Open your mind. LUT.
Lappeenranta University of Technology

ENERGYWATCHGROUP

Sustainable and Low-Cost Energy System for India Without Nuclear and Coal Base Load

By Christian Breyer, Ashish Gulagi and Hans-Josef Fell

Key Facts

- Energy supply, fully based on renewable energy, storage and distribution is the best and only option for India from the economic, ecological and technical points of view. Already today, wind and solar power are the most cost-effective options for energy investments. In 2030, fossil fuel and nuclear energy will be non-competitive with renewables. A future-oriented energy system in India should thus be based on solar PV, wind energy, battery storage and strong power grids.
- Fluctuating wind and solar energy supplemented by highly flexible bioenergy, hydropower, some geothermal energy and storage can provide electricity in India on an hourly basis and during all seasons throughout the year.
- Nuclear and coal-fired base load is not reasonable, as it disrupts a future-oriented system based on low-cost renewable energy.
- International experience has proven that a Feed-in-Tariff (FiT) enables the swiftest and the most cost-efficient market entry of renewable energy, storage and distribution systems. FiT also enables decentralized development in rural areas.
- Legal innovations on FiT can and should stimulate the integration and security of network systems, for example, through an incentive scheme for combined 100% renewable power solutions.
- Local manufacturing of cutting-edge technology enables low cost and high quality investments in India, as well as know-how transfer, education and new jobs.
- Research and development are essential for these developments.
- By investing in renewable energy, India has very high chances to join and even overtake the leading countries on renewable energy.

Introduction

In the coming decades, India's transition to a net zero emission energy system till 2050, as agreed in COP21, will be keenly observed by the world. Energy production is by far the largest source of greenhouse gas (GHG) emissions, especially in countries highly dependent on coal. The only way to dramatically reduce GHG emissions is to switch to renewable energy. Renewable sources not only guarantee energy security but also increase the living standard, boost local employment, reduce pollution, improve health and sustainable development. Renewables are also key in avoiding nuclear dangers, high cost of nuclear waste disposal and radioactive loads.

The potential of renewable energy resources in India, especially solar energy, is abundant. Wind energy has been the main supporting pillar of renewable energy development in India until now, yet a rapid decrease in solar PV prices has shifted the focus to solar PV. The latest initiatives of the Ministry of New and Renewable Energy of India aimed at tapping the renewable energy potential have been significant. They include setting the targets of 100 GW of solar and 60 GW of wind till 2022 [1] and the launch of the International Solar Alliance at COP21 [2].

Results

A 100% renewable energy modelling for India in 2030 shows that solar PV and wind will enable the lowest-cost energy system. An example of the Western region of India in a representative summer week (Fig. 1) and in a representative week during the monsoon period (Fig. 2) proves that the flexible operation of the renewable energy system is feasible. The black curve represents the hourly electricity demand in 2030, which is almost double the electricity demand in 2015. In the period of low solar radiation, wind and to some extent hydropower balance the system to provide electricity and to keep the energy system running without blackouts. Battery storage is of high importance for complementing solar PV over a cycle of 24 hours. The modelling takes into account the strong indications that storage costs will keep decreasing quickly, similar to PV [3].

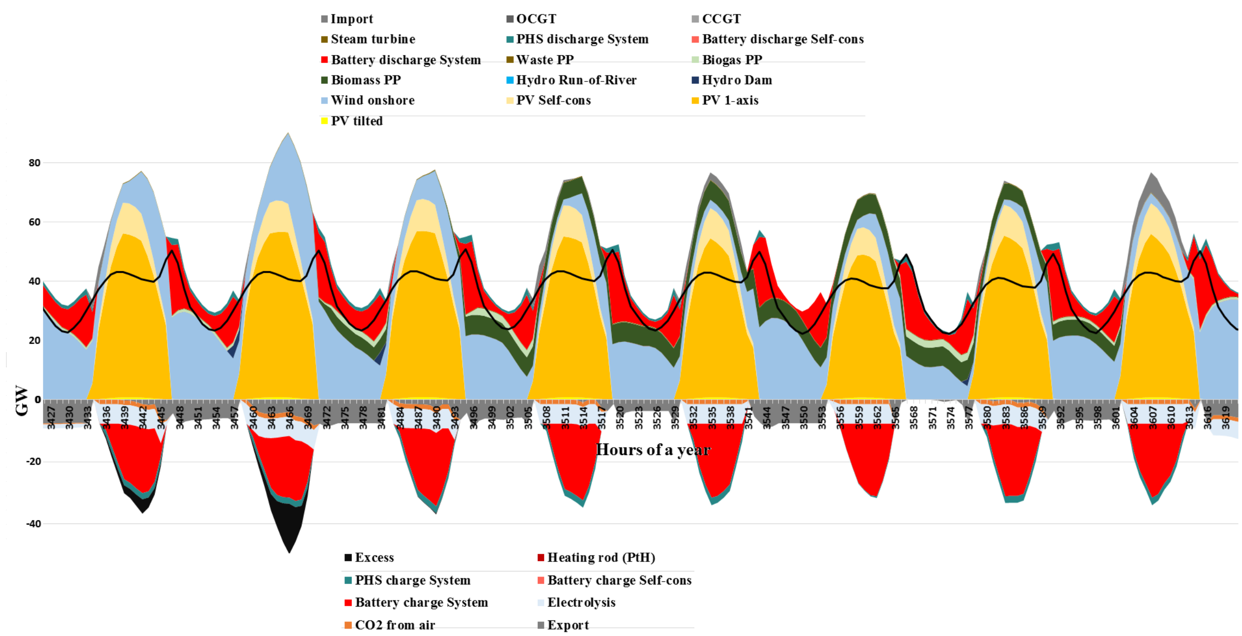

Fig. 1: Hourly generation profile for a representative week in a summer month for India West. The black curve represents the expected electricity demand of 2030, all shades of yellow represent PV (utility-scale plants, rooftop), light blue represents wind, green represents biomass, red represents battery charging and discharging, and excess energy is represented by black colour.

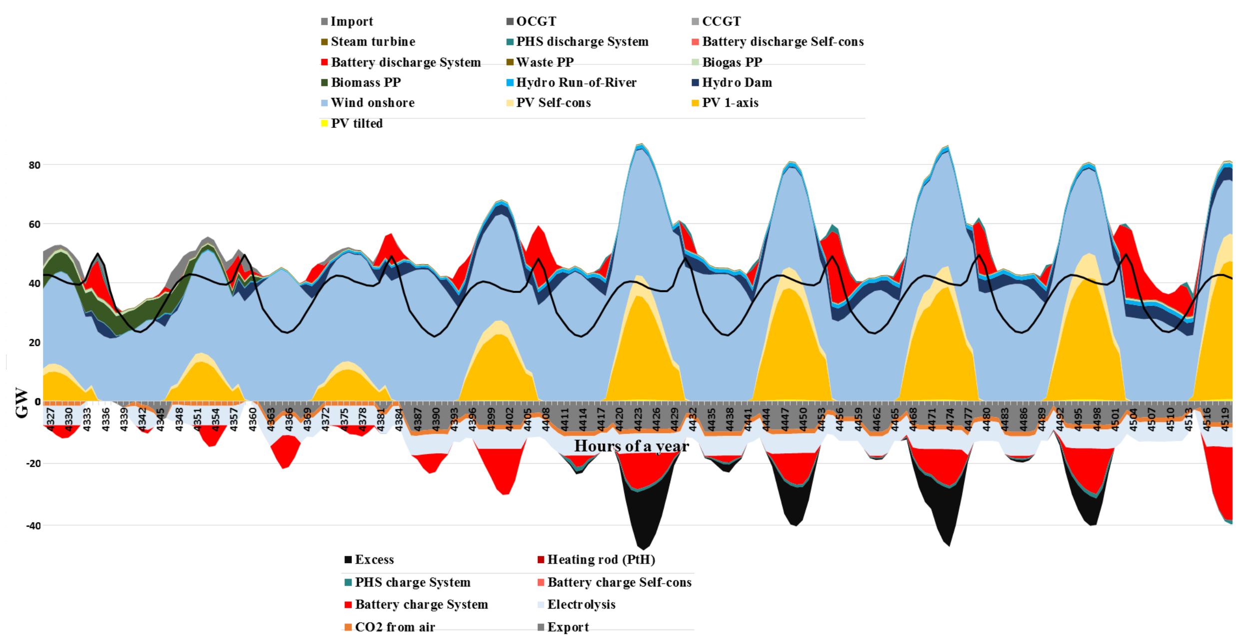

Fig. 2: Hourly generation profile for a representative week in a monsoon month for India West. The black curve represents the expected electricity demand of 2030, all shades of yellow represent PV (utility-scale plants, rooftop), light blue represents wind, green represents biomass, red represents battery charging and discharging, and excess energy is represented by black colour.

In 2030, the installed capacities of solar PV and wind in a 100% renewable energy system in India will be 727 GW and 191 GW, respectively, based on the modelling results. In 2030, the share of solar PV and wind will be 59% and 18% of the total electricity generation mix, respectively. This is the highest solar PV share the authors of this paper have found in their global studies in any region in the world [4]. The electricity generation mix as well as installed capacities of major renewable energy sources and storage in India in 2030 can be found in the Table 1 and Table 2 (Appendix).

The results based on financial and technical assumptions for 2030, lead to a cost level of 69 €/MWh_{el} (5,175 INR/MWh_{el})[1] for different regions in India to cover the 2030 electricity demand. Mainly solar PV and batteries will power the energy system in India. Batteries play a vital role in complementing solar PV electricity in the afternoon and at night. The cost assumptions for solar PV and batteries seem to be slightly conservative in this study, hence costs might be lower in reality. These results clearly prove that renewable energy sources are the most competitive and least-cost solution for achieving a net zero emission energy system. This is the first study of its kind for India.

Discussion

The base load nuclear and coal-fired power plants are not reasonable in an energy system fully based on renewable energy. The energy potential in India is much higher than the demand. Low-cost solar PV plus battery storage enables a very flexible electricity supply within a daily cycle. The seasonal cycle, in particular during the monsoon period, can be covered best by means of wind energy. Strong power grids enable the balancing of electricity generation and demand across India. Hydropower and highly flexible gas turbines are needed for balancing wind and solar. Renewable gas (biogas and power-to-gas) should substitute fossil gas as soon as possible. Plant-based fuels from re-greened degraded fields can be used in the power sector for providing flexibility but also in the transport sector. Gas infrastructure will be needed in any case also in the long-term, then based on a 100% renewable gas source with an evolutionary shift from fossil to renewable fuels, hence

[1] 1 € = 75 INR

most of the related infrastructure will not end up as stranded assets, which is very likely for all coal assets, but also most likely for the nuclear assets. These coal assets also fully violate the COP21 agreement. A mix of the mentioned renewable energy technologies will fully provide the energy services currently provided by large-scale power plants.

A further energy sector integration, in particular the transport sector, will further reduce the costs of the system. Electric vehicles will provide flexibility for the Indian energy system and energy system services. Best practices in Germany and Denmark prove that high shares of solar PV and wind energy can be handled in the power system with the highest possible stability of the energy system.

Further Research

The authors of this paper are fully aware that these results are the first research results for achieving a solid basis for the Indian future-oriented energy system. We will proceed with this research, but we could be much more effective in a well-supported research collaboration with leading Indian experts. We want to fully represent the entire energy system (including transport, heat, seawater desalination and industrial sector), integrate the electrification of people who have no access to electricity, as well as perform a full energy transition scenario from today to 2050 or 2070, or represent India in a higher regional resolution. The leading-edge LUT energy system model is further improved in a team of about 15 researchers, but the application and adaptation to Indian conditions needs to be done in collaboration with Indian experts. We are very open to respective international cooperation.

Appendix

Information about the authors:

Christian Breyer is Professor of Solar Economy at LUT, scientific chairman of the Energy Watch Group and has worked several years in the solar PV industry besides academic positions. His research team is the most read at ResearchGate of LUT and the most read in entire Finland on renewable energy.
Ashish Gulagi is a PhD researcher in the team of Christian Breyer. He received his B.Tech. at the Institute of Chemical Technology in Mumbai and his M.Sc. at LUT.
Hans-Josef Fell is founder and president of the Energy Watch Group, Member of the German Parliament from 1998 – 2013 and together the Hermann Scheer the author of the Renewable Energy Act (EEG).

Background to this paper:

This paper is based on scientific research at LUT on 100% Renewable Energy (RE) in India. The first published results comprise the scientific question of how a 100% RE power system would operate for the Indian conditions, based on real historical weather data, technical and financial assumptions for the year 2030, hourly modelling for all hours of an entire year and India separated into 10 regions.

The presented results are based on a research paper presented at the 32nd EU PVSEC Conference in Munich in June 2016. The paper is currently under review for publication in a scientific journal. A full presentation of results is also available, see the following links:

https://www.researchgate.net/publication/304179311_Solar_Photovoltaics_-_A_Driving_Force_towards_100_Renewable_Energy_for_India_and_SAARC

https://www.researchgate.net/publication/286935338_Electricity_System_based_on_100_Renewable_Energy_for_India_and_SAARC

Modelling Approach

For a 100% renewable energy based electricity system for India, modelling was performed using the LUT energy system model, which is based on a linear optimization of the parameters which are applied to the system under known constraints with the assumption of a perfect foresight of RE power generation and power demand [5]. The main aim of the system optimization is the minimization of the total annual energy system cost under the key restriction that the model guarantees for every hour of the year the total generation within the regions (10 for the case of India) and electricity exchange covers the local electricity demand. The input data for solar, wind and hydro for the model is based on a 0.45º x 0.45º spatial resolution (ca. 50-km) and optimized for a least cost solution. The model is the first to provide results on an hourly resolution for an entire year for India. The technical and financial assumptions related to the model can be found in the appendix. The financial assumptions for solar PV are conservative in this study, as the Central Electricity Regulatory Commission (CERC) [6] has documented the prices of utility scale PV for today only 7-20% higher than our assumptions in 2030.

Table 1: Installed RE technologies and storage capacities for India in 2030.

PV self-consumption	[GW]	145
PV optimally tilted	[GW]	3
PV single-axis tracking	[GW]	579
PV total	[GW]	727
CSP	[GW]	0
Wind energy	[GW]	191
Biomass power plants	[GW]	54
MSW incinerator	[GW]	2
Biogas power plants	[GW]	11
Geothermal power	[GW]	4
Hydro Run-of-River	[GW]	16
Hydro dams	[GW]	24
Battery PV self-consumption	[GWh]	0
Battery System	[GWh]	1264
Battery total	[GWh]	1264
PHS	[GWh]	44
A-CAES	[GWh]	18
Heat storage	[GWh]	0
PtG electrolyzers	[GW_{el}]	19
CCGT	[GW]	32
OCGT	[GW]	0
Steam Turbine	[GW]	0

Table 2: Electricity generation from major RE technologies and storage throughput for India in 2030.

PV self-consumption	[TWh]	188
PV optimally tilted	[TWh]	5
PV single-axis tracking	[TWh]	1146
PV total	[TWh]	1339
Wind energy	[TWh]	407
Hydro Run-of-River	[TWh]	56
Hydro dams	[TWh]	79
Battery total	[TWh]	400
PHS	[TWh]	11
A-CAES	[TWh]	0
Heat storage	[TWh]	0

Table 3: Financial assumptions for energy system components

Technology	Capex [€/kW]	Opex fix [€/kW]	Opex var [€/kWh]	Lifetime [a]
PV optimally tilted	550	8	0	35
PV single-axis tracking	620	9	0	35
PV rooftop	813	12	0	35
Wind onshore	1000	20	0	25
CSP (solar field)	528	11	0	25
Hydro run-of-river	2560	115.2	0.005	60
Hydro dam	1650	66	0.003	60
Geothermal energy	4860	87	0	30
Water electrolysis	380	13	0.0012	30
Methanation	234	5	0.0015	30
CO_2 scrubbing	356	14	0.0013	30

CCGT	775	19.4	0.001	30
OCGT	475	14.25	0.001	30
Steam turbine	600	12	0	30
Hot heat burner	100	2	0	30
Heating rod	20	0.4	0.001	30
Biomass CHP	2500	175	0.001	30
Biogas CHP	370	14.8	0.001	30
Waste incinerator	5240	235.8	0.007	20
Biogas digester	680	27.2	0	20
Biogas upgrade	250	20	0	20
	Capex [€/kWh]	Opex fix [€/kWh]	Opex var [€/kWh]	Lifetime [a]
Battery	150	10	0.0002	10
PHS	70	11	0.0002	50
A-CAES	31	0.4	0.0012	40
TES	24	2	0	20
Gas storage	0.05	0.001	0	50
	Capex [€/(kW$_{NTC}$*km)]	Opex fix [€/(kW$_{NTC}$*km)]	Opex var [€/kWh$_{NTC}$]	Lifetime [a]
HVDC line on ground	0.612	0.0075	0	50
HVDC line submarine	0.992	0.0010	0	50
	Capex [€/kW$_{NTC}$[2]]	Opex fix [€/kW$_{NTC}$]	Opex var [€/kWh$_{NTC}$]	Lifetime [a]
HVDC converter pair	180	1.8	0	50
	Capex [€/(m^3·a)]	Opex fix [€/(m^3 a)]	Opex var [€/m^3]	Lifetime [a]
Water desalination	2.23	0.09	0	30
	Capex [€/(m^3·h·km)]	Opex fix [€/(m^3·h·km·a)]	Opex var [€/m^3·h·km]	Lifetime [a]
Horizontal pumping and pipes	19.3	0.39	0	30
Vertical pumping and pipes	15.5	0.31	0	30

Table 4: Efficiencies and energy to power ratio of storage technologies.

Technology	Efficiency [%]	Energy/Power Ratio [h]	Self-Discharge [%/h]
Battery	90	6	0
PHS	85	8	0
A-CAES	70	100	0.001
TES	90	8	0.002
Gas storage	100	80*24	0

Table 5: Efficiency assumptions for energy system components for the 2020 and 2030 reference years.

	η_{el} [%]	η_{th} [%]
CSP (solar field)		51
Steam turbine	42	
Hot heat burner		95
Heating rod		99
Water electrolysis		84
Methanation		77
CO_2 scrubbing		78
CCGT	58	

[2] NTC – Net Transmission Capacity

OCGT	43	
Geothermal	24	
Biomass CHP	40	45
Biogas CHP	42	43
Waste incinerator	34	
Biogas upgrade		98

Table 6: Efficiency assumptions for HVDC transmission.

	Power losses
HVDC line	1.6 % / 1000 km
HVDC converter pair	1.4%

References

[1] Buckley T. and Sharda J., 2015. India's Electricity-Sector Transformation, Institute of Energy Economics and Financial Analysis, Ohio, http://ieefa.org/wp-content/uploads/2015/08/IEEFA-Indian-Electricity-Sector-Transformation-August-2015.pdf

[2] [ISA] - International Solar Alliance, 2015. Working Paper on International Solar Alliance, Ministry of New and Renewable Energy, Govt. of India, Gurgoan. http://isolaralliance.com/pdf/ISA-Working-Paper.pdf.

[3] KPMG, 2015. The Rising Sun - Disruption on the horizon, Report published in ENRich – KPMG Energy Conference, India. https://www.kpmg.com/IN/en/IssuesAndInsights/ArticlesPublications/Documents/ENRich2015.pdf

[4] Breyer Ch., Bogdanov D., Gulagi A., Aghahosseini A., Barbosa L.S.N.S., Koskinen O., Barasa M., Caldera U., Afanasyeva S., Child M., Farfan J., Vainikka P., 2016. On the Role of Solar Photovoltaics in Global Energy Transition Scenarios, 32nd EU PVSEC, Munich, June 20-24. https://www.researchgate.net/publication/304350788_On_the_Role_of_Solar_Photovoltaics_in_Global_Energy_Transition_Scenarios

[5] Bogdanov D. and Breyer Ch., 2016. North-East Asian Super Grid for 100% Renewable Energy supply: Optimal mix of energy technologies for electricity, gas and heat supply options, Energy Conversion and Management, 112, 176-190. https://www.researchgate.net/publication/291556438_North-East_Asian_Super_Grid_for_100_renewable_energy_supply_Optimal_mix_of_energy_technologies_for_electricity_gas_and_heat_supply_options

[6] [CERC] - Central Electricity Regulatory Commission, 2016. Determination of Benchmark Capital Cost Norm for Solar PV power projects and Solar Thermal power projects applicable during FY 2016-17, Petition from Government of India, New Delhi.