LUT Energy System Transition Model
- brief overview -
The entire modeling process can be divided into three main stages:

1. **Data preparation**
   - (Technical and financial assumptions)

2. **Model setup and simulation**
   - Power prosumers and individual heat producers simulation
   - System simulation
     - Power sector
     - Heat sector
     - Transportation sector
     - Industrial sector:
       - Industrial fuels
       - Desalination
       - CO₂ removal

3. **Results collection and evaluation**
   - (Installed capacities, annual generation, cost of system and components, cost of electricity, CO₂ emissions, etc.)

The source for this information is Bogdanov et al., 2019. Radical transformation pathway towards sustainable electricity via evolutionary steps. Nature Communications, 10, 1077.
LUT Energy System Transition Model
Overview: Sectoral perspective & key features

**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, CO₂)

**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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**Energy mass flows:**
- Electricity
- Heat
- Synthetic fuels/chemicals
- CO₂

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**Recent reports**

[link to report]

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**Diagram overview:**
- PV rooftop
- PV fixed-tilted
- PV single-axis tracking
- Wind onshore
- Wind offshore
- Hydro run-of-river
- Hydro dam
- Geothermal

**Demand:**
- Electricity & Heat

**Suppliers:**
- Bio-Waste PP & CHP
- Nuclear PP
- Coal PP & CHP
- ICE PP & CHP
- GT PP & CHP

**Transformers:**
- HVAC
- HVDC

**Energy storage:**
- PHES Battery A-CAES
- DACCCS
- SWRO
- TES

**Synthetic and Bio:**
- Gas and liquid fuels/chemicals

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**Contact:**
Christian.Breyer@lut.fi
LUT Energy System Transition Model
Overview: Key objectives of modelling

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

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

\[
\min \left( \sum_{r=1}^{\text{reg}} \sum_{t=1}^{\text{tech}} (\text{CAPEX}_t \cdot crf_t + \text{OPEX}_{\text{fix}_t}) \cdot \text{instCap}_{t,r} + \text{OPEX}_{\text{var}_t} \cdot E_{\text{gen},t,r} + \text{rampCost}_t \cdot \text{totRamp}_{t,r} \right)
\]

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

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

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

<table>
<thead>
<tr>
<th>Bottom-up long-term models</th>
<th>Foresight approach</th>
<th>Resolution</th>
<th>Transparency</th>
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<tr>
<td></td>
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<td>In time</td>
<td>In space</td>
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<tr>
<td>LEAP [120]</td>
<td>Perfect foresight</td>
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<td>MARKAL/TIMES [101,102]</td>
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<tr>
<td>Mahbub et al. [118]</td>
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<tr>
<td>LUT [114,117]</td>
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</table>
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
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**

<table>
<thead>
<tr>
<th>Fuel prices</th>
<th>Year</th>
<th>2020</th>
<th>2025</th>
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<th>2045</th>
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<td>10.0%</td>
<td>9.5%</td>
<td>9.0%</td>
<td>8.5%</td>
<td>8.0%</td>
<td>7.5%</td>
<td>7.0%</td>
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</tbody>
</table>

- 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

LUT Energy System Transition Model
more information ➤ Christian.Breyer@lut.fi
Assumptions
Solar energy upper limits

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

<table>
<thead>
<tr>
<th></th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
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</thead>
<tbody>
<tr>
<td>PV module efficiency</td>
<td>18.0%</td>
<td>20.0%</td>
<td>22.0%</td>
<td>24.5%</td>
<td>27.0%</td>
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<td>30.0%</td>
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<td>specific capacity</td>
<td>MW/km²</td>
<td>75.0</td>
<td>83.3</td>
<td>91.6</td>
<td>102.0</td>
<td>112.4</td>
<td>118.6</td>
</tr>
</tbody>
</table>

Solar PV upper limit for installed capacities (GW)

* 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