.



A global transition towards a 100% renewable electricity system will create over 36 million direct jobs in the power sector by 2050 – an increase from 19 million jobs added in 2015 (see Figure ES-5). Solar PV and storage technologies led by batteries are expected to be the prime job creators in the next decades and beyond. Renewable energy technologies can generate additionally 2 to 3 indirect jobs for every direct job generated by the sector, eventually creating stable growing economies across the world.

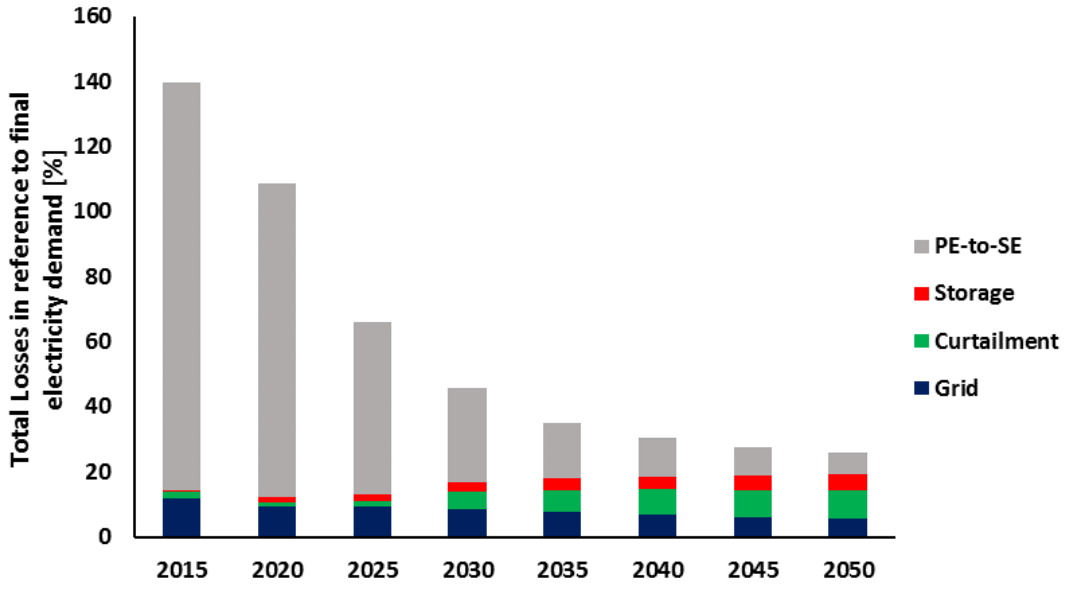
Figure ES-5: Jobs created globally during the energy transition from 2015 to 2050. Gas capacities in 2050 only use renewable based gas.



The results further highlight that a 100% renewable electricity system can increase the robustness of the system while decreasing overall energy system losses (see Figure ES-6). The total losses in a 100% renewable electricity system in 2050 are just around 21.6% of the total generation, compared to the current system with 58% of primary energy input lost. The overall energy system losses referenced to the final electricity demand decrease from 139% in 2015 to 26% in 2050, indicating far more efficient power systems globally. The huge losses of primary energy to secondary energy conversion of present thermal power plants (nuclear, coal, gas, oil, biomass) drastically reduce by 88%, mainly due to the phase out of thermal power plants.

Curtailment and storage losses increase to 8.5% and 4.8% of the final electricity demand, respectively. The shares of curtailment increase after 2030, mainly due to very low costs of renewable electricity, and this enables curtailment as a cheap flexibility option. Transmission and distribution grid losses decrease due to advanced grid management in presently emerging and developing countries.

Figure ES-6: Total losses (primary to secondary energy conversion, storage, curtailment and grid) of the global power system in reference to final electricity demand during the energy transition from 2015 to 2050.



POLICY RECOMMENDATIONS

The study results show that a global energy transition to 100% renewable electricity is no longer a question of technical feasibility or economic viability, but of political will. The global community can significantly accelerate this transition by implementing favourable political measures and frameworks.

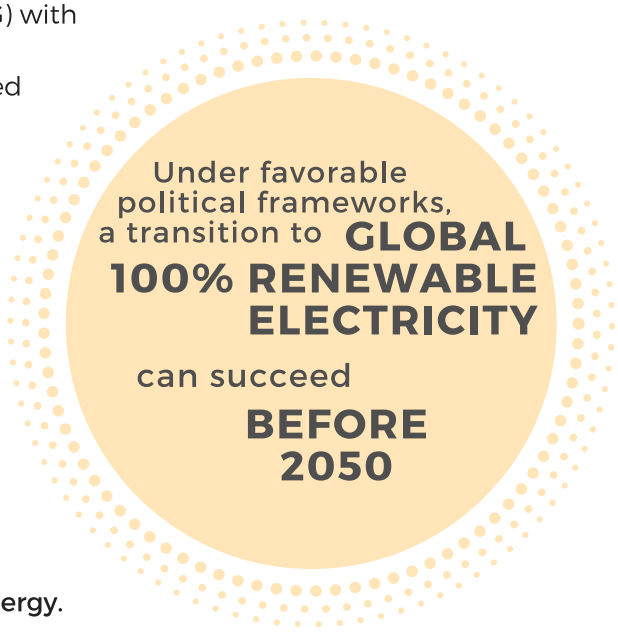
The first decisive prerequisite for a transition to renewable energy is public support. The second prerequisite is a clear legislative framework promoting the fast and steady growth of renewables on the one hand and the phasing out all subsidies to fossil fuel and nuclear energy generation on the other hand.

To ensure a smooth, fast and cost-effective transition to 100% renewable energy, governments need to adopt national legislative acts, which ensure the sufficient flow of private investment in renewable energy and storage technologies.

The following political measures and instruments are key:

- **Instruments, enabling direct private investments in renewable energy and other zero-emission technologies.**

  The German Renewable Energy Sources Act (EEG) with a fixed feed-in-tariff is one of the best-known and proven successful policy frameworks. We also need to implement new, innovative political measures encouraging investment in renewable energy, storage and network integration simultaneously. A reformed version of the EEG -a hybrid renewable power plant remuneration – enables just that. Tendering procedures should only apply for capacities above 40MW, as they otherwise limit investors to large companies and exclude investment from decentralized actors, such as cooperatives.



- **Phasing-out all state subsidies to fossil fuel and nuclear energy generation.**
- **Tax exemptions for investments in renewable energy.**
- **Replacement of the emission trading system with carbon and radioactivity taxes.**
- **Promoting research and education in the sphere of renewable energy and zero-emission technologies.**