CHEMICAL ENGINEERING TRANSACTIONS

VOL. 81, 2020

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Petar S. Varbanov, Qiuwang Wang, Min Zeng, Panos Seferlis, Ting Ma, Jiří J. Klemeš

ISBN 978-88-95608-79-2; **ISSN** 2283-9216

DOI: 10.3303/CET2081102

Enhanced Automated Targeting Model for Multi-Period Energy Planning

Karen Gah Hie Kong[a], Shirleen Lee Yuen Lo[a], Bing Shen How[a,*], Wei Dong Leong[b], Sin Yong Teng[c], Wendy Pei Qin Ng[d], Jaka Sunarso[a]

[a]Research Centre for Sustainable Technologies, Faculty of Engineering, Computing and Science, Swinburne University of Technology, Jalan Simpang Tiga, 93350, Kuching, Sarawak, Malaysia.
[b]Department of Chemical and Environmental Engineering, University of Nottingham, Jalan Broga, 43500, Semenyih, Selangor Darul Ehsan, Malaysia
[c]Brno University of Technology, Institute of Process Engineering & NETME Centre, Technicka 2896/2, 616 69 Brno, Czech Republic
[d]Curtin University Malaysia, Department of Chemical Engineering, CDT 250, 98009 Miri,Sarawak, Malaysia
bshow@swinburne.edu.my

The shortage of non-renewable power supplies and critical environmental issues such as climate change, urban sprawl, ozone layer depletion and excessive carbon emission are the main driving forces that urged many countries and non-profit organisations fully committed to seeking more sustainable energy sources and energy planning. Various Process Integration techniques have been developed, extended and utilized in the energy planning sector. Based on the literature review, the use of time-sliced based models in energy integration is still limited. This paper aims to develop time-sliced models that can be applied into an energy integration model that promises higher energy efficiency in power generation energy planning. To accomplish this, a two-stage framework involving (i) targeting and (ii) scheduling is proposed. The targeting step is to determine the minimum amount of renewable energy sources needed to meet the carbon emission limit whereas the scheduling step is to discover the optimal scheduling of introduced renewable energy sources to mitigate the total electricity bill. It is proposed that with the aid of adequate planning, the economic benefit of utilising renewable energy can be realized. A case study in Malaysia that incorporates an actual billing system is used to demonstrate the effectiveness of the model in reducing both carbon emission and energy cost simultaneously. With the use of the proposed framework and developed model, 46.9 % of electricity bill can be reduced while emission is reduced by 40 % compared to the initial emission.

1. Introduction

Global warming and climate change have always been a huge challenge for the global community and are yet to be solved. These issues are caused by the excessive generation of greenhouse gases, which has global heating effects and carbon dioxide (CO_2) represents a substantial part of these issues. According to the BP Statistical Review of World Energy (2019), Malaysia's carbon dioxide accounted for up to 250.3 Mt in 2018, which increased by 2 % compared to 2017. Electricity consumption has been the largest contributor to this enormous carbon emission due to the country's growing energy demand. The reliance of fossil-based energies for electricity generation and consumption is likely to grow in the near future as Malaysia has been gearing itself up for Industry 4.0 to boost its productivity growth (Moreira, 2019) and the International Energy Agency (IEA) had estimated the usage of renewables usage from 14 - 31 % in the next 20 y duration. Malaysian government has been putting tremendous effort to reduce the country's total carbon emission by 45 % in 2030 and get the country prepared to be carbon-free by 2050 (Lokmann, 2017), which can be performed by introducing the renewables energies technologies. However, the overall renewables, which only constitute about 2 % of the total power generation mix in Malaysia are comparatively expensive compared to fossil-based energies (Wan Abudllah et al., 2019). Tenaga Nasional Berhad is one of the largest electricity utility companies in Malaysia.

Paper Received: 29/03/2020; Revised: 03/06/2020; Accepted: 04/06/2020
Please cite this article as: Kong K.G.H., Lo S.L.Y., How B.S., Leong W.D., Teng S.Y., Ng W.P.Q., Sunarso J., 2020, Enhanced Automated Targeting Model for Multi-Period Energy Planning, Chemical Engineering Transactions, 81, 607-612 DOI:10.3303/CET2081102

However, the Maximum Demand charges, which comes from the highest level of electrical demand in a period during which the energy supply company may be required import energy from other regions may entail a relatively high charges that can overburden the customers. The renewables are required to be targeted at an exact period that enables the maximum demand level to be lowered down and reduce the maximum demand penalty. The newly proposed two-step-framework aims to provide a fundamental methodology for developing a time-sliced-based energy planning model. The model developed based on the framework proposed helps in optimising the power allocation in the power generation sector by reducing the electricity bill and achieving the carbon emission limit.

2. Literature Review

The selection of optimisation tools in handling optimisation problems depends on the problem nature itself. The continuous development of optimisation tools or techniques is essential as they are being extended to handle more complicated optimisation problems. For instance, Ooi et al. (2014) presented an optimised framework in carbon-constrained energy planning deployed with carbon capture and storage technologies by introducing renewable energy sources and allowing the carbon emission to be transferred internally within 15 y horizon of energy planning. Koltsaklis et al. (2014) and Muis et al. (2010) had designed and remodified a mixed-integer linear programming (MILP) model for optimal energy planning in Greek and Peninsular Malaysia. However, these works did not incorporate the time-sliced issue into their evaluation and optimisation model. This work aims to extend the framework by developing a mathematical model that considers multi-period scheme and the billing system utilised in Tenaga Nasional Berhad (TNB), which in the end can meet the carbon emission limit and minimise the total electricity bill simultaneously. As mentioned in Klemeš et al. (2018), no accurate multi-period-based optimisation models have been developed to address optimisation problems. The formulation of a multi-period power allocation model in the power generation energy planning sector has been proposed in this work to optimise the multi-period power allocation.

3. Methodology

The carbon emissions constrained energy planning optimisation problem can be formally stated as follows:

- Given a set of time intervals of 30 min in a day assigned as T = {1,2,…48}.
- Given the total energy demand in each interval as DEMAND= {D_{T1}, D_{T2},…D_{T48}}.
- Given the available energy sources, i.e., renewables energies and fossil-based energies are assigned as SOURCES= {S_R, S_F}, to be used to fulfil the total energy demand. Each energy supply has its emission factor,C_i, which is C_{Fossil} and $C_{Renewables}$.The product of energy demand emission factor gives the total carbon emission (E_T) with the equation, i.e, $E_{TN} = D_{TN}\, C_i$.
- Given the cost of energy utilised may vary due to different time period, the cost factor of each energy demand at each time interval can be named as, $CF_{Off\text{-}Peak}$, $CF_{Mid\text{-}Peak}$ and CF_{Peak}.
- The Maximum Demand value is the highest average value of energy demand at different time intervals (Off-peak, Mid-Peak and Peak period) so the value may differ across the time intervals and the charges ($MD_{Off\text{-}Peak}$, $MD_{Mid\text{-}Peak}$ and MD_{Peak}) of different time zone are listed in Table 1.
- In this work, the renewable energies are assumed to be solar energy and already in operation, the installation fee for the solar panel is negligible. Furthermore, the operation of the case study is also assumed to operate at steady-state condition.

The two-stage optimisation framework is proposed in this work. The first stage, Targeting, is to identify the minimum quantity of renewables to meet the carbon emission limit; while the second stage, Scheduling, is the optimal scheduling strategy to introduce the limited amount of renewable energy sources that reduce the maximum demand charges. The latter stage is crucial as it determines the value of maximum demand charges in the total bill. Each of the stages utilised different approaches, which are Carbon Emission Pinch Analysis (CEPA) and Automated Targeting Model (ATM) technique. The objective of this work is to minimise the total electricity bill and, in the meantime, meeting the emission limit and fulfil the required energy demand.

4. Model Formulation

4.1 Carbon Emission Pinch Analysis (CEPA) Targeting

Carbon Emission Pinch Analysis (CEPA) has been used to identify the minimum quantity of energy needed for different transportation types to meet their respective emission limit and transportation demand (Fakrul Ramil et al., 2017) and energy sector planning in Nigeria (Salman et al., 2018). In this case, CEPA is used to identify the minimum quantity of carbon-neutral energies for this problem and is demonstrated with a hypothetical example.

This work uses an approach known as linear programming to solve the targeting step. The key to choose a linear programming technique in this step because it promises a guaranteed-solution from the problem formulated (Lin, 2018). The developed model determines an exact value of the minimum amount of renewables with a carbon emission limit constraint. The objective function (as given in Eq(1)) is set to minimise the amount of carbon-neutral energy sources required in the optimisation problem.

$$Min\ S_{Total\ Renewables} = S_{Total\ Renewables} = S_{RT1} + S_{RT2} + \cdots + S_{RT48} \quad (1)$$

The carbon emission of each time interval is the product of energy demand and their respective carbon intensity, by using the Eq(2) as below:

$$E_{TN} = S_{F,TN}C_{Fossil} + S_{R,TN}C_{Renewables} \quad \forall N \quad (2)$$

The total energy supply (either fossil-based or renewables) are required to fulfil the energy demand, given as:

$$D_{TN} = S_{F,TN} + S_{R,TN} \quad \forall N \quad (3)$$

As for the carbon emission limit (E_L), it is targeted to be reduced to 40 % lower than the initial emission (E_i):

$$E_L = E_i \times 0.6 \quad (4)$$

The formulation above develops as the first linear programming model (LP) and is solved using global solver. The formulated model is then solved using optimisation software, LINGO V18 (LINGO Systems Inc, 2020) and the results are plotted as a Composite Curve as shown in Figure 1(a).

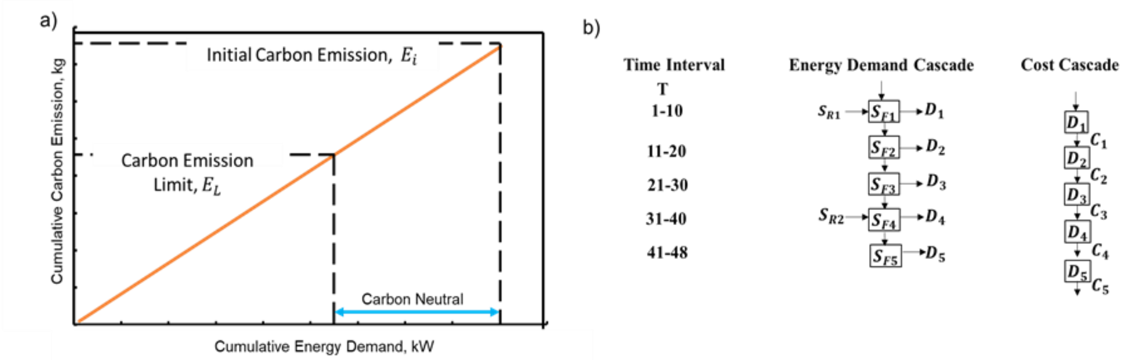

Figure 1: (a)Targeting for a minimum quantity of carbon-neutral sources; (b) Fundamental Framework for a different time interval

4.2 Automated Targeting Model (ATM) Scheduling

A fundamental optimisation ATM framework is proposed here to the scheduling concept for total electricity bill cost reduction (Figure 1(b)). Similar to the targeting step, the developed model aims to determine the minimum electricity bill by reducing the maximum demand value of each time period. As shown in Figure 1(b), Energy Demand cascade and cost cascade are performed. The total energy demand across all time intervals are conducted and arranged according to their respective time period. The objective function of this step is to minimize the total cost of across all the time intervals which the equation can be defined as Eq(5). The relationship of the total energy demand and the cost can be mathematically expressed as in Eq(6) to Eq(7):

$$Min\ Cost_T = C_{T1} + C_{T2} + \cdots + C_{T48} \quad (5)$$

$$C_{TN} = (S_{FTN} * C_F) + (S_{RTN} * C_R) \quad \forall N \quad (6)$$

Eq(7) shows the relationship between energy demand and different energy supplies at different time intervals to ensure the energy demand is fulfilled.

$$D_{TN} = S_{FTN} + S_{RTN} \quad \forall N \quad (7)$$

Additional constraint needs to be added to limit the energy usage supplied by Tenaga Nasional Berhad by only supply 70 % of the highest energy usage across all time intervals. The function can be expressed as Eq(8).

$$S_{FTN} < Highest\ Energy\ Usage\ in\ Peak\ Period \times 70\ \% \quad \forall N \quad (8)$$

Tenaga Nasional Berhad has its unique calculation which is represented by Eq(9).

$$Cost_T = (D_{TN} * Cost\ Factor) + (Highest\ Average\ Maximum\ Demand * Maximum\ Demand\ Cost) \quad (9)$$

The second linear programming (LP) model is again solved using LINGO V18 and the optimum solution can be generated using global solver function in LINGO V18. The calculated solution will result in the exact time period and rigorous amount of carbon-neutral sources to be placed at that particular time interval.

Table 1: Cost Factor of each time intervals (Tenaga Nasional Berhad, 2014)

Time Interval	Time Zone	Cost Factor[a] (RM/kW)	Maximum Demand Cost[b] (RM/kWh)
0000-0800	Off-Peak	0.202	N/A
0830-1100	Mid-Peak	0.310	35.00
1130-1200	Peak	0.390	38.30
1230-1400	Mid-Peak	0.310	35.00
1430-1700	Peak	0.390	38.30
1730-2130	Mid-Peak	0.310	35.00
2200-2400	Off-Peak	0.202	N/A

[a] Data obtained from Tenaga Nasional Berhad (2014)
[b] Data obtained from Malaysia Energy Commission (2014)

5. Case Study

A hypothetical example has been demonstrated as a case study to be applied in the developed model. The energy usage of each time interval is tabulated in Table 2.

Table 2: Energy Usage of sample building

Time Interval	Energy Usage (kW)	Time Interval	Energy Usage (kW)	Time Interval	Energy Usage (kW)	Time Interval	Energy Usage (kW)
1	229.0735	13	199.2967	25	515.2068	37	509.3742
2	225.2935	14	205.0217	26	517.6999	38	513.7304
3	230.1422	15	193.1337	27	536.417	39	522.5509
4	231.1124	16	191.9594	28	526.2507	40	521.8292
5	223.445	17	238.2239	29	528.1383	41	530.5253
6	221.5743	18	266.0278	30	532.0152	42	542.5888
7	213.5395	19	317.7769	31	525.9759	43	533.8071
8	209.6321	20	361.3269	32	515.8652	44	476.9998
9	205.4712	21	491.9558	33	497.5896	45	339.2704
10	202.7206	22	520.2654	34	501.1247	46	276.1561
11	202.0423	23	510.3378	35	505.5025	47	256.2149
12	200.4014	24	505.981	36	494.8704	48	235.9339

By declaring a 40 % carbon emission reduction, the case sample has been set to have a carbon emission limit of 0.25 Mt (initial carbon emission=0.37 Mt). Few assumptions are made for this case study:

1. The renewables are assumed to be solar energy sources; while its cost factor is set at RM0.45/kW.
2. The carbon intensity of fossil-based-energies is fixed at 0.693 kg/kWh (Abdul-Azeez., 2016) while the carbon intensity of carbon-neutral sources is assumed to be 0.024 kg/kWh (Wade, 2016).

The installation fee for solar energy sources is negligible in this case. Based on the first targeting model, and solving the objective function in Eq(1) subjected to the constraints from Eq(2) to Eq(6) for the case study, the model generated a result that a minimum amount of 7,514 kW of carbon-neutral energy sources is required. Figure 2(a) shows an illustrative result from the developed model. The amount of carbon-neutral energy sources is then reinserted to Eq(2), as a constraint in the second scheduling model. The objective in the second scheduling model is to minimize the total electricity bill with a given amount of carbon-neutral energy sources. Note that the main expenses in the total electricity bill come from the maximum demand charges so the maximum demand value is required to be reduced to its minimum value across all the time intervals. The results and the maximum demand value of each time period are generated as illustrated in Figure 2(b) and Table 3.

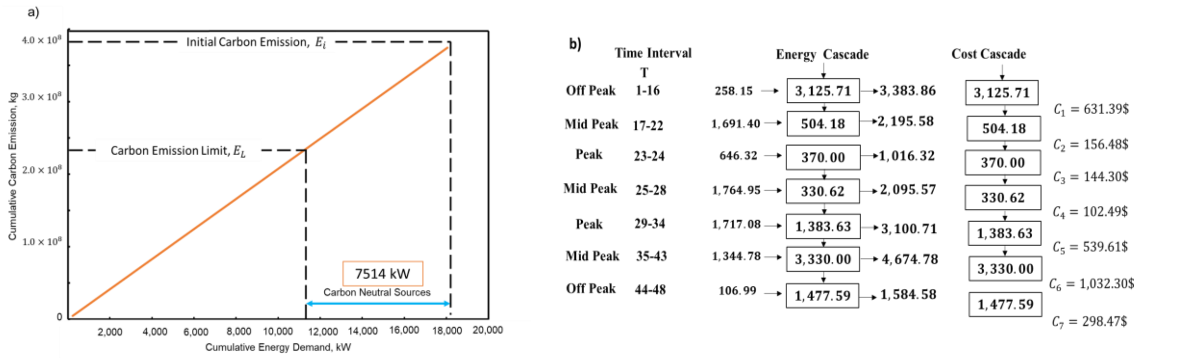

Figure 2: (a) Targeting minimum amount of carbon-neutral energy sources; (b) Scheduling step for different time intervals

Table 3: Average Maximum Demand Value of each time zone

Time Interval	Time Zone	Total Energy Usage (kW)	Total Time Interval	Average Maximum Demand (kW)
17-22, 25-28, 35-43	Mid-Peak	5,676.44	19	298.76
23-24, 29-34	Peak	0	8	0

Figure 3 shows the comparative analysis of the total electricity bill before and after the optimization.

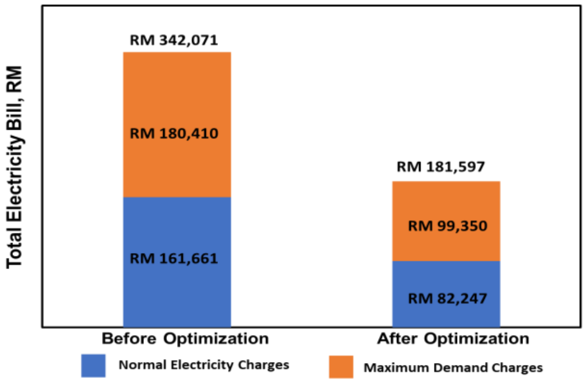

Figure 3: Comparative results before and after optimisation

6. Discussion

The results generated from the developed model proved that the electricity bill has been significantly reduced compared to the initial electricity bill by around 46.9 % for a cycle of the billing system. To note, the maximum demand value has significantly reduced from 542.6 kWh to 298.76 kWh. The reliance on fossil-based energy sources shall be reduced by 58 % in this case as renewable energy sources are utilised to meet the emission target. The proposed framework and the case study performed in Malaysia had successfully demonstrated and indicated how optimal scheduling strategy helps in energy planning by providing economic benefits. Both targeting and scheduling steps proposed in this study works as a continuous effort in this carbon-constrained optimisation problem. By looking at the comparative results illustrated in Figure 3, the fundamental framework proposed in this work had critically demonstrated the effectiveness of the model in reducing the electricity bill and verify the optimal usage of renewable energy sources in a sample energy usage profile. However, results validation cannot be carried out at this stage as no relevant work has been carried out before.

7. Conclusion

This work proposed a brand-new multi-period optimisation framework and developed a linear programming (LP) model which consists of two steps, (i) Targeting and (ii) Scheduling, that aims to solve the carbon-constrained energy planning by introducing renewables. The proposed framework has been applied to a case study in

Malaysia incorporated with the Tenaga Nasional Berhad billing system. The developed model provides the optimal scheduling of inserting the limited amount of renewables at different time intervals but ensures the electricity bill to be minimised at the end. The model developed for the specific case study indicates that the total electricity bill can be reduced by 46.9 % by using the optimal scheduling strategy generated and reduce the reliance of fossil-based energy sources by 58 % in the power generation sector. This justifies the effectiveness of the framework proposed in energy sources allocation. The main limitation of this work is the selection of the renewables used in this framework which solar is assumed but the choice of the renewables depends on geographic variability, site restrictions, and financial constraints.

Acknowledgements

The authors would like to acknowledge the financial support from Swinburne University of Technology (Sarawak Campus) via Research Micro Fund [9-1372 RMFST].

References

Abdul-Azeez I.A., 2016, Measuring and monitoring carbon emission to promote low-carbon development in Johor Bahru, Malaysia Sustainable Cities Program <malaysiacities.mit.edu/paperadeyemi> accessed 20.03.2020.

BP Statistical Review of World Energy, 2019, BP <www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-full-report.pdf> accessed 28.03.2020.

Ramli A.K., Muis Z.A., Ho W.S., 2017, Carbon Emission Pinch Analysis: An application to transportation sector in Iskandar Malaysia 2025, Chemical Engineering Transactions, 56, 343–348.

Klemeš J.J., Varbanov P., Walmsley T.S., Jia X., 2018, New directions in the implementation of Pinch Methodology (PM), Renewable and Sustainable Energy Reviews, 98, 439–468.

Koltsaklis N. E., Dagoumas A. S., Kopanos G. M., Pistikopoulos E. N., Georgiadis M. C., 2014, A spatial multi-period long-term energy planning model: A case study of the Greek power system, Applied Energy, 115, 456–482.

Lin J., Magnago F., Alemany J.M., 2018, Optimization methods applied to power systems: current practices and challenges, In: Zobaa A.F., Abdel Aleem S.H.E., Abdelaziz A.Y. (Eds.), Classical and Recent Aspects of Power System Optimization Methods, Academic Press, Cambridge, US, 1–18.

LINGO 18.0, 2020, LINGO Systems Inc <www.lindo.com/index.php/lshome> accessed 28.03.2020.

Lokman T., 2017, PM: Malaysia on course to reduce carbon emissions by 40 pct by 2020, News Straits Times, <www.nst.com.my/news/nation/2017/12/310231/pm-malaysia-course-reduce-carbon-emissions-40-pct-2020> accessed 25.03.2020.

Malaysia Energy Commission, 2014, Enhanced time of use (ETOU) tariff scheme, <www.tnb.com.my/faq/etou/>, accessed 21.03.2020.

Moreira C.F., 2019, Malaysia's Industry 4.0 Journey-What and Why, <www.enterprisetv.com.my/malaysias-industry-4-0-journey-what-and-why/>, accessed 28 March 2020.

Muis Z. A., Hashim H., Manan Z. A., Taha F. M., Douglas P. L., 2010, Optimal planning of renewable energy-integrated electricity generation schemes with CO2 reduction target, Renewable Energy, 35, 2562–2570.

Ooi R.E.H., Foo D.C.Y., Tan R.R., 2014, Targeting for carbon sequestration retrofit planning in the power generation sector for multi-period problems, Applied Energy, 113, 477–487.

Salman B., Nomanbhay S., Foo D.C.Y., 2019, Carbon Emissions Pinch Analysis (CEPA) for energy sector planning in Nigeria, Clean Technologies and Environmental Policy, 21, 93–108.

Tan R.R., Foo D.C.Y., 2007, Pinch analysis approach to carbon-constrained energy sector planning, Energy 32, 1422–1429.

Tenaga Nasional Berhad, 2014, Pricing and tariffs-industrial tariffs, <www.tnb.com.my/commercial-industrial/pricing-tariffs1>, accessed 21.03.2020.

Wade A., 2016, Carbon Footprint of solar panels under microscope, Euractiv <www.euractiv.com/section/energy/opinion/mondaycop22-lower-co2-emissions-with-lower-carbon-solar-energy/1057375/>, accessed 21.03.2020.

Wan Abdullah W.S., Osman M., Ab Kadir M.Z.A., Verayiah R., 2019, The potential and status of Renewable Energy Development in Malaysia, Energies, 12, 1–16.

World Energy Outlook, 2019, International Energy Agency (IEA), <www.iea.org/reports/world-energy-outlook-2019>, accessed 28.03.2020.