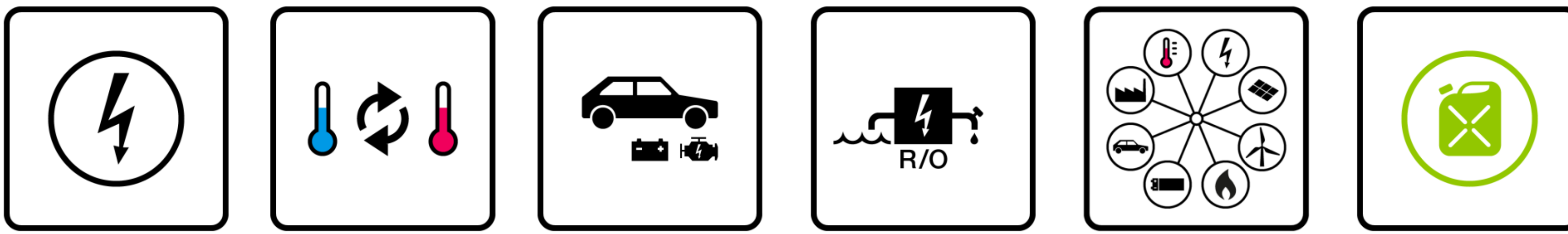
LUT Energy System Transition Model

- brief overview -



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Overview: Data flow

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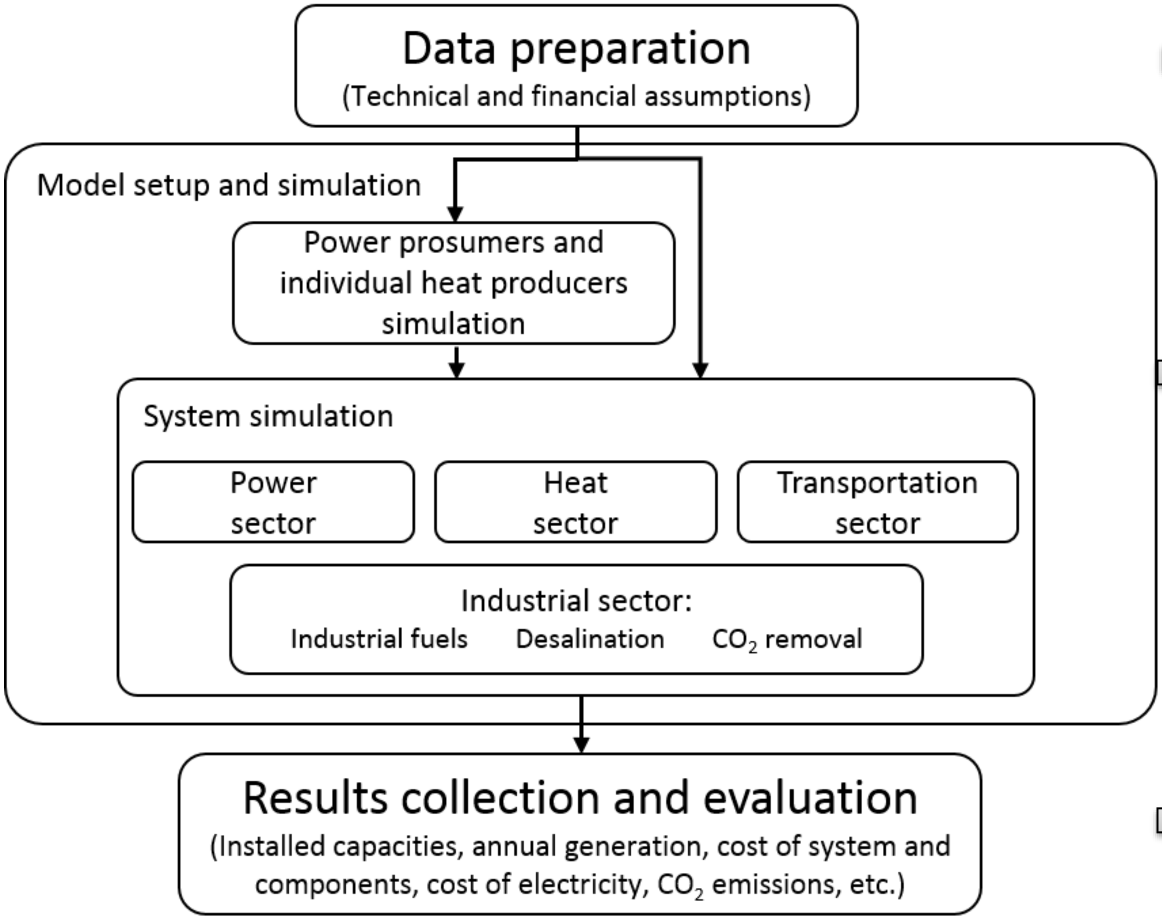
The entire modeling process can be divided into three main stages:



Here all data is read from input files and the model is compiled: All demands, assumptions

Here the compiled model of the system is optimised with the solver (Mosek, Gurobi or CPLEX). We use Mosek.

Here the optimisation results are read and organised in the desired structure. These results – installed capacities and hourly utilisation of technologies and resources are used for calculations of costs shares and other metrics for further evaluating the results

source: [Bogdanov et al., 2019. Radical transformation pathway towards sustainable electricity via evolutionary steps. Nature Communications, 10, 1077]

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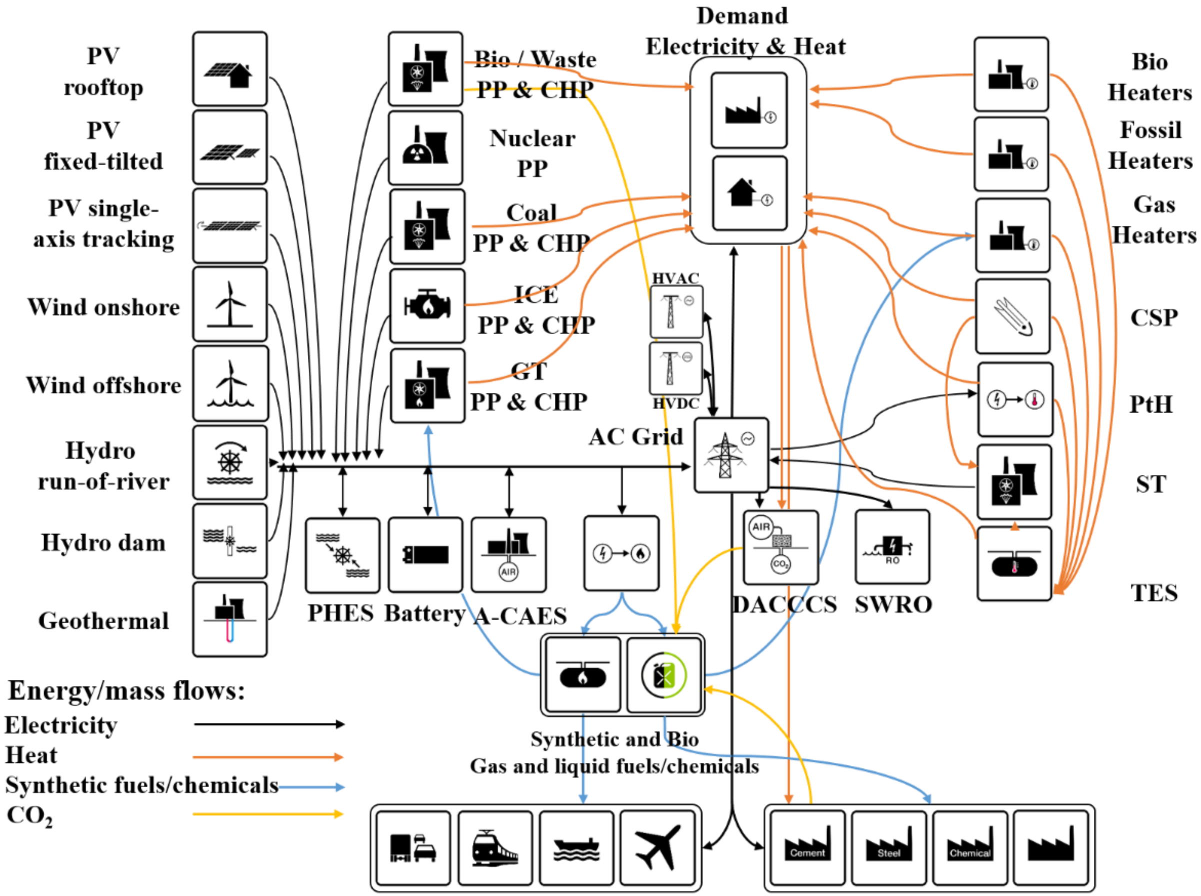
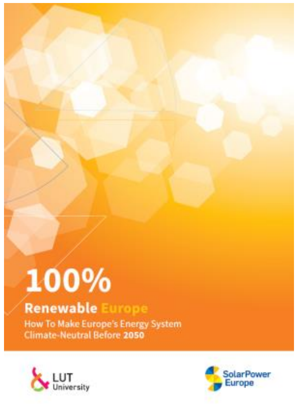
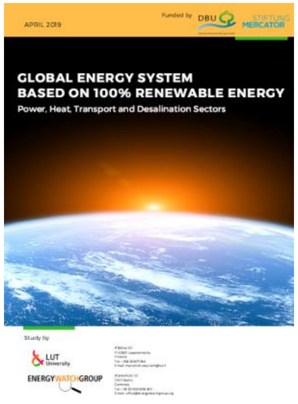
Overview: Sectoral perspective & key features



recent reports



[link to report]



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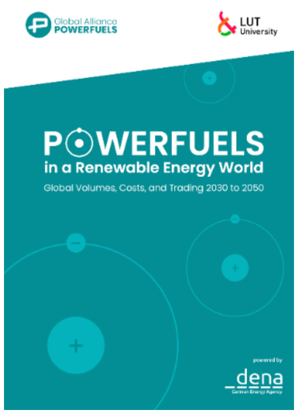

[link to report]

Key features:

- full hourly resolution, applied in global-local studies, comprising about 120 technologies
- used for several major reports, in about 50 scientific studies, published on all levels, including Nature
- strong consideration on all kinds of Power-to-X (mobility, heat, fuels, chemicals, desalinated water, CO_2)

source: Bogdanov et al., 2021. Full energy sector transition towards 100% renewable energy supply: integrating power, heat, transport and industry sectors including desalination, Applied Energy, 283, 116273

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Overview: Key objectives of modelling

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Definition of an optimally structured future energy system based on 100% RE

- optimal set of technologies, best adapted to the availability of the regions' resources
- optimal mix of capacities for all technologies and according to the sub-regions in Indonesia
- optimal operation modes for every element of the energy system
- least cost energy supply for the given constraints
- GHG emissions

Key input data

- historical weather data for: solar irradiation, wind speed and hydro precipitation
- available sustainable resources for biomass and geothermal energy
- synthesised power load data
- energy services demand for all sectors
- efficiency/ yield characteristics of RE plants
- efficiency of energy conversion processes
- capex, opex, lifetime for all technologies
- min and max capacity limits for all RE resources
- nodes and interconnections configuration

Key features

- bottom-up techno-economic model
- myoptic (5-yrs) & perfect foresight (8760 h)
- linear optimisation model
- hourly resolution
- multi-node approach
- multi-sector design
- multi-scenario variation/sensitivity
- technology-rich
- flexibility and expandability
- enables energy transition modeling
- transition scenarios in 5-year steps

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Overview: Target function & energy balance

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The two central equations are the target function and the energy balance

- **Target function: minimum annualised cost of the entire energy system**

$$\min\left(\sum_{r=1}^{reg}\sum_{t=1}^{tech}(CAPEX_t \cdot crf_t + OPEXfix_t) \cdot instCap_{t,r} + OPEXvar_t \cdot E_{gen,t,r} + rampCost_t \cdot totRamp_{t,r}\right)$$

- **For every hour of the year energy supply and demand must be balanced**

$$\forall \mathrm{h} \in [1,8760]\ \sum_t^{tech} E_{gen,t} + \sum_r^{reg} E_{imp,r} + \sum_t^{stor} E_{stor,disch} = E_{demand} + \sum_r^{reg} E_{exp,r} + \sum_t^{stor} E_{stor,ch} + E_{curt} + E_{\boldsymbol{grid}}$$

- **All energy sectors and regions are coupled, and have to fulfill these two central equations**

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Overview: Long-term models in comparison

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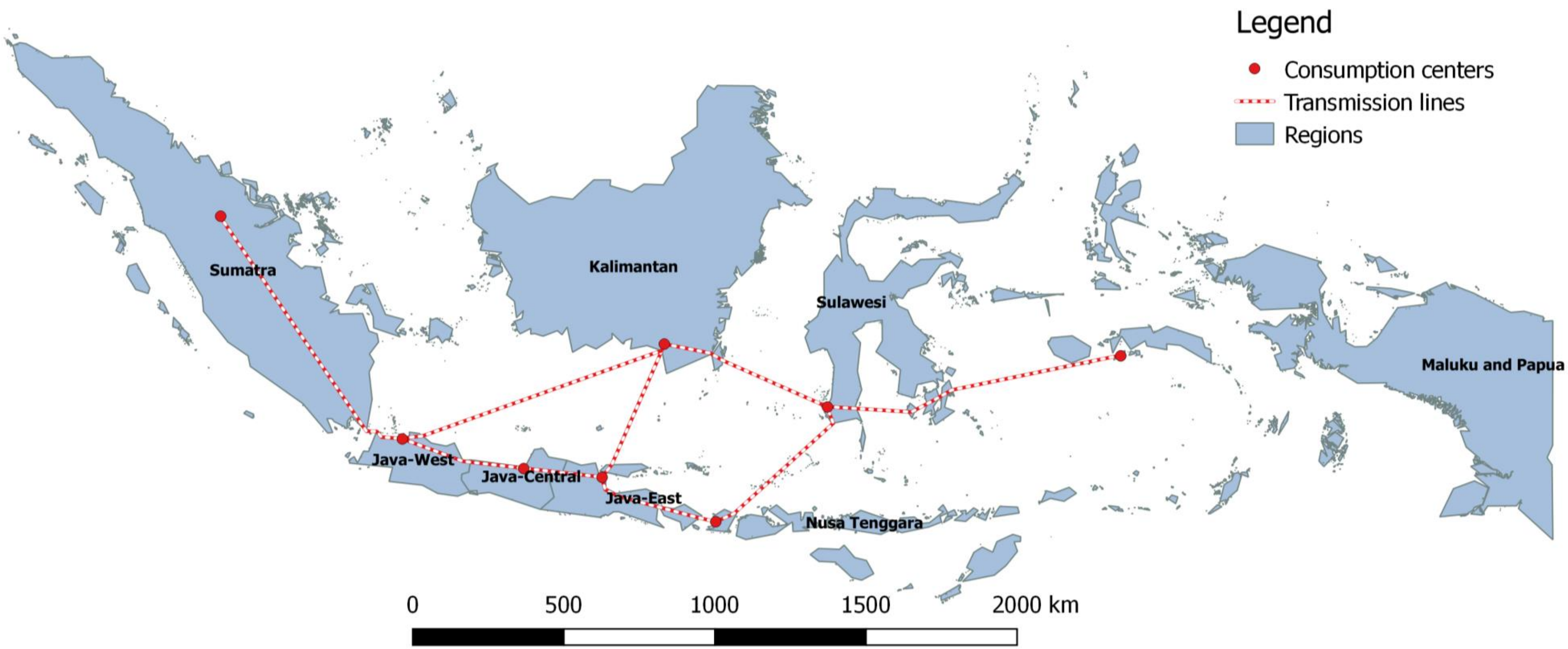
Bottom-up long-term models	*Foresight approach*	*Resolution*				*Transparency*
		In time	*In space*	*In techno-economic detail*	*In sector coupling*	
LEAP [120]	Perfect foresight	Low	Low	Low	High	Medium
MARKAL/TIMES [101,102]	Perfect foresight	Low	Medium	Low	High	Low
OSeMOSYS [104,105]	Perfect foresight	Low	Medium	Low	High	High
Temoa [107,108]	Perfect foresight	Low	Medium	Low	High	High
MESSAGE [110]	Perfect foresight	Low	Medium	Low	High	Low
Balmorel [112]	Perfect foresight	High	High	Medium	Low	High
eMix [121]	Perfect foresight	Medium	Medium	High	Low	Low
EPLANoptTP [119]	Perfect foresight	High	Low	Low	High	Medium
Mahbub et al. [118]	Myopic	High	Low	Low	High	Medium
LUT [114,117]	Myopic	High	High	Medium	High	Medium

- **We have been ranked as one of the more advanced energy models among all available energy models, which is capable of handling long-term energy transitions with high time resolution, high geospatial spread and importantly built-in sector coupling**
- **MESSAGE is the only Integrated Assessment Model (IAM). It is a leading IAM. AIM/CGE is comparable.**

source: Prina et al., 2020. Renew Sustain Energy Rev, 129, 109917

Assumptions

Country structure



- **Indonesia is structured into 8 regions: Sumatra, Java West, Java Central, Java East, Nusa Tenggara, Kalimantan, Sulawesi, Maluku and Papua**
- **Regions can be interconnected with power lines, as indicated in the diagram**
- **Data are allocated to regions for energy services demand and energy resource potential**

Scenarios

CPS, DPS and BPS

- The Indonesia energy system transition is modelled for 3 distinctive scenarios, with a cost optimised energy mix determined for each, Current Policy Scenario (CPS), Delayed Policy Scenario (DPS) and Best Policy Scenario (BPS)

CPS

- Minimum ambition pathway
- High system inertia
- No phase-out of fossil fuels
- Around 89% increase in GHG emissions by 2050*
- Delayed introduction of GHG emission cost
- Global Paris Agreement violated (1.5°C - 2°C), as GHG emissions do not stabilise but further increase until 2050

DPS

- Medium ambition pathway
- Medium system inertia
- Partial phase-out of fossil fuels by 2050
- About 75% reduction in GHG emissions by 2050*
- Delayed introduction of GHG emission cost
- Global Paris Agreement achieved (1.5°C - 2°C)

BPS

- High ambition pathway
- Low system inertia
- Phase-out of all fossil fuels
- 100% reduction in GHG emissions by 2050
- Early introduction of GHG emission cost
- Global Paris Agreement achieved with high ambition (1.5°C)

* reference year for GHG emission development is the year 2020

Assumptions
Fuel prices, WACC

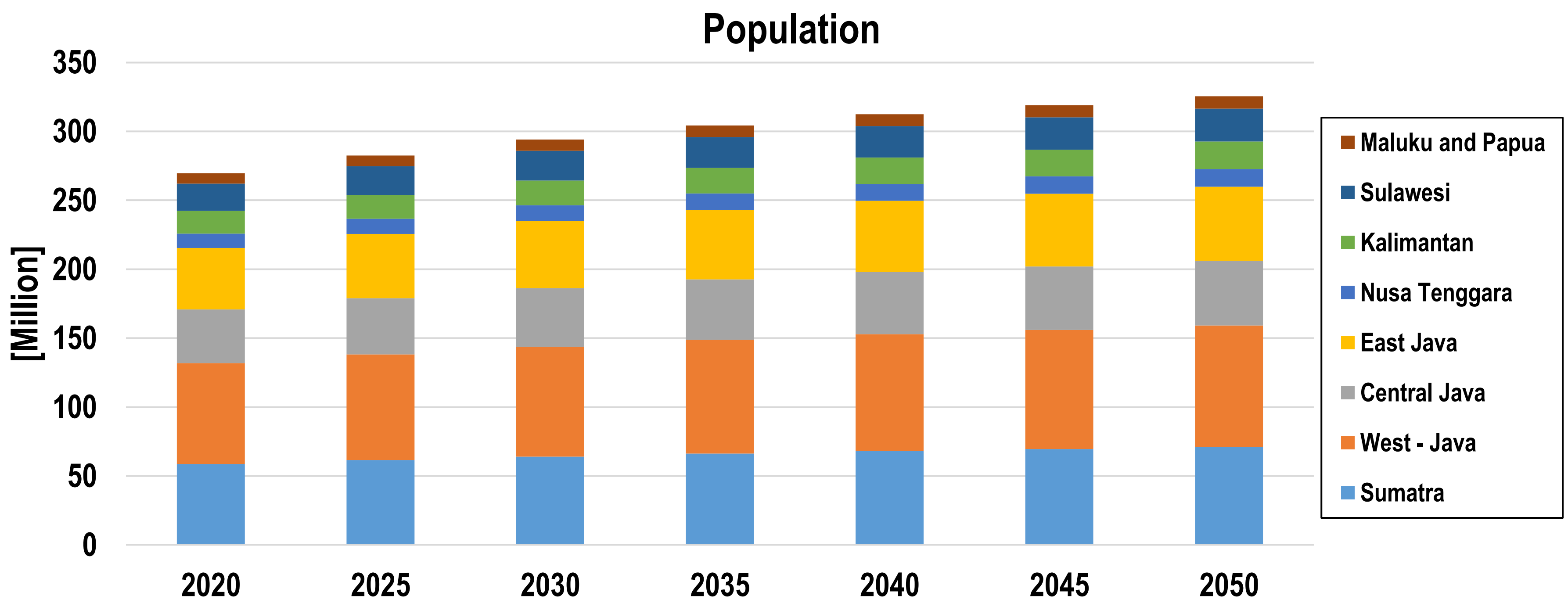
	Year	2020	2025	2030	2035	2040	2045	2050	
Fuel prices	Coal	10.3	11.3	12.4	13.8	15.0	15.0	15.0	€/MWh,th
	Light fuel Oil	39.9	45.1	50.3	49.8	49.3	49.3	49.3	€/MWh,th
	fossil gas	22.3	30.1	32.7	36.1	40.2	40.2	40.2	€/MWh,th
GHG emissions*		9	32	45	57	68	80	91	€/ton
WACC		10.0%	9.5%	9.0%	8.5%	8.0%	7.5%	7.0%	

- coal, oil, fossil gas price for 2020 based on IESR/LUT data. Future projections based on growth rates according to Bloomberg and IEA

Exchange rate used uniformly
1€ = 1.1$

* depends on the scenario, for BPS it starts from 2020 and for DPS and CPS it starts from 2030

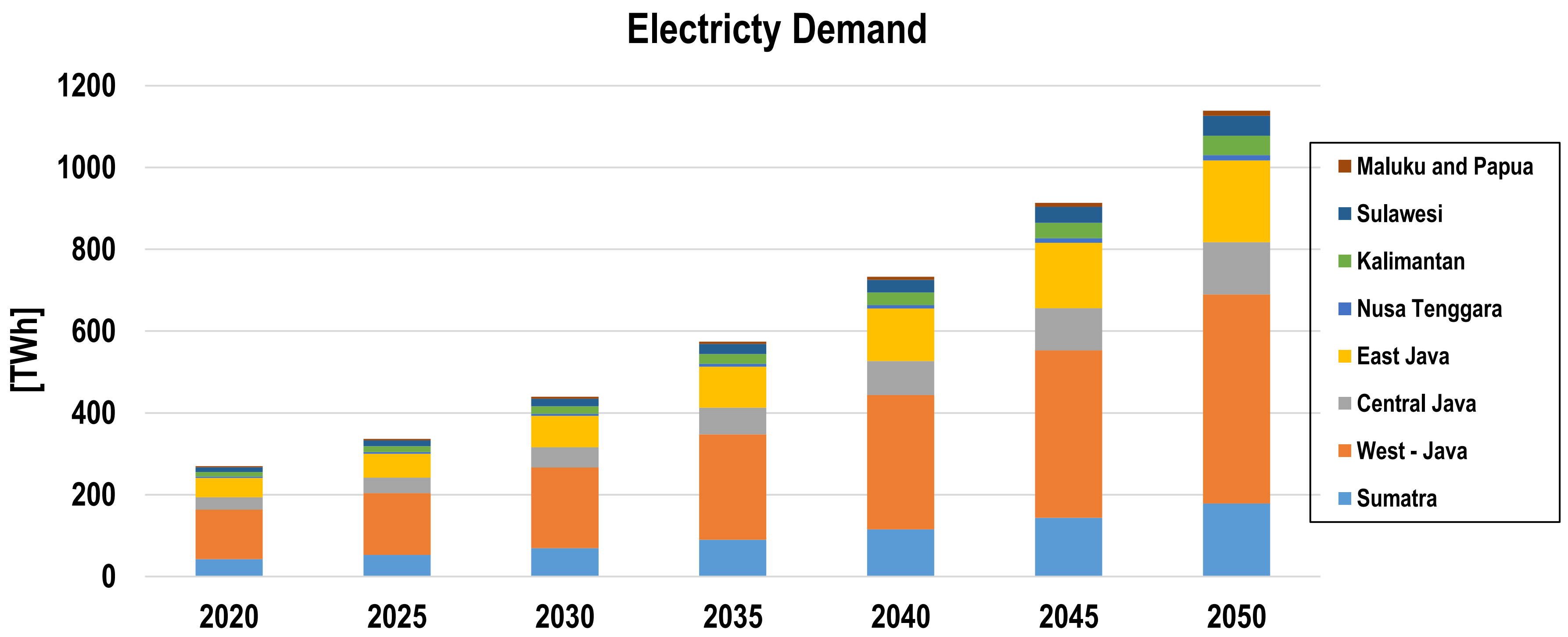
Assumption
Population



source: Institute of Essential Services Reform

Assumptions

Electricity Demand Power Sector



- growth rate – 4.4%
- strong increase in GDP and per capita electricity growth considered in total electricity demand during the transition

source: Institute of Essential Services Reform

Assumptions

Solar energy upper limits

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The upper limit of solar PV capacity for each of the regions is calculated based on area availability*, PV module efficiency, and respective specific capacity.

Area limits

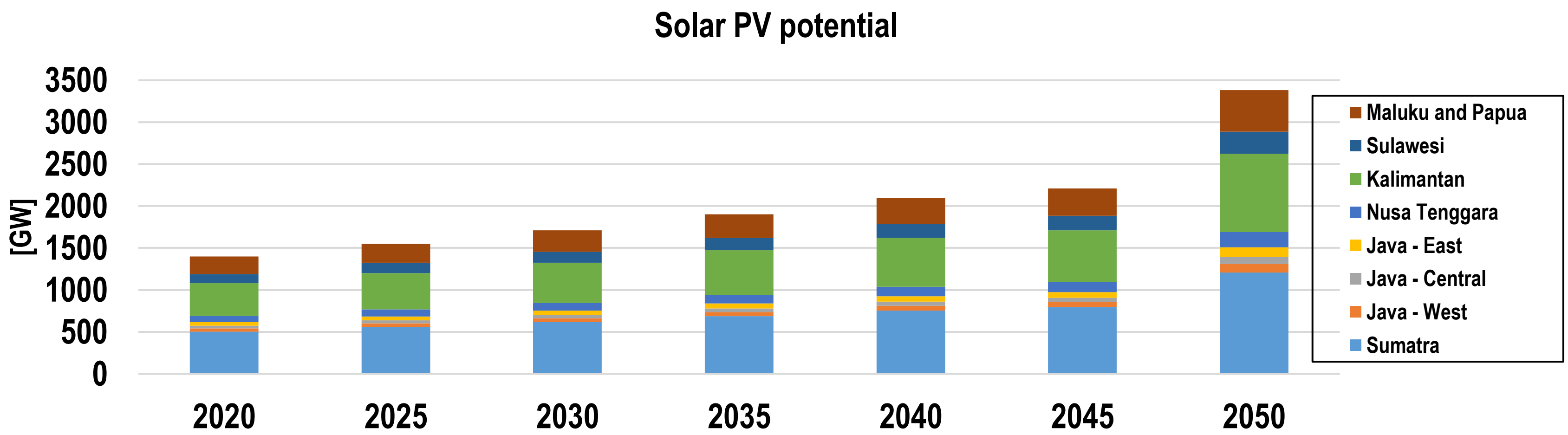
- a 50% cap on the area availability (after excluding forest and water) is added till 2045; and in 2050, 60% can be used for PV installations;
- Java: 3% of the land area is available till 2045, and 4% in 2050; all other regions: 6% of the land area is available

PV module efficiency and specific capacity

module efficiency increase based on Vartiainen et al. (2020), Progress in PV, 28, 439-453

		2020	2025	2030	2035	2040	2045	2050
PV module efficiency		18.0%	20.0%	22.0%	24.5%	27.0%	28.5%	30.0%
specific capacity	MW/km²	75.0	83.3	91.6	102.0	112.4	118.6	124.8

Solar PV upper limit for installed capacities (GW)



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more information ► Christian.Breyer@lut.fi

* land availability here is after excluding area occupied by forest and water

Summary

- LUT model is ranked among the most sophisticated long-term energy system models
- Validation of the LUT model in more than 50 scientific articles
- Multi-node, multi-sector, multi-scenario hourly bottom-up model
- Cost optimised pathways for defined scenarios
- LUT model is optimised for the core features of energy systems of the 21st century: renewable electricity and sector coupling, in addition to all classical fuels, plants and demands

Thank you !

Further information and all publications at:
https://www.scopus.com/authid/detail.uri?authorId=39761029000

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