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Application of best practice for setting minimum energy efficiency standards in technically disadvantaged countries: Case study of Air Conditioners in Brunei Darussalam

Xunpeng Shi *

Energy Studies Institute, National University of Singapore, Singapore

HIGHLIGHTS

- Setting MEPS requires significant data, financial resources and technical capacity.
- Application of best practice in technical disadvantaged countries (TDCs) was demonstrated.
- Best practice was successfully applied to Brunei for its AC MEPS.
- For Brunei, COP at 2.9 is recommended and 15% efficiency improvement is achievable.
- The methodology is applicable to other appliances in any TDCs.

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ABSTRACT

Application of the best practice of setting minimum energy performance standards (MEPS) in technically disadvantaged countries (TDCs) faces many barriers. The best practice of determining MEPS has a comprehensive analytical framework including engineering-economic analysis, life-cycle cost-benefit analysis, as well stakeholders' and market impact assessments. However, TDCs usually are lack of reference product classes, market data, and other necessary inputs data. This study demonstrated how to overcome those barriers to apply the best practice to TDCs using the actual experience in setting initial MEPS for Air Conditioners (ACs) in Brunei from scratch with limited secondary data as an example. The series of application works include definition of the product classes and the baseline group; collection of market data; formulation of cost-efficiency relationship from the market data; examination of the economic, environmental, and financial impacts of various MEPS options; revealing of the consumers' willingness to pay; and analysis of the impacts and responses from the industry and consumers. The coordination with the compliance of the Montreal Protocol was also considered. The methodology should also be applicable to setting MEPF for other appliances in any TDCs.

1. Introduction

The improvement of energy efficiency (EE) is a cost-effective policy measure to achieving sustainable energy development but realizing the significant potential efficiency gains often needs strong policy actions [1]. Minimum energy performance (efficiency) standards (MEPS)[1] and energy labeling are two of the most frequently used tools of any energy efficient and conservation program for appliances [2]. MEPS introduces market transformation by eliminating products that fall below the MEPS from the market

[1] MEPS is also frequently referred to as 'minimum energy efficiency standards'. In this paper, both terms are used interchangeably.

Abbreviations: AC, Air Conditioner; BTU, British Thermal Unit; CLASP, Collaborative Labeling and Appliance Standards Program; COP, Coefficient of Performance; DES, Department of Electricity Service, Prime Minister Office, Brunei; EE, energy efficiency; GWP, Global Warming Potential; LCC, the life-cycle cost; MEPS, minimum energy performance standards; NPB, net present benefit; ODP, Ozone Depletion Potential; OEM, Original Equipment Manufacturer; PAMS, Policy Analysis Modeling System; PBP, payback period; S&L, standards and labeling; SCC, Social Cost of Carbon; TDCs, technically disadvantaged countries; UEC, Unit Energy Consumption; WTP, willingness to pay.

* Address: 29 Heng Mui Keng Terrace, Block A #10-01, Singapore 119620, Singapore. Tel.: +65 65165360 (DID); fax: +65 67751831.

E-mail address: xunpeng.shi@gmail.com

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and encouraging suppliers to bring in more energy efficient appliances [3]. Although MEPS is regulatory and compulsive, it may be cost-effective for governments to achieve key environmental, energy security and economic policy objectives [3]. However, the sustainability of the MEPS program depends on how the MEPS level is specified.

From policy makers' perspective, setting MEPS not only need life cycle costs and benefits analysis (LCC analysis) on costs, benefits, and the environment, but also need analysis on other stakeholders, who otherwise might make the policy unworkable or against the government principles, such as protect the disadvantaged groups [4–6]. In those developed counties that has the best practice in MEPS policy making, such as US [6] and Australia [4], justification of MEPS involved detailed evaluation of MEPS's technological feasibility; LCC impact; availability of the higher efficiency appliances in the market; the potential impact on the major stakeholders such as manufactures, households, and the business sectors and issues such as jobs and low income consumers [4–6].

LCC analysis on economic, financial and environmental impact are fundamental part of the best practice. The LCC analysis can ensure that government-mandated programs do not pose a financial burden to consumers and the MEPS has a positive impact on the nation. This LCC analysis has been well accepted in the literature, such as Cardoso et al. [7], Letschert et al. [8], Lu [9], Ni [10], Mahlia et al. [11], Nogueiraa et al. [12], Tao and Yu [13], Vendrusculo et al. [14]. Currently, LCC analysis has been undergone various extension. Bottom up applications of the LCC analysis were also recorded in the recent literature [15].

There are also other recent literature that examines advanced technical details for applying the LCC approach. Siderius [16] introduced the experience curve to modeling the declining trend of product costs, which are currently assumed to be linear. By integrating the experience curve to LCC analysis to appliances in EU, a study [16] found at least twice the energy savings compared to the current approach can be achieved in the case of driers and refrigerator–freezers. This extension of methodology, despite academically sound, however, introduces additional complication to the model and may not be transparent to policy makers. However, in the policy making, the LCC cost-benefit analysis is not the only criterion for deciding a new MEPS because other factors, such as national benefits and environmental protection, must be considered [14].

Another key component of the best practice is to examine the impact on consumers and reveal their responses. The finding of Zeng et al. [17] suggests that MEPS is limited by consumers' willingness to pay (WTP) for efficient products: most consumers in China are only willing to pay less than 10% more for efficient appliances. The WTP of Chinese consumers, however, is noticeably lower than those in European countries, who were found on average to be willing to pay 44% and 50% more for higher efficiency refrigerators and TVs, respectively [17]. Even in oil producing countries, such as Saudi Arabia, the average WTP for energy efficiency products is about 15% [18]. Nevertheless, overtime, the limited WTP may not be a significant barrier for adoption of high efficiency products because as many studies have found, higher efficiency was achieved with declined appliance prices. Meyers et al. [5] found that the purchase cost of fridges would go down after the introduction of MEPS. An IEA report found that in the US, energy consumption of refrigerators and freezers reduced 60% between 1980 and 2001 due primarily to the introduction of MEPS in 1993 [19]. The Chinese case study [17] also shows that an effective incentive set by subsidy may have to be at the size of 20–30% of the retailing prices. As summarized in the literature [4,20], many studies revealed that consumers have extremely high discount rates between 20% and 100%.

This best practice from developed countries, however, are too luxurious to be followed by countries with limited technical resources and data, or TDCs, such as Ghana [21]. Such a TDC often lacks of input data, cannot afford or has no technical capacity to conduct engineering analysis, or has not capacity to provide other systematic support. As shown in the Saudi case [22], the engineering analysis not only needs manufacturing of a prototype product, but also needs technical standards and testing facilities. While a previous study [23] has discussed the initial setting of EE standards in a developing country without sufficient data, other factors that policy makers have to consider were not discussed and thus it offers limited practical guidance. All these academic studies focus on estimation of the economic and environmental impact but have not addressed policy makers' other concerns and thus their findings and experience are not sufficient for policy makers to determine a MEPS level.

This study demonstrates how to apply the best practice for determining MEPS in a TDC using Brunei as an example. It presents a comprehensive assessment of factors such as impact on consumers, vendors and manufacturers that are often the top concerns of policy makers. This study also shows how to collect data that were not available. The paper is motivated by the need of determining an initial MEPS for Brunei, which has no labeling activity, no market data, generally lacks of other support data, and lack of testing equipment and testing capability in its own climate condition.

The paper makes contributions to the literature in a number of ways: first, it demonstrates practical and replicable ways to implement the best practice in a TDC. Second, it proposes some actual ways to collect various localized data, such as energy use pattern, consumers' WTP for high efficiency products and their implied discount rate. Third, this paper demonstrates an econometric method that has not been reported in the literature, to disaggregate actual market data, in which the price-efficiency relationship is often complicated by brands, sizes and other features and thus is not monotonic. Overall, through building the model from scratch, the present analysis uses first hand actual market data that were collected for this study and its methodologies could be replicable in other TDCs that have limited data, resources and capacity and for other appliances. The methodology can also be applied to determining energy efficiency standards other than MEPS.

This paper is organized as follows: after the introduction, the next section provides a background information for the Bruneian case study. Section 3 explains details on the methodology and data to allow the work to be reproduced. This is followed by empirical results from the modeling as well as stakeholders' analyses. Section 5 examines a special issues for ACs, that is, compliance of the Montreal Protocol. The last section concludes the paper with recommendations on MEPS for Brunei's ACs.

2. Energy efficiency initiatives and ACs market in Brunei

Despite the abundance of oil and gas, the high per capita consumption of energy and related CO_2 emissions post significant challenges to the sustainable development of Brunei Darussalam (hereafter Brunei). With a population of just over 400 thousand, Bruneians enjoy a high standard of living. Its per capita GDP at price in 2012 is US$ 41127 (all monetary terms have been converted into US$ unless indicated otherwise), ranked as the 19th highest in the world [24]. The high income, abundance of oil and gas, and cheap energy prices lead to a high consumption of energy and underinvestment in energy efficiency [25]. Per capita primary energy supply was 9.4 tons in 2010 and electricity consumption was around 8507 kW h in 2011, ranked 15th highest in the World [24]. According to one estimation, the average household electricity consumption was 1987 kW h/month, which is almost triple that of Singapore (784 KW h/month) [26]. The country also ranks fourth in the world for CO_2 emission per capita basis according to 2010 data [24].

Unfortunately, similar to the case of Saudi Arabia, consumers does not care much about energy saving [18]. The general economic theory of payback from investment on EE appliances is not working well as it should because electricity tariff is too low to generate attractive revenue from energy saving. Given the current energy prices level, adoption of high EE appliance but costly appliances will not be as attractive to private energy users at a market based energy price. Overall, Brunei lagged behind the region in implementing EE initiatives. Reasons could be a lack of awareness in the general public and limited human and technical capacity to initiate energy efficiency initiatives. The high income level in Brunei, however, implies that there might be a higher level of affordability to high EE products. Under this circumstance, energy efficiency initiatives need political determination.

Recently, the Bruneian government makes various plans to promote energy efficiency initiatives. In line with other APEC countries, the economy sets an ambitious goal of a 45% energy intensity improvement by 2035 (using 2005 as the base year) [27]. Energy efficiency standard & labeling (hereafter S&L) is the first and flagship energy efficiency program under development. The Brunei Energy Efficiency Standards and Labeling Order was in the process of legislation from 2014 [3].

Air conditioning appliances are selected as the first product group to be regulated under the S&L program due to its high share of electricity consumption and the significant energy saving potential. Since cooling consumes more than 60% of electricity in the residential sector and more than 70% of electricity in the commercial sector, higher efficiency ACs are expected to more than halve the energy use in these two sectors [26]. There is a high penetration of ACs in Bruneian households. On average, 85% households have ACs and each household has 3.5 ACs [28].

Although the Bruneian S&L on ACs focuses on the single split and window air conditioner, in this study, we focus on single split models only. The methodology cannot be applied to window units because there are only a few models in the Bruneian market and thus cannot be generalized to get meaningful data for the modeling analysis. According to our survey to AC vendors, in 2012, 27,968 units of single split ACs was sold by a handful AC vendors. More than 80% of ACs sold in 2012 was imported from either Malaysia or China, which have an almost equal market share. Thailand is the third largest country of origin for ACs in Brunei in 2012. The market survey also shows that inverter ACs, which is often more efficient than non-inverter ACs, only account for 16.9% of market share (Fig. 1).

Panasonic is the market leader in the Brunei market, followed by Carrier, York, Aifa, Fujiaire and General in the order of market share. Each of these brands has a market share of not less than 5%.[2] Each brand only authorizes one official supplier (vendor). But one vendor may sell more than one brand. However, none of these vendors has manufacturing activities in Brunei. Therefore, vendors' ability of adapting to the changes required by MEPS is dependent on manufacturers' capability. As long as the proposed Bruneian MEPS is not higher than those of the neighboring countries such as China, Malaysia and Singapore, more efficient models are already in the market and thus the vendors should have no difficulty to source products.

Nevertheless, as the energy efficiency patterns in the market are different, the impact of MEPS regulation will be disproportionate among brands. Some vendors may focus on low efficiency[3] products and while other vendors focus more on highly efficient ones (Fig. 2). The vendors of those relatively lower energy efficient products will face more dramatic change of models and thus should be carefully consulted.

In general, the energy performance of ACs sold in the Bruneian market is lower than those countries that Brunei's ACs are produced (Fig. 2; Table 1). The key reasons for the lower efficiency are the lack of EE S&L program and relative low electricity price. China, Singapore and Thailand have been implemented MEPS and mandatory labeling for a long time while Malaysia has a voluntary labeling for some time and its MEPS was announced in 2014 [3]. Therefore, low efficiency products from those markets are more likely to be dumped to the Bruneian market.

Despite there are plentiful predecessors, Brunei can hardly get a comprehensive reference from the literature. First, Brunei does not have EE labeling levels (product classes) which can be used as reference to set the MEPS. While other countries, such as Malaysia, China, Singapore and Thailand, have set labeling long ago and thus can set MEPS at any of the labeling level. Given a lack of reference, MEPS was initially proposed to be simply benchmarked with Singapore's [29]. However, such proposal cannot address the concerns of the stakeholders who might upset the Bruneian Monarchy who does not want to hear complaints. Second, the academic studies, such as Cardoso et al. [7], Vendrusculo et al. [14], Letschert et al. [8] often rely on many secondary data, such as cost-efficiency relationship which were not available, and do not cover many other policy issues that policy makers are concerned with, such as impact on disadvantaged households and the business sector. Third, the best practice from developed countries such as Australia and the US cannot be extended to Brunei because of a lack of local expertise as well technical and financial ability to reveal key parameters and produce prototype products. Lastly, there is no recent experience in determining initial level of MEPS without any prior EE standard or labeling foundation because most countries have initiated their set MEPS programs long ago. The recent literature of MEPS focus on either ex-post assessment of ACs, such as Grignon-Masse et al. [30], or on the industry sector, which has different characteristics from the residential sector, such as industrial motors [10,31]. Therefore, this study has explore many ways to overcome the barriers in applying the best practice to a TDC.

3. Methodology and data in the context of technically disadvantaged countries

3.1. Overview of methodology and data sources

In order to setting a MEPS level, the LCC analysis on costs and benefits, is necessary but not enough. The impact of MEPS on market prices, on low-income consumers, and on manufactures and jobs, are also key concerns for policy makers who need the public support for implementation and need to protect disadvantaged groups. With the introduction of MEPS, some low efficiency but cheap appliances may not be available and thus limit customers' choice and may even change purchasing decisions [2]. The manufactures and the business sector have to be considered to ensure MEPS's technological feasibility and availability of the higher efficiency appliances in the market [6].

This best practice to sets initial MEPS level from scratch that meets policy makers' demand in developed countries includes

[2] According to the agreement with the vendors, we cannot publish the market share data but can provide for private reference.

[3] In Brunei, EE level of ACs is indicated in Coefficient of Performance (COP), which are measured according to ISO5151 standard; and COP of inverter ACs are measured by a weighted average of 60% half load and 40% full load.

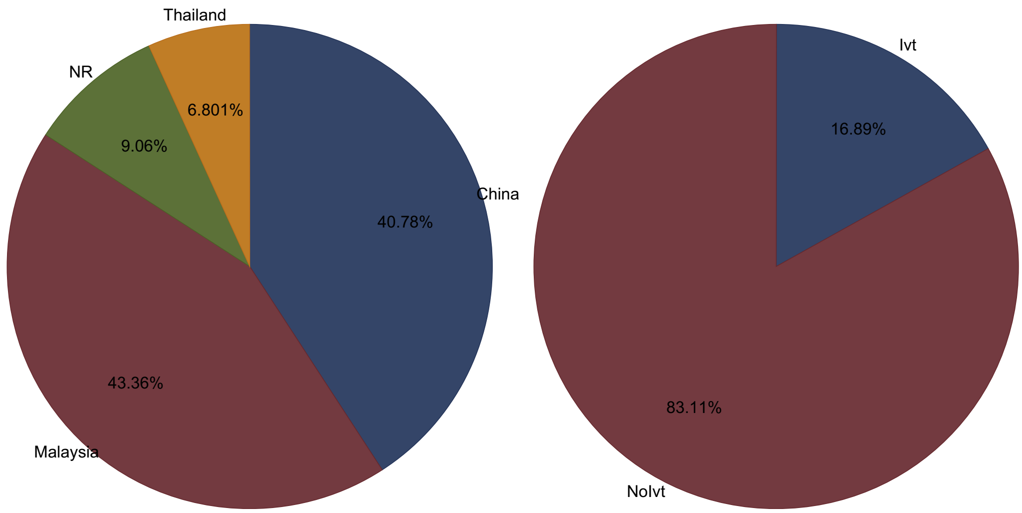

Fig. 1. Countries of origin and share of inverter of ACs in Brunei in 2012. *Source*: calculation based on the market survey data conducted for this study.

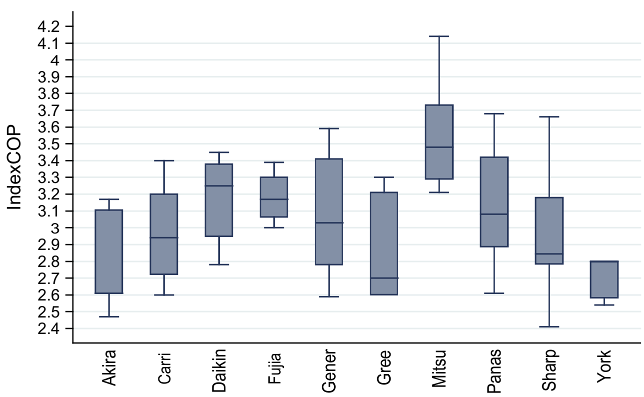

Fig. 2. Energy efficiency of ACs by brand. *Note*: some brands did not submit energy efficiency data and thus were not included here. *Source*: Author's calculation based on the market survey data conducted for this study.

comprehensive analysis such as techno-economic modeling, stakeholder consultation, survey and household impact analysis [4,6]. Despite Brunei is a TDC, we follow the best practice to ensure the quality of the policy making. The Collaborative Labeling and Appliance Standards Program (CLASP)'s Policy Analysis Modeling System (PAMS) model [32], which has been used by rigorous researchers, such as Cardoso et al. [7], Vendrusculo et al. [14], and Letschert et al. [8] in justifying MEPS levels, is adopted. This model is consistent with the LCC analysis and national impact analysis used by the US DOE in support of its rulemakings on appliance EE standards [33,6] and the model of the Australian Ministerial Council on Energy in estimating options for revising AC MEPS in 2010 [34].

The paper further explores each MEPS option by examining the impact on the business sector, the consumers and the nation. The stakeholder consultations assesses the acceptance level of vendors and builds consensus between the government and the industry. The household income impact analysis evaluates the impact on households, in particular, low income households, which is a major concern of the government. The coordination with phase out of ozone depleting gas which specifically applied to ACs was also discussed.

The key data were collected by the Authors. The data on ACs sales volume and prices by band, type (window, single split, or

Table 1
MEPS for single split ACs in selected countries. *Source*: Authors' compilation from each country's regulatory documents.

Country	Indicator	Inverter or non-inverter	Cooling capacity[1]	Minimum COP
Singapore (Up to 2013)	EER (w/w)	Inverter	<7 kW	2.96[2]
			⩾7 kW	2.64[2]
		Non-inverter	<7 kW	2.96
			⩾7 kW	2. 50
Singapore (Current)		Inverter	<10 kW	WCOP 3.34 and COP 3.06
			⩾10 kW	WCOP 2.78
		Non-inverter	<10 kW	3.34
			⩾10 kW	2.78
Thailand	EER (w/w)	All	⩽8 kW	2.82
			⩾8–12 kW	2.53
Malaysia	EER (BTU/w.h)	All	<4.5 kW	9.56–10.36 (2.80)
			⩾4.5 to <7.1 kW	8.03–8.93 (2.35)
China	EER (w/w)	Non-inverter	⩽4.5 kW	3.2 (2.6)
		(number in ( ) was up to 2010)	4.5 < CC ⩽ 7.1 kW	3.1 (2.5)
			7.1 < CC ⩽ 14 kW	3 (2.4)
	SEER (w.h/w.h)	Inverter (cooling only)	⩽4.5 kW	4.3 (3.0)
		(number in ( ) was data up to 2013)	4.5 < CC ⩽ 7.1 kW	3.9 (2.9)
			7.1 < CC ⩽ 14 kW	3.5 (2.8)

Note: WCOP: Weight COP = 0.4 $*$ Full-load COP + 0.6 $*$ Half-load COP.

others), technology (inverter or no inverter) and capacity were collected by the Author with the assistance of the Bruneian government. All ACs vendors are asked to report these data for 2012, and later for 2013. To understand consumers' WTP, a survey was conducted during the Brunei Energy Week held on 24–29 March 2014. Vendors' responses to the proposed standards were collected through individual interviews. Social economic indicators, electricity tariff were collected from public sources.

3.2. Introduction to the techno-economic model

The PAMS model examines the economic, energy and environmental impact of each of the MEPS options and recommends the favorable MEPS ones. PAMS is a spreadsheet model that informs policy makers on cost-benefit of future EE programs from two distinct but related perspectives: (1) The Consumer Perspective (unit level) which examines costs and benefits from the perspective of the individual household or enterprise. The calculation from the consumer perspective is called LCC calculation. (2) The National Perspective (national level) projects the total national costs and benefits including financial benefits, energy savings and environmental benefits.

Impact on consumers will be represented by the payback period, which is the amount of time needed to recover increased costs for higher efficiency appliances. Incremental costs and energy savings are calculated by comparing high efficiency appliances (alternative/policy case) to baseline units (base case),[4] which assumes that the proposed standards were not implemented. The Model will capture the difference between the baseline and alternatives. Detailed discussion on the methodology and user instruction can also be found at the CLASP website [35].

Input data to the PAMS model typically describe the engineering, operational, economic, and market characteristics of the energy-consuming equipment under consideration (ACs in this study), which is currently on the market or might come to market with the implementation of MEPS regulation. The key inputs to the PAMS model are: national shipments forecasts; (marginal) electricity price; Unit Energy Consumption (UEC); ACs system characteristics (engineering data); years of standards implementation; and social discount rate. Some of these data, excepted for some countries, have been included in the model either through model estimations or historical data [35] while other needs to be estimated in the subsequent subsections.

3.3. Energy efficiency classification and the baseline group

Unlike other countries in the region where labeling programs have been in place before MEPS were started, such as China, Malaysia and Singapore, Brunei does not have an existing classification of energy efficiency levels and thus we have to develop our own way of categorization. Since only a small proportion of ACs has efficiency level less than 2.6, we set the models with efficiency less than 2.6 as the baseline group.

This study aligns proposed MEPS with the MEPS that other countries are using, to minimize costs of compliance from manufacturers since the manufacturing technologies are already in use in those countries (Table 1). In addition, Singapore's higher ticks (4 ticks at 3.78) and lower one at 2.7 as technical options for producing the cost-efficiency curve. However, the group break at 4.5 kW that is adopted in China and Malaysia will not be adopted in Brunei because of the argument that this discontinuity may lead to ambiguity around the boundary size [4] and two Brunei's specific factors: (1) the AC market size in Brunei is not as huge as in China; (2) comparing with Singapore, most air conditioner in Brunei belong to the same category. As shown in Fig. 3, the most popular ACs in terms of energy efficiency level at level 2.6 ($2.60 \leqslant$ Coefficient of Performance (COP) < 2.7). The next popular efficiency level is at 2.9 ($2.9 \leqslant \text{COP} < 3$). Efficiency levels greater than 3.76 are available in the market, but comprise only a small amount of total sales. By cooling capacity, 3.5 and 5.3 kW h are the two most popular models.

3.4. Cost and efficiency relationship

The cost and efficiency relationship is the key parameter to specify the alternative MEPS levels. The relationship, named "Engineering Data" in PAMS, will be used in the LCC and PBP analyses [36]. Ideally, there is a single representative curve that shows the relationship between EE levels and costs that can be used to estimate stepwise improving EE and corresponding costs. This production costs could be further marked up to estimate consumer (market) prices. For example, the US DOE developed the EE and costs relationships through a bottom up approach: developed a prototype equipment, listed possible EE improvement designs (technical analysis), got feasibility (screening analysis) and costs information of each EE level from manufacturers, and inferred the final market prices through markups [6]. Creation of prototype product in this method is expensive, time consuming and needs detailed manufacturing information, which is often not available in TDCs, including Brunei. Since more than 40% of Brunei's AC products are sourced from China, and the cost-efficiency data for China's ACs have been reported recently, the Chinese data could be a useful approximation of the Brunei market.

The second way that has been used is to construct the curve through aligning the different EE of existing models in the market, which has been used in a Chilean case study [8]. By picking the lowest cost AC at each efficiency level as representative of the "base" engineering cost (with markup), it may be possible to correct roughly for the brand effect and approximate the manufacturer's decision making process. However, it will still not be possible to exclude the price difference due to other different features, notably size difference.

In constructing the Bruneian engineering data, we proposed to use econometric regression on the data of models with different price and efficiency level, but the same size,[5] to find a function that best fit these data and then forecast price of each hypothetic efficiency level (Eq. (1)).

$$\ln(\text{price}) = \alpha + \beta \ln(\text{COP}) + \varepsilon \quad (1)$$

where $\ln(\text{price})$ is the market price of the model while $\ln(\text{COP})$ is its energy efficiency level. Where α is a constant and ε is an error term. Although there might be different price strategies for different brands, this regression will minimize the impact of such non-technical issues.

The data used are survey data of the Bruneian AC market. Since 3.5 kW and 5.1 kW are the most popular size (Fig. 3), their data are used as representative of Bruneian AC market. We ran separate regression for AC models at the two different sizes to control the effect of size on prices. The estimated parameters are reported in Table 2.

This method is better than linear prediction of the cost –efficiency curve that is used in the Australian case [4], which failed to account for increasing marginal costs of manufacturing higher efficiency products. Compared with the engineering data used in

[4] The baseline may also have some energy savings. Natural energy efficiency improvement of ACs and declined or product prices could lead to adoption of more efficient ACs.

[5] Ideally, the brand should also be identical. However, it is difficult to find all the necessary models from one single brand. Nevertheless, the application of econometric method can remove random brand effects and thus minimize brand bias.

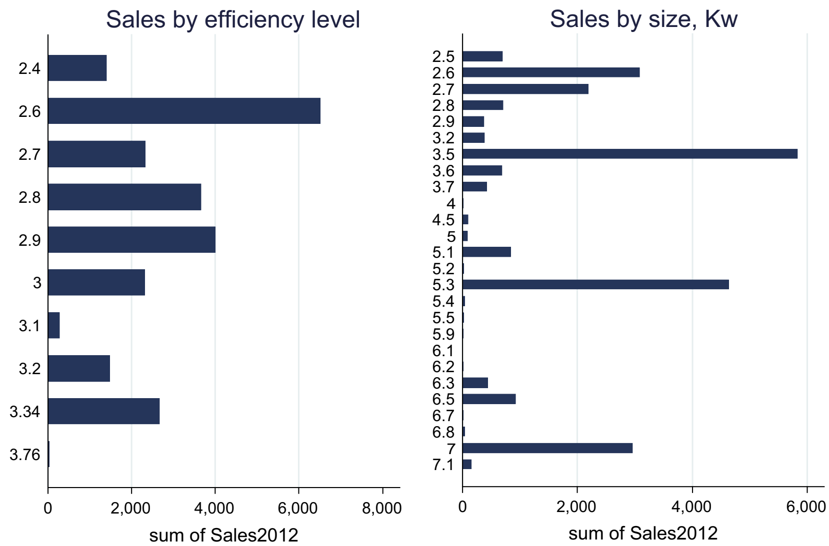

Fig. 3. ACs sold in 2012 by efficiency level and size. *Source*: Author's estimation based on survey data.

Table 2
Estimated cost-efficiency relationship.

	China data		BN 3.5		BN5.3	
	Coeff	Std Err	Coeff	Std Err	Coeff	Std Err
Dependent variable: ln(price)						
Efficiency (ln(COP))	2.35***	0.11	2.1***	0.18	1.34***	0.43
Constant	3.86***	0.15	3.79***	0.2	4.95***	0.48
Number of observations	24		16		11	
R2	0.96		0.9		0.52	

Note: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

the previous studies [35,6], this methodology is cost effective, is convenient to apply, and has no implicit assumption on percentage of markups. It can also generate a representative engineering data when price and efficiency level are not monotonic. This method, however, cannot be traced back to technical designs and thus we do not know which of those designs cause a cost and performance difference.

According to the method suggested by the PAMS model [35], the most popular model from the baseline group (COP < 2.6), York TLEA/TLDA09 model (with a COP of 2.52) is chosen as a baseline unit. The baseline prices in each case are: $313 for 3.5 kW in Brunei, and $492 for 5.3 kW in Brunei. To combine the results from

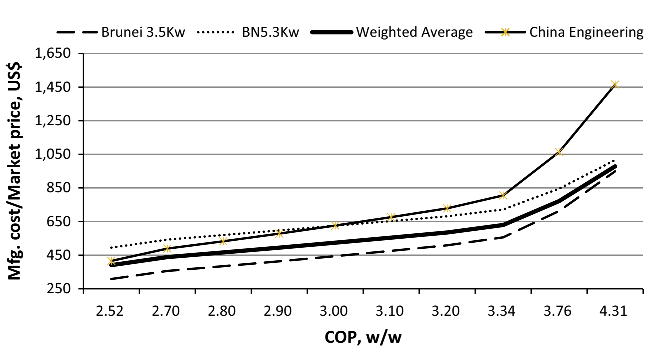

Fig. 4. Price-efficiency curve for single split ACs in Brunei market. *Source*: The Bruneian Data was estimated from market survey data. The Chinese data was estimated by the model based on original engineering data from Shah et al. [37].

the two representative sizes, we averaged the two estimated prices using their sales volume as a weight. The price-efficiency curve, rescaled as relative to basic unit, is shown in Fig. 4. The lower average price of Brunei's ACs than that of China's ones at any given level could be due to different in size of the representative units.

3.5. Energy use analysis and other data inputs

The energy use analysis is to determine the annual energy of ACs at specific efficiency levels. We assess the energy use of the basic unit, which has an energy efficiency level of 2.52. Based on the survey, the average size of all model of split ACs sold in Brunei market are 4.55 kW. The rated power input is obtained by dividing the cooling capacity by COP.

However, ACs will not operate at full load all the time. Based on a previous measurement [29] and consultation with energy experts and AC engineers during a stakeholder meeting, we take 70% as the load factor.

Based on surveys of energy and AC experts during a stakeholders' consultation meeting, and confirmed by the Department of Electricity Services (DES, the national utility company), the mean daily operation time of residential ACs is set at 10 h. Furthermore, in a country with little temperature variation across the year, AC usage pattern is assumed to be the same across the year. The parameters and result is shown in Table 3.

However, we do not expect all the ACs to run continuously all around a year. One fact is that only 65,437, or about 80% of the resident premises are usually occupied [38], which means by household, 20% ACs will not be run. Even in those occupied houses, not all ACs will on an average be used. Given these concerns, we consider one additional scenarios of 80% of the national average UECs.

The sales and stock forecast which were generated in the PAMS model [35] were calibrated using the 2012 sales data. The historical and future stock was inferred using the growth rate implied in the original data in the PAMS model, which is 2% up to 2015 and 1% from 2016 to 2030.

The electricity tariff is set at 0.06 $/kW h, which is corresponding to the tariff at the step 600–2000 kW h per month published by the DES [39]. Based on the historical average growth rate of GDP between 1983 and 2012 [24], the annual income growth is assumed to be 2%. The life time of ACs was set at 10 years, 2 years

Table 3
Electricity consumption for the baseline unit.

Cooling capacity (1)	COP (2)	(Rated) Electric Power Input (3) = (1)/(2)	Operational time		Load factor (6) %	Annual electricity consumption, kW h (7) = (3) * (4) * (5) * (6)
			Hours/day (4)	Days/year (5)		
4.55	2.52	1.81	10	365	0.7	4625

Table 4
Other inputs to the PAMS model.

Input	Value	Remark (source of information)
CO_2 emission factors for electricity production	0.798 kg per kW	2010 data [40]
Electricity price (for residency)	US$.064 (BD$ 0.08)	DES
Consumer discount rate (for individuals)	10%	PAMS model [35]
National discount rate	7%	US DOE [6], EEEC [4]
Transmission loss	4.86%	2011 data [24]
Electrification rate	99.7%	2010 data [24]
Life time	10	Cardoso et al. [7]
Income growth	2% yearly	Historical average [24]
Exchange rate	1US$ = 1.25 BN$	2013 average

lower than assumed in the literature [7,37] for the consideration that ACs are run all the year and thus will have short life span than those used seasonally. The CO_2 emission factors for electricity production was take from IEA [40]. Other inputs are summarized in Table 4.

4. Empirical results

This section presents the results from the PAMS model and the stakeholders' impact analysis and consultations. The Bruneian weighted average cost and efficiency relationship was used for the major calculations while the Chinese engineering data was used to check the robustness of the results. Since the results are sensitive to consumer discount rate and UEC, we take 80% UEC and 10% discount rate as the reference scenario for the analyses.

4.1. Identify the favorable MEPS options: Unit level analysis

The favorable MEPS level should at least have no-negative savings with acceptable payback period [35]. Table 5 shows the LCC analysis results for seven sets of possible MEPS levels. The MEPS levels examined was taken from those standards that are either being used, or have been used in countries related to Brunei's AC markets: China, Malaysia and Singapore (Table 1). At the reference case, the projected economic impacts of the new standards on individual consumers are positive and payback periods are between 3.41 and 4.39 years. With the increase of MEPS, there is a monotonic increase in LCC savings. These results tend to support the highest MEPS level among the candidates.

However, a higher discount rate will challenge the preference. Although 10% discount rate is used for the reference case, there is an argument that consumers regularly ignore operating costs and usually have an internal discount rate of 20–50% in choosing EE equipment [4]. Such myopic behavior can be explained by reasons such as uncertainty over future energy savings, hidden costs such as searching costs for new products, and the irreversibility of investments [41]. We apply a mid-level point of the observed discount rate (20%), which is also frequently demonstrated in the literature [20], to check the results. In this case, MEPS2.9 delivers the highest LCC savings, followed by MEPS2.8, and MEPS2.96 while MEPS 3.34 will result in negative LCC savings (Table 5).

Table 5
Estimated impact of different MEPS options at unit level.

Data source	MEPS options Efficiency improvement	2.8 11%	2.9 15%	2.96 17%%	3.00 19%	3.1 23%	3.2 27%	3.34 33%
Brunei Average Data								
	Cost addition (%)	19	27	31	34	42	50	61
100% UEC	Payback Year	2.73	2.87	2.95	3.01	3.15	3.3	3.51
	LCC savings (10%)	95	119	132	139	155	168	180
	LCC savings (20%)	23	26	26	25	22	16	4
	LCC savings (30%)	10	8	6	4	−3	−12	−28
80% UEC	Payback Year	3.41	3.58	3.69	3.76	3.94	4.12	4.39
	LCC savings (10%) (reference case)	61	74	81	85	92	95	96
	LCC savings (20%)	17	18	17	15	10	3	−11
	LCC savings (25%)	4	0	−4	−7	−15	−26	−44
China EE Data								
	Cost addition (%)	28	39	46	51	63	75	94
100% UEC	Payback Year	4.2	4.46	4.63	4.74	5.01	5.3	5.72
	LCC savings (10%)	54	61	63	63	59	50	29
	LCC savings (15%)	23	20	16	13	0	−17	−48
80% UEC	Payback Year	5.25	5.58	5.78	5.92	6.27	6.63	7.5
	LCC savings (10%)	20	16	12	8	−5	−23	−55
	LCC savings (12%)	9	2	−4	−10	−26	−46	−82

Table 6
Estimated national benefits of various MEPS options.

MEPS options		2.8	2.9	2.96	3	3.1	3.2	3.34
Electricity costs saving through 2030, Mn$		36.4	47.7	54.2	58.3	68.2	77.4	89.4
Increased costs through 2030, Mn$		17.6	24.2	28.3	31.1	38	45.2	55.6
NPB (Mn $) through 2030		18.8	23.5	25.9	27.2	30.2	32.2	33.8
Site energy saving	in 2030 (GW h)	106	139	158	170	199	226	261
	through 2030 (GW h)	1010	1324	1502	1617	1890	2147	2480
Source energy saving	through 2030 (Mtoe)	0.30	0.40	0.45	0.48	0.56	0.64	0.74
CO_2 emissions mitigation	through 2030 (MT)	0.85	1.11	1.26	1.36	1.59	1.80	2.08

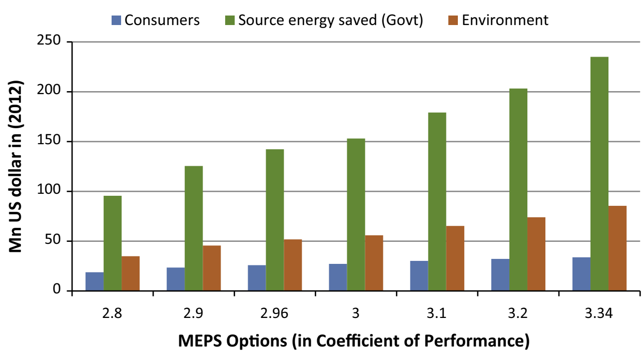

Fig. 5. Benefits of consumers, government, and the environment through 2030.

Table 7
Non-compliant models and volume under proposed MEPS options.

MEPS	Sales (Units)	Models (#)	Non-compliance volume (%)	Non-compliance models (%)
2.70	2335	13	32	17
2.80	3662	9	41	32
2.90	4007	9	56	41
2.96	3992	8	72.5	50.0
3.00	2315	3	73	51
3.10	279	7	82	54
3.20	1483	16	83	62
3.34	2668	17	89	79

Source: Author's calculation based on the market survey data.

The robustness analysis offers additional information. As for with China's data in the case of 100% UEC scenario, the payback period will be more than 5 years while more than two third of responses in our survey would not accept a payback period of more than 5 years. This means that MEPS should be set not more than 3.0.

The estimated impact on the government and the environment will be discussed in the following subsections, while the factors that are not captured by the model, such as the opinions of consumers and vendors will also be discussed.

4.2. National impact analysis

The results of national impact assessment are summarized in Table 6 for each of the evaluated alternatives. All results are calculated relative to the baseline case. The start year of MEPS is set at 2015 and all the prices are calculated in 2012 US Dollar.

All the alternatives will result in significant energy savings and in positive net present benefit (NPB) compared to the base case (Table 6). The total amount of energy the MEPS standards will save throughout 16 years is equivalent to 11.5–29.4% of total primary consumption in 2012. At MEPS2.9, the annual savings of electricity would be 82.8 GW h (correspondent to 1324 GW h total savings in the period of 2015–2030), which is equivalent 2.2% of electricity consumption of total 3725 GW h in 2012 [26].

Compared with customers' benefits, the government benefits are much higher. When estimated at natural gas price of $8 per million BTU and a 7 percent discount rate, the source energy saving are ranging from $95.6 million (MEPS 2.8) to $235.0 million and more than four times that of the consumers' NPVs (Fig. 5). This is expected since electricity is heavily subsidized. The avoided subsidy payment may be able to cover the full incremental manufacturing costs of more efficient products and thus the government could promote market transformation without additional costs and without change of electricity subsidy policy [42]. That is to say, the government can redistribute some of its fiscal benefits to consumers through such policy as rebate or subsidies for energy efficient products. In addition, the energy savings produced by MEPS will have significant positive environmental benefits. When evaluated at US Social Cost of Carbon (SCC, $41/ton) [6], the environmental benefits are much higher than consumers' benefits.

4.3. AC vendors' impact analysis

The expected market transformation resulting from MEPS has to be carefully evaluated. If the MEPS is set at 2.9 or above, more than a half of sales volume and more than 40% models (according to 2012 market data) would be wiped out from the market (Table 7). Such a dramatic market transformation will hardly be supported by any practical guidance or theory. As a reference, China MEPS revisions in 2012 was generally aimed at only eliminating the bottom 20%, or least efficient models from the market [43]. This is due to the large domestic manufacturing capacity in China, which cannot be changed dramatically.

Even if vendors could introduce more efficient models and pass the costs to the consumers, the difference in models and performance of the new models may change the competitiveness of their products and thus some of these vendors may lose their market share. Previous studies have shown that, due to price discrimination, with the introduction of MEPS, discontinuous price drops occur in the market because prices in mid-low efficiency segments of the market are more likely to drop, rather than increase [44]. While this finding is good news for consumers and policy makers, it is a bad news for vendors as they will loss profit margin in many of their existing products.

To build consensus from the business sector, those vendors who are likely be affected by the MEPS were interviewed. Vendors whose products have high efficiency, however, were not interviewed since they are unlikely to be adversely affected by MEPS regulation. This is also a practice that was used by the US DOE [6]. Seven vendors who represented 12 brands and more than 90% of sales volume in 2012 were interviewed (Fig. 6).

The interviews imply that phase out of a large market volume could be possible and the practice of removing 20% sales in China and Singapore could be conservative for Brunei's case. The majority of vendors are open to any level of MEPS and are ready to replace all their existing models with higher efficiency models

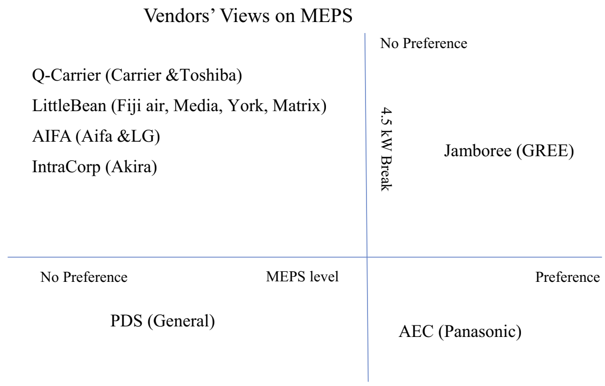

Fig. 6. Vendors' views on AC MEPS. *Note*: worlds in () are the brand that the vendor is sailing.

Table 8
Estimated incremental equipment cost on household expenditure.

MEPS options	Incremental prices	Annual expenditure of household (%)	
		Average (%)	Lowest income (%)
2.7	47.9	0.17	0.39
2.8	75.7	0.27	0.62
2.9	104.2	0.37	0.86
2.96	121.5	0.44	1.00
3.0	133.4	0.48	1.10
3.1	163.5	0.59	1.35
3.2	194.3	0.70	1.60
3.34	238.7	0.86	1.97

Note: The incremental prices were estimated based on the regression of market data as in Section 3.2. By the estimation, the baseline unit (with a COP of 2.52) is US$391.

which are already available in other markets. One reason for this higher level of acceptance could be that the market segmentation is expected to be stable and thus vendors do not have to worry about losing market share as long as there is a level playing field for all the vendors. Furthermore, if price hike does happen, higher costs mean higher margin to vendor as well. Another reason is that vendors have anticipated the changes and have introduced more efficient products.

The third reason for the high flexibility could be that most low cost brands often use Original Equipment Manufacturer (OEM) and thus can adjust their models without bearing costs of adjustment. Actually, most OEM brands are manufactured in China where domestic MEPS is already at 3.2 level and thus manufacturers do not need to make any additional efforts for producing higher efficiency products. On the contrary, production costs could even be reduced due to the economies of scale in the manufacturing of high efficiency products [45].

Fourthly, compliance cost, a major concern of vendor has been cleared by the design of the regulatory framework. The draft <Energy Efficiency Standards and Labeling Order, 2014> proposes to set a regime that does not require any additional test of products and does not charge any administrative costs to vendors [3].

Lastly, the observation that AC models often last only 1–3 years [4] will further mitigate the impact of removing noncompliance models on consumers.

4.4. Households' impact analysis

Although Brunei is a rich country, the need to make MEPS feasible and affordable for the lower income groups to purchase energy efficient appliances is still outstanding since the Sultan

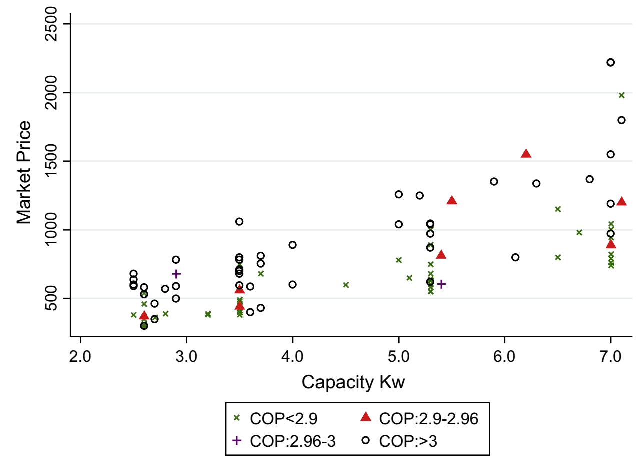

Fig. 7. Market prices of ACs models with different capacity and efficiency level. *Sources*: Author's calculation from the market survey data.

does not like complains. We found that there is no particular type of product/feature/product size that is removed from the market by the introduction of MEPS, i.e., the models available that meet MEPS will still meet a wide range of consumer requirements.

We analyze the price impact on consumers under two typical scenarios: (1) customers stick to their original brands; and (2) customers switch to cheaper brands. In the first scenario, we found that given the high income level in Brunei, the price impact to customers is manageable. According to the <2010/2011 Household Expenditure Survey>, the average monthly household expenditure in 2010/11 was BN$ 2895 while the average monthly household expenditure for the lowest 10 per cent of households by income was 1265 BN$ [28]. Assuming the MEPS is set at a high end of 3.34, the maximum increase of equipment costs, given everything else, including brand is equal, is BN$ 238.7 (1US$ = BN$1.25), about 0.86% and 1.97% of annual household expenditure of the average household and the lowest income household, respectively (Table 8). This low percentage demonstrated that first cost barrier to EE products, which are prevailing in the literature [42], is unlikely to present in Brunei.

In the second scenario, the impact of incremental cost due to MEPS, even at modest levels as shown in the first scenario, can be further mitigated. Fig. 7 shows that, without considering brand difference, at each cooling capacity levels, high efficiency (COP more than 3) but cheap ACs are always available in the market. For example, ACs with COP 3 but have market prices at the lowest level exist in all the four popular capacity levels. This finding is consistent with some previous studies which find that price did not relate to the efficiency of the product [16,46].

This means that if consumers are sensitive to the price and can switch to cheaper options, MEPS will not affect them too much.

This impact might be further mitigated in the future when efficient products gain market share and thus economic scale and competition will bring their prices further down. There is evidence that MEPS do not raise the price of the regulated appliance. In the case of Japan, the stringent Top Runner standard actually led to increased competition and a drop in prices [44]. A US case study [5] also identifies that purchase cost of fridges went down after the introduction of MEPS. Previous studies also show that even without efficiency change, the average market price of regulated products will go down, and not increase, due to price discrimination strategy of firms [44]. Historical data in the past several decades also demonstrate that manufacturing costs and residential prices of efficient appliances have declined, a phenomena that is empirically modeled as an experience curve [45]. For these reasons, our price impact analyses are conservative.

Table 9
Key factors that influence purchase of an air-conditioner.

#	Answer	Percentage Bar	Response (out of 110)	%
1	Brand		76	69%
2	Technical specification		55	50%
3	Price		78	71%
4	Payment terms (e.g. cash, installment, etc)		5	5%
5	Recommendation from friends or relatives		6	5%
6	Salesman's influence		3	3%
7	Warranty period		42	38%
8	Commercial advert		3	3%
9	Energy label		59	54%
10	Others, please specify:		3	3%

Source: Survey conducted during the Brunei Energy Week 2014 (24–29 March).

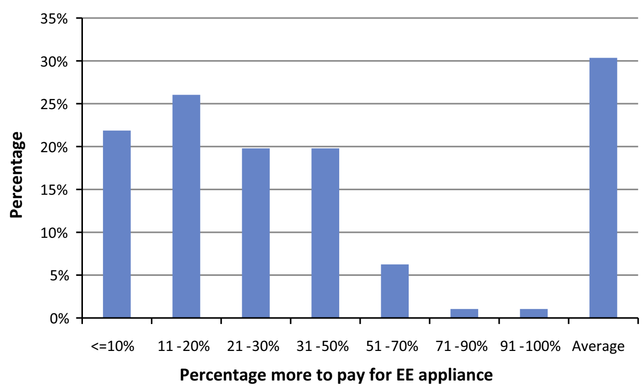

Fig. 8. Consumers' willingness to pay (additional, %) for energy efficient appliances. *Source*: Survey conducted during the Brunei Energy Week 2014 (24–29 March).

To understand consumers' WTP, a survey was conducted during the Brunei Energy Week held on 24–29 March 2014. Visitors to the event were invited to fill an online questionnaire. Two questions that provided data for the analysis are "Which factor encourages you to purchase energy efficient appliances the most?" and "How much more (in terms of percentage of prices) are you willing to spend on energy efficient appliances?" More than 100 effective responses were recorded. While this survey may suffer from sample selection bias, it is the first attempt in Brunei to collect the information necessary for making the decision on MEPS of ACs. As shown in Table 9, Brunei consumers place price as their top concern in choosing an AC product, which can further mitigate the potential price impact.

In addition, according to the survey, among 96 responses, the average price premium Bruneian consumers are willing to pay for more efficient products is about 30% of its non-efficient counterpart (see Fig. 8), which is the same as the Swedish consumers, higher than the Chinese consumers (less than 10%) but lower than the average European consumers (44–50%) [17]. Our findings of WTP is reasonable when considering the relative income levels among consumers in China, Brunei and European. Given this WTP, we expect the increased costs should not go beyond US$119, which indicates a maximum acceptable MEPF level of 2.9. To summarize, this study suggests MEPS of 2.9 as a highest conservative target and 3.0 as the highest recommendable target.

5. Coordination with phase-out of ozone depleting refrigerants

In the case of ACs, one additional factor has to be considered is the coordination with the implementation of the Montreal protocol, which will limit the use of refrigerants. The setting of MEPS is closely related to the Montreal protocol and a dramatic market transformation strategy may be needed. Currently, all the non-inverter ACs in the Bruneian market are using HCFC 22 (R22) as refrigerant (HCFC). Due to its significant Ozone Depletion Potential (ODP) and Global Warming Potential (GWP), the Montreal Protocol mandated to gradually reduce consumption of HCFC refrigerant since 1996 until its total abolition in the advanced countries by 2020 and the developing world by 2030.

China and Malaysia, the major manufacturing bases for Bruneian ACs, have started to control the manufacturing of R22 ACs. China has gradually reduced the use of R22 through allocating quota of R22 [47] and replacing R22 by R290 in AC industry [48]. Malaysia prohibits the production and import of R22 ACs below 7.1 kW from 1 January 2015 (Malaysia Department of Environment [49]). Brunei has banned importation and installation of HCFC based room AC equipment for government projects.

Those alternative refrigerants being commercialized, such as R410A, R32, R290, L41, DR5 and ARM series, have seen significant improvement in the efficiency scale of ACs. For example, the R290 based ACs sold in India satisfies the 5 star rating (COP of 3.1) for energy labels [50]. One possible reason is that one of the criteria in developing these alternatives is energy efficiency.

If Brunei implements the Montreal Protocol plan as scheduled and ban the import of ACs with R22 refrigerant, ACs with COP less than 2.9 will unlikely be existing in the market because high efficiency of the R22 alternatives [50]. With these concerns, MEPS candidates lower than 2.9 are not recommended.

6. Conclusions and policy implications

From the policy makers' perspective, setting MEPS requires consideration of various factors, including both technical and economic analyses, life cycle cost-benefits analysis, impact assessment on various stakeholders, and stakeholders' consultation. Such a best practice requires strong technical and financial capacity and data availability, which are often absent in TDCs. Those TDCs, however, are the main stream countries who do not have MEPS regulations. An application to TDCs thus have important academic and practical policy values.

This study demonstrated how to overcome those barriers to apply the best practice to TDCs using the actual experience in setting initial MEPS for Air Conditioners (ACs) in Brunei from scratch with limited secondary data as an example. Innovations for this study including definition of baseline unit, construction of cost-efficiency relationship, consultation with stakeholders, assessment of impact on consumers, and calculation of unit energy consumption; as well as revealing of key data such as consumers' discount rate and WTP through first hand activities. Surveys and interviews to both vendors and consumers were employed to collect some key data that were not available.

In the Bruneian case, the various MEPS options proposed and modeled result in varying amounts of impact on energy savings, CO_2 emissions, consumers, industry and government. Despite low electricity prices, the high intensity (all year around) of usage makes highly energy efficient ACs economically attractive to rational customers. The LCC analysis on unit product level suggests that all MEPS levels could lead to significant LCC savings while COP 2.8, 2.9 and 2.96 are desirable MEPS levels with 2.9 being the most robust to different discount rates.

Considering the robustness of LCC analysis, coordination with phase out of ozone depleting gas, and the impact on vendor and consumers, COP 2.9 is recommended to be the initial MEPS level. Interviews with vendors reveal that the industry welcomes the MEPS proposal, as they are open to various MEPS options. Further analysis on Montreal Protocol suggests that MEPS should be set, not lower than 2.9. A consumer subgroup analysis indicates that the incremental costs only account for a small proportion (less than 2%) of annual expenditure for the lowest 10% households by income. Therefore, this study suggests that Cop 2.9 to be the initial MEPS for Brunei and implies that Brunei can achieve 15% energy savings without shocks to the society. It worth to note that the methodology proposed in this study can also be applied to setting MEPF for other appliances in any TDCs.

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