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Integrated Electricity Planning Comprise Renewable Energy and Feed-In Tariff

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Abstract: Problem statement: Mitigation of global warming and energy crisis has called upon the need of an efficient tool for electricity planning. This study thus presents an electricity planning tool that incorporates RE with Feed in-Tariff (FiT) for various sources of Renewable Energy (RE) to minimize grid-connected electricity generation cost as well as to satisfy nominal electricity demand and CO_2 emission reduction target. **Approach:** In order to perform these tasks, a general Mixed Integer Linear Programming (MILP) model was developed and implemented in General Algebraic Modeling System (GAMS). The RE options considered including landfill gas, municipal solid waste, palm oil residue and hydro power. While the model presents a general approach for electricity planning, Iskandar Malaysia is applied as a case study in this research. **Results:** By considering the cost, FiT, availability of the Renewable Energy Source (RES) and limit of RE fund for FiT remuneration in Malaysia. The optimization result indicates that Iskandar Malaysia can satisfy the set target of 40% carbon emission reduction by 2015 by implementing biomass RE. **Conclusion:** It's revealed that a total of 875 MW of RE is required from Biomass Bubbling Fluidized Bed (BBFB) using various palm oil biomass fuel (mesofiber-215 MW, Empty Fruit Bunch (EFB)-424 MW and kernel-236 MW). However, this increases the Cost of Electricity (COE) by 69-6.5% cents/kWh.

Key words: Renewable energy, feed in-tariff, electricity generation, processing residue, general algebraic, modeling system, generation mix, emission reduction

INTRODUCTION

Increasing Renewable Energy (RE) share had been the goal is many countries over the world, however, due to the high cost of RE compared to conventional resources (fossil fuel), the development of RE into the generation mix is rather slow. In order to promote and increase RE development, Feed-in Tariff (FiT) had been introduced and since, been implemented in 63 jurisdictions worldwide rendering it as the most effective policy at stimulating rapid development of RE (Klein *et al*., 2006; Couture and Gagnon, 2010).

FiT policies are designed to offer guaranteed prices for fixed periods of time for electricity produced from RE depending on its type of technology, size of installation, quality of the resource and other variables (Couture and Gagnon, 2010; Mendonca, 2007). The remuneration of FiT can be classified as either dependent or independent from the actual electricity market price (Klein *et al*., 2006; Couture and Gagnon, 2010). Market-independent FIT policies are generally known as fixed-price policies, since they offer a fixed or minimum price for electricity from RE delivered to the grid while market-dependent FIT policies are generally known as premium price policies, or feed-in premiums, since a premium payment is added above the market price (Mendonca *et al*., 2009).

In order to increase the development of RE in Malaysia, Malaysia Government had proposed FiT to be launched by the mid of 2011 emphasizing on solar PV, biomass, biogas and mini-hydro. The FiT introduced is under the classification of an independent FiT policy covering for RE up to a maximum capacity of 30 MW, while different rate is set for different range of RE size (Chua *et al*., 2011). In order to ensure a stable funding for FiT, Pusat Tenaga Malaysia (PTM) had introduce a RE fund which collects 2% of consumers electricity bill to fund for the incentive under FiT. The fund is mainly used to equalize the price between non-renewable and renewable sources of energy (Chua *et al*., 2011).

This study developed a Mixed Integer Linear Programming (MILP) model for Islander Malaysia to plan an optimum fleet-wide electricity generation mix from various sources incorporating RE and FiT using General Algebraic Modeling System (GAMS).

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MATERIALS AND METHODS

The model is formulated with the objective function to minimize the cost of power plants (Mirzaesmaeeli *et al.*, 2010). In this model, it consists of 4 types of electricity generation, existing Fossil Fuel (FF), new FF, new RE and new RE biomass (separated from other RE due to various fuel sources). The capital cost for existing FF power plant is assumed to be paid off and thus, it is omitted from the objective function. An additional retrofitting cost is included for fuel switching (coal to natural gas).

Superstructure: The superstructure incorporates the 4 types of electricity generation. FF power plant (existing and new) consists of Natural Gas Combined Cycle power plant (NGCC), natural gas combustion turbine (NGCT) and Pulverized Coal (PC). New RE power plant consists of Municipal Solid Waste (MSW), Landfill Gas (LFG), biogas, hydro, Large solar Photovoltaic (LPV) and small Solar Photovoltaic (SPV). While, new RE biomass power plant consists of Biomass Combined Cycle (BCC) and Biomass Bubbling Fluidized Bed (BBFB) with 3 different fuels (empty fruit bunch, EFB, microfiber and kernel). An illustration of the superstructure is as shown in Fig. 1.

Objective function: The objective function is formulated as the total cost subtract with the total remuneration from FiT. The costing included in the objective function is the cost of existing FF power plant (fixed and variable Operating and Maintenance (O&M) cost), fuel cost of existing FF power plant, cost of new FF power plant (capital, fixed and variable O&M cost), fuel cost of new FF power plant, cost of new RE (MSW, LFG, biogas, hydro, LPV and SPV) power plant (capital, fixed and variable O&M cost), cost of new biomass power plant, fuel cost of biomass, retrofitting cost for retrofitting burner to utilize coal fuel to natural gas. The remuneration on the other hand, includes the FiT for each RE Eq. 1:

$$\begin{aligned}
\min f(i,j,k,l,m,n,) = {} & \underbrace{\sum_i \sum_{k\in FF} \sum_{n\in FC} E^{FF}_{ik} C^{FC}_{km}}_{\text{(Cost of existing FF)}} + \\
& \underbrace{\sum_i \sum_{k\in FF} E^{FF}_{ik} C^{FF}_{k}}_{\text{(Fuel cost of existing FF)}} + \underbrace{\sum_{k\in FF} \sum_{m\in FF} E^{FF}_{k} C^{FC}_{km}}_{\text{Cost of new FF}} + \\
& \underbrace{\sum_{k\in FF} E^{FF}_{k} C^{FF}_{k}}_{\text{(Fuel cost of new FF)}} + \underbrace{\sum_j \sum_{k\in RE} \sum_{m\in RE} E^{RE}_{jkn} C^{RE}_{km}}_{\text{(Cost of new RE)}} \\
& \underbrace{\sum_j \sum_{k\in BI} \sum_l \sum_{m\in BI} \sum_n E^{BI}_{jkln} C^{BI}_{kln}}_{\text{(Cost of new RE biomass)}} + \\
& \underbrace{\sum_j \sum_{k\in BI} \sum_l \sum_{m\in BI} \sum_n E^{BI}_{jkln} P^{BI}_{kl}}_{\text{(Fuel Cost of new RE biomass)}} + \\
& \underbrace{\sum_i \sum_{j\in FF} E^{FF}_{ij} C^{FF}_{ij}}_{\text{(Retrofitting cost)}} - \underbrace{\sum_j \sum_{k\in RE} \sum_n E^{RE}_{jkn} FIT^{RE}_{kn}}_{\text{(Feed-in tariff for RE)}} - \\
& \underbrace{\sum_j \sum_{k\in BI} \sum_l \sum_n \sum_n E^{BI}_{jkln} FIT^{BI}_{kl}}_{\text{(Feed-in tariff for RE biomass)}} +
\end{aligned} \tag{1}$$

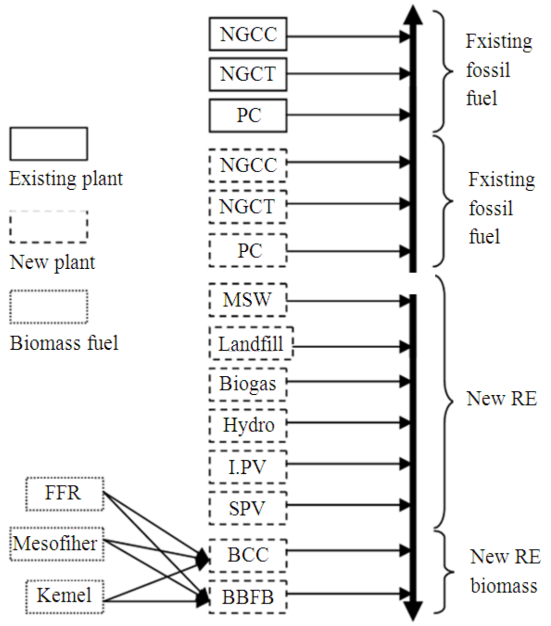

Fig. 1: Superstructure for existing and new technology

Indices:
i = Existing fossil fuel plants
j = RE power plants
k = Type of power plants
l = Biomass fuel
m = Costing
n = Range for FiT

Sets:
FF = Fossil Fuel
FC = Existing Fossil Fuel Costing (Without Capital Cost)
RE = Renewable Energy
BI = Biomass RE

Scalars:
AT = Average Electricity Tariff
REF = Percentage contributed to RE Fund
Red = Percentage reduction of CO_2
CO_2^c = Current CO_2 emission (kMetric Tonne)

Parameters:
C_{km} = Cost 'm' for type of power plant 'k'
C^{BI}_{klm} = Cost 'm' for type power plant 'k' using biomass fuel 'l' operating with biomass 'k'
P_k = Price of fuel for type of power plant 'k'
P^{BI}_{kl} = Price of biomass fuel 'l' for type power plant 'k'
FiT^{BE}_n = Feed-in Tariff for RE with range 'n'

FiT_n^{Bl} = Feed-in Tariff for BI with range 'n'
R_{ij} = Retrofitting cost for power plant 'i' to type power plant 'k'
X_i = Capacity of existing fossil fuel plant
Cap_i = Capital cost of existing fossil fuel plant
V^{MSW} = Conversion rate of MSW (kg) to energy
V^{Lfill} = Conversion rate of MSW (kg) to energy (landfill)
B_i = Biomass Fuel Availability
CO_{2k}^{FF} = CO_2 emission of fossil fuel

Integer variables:
E_{ik} = Electricity generation of existing fossil fuel power plant 'i' for type of power plant 'k'
E_k = Electricity generation for type of power plant 'k'
E_{jkn} = Electricity generation of RE power plant 'j' for type of power plant 'k' with range of FiT 'n'
C_{ikln}^{Bio} = Electricity generation of RE power plant 'j' for type of power plant 'k' using biomass fuel 'l' with range of FiT 'n'

Continuous variables:
A = Adjusted cost ($)
COE = Cost of Electricity ($/kWh)

Constraints:
Annual electricity demand constraint: The summation of electricity generation from all sources (FF and RE) must be equal or greater than the required demand as shown by Eq. 2:

$$\begin{aligned}&\sum_i\sum_{k\in FF}E_{ik}^{FF}+\sum_{k\in FF}E_k^{FF}+\sum_j\sum_{k\in RE}\sum_n E_{jkn}^{RE}\\&+\sum_j\sum_{k\in Bl}\sum_l\sum_n E_{jkln}^{Bl}\geq \text{Demand}\,(\text{MW})\end{aligned} \qquad (2)$$

Existing FF power plant constraints: The electricity generation E_{ij}^{FF} must be equal or less Than X_i. Meanwhile, X_i, represents the capacity of each existing FF power plant. The formula is as shown by Eq. 3:

$$\sum_{k\in FF}E_{ik}^{FF}\leq x_i\ (\text{MW}),\ \forall i\in FF \qquad (3)$$

Renewable energy constraint: Electricity generation from renewable energy, E_{jkn} must be equal or less than the availability as shown by Eq. 4:

$$E_{jkn}\leq \text{RE availability (MW)},\ \forall k\in \text{bijogas, SPV, LPV} \qquad (4)$$

MSW/landfill constraint: There are two technologies to convert waste to energy, direct utilization or capturing landfill gas from decomposing waste. However, since both have different conversion rate (mass to energy), v^k. The summation of E_{jkn}^{MSW}/V^{MSW} and $E_{jkn}^{Lfill}/V^{Lfill}$ must be equal or less than the available mass. The formula is shown by Eq. 5:

$$\frac{E_{jkn}^{MSW}}{V^{MSW}}+\frac{E_{jkn}^{Lfill}}{V^{Lfill}}\leq \text{MSW Availability (kg)} \qquad (5)$$

Biomass constraint: Electricity generation, E_{jkln}^{BI} from biomass must be equal or less than the available fuel resources as shown by Eq. 6:

$$\sum_j\sum_{k\in BI}\sum_n E_{jkln}^{BI}\leq B_I\,(\text{MW}),\qquad \forall k \qquad (6)$$

CO_2 emission constraint: To meet the carbon emission reduction targets, the summation of fossil fuel emission must be equal or less than the reduction requirement as shown by Eq. 7:

$$\sum_i\sum_{k\in FF}E_{ik}^{FF}\,CO_{2k}^{FF}+\sum_{k\in FF}E_k^{FF}CO_{2k}^{FF}\leq(1-\text{Red})CO_2^c \qquad (7)$$

RE fund constraint: FiT remuneration must be less or equal to the RE fund as shown by Eq. 8:

$$\begin{aligned}&\sum_j\sum_{k\in Bl}\sum_l\sum_n E_{jkln}^{Bl}FiT_{kn}^{Bl}+\sum_j\sum_{k\in Bl}\sum_n E_{jkn}^{RE}FiT_{kn}^{RE}\\&\leq\begin{pmatrix}\sum_j\sum_{k\in FF}E_{ik}^{FF}+\sum_{k\in FF}E_k^{FF}+\\\sum_j\sum_{k\in RE}\sum_n E_{jkn}^{RE}+\sum_j\sum_{k\in Bl}\sum_l\sum_n E_{jkln}^{BI}\end{pmatrix}\\&\times AT\times REF\end{aligned} \qquad (8)$$

Upper and lower Boundaries: As specific ranges are given for FiT, boundaries are set for the capacity of RE electricity generation. The formula is shown through Eq. 9a-9i. For illustration, Eq. 9a-9i given in the range for the FiT in Malaysia.

Range 'n1':

$$0\leq E_{jkn}\leq 10\ \forall\ \text{biomass, MSW} \qquad (9a)$$

$$0\leq E_{jkn}\leq 1\ \forall\ \text{SPV} \qquad (9b)$$

$$0\leq E_{jkn}\leq 4\ \forall\ \text{biogas, LFG} \qquad (9c)$$

Range 'n2':

$$10< E_{jkn}\leq 20\ \forall\ \text{biomass, MSW} \qquad (9d)$$

$$1< E_{jkn}\leq 10\ \forall\ \text{LPV} \qquad (9e)$$

$$4< E_{jkn}\leq 10\ \forall\ \text{biogas, LFG} \qquad (9f)$$

Table 1: Costing, carbon emission and RE availability Malaysia, 2010 (EIA, 2010)

Power plant	Capital cost[1] ($/MW)	Fixed O and M ($/MW)	Variable O and M ($/MW)	Fuel price, P_i ($/MW)	CO_2 (kMetric tonne)	Existing power plant (MW)	RE availability (MW)
NGCT	974000	6980	128772.0	203159.50	5.04	226	-
NGCC	978000	14390	30046.8	132003.31	3.28	893	-
PC	2521000	23370	37230.0	223856.63	7.20	2100	-
MSW	3860000	100500	43800.0	0.00	-11.51	-	717.17*2
Landfill	8232000	373760	72970.8	0.00	-11.51	-	717.17*2
Biogas	8232000	373760	72970.8	0.00	-11.51	-	47.00
Hydro	3076000	13440	0.0	0.00	0.00	-	0.00
LPV*3	4755000	16700	0.0	0.00	0.00	-	∞
SPV*3	6050000	26040	0.0	0.00	0.00	-	∞
BCC.EFB	7894000	338790	145766.4	129777.78	0.00	-	426.00
BCC.Fiber	7894000	338790	145766.4	126818.68	0.00	-	215.00
BCC.Kernel	7894000	338790	145766.4	153873.33	0.00	-	297.00
BBFB.EFB	3860000	100500	43800.0	141897.90	0.00	-	424.00
BBFB.Fiber	3860000	100500	43800.0	138662.45	0.00	-	215.00
BBFB.Kernel	3860000	100500	43800.0	168243.77	0.00	-	297.00

*1: The capital cost is amortized over a period of 20 years with an interest rate of 15%; *2: MSW and landfill gas power plant share the same source (kMetric Tonne). The conversion rate from waste to energy for MSW, v^{xsw} is 0.1437 (MW/kMetric Tonne) and landfill, $v^{Landfill}$ is 0.0739 (MW/kMetric Tonne); *3: Due to the intermittency of solar energy, 1 MW capacity of photovoltaic is insufficient to meet the actual demand of 1 MW of electricity. With an average sunlight of up to 6 h/day, the cost of solar PV would be 4 times higher to sufficiently meet the required demand

Table 2: Feed-In Tariff for various RE (PTM, 2010; Hashim and Ho, 2011)

RE utilisation	Years	RM/kWh	Degression (%)
Solar PV			
< 1 MW	21	1.14	8.0
> 1 MW < 10 MW	21	0.95	8.0
> 10 MW < 30 MW	21	0.85	8.0
Bonus for BIPV	21	0.25	8.0
Biomass			
< 10 MW	16	0.31	0.5
> 10 MW < 20 MW	16	0.29	0.5
> 20 MW < 30 MW	16	0.27	0.5
Bonus for gasification	16	0.02	0.5
Bonus for MSW	16	0.10	1.8
Biogas			
< 4 MW	16	0.32	0.5
> 4 MW < 10 MW	16	0.30	0.5
> 10 MW < 30 MW	16	0.28	0.5
Bonus for landfill	16	0.08	0.5

Range ‘n3’:

$$20 < E_{jkn} \leq 30 \ \forall \text{ biomass, MSW} \quad (9g)$$

$$10 < E_{jkn} \leq 30 \ \forall \text{ LPV} \quad (9h)$$

$$10 < E_{jkn} \leq 30 \ \forall \text{ biogas, LFG} \quad (9i)$$

Case study: This model is constructed to provide a road map for Islander Malaysia to implement RE in the total energy generation mix of 1997 MW by 2015 with a carbon emission reduction ranging from 10-40%. As of current, 5 power plants consisting of 1 NGCT power plant located in Pair Gudang (i-1), 3 NGCC power plant, all located in Pasir Gudang (i-2-4) and 1 PC power plant located in Tanjung Bin (i-5), summing up to a capacity of 3219 MW. Several assumptions were drawn in order to simplify the model. The list of assumption is as listed below:

- Currently, the energy generation in Iskandar Malaysia is generated from natural gas (78.8-1119% MW) and remaining is generated from coal (21.2-287% MW) Malaysia, 2010
- Current cost of electricity if 3.85 cents/kWh.
- Biomass resource is only from palm oil residue
- The only feasible source to produce biogas is from Palm Oil Mill Effluent (POME)
- All RE is considered to be carbon neutral.
- Average electricity tariff is taken to be $ 0.0833 kWh^{-1}

To increase the validity of the model, several data were collected directly from Iskandar Malaysia, PTM and U.S. Energy Information Administration (EIA, 2010) as shown in Table 1 and 2.

Other data used in this model includes, retrofitting cost, R_{ik}^{FF} to retrofit PC to NGCC power plant ($ 23676.79/MW) and current carbon emission, $CO2^{C}$ (6133.93 kMetric Tonne) Malaysia, 2010. To calculate the COE, the omitted capital cost of existing FF power plant would have to be included. The equation to adjust the total cost and to calculate the cost of electricity is as shown by Eq. 10 and 11:

$$A = f(i, j, k, l, m, n) + \sum_i \sum_{k \in FF} E_{ik}^{FF} \text{Cap}_i \quad (10)$$

$$C0E = \frac{A(\$)}{\text{Total energy generated (kWh)}} \quad (11)$$

RESULTS

Since the United Nations Climate Change Conference 2009 (COP15), Malaysia had set a target to reduce carbon emission by 40% as announced by the sixth and current Prime Minister of Malaysia, Dato’ Seri Najib Razak.

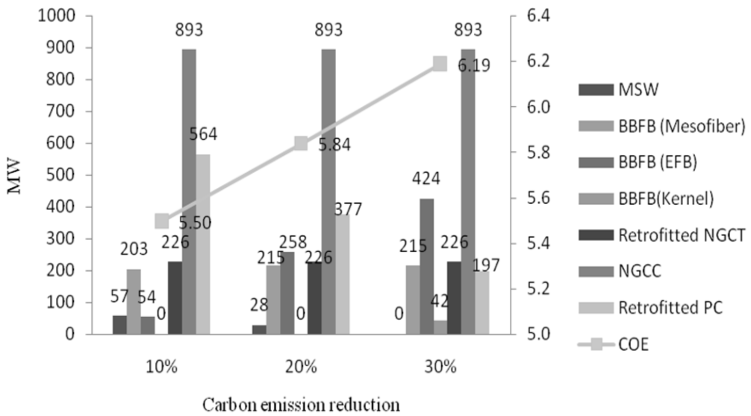

Fig. 2: Effect of carbon emission reduction on COE

This section discussed the findings from sensitivity analysis conducted on the model exploring the effects of carbon emission targets toward the cost of electricity and participation of RE. The model includes two methods for carbon reduction, fuel-switching (from coal to natural gas) and implementation of RE. The result of this study is as shown in Fig. 2.

DISCUSSION

Referring to Fig. 2, it can be seen that fuel-switching of PC power plant to NGCC power plant is required for all cases as it proves to be cost effective and a good solution to carbon emission reduction. However, fuel-switching alone could not ultimately reduce the carbon emission and in order to achieve further reduction RE is required. To achieve 10% carbon reduction, a total of 314 MW of RE is required, consisting of 2 MSW power plant adding up to a total of 57 MW (range: 21-30 MW), 27 BBFB (mesofiber) power plant with a total of 203 MW (range: 21-30 MW) and 2 BBFB (EFB) power plant with total of 54 MW (range: 21-30 MW). Two main factors contributes to the selected choice are low costing of these technologies and low FiT (constrained due to RE funding) compare to the other RE (higher range is selected due to lower FiT). While mesofiber and EFB are chosen above kernel as the fuel for BBFB is primarily due lower fuel cost.

To achieve higher carbon emission reduction (20%), the total participation of RE in the generation mix have to be increase by additional of 187 MW. Amount of MSW decrease from 57-MW, BBFB (Mesofiber) increases from 203-215 MW and BBF (EFB) increases from 54-258 MW (all power plants are of the higher range: 21-30 MW). The decrease of MSW participation of due to insufficient funding from RE fund to sustained a stable remuneration. As mesofiber biomass fuel approaches its availability limit, EFB is then used. With 2% of electricity bill contributed to RE fund, it is insufficient to provide enough remuneration to achieve a carbon reduction of 40%, the maximum reduction it could achieve is only 29.62%. Under these scenario, the participation of RE is up to 681 MW, with RES only from biomass (BBFB) with 215 MW from mesofiber, 424 MW from EFB and 42 MW from kernel. Even with incentives from FiT, the cost of RE is still higher than the cost of conventional FF power plant and thus, the COE increases gradually as the carbon emission reduction increases. The COE increases as much as 60.78% hitting a value of 6.19 cents/kWh.

In order to increase the carbon reduction up to 40%, the funding toward RE fund have to be increase, this can be achieve by increasing the percentage collected from electricity bills for RE fund by 0.57% achieving a total contribution of 2.57% or increase the average price of electricity from $ 0.0833/kWh to $ 0.107/kWh (as much as 28.45%). Under this new settings, the contribution from RE is yet again, only from biomass with a total of 875 MW (mesofiber-215 MW, EFB-424 MW and kernel-236 MW). The COE then increases to 6.5 cents/kWh (increment of 68.83%) with all the power plant in the range from 21-30 MW.

CONCLUSION

A MILP model for the optimal planning of grid-connected electricity generation schemes has been developed for IM to meet a specified RE mix target by considering the factor of cost, FiT and carbon reduction. The results indicated that, the selection of type of RE power plant is mainly driven by the cost, FiT, RE fund and the availability of RES.

With FiT introduced, in an investor point of view, it would be more profitable to select the RE with higher remuneration and higher rate of return; however that itself cannot be used as the main criteria in selection of RE projects. To ensure a stable economic, the authority should introduce a quota system which promotes the suitable RE project to be given priority. One method to decide on the priority depends very much on the availability and cost of the resource and the RE fund availability.

In this study, to achieve a 40% reduction of carbon emission, the model had selected 875 MW of RE entirely from biomass resources (mesofiber -215 MW, EFB-424 MW and kernel-236 MW) while the remaining demand is met by NGCC. This indicates that focus on biomass resources should be given priority in Malaysia as Malaysia has an abundant amount of biomass especially from palm oil residue. In this scenario, the COE increased by 68.83% to 6.5 cents/kWh. Out of the FF power plants, NGCC is selected due to its low cost, high efficiency and low carbon emission.

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