Modelling a Low-Carbon Power System for Indonesia, Malaysia and Singapore

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Abstract

The power demand of Indonesia, Malaysia and Singapore is predicted to increase dramatically in the next decades. Due to abundant reserves of coal and gas in the region, the extensive use of fossil fuels is most likely to cover the future power demand of these countries, leading to an enormous growth of CO_2 emissions. In this paper, we analyse the impact of restrictions on CO_2 emissions on the power supply of Indonesia, Malaysia and Singapore in the year 2035. Based on a reference scenario without restrictions on CO_2 emissions, cost-minimal options for a more sustainable power supply with lower CO_2 emissions are developed. In our study, we use a linear programming model that optimises power systems in hourly time steps by minimising their total generation and transmission cost.

Results show that even without CO_2 restrictions, the generation potential of geothermal, hydro and biomass is almost completely used. Without restrictions, CO_2 emissions related to power generation increase from 217 mio. tons in 2012 to 944 mio. tons in 2035 as the power generation is strongly based on coal. The construction of gas-fired power plants and solar PV reduces CO_2 emissions most cost-efficiently. Further cost-minimised reduction of CO_2 emissions requires the installation of wind turbines. The construction of international transmission lines has the potential to save total cost of generation and transmission in the order of some percent.

I. Introduction

The annual GDP growth rate in the Association of Southeast Asian Nations (ASEAN) is among the highest in the world (predicted to be 4.6 % until 2035 [1]). Linked to the enormous economic growth in the region, the demand for electricity will increase by an annual growth rate of 6.5 % until 2030 [2]. That means an increase in the demand for electricity by a factor of 2.7 in the next 16 years.

Based on these figures, it is obvious that covering the future demand for electricity is a major challenge for the ASEAN countries. Currently, the power demand in ASEAN is mainly satisfied by fossil fuels. Electricity generated by coal amounts to 31 %, by natural gas to 44 % and by diesel and oil to 10 % of the total power generation in the region [1].

With shares of 80.6 % of coal, 73.3 % of natural gas and 51.9 % of oil, Indonesia and Malaysia hold the most abundant proven reserves of fossil fuels in ASEAN [1]. That makes them less dependent on imports of fossil fuels compared to other countries in the region. Thus, the extensive use of fossil fuels seems to be an appropriate option to cover the future demand for electricity of Indonesia and Malaysia. Singapore hardly holds any reserves of fossil fuels and its potential of renewable sources of energy is very limited. Hence, its future power supply is most likely to be based on imported fossil fuels.

However, the heavy use of fossil fuels to cover the growing demand for electricity will increase the emissions of CO_2 in ASEAN significantly.

In this paper, the power system of Indonesia, Malaysia and Singapore in the year 2035 is modelled. Based on a solely cost-optimised BAU-scenario, cost-effective options for a future power supply with reduced CO_2 emissions are developed. In our optimisation, we use the mixed-integer linear programming model URBS [3] which yields a cost-optimal solution. Thereby, power generation as well as transmission is considered.

Chang and Li [4] as well as Kutani [5] analysed the power systems of many countries in South East Asia in order to minimise their total generation and transmission costs. They found that an enhanced international power trade leads to lower total power

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generation costs in ASEAN. In their analysis, they also used linear programming models to optimise the power supply on a yearly base.

In our research, we go beyond that approach by introducing an hourly time resolution. This allows us to study the impacts of hourly load fluctuations as well as the change of intermittent power generation from wind and solar PV.

We will first describe the model URBS and its input data in the next section. After presenting the scenarios and results of the study in Section III, Section IV provides the main conclusions of the paper.

II. Optimisation Model and Data

A. Model description

In our scenario optimisations we use the linear programming model URBS. It optimises power systems in various regions simultaneously with respect to their total cost. The model includes the construction of new power generation and transmission capacity as well as an hourly match of power demand and generation. Fig. 1 shows the basic structure of the model and its main inputs and outputs.

URBS finds a system configuration to meet a predetermined demand for electricity with minimal total annual costs c by using hourly time steps t.

The total cost comprise the annuity of investment costs $c^{inv}(g,r)$ and the annual fixed costs (e.g., due to maintenance) for generation $c^{fix}(g,r)$ as well as variable costs $c^{var}(g,r,t)$ of each power generation technology g (e.g., gas CCGT, solar PV) in every modelled region r. Moreover, investment and fixed costs of transmission are considered, depending on the length of the respective transmission line tl.

The model optimises the power system of all regions by minimising its total cost of generation and transmission:

$$\begin{aligned} min\ c = \Big\{ &\sum_{g,r} \left\{ c^{inv}(g,r) + c^{fix}(g,r) \right\} \\ &+ \sum_{g,r,t} \left\{ c^{var}(g,r,t) \right\} \\ &+ \sum_{tl} \left\{ c^{inv}(tl) + c^{fix}(tl) \right\} \Big\} \end{aligned} \quad (1)$$

Herein, the annuity of the investment costs $c^{inv}(g,r)$ is calculated from the total investment costs $C^{inv}(g,r)$ of the respective power generation technology. The annuity of the particular generation technology depends on the depreciation rate i and the respective depreciation period n:

$$c^{inv}(g,r) = C^{inv}(g,r) \cdot \frac{(1+i)^n \cdot i}{(1+i)^n - 1} \quad (2)$$

$C^{inv}(g,r)$ is assumed to correlate linearly with the generation or transmission capacity that is constructed.

The variable generation costs $c^{var}(g,r,t)$ are calculated by the power generation $p(g,r,t)$, the efficiency $\eta(g)$ and the variable operating costs $c^{op}(g)$ of the respective power generation technology as well as fuel costs $c^{fuel}(g,r)$:

$$c^{var}(g,r,t) = p(g,r,t) \cdot \left\{ \frac{c^{fuel}(g,r)}{\eta(g)} + c^{op}(g) \right\} \quad (3)$$

The fixed costs $c^{fix}(g,r)$ are linearly correlated with the installed power generation capacity $k(g,r)$.

The model solves Eq. (1) under various constraints. The main restriction is that the demand for electricity $\delta(r,t)$ of a specific region r has to be satisfied in each time step by regional generation $p(g,r,t)$ and net imports $imp(r,t)$ into the particular region, considering distribution losses $dl(r,t)$:

$$\sum_{g} p(g,r,t) + imp(r,t) - dl(r,t) \geq \delta(r,t) \quad (4)$$

Furthermore, the power generation in each time step $p(g,r,t)$ has to be lower than the installed capacity $k(g,r)$ multiplied by an availability factor $af(g,r,t)$:

$$p(g,r,t) \leq k(g,r) \cdot af(g,r,t) \quad (5)$$

Power generation is modelled as a transformation process of input to output commodities. Input commodities are gas, coal, biomass, hydro, and geothermal as well as the intermittent resources wind and solar. Electricity and CO_2 emissions are modelled as output commodities.

The amount of CO_2 emissions caused by fossil fuels can be restricted in the model. The upper bound of CO_2 emissions λ is formulated as follows, adding up the CO_2 emissions of each power generation technology in every region and time step.

$$\sum_{g,r,t} e(g,r,t) \leq \lambda \quad (6)$$

In the model, we distinguish between power plants using intermittent sources of energy and modulating power plants.

Power plants using intermittent sources of energy: As the capacity factors of these power plants depend on exogenous data (e.g., weather data), the model can not decide how much electricity their installed generation capacity produces in each time step. For this reason, the capacity factors of power plants using intermittent sources of energy is considered by an hourly time series determined before the optimisation process. Generation technologies using wind and solar PV are modelled as these types of power plants.

Modulating power plants Modulating power plants use stock commodities to generate electricity. As they can operate on part load and their power generation is not determined exogenously, the model decides in each time step how much electricity they produce. All generation technologies fired with fossil fuels are modelled as modulating power plants as well as biomass and geothermal power plants. Furthermore, hydro power plants are also modelled as modulating power plants due to the fact that most of the hydro power capacity in the modelled region is represented by storage power plants.

Transmission Regarding the transmission system, the model is able to consider the construction of new power transmission lines between the regions.

Transmission losses are defined by the length of the respective transmission line. Losses of the distribution grid are considered for each region, whereas costs for the distribution grid are not included in the model.

B. *Input data*

Spatial resolution In this paper, we divide Indonesia, Malaysia and Singapore into 7 regions in our modelling framework as depicted in Fig. 2. The modelled regions are: Sumatra, Java, Kalimantan, Indonesia East, Malaysia Peninsula, Malaysia Borneo and Singapore.

Transmission The routes of the transmission lines between the regions are shown in Fig. 2. The connection between Singapore and Peninsular Malaysia is the only existing transmission line in 2012 with a maximum capacity of 400 MW. The investment costs for transmission lines are calculated by their respective overland and submarine length according to Table 7. The annual fixed costs of the transmission lines amount to 1 % of their investment costs. Power losses of transmission lines are assigned to 5 % per 1000 km of distance. The distribution losses amount to 6.95 % in Indonesia [7], 6.58 % in Malaysia [8] and 4.88 % in Singapore [9].

Demand for electricity The demand for electricity and its predicted annual growth rate are listed in Table 1 for each country. The net import into a spe-

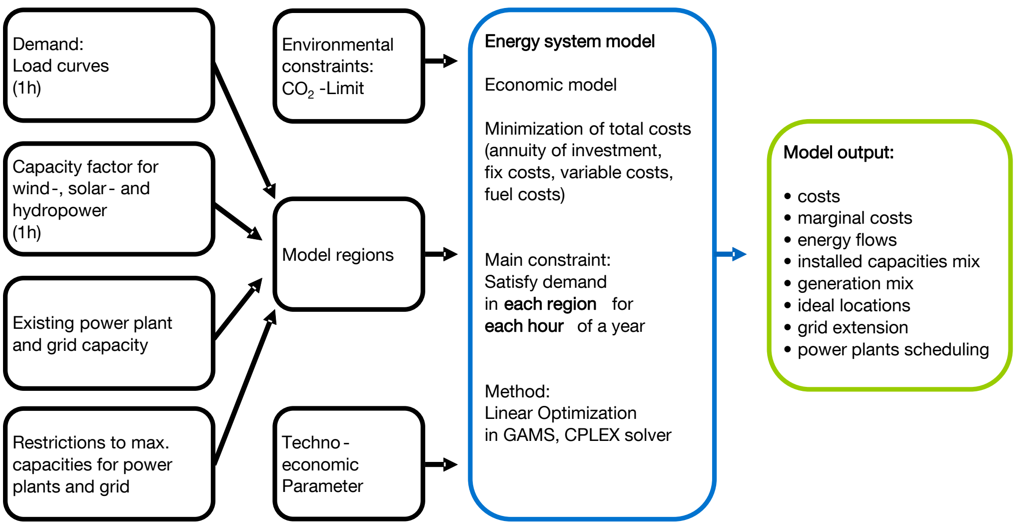

Fig. 1: *Overview of the model URBS. [6]*

cific country is set to a maximum of 20 % of its annual power demand. The hourly load curves of the demand for electricity vary between Indonesia [7], Malaysia [10] and Singapore [11] but are assumed to be equal in the regions within a particular country.

Table 1: *Electricity demand in 2012 [7, 9, 12] and its annual growth rate forecasts to 2035 [2].*

Region	Electricity demand [TWh]	Growth rate
Indonesia	175.4	7.7 %
Malaysia	111.7	4.4 %
Singapore	42.6	2.9 %

Fuels Table 2 lists the fuel prices in 2012 in the modelled regions. The price forecasts of fossil fuels in South East Asia in 2035 are taken from [1] and shown in Table 3. They are assumed to be the same for all modelled regions.

Table 3: *Fossil fuel prices in 2035 in US$/MWh [1].*

Fuel	Fuel price in 2035 in US$/MWh
Coal	17.2
Gas	51.2
Oil	75.3

Power generation capacity The generation capacity of the initially installed power plants in 2012 is taken from [7] and [16] and is shown in Table 9. The maximum power generation from geothermal, biomass and hydro in Indonesia and Malaysia is set to 50 % of their respective technical potentials (see Table 8). The capacity factor of hydroelectric power plants is assigned to 0.35.

Economic and political framework The investment, fixed and variable costs of the different power plant types and transmission lines are listed in Table 7. Furthermore, Table 7 shows the efficiency, the load factor and the depreciation period of the particular power plant types and transmission lines. The depreciation rate is set to 7 %. All quoted costs and prices refer to 2012US$.

It is assumed that Singapore will not construct any coal-fired power generation capacity due to their negative impacts on local air quality. Moreover, we restrict the expansion of new power generating capacities on the technologies illustrated in Table 7 and exclude the construction of nuclear power plants.

Capacity factors of wind and solar PV The hourly capacity factors of wind and solar PV are calculated from weather data in a separated step before the optimisation process. These are as follows:

- Wind: Hourly measured mean wind speeds are transformed to electric output power by applying a typical characteristic curve of a wind turbine according to [17].
- Solar PV: Photovoltaic power output is derived linearly from hourly global horizontal irradiation according to [17].

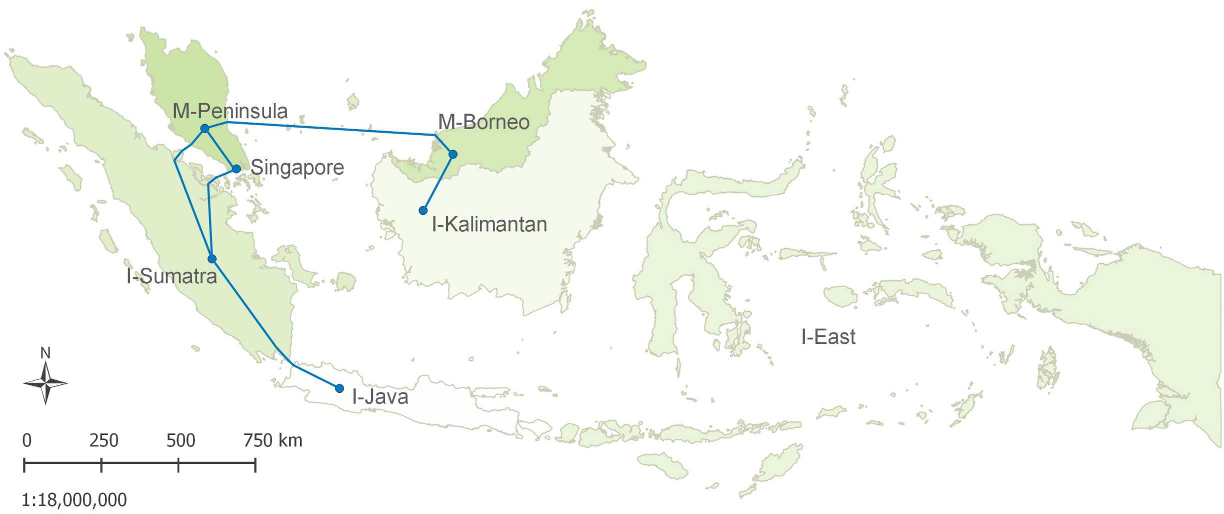

Fig. 2: *Regions used in the modelling framework.*

For the hourly weather situation we use a reference year for each country. Therefore, we have selected a year between 2000 and 2012 where the full load hours of wind and solar PV were closest to their annual average values. The used weather data is taken from NASA [18] and was processed in [17] to calculate the respective availability factors. In processing the data, the measurement points of [18] were spatially aggregated to the regions we use. In this aggregation process, the sites were weighted by the full load hours of the respective energy source (wind, solar).

Emissions of CO_2 To determine CO_2 emissions, the specific CO_2 emissions of the considered fossil fuels are listed in Table 4.

Table 4: *Specific CO_2 emissions of fossil fuels [19].*

Fossil fuel	Specific emissions in kg CO_2 /MWh_{th}
Coal	346
Diesel	267
Gas	202
Oil	264

III. Scenarios and Results

A. Model Validation

Before analysing future scenarios, the model is validated by comparing the modelled and optimised electricity generation of Indonesia, Malaysia and Singapore to their actual values in 2012. The comparison is depicted in Fig. 3 and shows high accordance for all modelled countries.

In the following, the power system of Indonesia, Malaysia and Singapore in 2035 is modelled and optimised in various scenarios. For all the scenarios, the power generation capacity of 2012 is assumed to be installed. In addition to these capacities, new power plants can be constructed to cover the increasing demand for electricity. The scenario without construction of new transmission lines and without restrictions on CO_2 emissions serves as a reference. Compared to this scenario, CO_2 emissions are reduced by 25 , 50 and 75 %. Based on these scenarios, the impact of the construction of new transmission capacity on total generation and transmission cost as well as on CO_2 abatement costs is analysed.

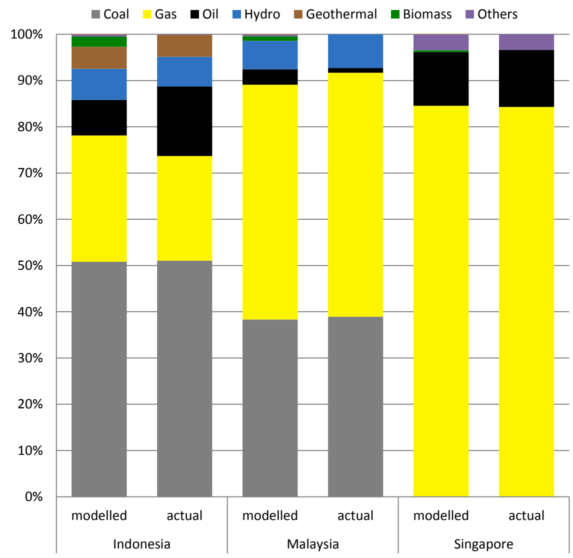

Fig. 3: *Comparison of actual and modelled power mix of Indonesia, Malaysia and Singapore in 2012.*

B. Power system optimisation in 2035 without construction of new transmission lines

First, there is no restriction on CO_2 emissions and the construction of new transmission lines between the regions is not allowed. The cost-optimised power generation mix for Indonesia, Malaysia and Singapore in this reference scenario is illustrated in Fig. 4.

Malaysia, and especially Indonesia cover their strongly increasing demand for electricity mainly by coal in this scenario. This raises the share of coal in the power mix of Indonesia, Malaysia and Singapore from about 40 % in 2012 to approx. 70 % in 2035, increasing the power generation by

Table 2: *Fuel prices in 2012 in* US$/MWh *[1, 7, 8, 13, 14, 15].*

Fuel	I-Sumatra	I-Kalimantan	I-Java	I-East	Malaysia	Singapore
Biomass	3.41	3.41	3.41	3.41	3.41	3.41
Coal	12.72	8.48	12.78	15.27	16.72	16.72
Diesel	47.99	47.99	47.99	47.99	60.24	128.65
Gas	15.68	8.74	17.16	8.74	15.59	61.38
Oil	89.48	90.05	92.84	91.26	64.18	64.18

coal from 146.3 TWh in 2012 to 1026.0 TWh in 2035. Even though the power generation by gas increases in Singapore, the total amount of electricity generated by gas in all countries decreases by 35 % from 142.2 TWh in 2012 to 92.0 TWh in 2035.

It is remarkable that even without CO_2 limitations, more than 22 % of the elecricity in 2035 is generated by renewable sources of energy, mainly hydro (9.8 %), geothermal (7.8 %) and biomass (4.7 %). The full potential of geothermal (14 GW) and most of the power generation potential of hydro (46.4 GW) and biomass (9.4 GW) (see Table 8) are exploited. In contrast, generation capacities using solar or wind as energy source are not constructed.

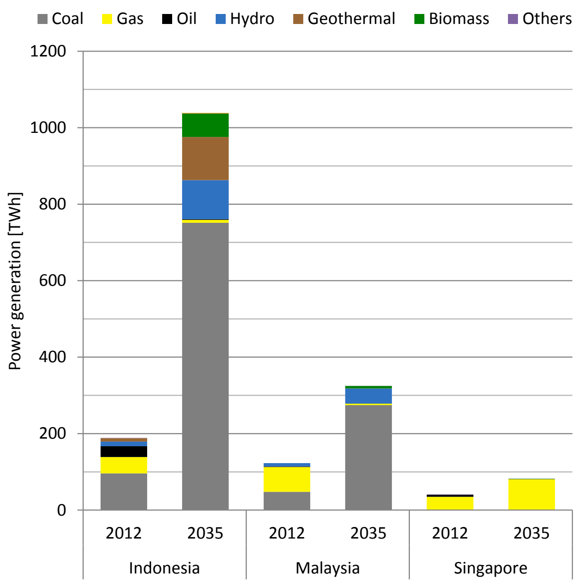

Fig. 4: *Modelled power generation by fuel type in 2012 and in 2035 without restrictions on CO_2 emissions and without construction of transmission lines.*

Even though the electricity generated by geothermal, biomass and hydro increases substantially, the specific CO_2 emissions per generated kWh rises from 614 g/kWh in 2012 to 653 g/kWh in 2035 due to the strong use of coal to produce electricity.

However, as the demand for electricity grows heavily, there is a strong increase in absolute CO_2 emissions from 217 million tons in 2012 to 944 million tons in 2035. The question arises, how this situation can be changed into a less-carbon power supply in the future. In order to do that, CO_2 emissions are restricted by 25 %, 50 % and 75 % compared to the reference case. For these three scenarios, the total power mix of Indonesia, Malaysia and Singapore in 2035 is shown in Fig. 5.

As natural gas has lower specific CO_2 emissions than coal (see Table 4) and as the mostly used combined cycle gas turbines (CCGT) are more efficient than coal-fired power plants (see Table 7), reducing CO_2 emissions by 25 % (50 %) increases the share of electricity from gas fired power plants from 6.4 % to 17.1 % (41.7 %). Furthermore, 11.3 % (14.9 %) of the electricity is produced by solar PV. As most of their power generation potential is already exploited without any restrictions on CO_2 emissions, the shares of geothermal, hydro and biomass remain on the same level compared to the reference scenario.

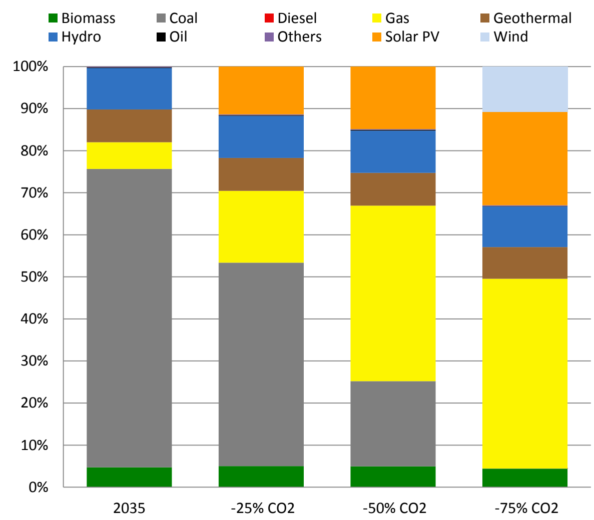

Fig. 5: *Total power mix of Indonesia, Malaysia and Singapore in 2035 with different restrictions on CO_2 emissions and without construction of new transmission lines.*

A reduction of CO_2 emissions by 75 % compared to the reference scenario leads to the disappearance of coal from the power mix of Indonesia, Malaysia and Singapore in 2035. The share of gas in the power mix amounts to 45.1 %. While the amount of electricity generated by biomass, hydro and geothermal is the same like in the reference scenario, solar PV (22.2 %) and wind (10.8 %) are contributing substantially to cover the demand for electricity. However, even though the total share of renewable energy sources in the power mix amounts to 54.6 %, the total CO_2 emissions are by 8.8 % higher than in 2012.

Reducing CO_2 emissions in the different scenarios leads to higher total cost of power generation. On the one hand, more expensive generation technologies and fuels are used and on the other hand, backup capacity is needed due to the use of intermittent sources of energy. Therefore, the installed power generation capacity increases with stronger CO_2 restrictions. The power generation capacity that is constructed in addition to the initially installed capacity to cover the future power demand is shown in Fig. 6.

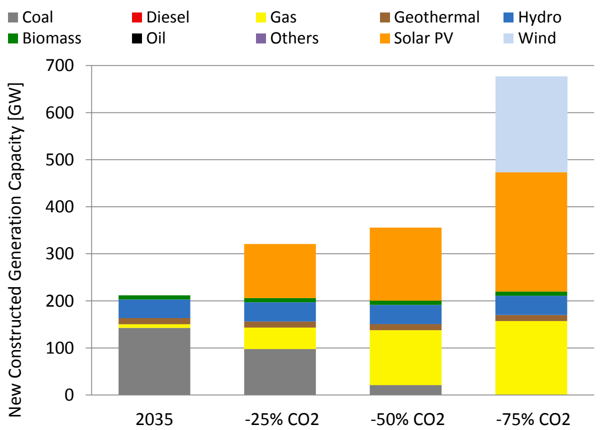

Fig. 6: *Generation capacity constructed in addition to the initially installed capacity for different restrictions on CO_2 emissions*

For the scenarios discussed so far, the cost per generated kWh of electricity, often referred to as levelised cost of electricity (LCOE), is shown in Fig. 7. Reducing CO_2 emissions by 25 % (50 %) causes a relatively moderate rise of the LCOE from 6.3 US$ct/kWh to 7.1 US$ct/kWh (8.1 US$ct/kWh). A reduction of CO_2 emissions by 75 % increases the LCOE more severely to 10.6 US$ct/kWh.

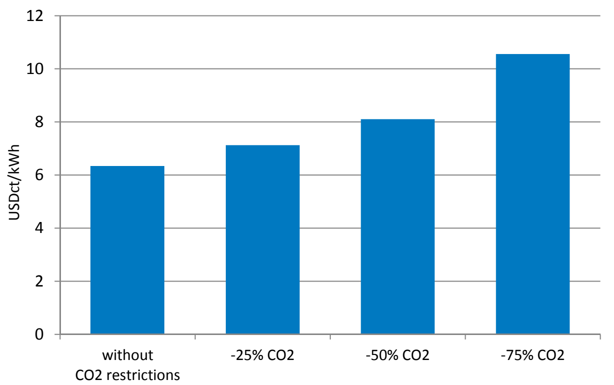

Fig. 7: *Levelised cost of electricity (LCOE) with different restrictions on CO_2 emissions and without construction of new transmission lines.*

There is not only an increase in LCOE with stronger restrictions on CO_2 emissions, the additional generation costs related to the abated CO_2 emissions also increase. Table 5 lists the CO_2 abatement costs for the different scenarios. The abatement costs in Table 5 are calculated by dividing the difference of total cost by the absolute difference of CO_2 emissions compared to the reference scenario.

Reducing CO_2 emissions by 75 % leads to significantly higher CO_2 abatement costs (84.36 US$/t$CO_2$) compared to lower restrictions on CO_2 emissions (48.19 US$/t$CO_2$ for a reduction of CO_2 emissions by 25 % and 53.30 US$/t$CO_2$ by 50 %, respectively).

C. Power system optimisation in 2035 with construction of new transmission lines

In the following, we analyse the impact of the construction of new transmission lines as shown in Fig. 2 on the total cost of generation and transmission and on the CO_2 abatement costs.

Table 6 compares the total cost of generation and transmission *c* with and without construction of new transmission lines. In all scenarios, a reduction of total system costs by transmission lines is observed. Even though the relative reduction of the total cost by an inter-regional power grid is rather low (maximum 4.15 % in the scenario with a reduction of CO_2 emissions by 75 %), the absolute saving potential is remarkable: 0.61 bnUS$ in the scenario with a reduction of CO_2 emissions by 25 %, 0.55 bnUS$ by 50 % and 6.55 bnUS$ by 75 %. As shown in Table 5, the construction of new transmission lines decreases the CO_2 abatement costs moderately.

Table 5: *CO_2 abatement costs in US$/ t$CO_2$.*

Scenario	Construction of transmission lines	
	Without	With
–25 % CO_2	48.19	45.60
–50 % CO_2	53.30	53.07
–75 % CO_2	84.36	74.89

Table 6: *Reduction of total cost of generation and transmission by construction of new transmission lines.*

Scenario	Reduction of total cost by construction of new transmission lines	
	in bn US$	in %
–25 % CO_2	0.61	0.59
–50 % CO_2	0.55	0.49
–75 % CO_2	6.55	4.15

IV. Conclusion

In our analysis, we showed the challenge for Indonesia, Malaysia and Singapore to cover their demand for electricity in 2035. If their power system is developed at minimum total cost, the power generation potentials of geothermal, hydro and biomass are almost completely exploited. Simultaneously, the heavy use of coal-fired power plants increases the CO_2 emissions related to power generation from 217 million tons in 2012 to 944 million tons in 2035.

To reduce CO_2 emissions, the construction of gas-fired power plants and solar PV instead of coal power plants is the most cost-efficient solution. Further cost-minimised reduction of CO_2 emissions is achieved by increasing the use of solar PV and wind turbines to produce electricity. In order to keep CO_2 emissions at around the current level, 203 GW of wind and 253 GW of solar PV capacity have to be installed.

Not only the levelised cost of electricity (LCOE), but also the abatement costs of CO_2 emissions are increasing with stronger restrictions on CO_2 emissions.

The construction of inter-regional power transmission lines decreases the total costs of generation and transmission moderately.

Power generation in off-grid applications is not considered in our model so far. Especially in Indonesia where 66 million people (27 % of the population [1]) do not have access to electricity, off-grid applications could play an important role to increase the electrification rate. Herein, further research is needed, especially on the integration of renewable energy sources due to their possible cost saving potential in off-grid systems.

Symbols

Sets	
t	Time steps
g	Generation technologies
r	Modelled regions
tl	Transmission lines

Variables	
c	Annual total cost
$p(g,r,t)$	Power generation
$imp(r,t)$	Electricity net import
$k(g,r)$	Power generation capacity
$e(g,r,t)$	CO_2 emissions

Parameters	
$c^{inv}(g,r)$, $c^{inv}(tl)$	Annuity of investment costs
$C^{inv}(g,r)$	Total investment costs
$c^{fix}(g,r)$, $c^{fix}(tl)$	Annuity of fixed costs
$c^{var}(g,r,t)$	Annuity of variable costs
$c^{fuel}(r)$	Fuel costs
$c^{op}(g)$	Variable operation costs
$dl(r,t)$	Distribution losses
$af(g,r,t)$	Availability factor
$\delta(r,t)$	Electricity demand
i	Depreciation rate
$n(g)$	Depreciation period
$\eta(g)$	Efficiency
λ	Upper bound of CO_2 emissions

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Appendix

Table 7: *Generation technologies considered in this study: Investment costs in* US$/MW *from [24], fixed cost in* US$/MW/yr *from [22, 25], variable costs* US$/MWh *from [22], efficiency from [24, 26], availability factor from [21, 25], and depreciation periods from [25] and own assumptions.*

Technology	Fuel	Investment costs c_{inv} [US$/MW]	Fixed costs c_{fix} [US$/MW/yr]	Variable costs c_{var} [US$/MWh/yr]	Efficiency η	Availability factor af	Depreciation period [yr]
Steam	Biomass	2,030,000	105,630	5.26	0.35	0.85	20
	Coal	1,200,000	31,180	4.47	0.39	0.85	45
	Gas	1,200,000	31,180	4.47	0.39	0.85	20
	Oil	1,200,000	31,180	4.47	0.39	0.85	20
Gas turbine	Gas	400,000	7,040	10.37	0.38	0.95	20
	Oil	400,000	7,040	10.37	0.38	0.95	20
	Diesel	400,000	7,040	10.37	0.38	0.95	20
Combined cycle	Gas	700,000	15,370	3.27	0.58	0.87	30
	Oil	700,000	15,370	3.27	0.58	0.87	30
Engine	Diesel	500,000	15,000	0.00	0.35	0.95	20
	Gas	500,000	15,000	0.00	0.30	0.95	20
	Oil	500,000	15,000	0.00	0.30	0.95	20
Hydroelectric	Hydro	1,900,000	14,130	0.00	1.00	1.00	50
Geothermal	Heat	1,890,000	100,000	0.00	1.00	0.92	20
Solar PV	Insolation	1,170,000	24,690	0.00	1.00	1.00	20
Wind turbine	Wind	1,420,000	39,550	0.00	1.00	1.00	20

Transport

Type	Specific investment costs [US$/MW/km]	Annual fixed costs [US$/MW/km]	Losses [%/1000 km]	Depreciation period [yr]
Overhead line	500	5	5	40
Submarine cable	3,000	30	5	40

Table 8: *Considered power generating potential of biomass, geothermal and hydro in 2035 in* MW. *Biomass potential of Indonesia from [38], geothermal potential of Indonesia from [34], hydroelectric potential of Indonesia from [37], potentials of Malaysia from [20].*

	Indonesia				Malaysia		
	Java	Kalimantan	East	Sumatra	Borneo	Peninsular	Singapore
Biomass	1,657	7,165	4,778	6,415	526	350	23
Geothermal	4,915	26	2009	7,051	0	0	0
Hydro	2,361	10,800	16,800	7,800	11,000	1,983	0

Table 9: *Installed generation capacity in 2012 in* MW *[7, 16].*

Technology		Indonesia Java	Indonesia Kalimantan	Indonesia East	Indonesia Sumatra	Malaysia Borneo	Malaysia Peninsular	Singapore
Steam	Biomass	4.50	13.98	19.00	572.82	136.33	26.0	23.09
	Coal	12,077.00	403.00	401.50	882.00	480.00	7,449.00	0.00
	Gas	20.00	16.00	0.00	25.00	20.00	6.00	1,250.00
	Oil	2,486.00	14.46	53.20	260.00	0.00	1,371.00	3,450.00
Gas turbine	Gas	1,699.00	90.40	20.00	480.00	543.60	3,356.00	440.00
	Oil	660.00	40.00	127.20	381.70	203.40	338.70	217.00
	Diesel	449.00	14.00	0.00	0.00	99.00	0.00	411.00
Combined cycle	Gas	4,766.00	60.00	150.00	364.00	605.00	9,533.40	4,382.00
	Oil	1,496.00	0.00	0.00	0.00	0.00	948.32	848.00
Engine	Diesel	513.53	361.27	664.57	513.53	79.24	17.72	24.00
	Gas	25.40	25.40	0.00	156.45	0.00	0.00	1.00
	Oil	165.70	181.40	328.60	711.50	567.00	232.50	56.90
Hydroelectric	Hydro	2,488.00	31.84	514.40	1,097.46	490.30	1,982.81	0.00
Geothermal	Heat	1,064.00	0.00	45.00	0.00	0.00	0.00	0.00
Solar PV	Insolation	0.00	0.00	0.14	0.00	0.00	0.01	0.02
Wind turbine	Wind	0.00	0.00	0.00	0.00	0.15	0.00	0.00