Research Article

Socio-Economic Benefits of CO_2 Mitigation Pathways to NAMAs in Thai Residential Sector

Nichapat Kongwanarat and Bundit Limmeechokchai*
Sirindhorn International Institute of Technology, Thammasat University Rangsit Campus, Khlong Nueng, Khlong Luang, Pathum Thani 12120, Thailand

Abstract

As part of an international effort to stabilize the global temperature, the concept of Nationally Appropriate Mitigation Actions (NAMAs) was generated and materialized to serve as a platform for developing countries to take part and show their commitments in greenhouse gases (GHGs) reduction. This study explores socio-economic benefits of two pathways in which NAMAs can be realized in Thailand's residential sector. Scenarios in the first pathway, called NAMA, are subjected only to CO_2 emission constraints, and in the second pathway, called NAMAe, are subjected to both CO_2 emission and energy demand constraints. In each pathway, there are three scenarios with low (L), median (M) and high (H) CO_2 reduction targets. The AIM/Enduse, which is a cost optimization model, is chosen to carry out the analyses of CO_2 mitigation, energy demand and average abatement cost (AAC), which are the economic benefits. The social benefits of each scenario are judged using a mathematical expression to predict the future Human Development Index (HDI) score that would result from the mitigation in each scenario. Results show that more efficient technologies are adopted in the NAMAe scenarios causing their energy demands to be lower than the NAMA scenarios by about 1%; however, there is no difference in the amount of CO_2 reduction between the two pathways. The NAMAe-M scenario shows the highest amount of energy demand reduction of 10.4% in 2020 when compared to the BAU scenario. Among the energy efficient scenarios, NAMAe-L is predicted to result in the highest HDI scores of 0.687 in 2020.

Keywords: CO_2 mitigation; NAMAs; Human Development Index; Thailand's residential sector; AIM/Enduse

1. Introduction

1.1 Background of NAMAs

The concept of Nationally Appropriate Mitigation Actions or NAMAs was first originated in the Bali Action Plan in 2007 during the 13th Conference of the Parties (COP13) [1]. From the brief mentioning of NAMA in COP13, it has, now, evolved into a mechanism for developing countries to get international support, show their commitment in reducing Greenhouse Gas (GHG) Emissions, and share their knowledge on GHG mitigations.

During COP15 in 2009, the Copenhagen Accord mentioned NAMAs with international support for the first time. This was referred to as 'supported NAMA' which also implied that countries can implement NAMAs without international support [2]. These two types of NAMAs – internationally supported and domestically supported NAMAs – were explicitly distinguished in the

***Correspondence** : bundit@siit.tu.ac.th
DOI 10.14456/tijsat.2016.16

Cancun Agreement during COP16. Furthermore, the Cancun Agreement stated that the common goal of NAMAs is a deviation of emissions relative to the 'business as usual' emissions in 2020 [2].

Another important outcome of COP16 is the recognition "*that deep cuts in global greenhouse gas emissions are required to hold the increase in global average temperature below 2°C above pre-industrial level*" [3]. The 2°C threshold is reported in the IPCC's Fourth Assessment Report as a temperature limit that would cause an irreversible impact on climate change if it was to be exceeded. To avoid this catastrophic impact, developed countries have to reduce their emissions by 40% below the 1990 levels by 2020; and the developing countries have to take actions that would significantly reduce their emission levels [2]. Thus, NAMAs serves as a platform for developing countries to contribute to this global effort.

A NAMA pledge submitted to the UNFCCC is not legally binding and is completely voluntary [4]. However, it can be included into a COP decision later on if a country wishes, thereby becoming legally binding. The scope of NAMAs has not been identified and it is left to the discretion of each country to come up with suitable actions for their specific circumstances. It is also emphasized that the mitigation actions must be suited with each country's social and economic conditions and that social and economic development as well as poverty eradication are the first and overriding priorities for developing countries [2]. Thailand communicated its NAMA pledge to UNFCCC in December 2014.

1.2 Current situation of Thai residential sector

In 2011, Thailand's final energy consumption amounted to 70,562 ktoe which was an annual average increase of 3.6% from 2005. Petroleum products, mostly consumed in the transport sector, had the highest consumption share of 57.6%. The second most consumed fuel was electricity at 22.1%; and traditional biomass and renewable fuels accounted for 18.6% of the total consumption. Natural gas and coal products covered the rest of the consumption needs [5].

Out of all economic sectors in Thailand, the residential sector was the third biggest energy consuming sector after transport and manufacturing in 2011. The residential sector consumed 22% and 40% of the nation's electricity and liquefied petroleum gas (LPG) demand, respectively. In addition, the residential sector alone consumed 88% of wood and was the sole consumer of charcoal [5]. These traditional biomass fuels and LPG are consumed almost entirely for the purpose of food preparation.

Thailand's residential sector can be divided into three areas which are 1) the rural area, 2) the municipal area and 3) the greater Bangkok area. In 2011, rural households consumed 75% of the sector's total demand. These residences consumed most of the traditional biomass and LPG. As for electricity, the majority of the consumption needs were from the greater Bangkok residences.

Thailand's residential sector is one of the key players in reducing the amount of electricity consumption and emissions related to electricity production. Moreover, the residential sector can play a significant role in the conservation of traditional biomass fuels and LPG. Thus, it is essential for energy management programs involving the use of electricity, LPG and traditional biomass to target the residential sector in order to obtain a successful outcome.

This study proposes to investigate the socio-economic benefits of two approaches to NAMAs for Thailand's residential sector through energy modeling. The first approach is to restrict only the amount of CO_2 emissions. The second approach would restrict the amount of CO_2 emissions and the amount of traditional biomass demand. For each approach, three scenarios are constructed with low, median, and high CO_2 reduction level. The economic benefits of each scenario are judged through the use of the average abatement cost (AAC); and the social benefits are quantified using the Human Development Index (HDI).

The HDI is selected in this study as a social indicator for NAMAs because of its strong connection to the consumption of traditional biomass. The HDI consists of three components which are longevity, educational attainment and income [6].

Extensive use of traditional biomass can bring down the HDI score as it negatively impacts the health and the living standards of the population. Incomplete combustion of biomass releases toxic fume which can cause acute respiratory infection (ALRI), chronic obstructive pulmonary disease (COPD) and lung cancer [7-8], thus reducing the life expectancy of the population. Moreover, gathering biomass fuel for daily use also leaves little time for women and girls, who usually perform this task, to go to school or engage in activities which generate income [9].

This study also seeks to establish the mathematical relationship between the HDI and the amount of biomass consumed in the residential sector and show how it can be used to evaluate the social benefits of energy policy.

2. Methodology

An energy model of Thai residential sector is created using the AIM/Enduse model. The study period begins in 2005 and, to be consistent with the NAMAs project, ends in 2020.

Results for energy demand and CO_2 emissions are given directly by the model. The AAC is calculated based on the model results. To quantify the social impact of policies in each scenario, the relationship between the HDI and the demand of biomass fuel in the residential sector is developed.

This section describes how the model is constructed and how the HDI is mathematically linked to biomass consumption.

2.1 AIM/Enduse Model

The AIM/Enduse is one of the models in the Asia-Pacific Integrated Model or AIM family, which are a set of models developed for climate and environmental policy assessment [10]. The model was developed by the National Institute for Environmental Studies, Japan, and Kyoto University

The structure of the AIM/Enduse can be divided into three components which are energy, energy technology and energy service. These components simulate how energy goes from its source and reaches the end-users. The energy technology consumes energy in order to produce energy service; and the energy service is utilized by the end-users.

The model is a recursive dynamics optimization model which seeks to minimize the cost of each energy scenario. Given constraints such as CO_2 emission and energy demand limits, availability of technologies, and energy service demand, the model selects a set of technologies which has the lowest combined total costs. These costs are initial investment cost, operational cost, emission tax and energy tax [11].

This study only looks at policies which promote the use of efficient technologies in households. Thus, the energy model is set up so that there are at least two technologies which can provide the same energy service. The technologies can be categorized as existing, efficient and advanced technology where the advanced technology has the highest efficiency, therefore consuming the least amount of energy followed by the efficient and existing technology, respectively. Advanced technology also has the highest investment cost.

For each energy service, the model selects a combination of technologies to satisfy the minimum cost objective. The technology selection is also subjected to technology availability, and emission and energy service demand constraints.

2.2 Model structure

The residential sector model is divided into three areas which are 1) Bangkok, 2) municipal and 3) rural area. Each household consumes six energy services including lighting, heating, cooling, entertainment, cooking and others. The appliances which are available for each service are listed in Table 1 and Table 2. Existing technologies are also available for all appliances but are not shown in the tables for simplicity. From Table 1, efficient lamp refers to T5 lamp; and advanced lamp refers LED lamp. For water heater, the advanced technology is the solar water heater; and, for television, the efficient technology is the LCD television.

2.3 Scenario descriptions

This study involves seven scenarios in total. The first is the business-as-usual (BAU) scenario, in which, only existing appliances are available. The other six scenarios can be categorized into two sets representing two pathways to NAMAs. The first set is referred to simply as NAMA and the other as NAMAe.

In the base year 2005, the model is constructed so that the energy demand closely follows *Thailand Energy Situation 2005* [12]. In the BAU scenario, electricity demand of the residential sector is forecasted by multiplying the forecasted electricity output of the power sector in [13] with the electricity consumption share of the residential sector in [14]-[18]. After 2010, the average share is used to forecast the electricity demand. Other fuels are forecasted by keeping the same fuel mix as 2010.

The NAMA and NAMAe scenarios contain three sub-scenarios with three levels of CO_2 mitigation. The mitigation levels of the sub-scenarios are low (L) with 7%, median (M) with 15% and high (H) with 20% of CO_2 reductions from the BAU scenario in 2020. The NAMA scenarios are subjected to CO_2 emission limits; and, the NAMAe scenarios are subjected to both the CO_2 emission and energy demand limits so that the biomass fuel demand does not exceed the demand forecasted for the BAU scenario. In short, the energy efficient scenarios are NAMA-L, NAMA-M, NAMA-H, NAMAe-L, NAMAe-M and NAMAe-H.

To make each scenario more realistic, constraints are put on the availability of efficient and advanced technologies as shown in Table 1 for electrical appliances and in Table 2 for non-electrical appliances. In Table 1, the remaining technology shares are filled by existing technologies. Technologies in Table 2 provide the same service; this, to give the model room to choose, the sum of the availability is more than 100%.

Table 1. Electrical appliance availability in 2020.

Service	Technology	Low mitigation		Median mitigation		High mitigation	
		EFF	ADV	EFF	ADV	EFF	ADV
Lighting	Lamp	15%	10%	30%	10%	40%	20%
Cooling	Fan	15%	-	30%	-	40%	-
	A/C	15%	-	30%	-	40%	-
	Fridge	15%	-	30%	-	40%	-
Heating	Pot	-	-	15%	-	30%	-
	Iron	-	-	15%	-	30%	-
	Water heater	15%	10%	30%	20%	40%	20%
Entertain-ment	TV	15%	-	30%	-	30%	-
	Stereo	-	-	15%	-	15%	-
	Computer	-	-	15%	-	15%	-
Cooking	Rice cooker	15%	-	30%	-	40%	-
	Pan	15%	-	30%	-	40%	-
Other	Pump	-	-	15%	-	30%	-
	Washer	-	-	15%	-	30%	-
	Other	-	-	-	-	-	-

EFF – Efficient technology ADV – Advanced technology

Table 2. Non-electrical appliance availability in 2020.

Stove type	Low and Median mitigation	High mitigation
Charcoal	27%	26%
Efficient Charcoal	20%	20%
Wood	21%	21%
Efficient Wood	16%	16%
LPG	16%	16%
Efficient LPG	13%	13%
Paddy husk	16%	10%

2.4 Average abatement cost (AAC)

Using the results of CO_2 emissions and the total annualized investment cost given directly by AIM/Enduse, the average abatement cost of each scenario can be calculated using the following equation

$$AAC = \frac{\sum_i BAUCost_i - \sum_i NAMACost_i}{CO_2 \text{ abated}} \quad (1)$$

where; i is the year from 2005 to 2020.
The total annualized investment cost is calculated using a discount rate of 10% and includes technology, operational, maintenance, and energy costs.

2.5 Social development indicator

According to the rationale presented, the HDI is proposed as a social development indicator for energy policies. A mathematical relationship between the HDI and the biomass fuel mix (BFM) in the residential sector is developed using the residual least squares method. The preliminary scatter plot of HDI vs. BFM shows an inverse quadratic trend; thus, the mathematical expression is expected to be in the form,

$$y_i = \beta_2 x_i^2 + \beta_1 x_i + \beta_0, \quad (2)$$

where y is the HDI; and x is the BFM.

To derive the expression, three sets of data which are 1) HDI, 2) biomass consumption in the residential sector and 3) residential sector energy consumption for different countries are collected. The up-to-date HDI scores are available in the *Human Development Report 2013* for 187 countries in various years [19]. The other data sets are taken from the energy balance tables provided on the International Energy Agency (IEA) website for 132 countries from 1990 to 2011 [20]. From the IEA website, the BFM for each country can be calculated by dividing the corresponding biomass consumption by the energy demand of the sector. Next, the BFM is paired up with the HID of the same country and year. In total, there are 743 data points available for the regression process. Table 3 shows 15 data samples.

Table 3. Data samples for social development indicator analysis.

Country	Year	BFM	HDI
Argentina	2000	0.045	0.755
Azerbaijan	2011	0.025	0.732
Canada	2005	0.059	0.906
China	2010	0.566	0.689
India	2010	0.764	0.547
Iran	2005	0.002	0.685
Luxembourg	2010	0.035	0.875
Malaysia	1990	0.593	0.635
Myanmar	2000	0.986	0.382
Nicaragua	1990	0.945	0.608
Norway	2011	0.159	0.953
Poland	2000	0.132	0.778
Sri Lanka	2005	0.905	0.683
Thailand	2010	0.598	0.686
Viet Nam	2011	0.682	0.614

Outliers in the data set are eliminated through the analysis of residuals. After obtaining the regression model, the standardized residuals are computed according to (3); where d is the standardized residual; e is the residual of the regression model and σ^2 is the variance of the data set [21]. Assuming that the residuals are normally distributed, data points with standardized residuals outside of the interval (-2, 2) are eliminated as outliers. Once the outliers are eliminated the regression and the elimination process are repeated until the improvement of the coefficient of determination, R^2, is less than 5%. This is the sum of squared deviations from the mean of x; n is the sample size and $t_{\alpha/2,n-2}$ is the upper-tail 100$\alpha/2$ percentage point of the t-distribution with $n-2$ degrees of freedom [21]. The upper-tail 100$\alpha/2$ percentage point of the t-distribution is taken from [22]. The 95% confident limits will be given as a result.

3. Results and Discussion

3.1 Technology selections

To achieve the specified mitigation levels, all selected efficient and advanced electrical appliances have to be adopted at the highest availability rates as shown in Table 1. At the low mitigation level, all available efficient and advanced technologies have to be adopted. At the median mitigation level, all technologies have to be adopted except efficient pot, computer, pump and washer. Lastly, at high mitigation level, efficient computer and appliance in the other service can be left out of the mitigation plan.

For non-electrical cook stoves, the paddy husk stove is eliminated from all scenarios due to its decreasing share during 2005-2015; and Table 4 shows the results for other cook stoves. The results suggest the stop criteria. The assumption of normal distribution is checked prior to the elimination with a normal probability plot of the residuals.

$$d_i = e_i \big/ \sqrt{\sigma^2} \,, \tag{3}$$

After the final regression model is obtained, confidence intervals are also calculated using (4) in order to capture the uncertainty in predicting future observations. In (4), y_o is the future observation; x_o is the regressor variable of interest; $\bar{x}$ is the sample mean of x; S_{xx} is that efficient charcoal, wood, and LPG stove should be adopted at the highest possible rates in all scenarios as they are the cheapest mitigations among the cook stoves. Other stove types are subjected to the scenarios constraints and are discussed in the next section.

technologies alone would not be enough. The optimized solution is to switch from LPG to biomass fuels for cooking because of the carbon neutral assumption of biomass. This further reduces the emissions. However, since the efficiencies of biomass cook stoves are lower than the LPG stove, the energy demand level of the NAMA-H scenario is higher than the NAMA-M scenario.

Table 4. Cook stove selection results in 2020.

Stove type	Charcoal	Efficient charcoal	Wood	Efficient wood	LPG	Efficient LPG
NAMA-L	14 %	20 %	21 %	16 %	16 %	13 %
NAMAe-L	18 %	20 %	18 %	16 %	16 %	13 %
NAMA-M	16 %	20 %	21 %	16 %	13 %	13 %
NAMAe-M	20 %	20 %	18 %	16 %	13 %	13 %
NAMA-H	22 %	20 %	21 %	16 %	8%	13 %
NAMAe-H	25 %	20 %	18 %	16 %	8%	13 %

Similar energy demand trends among the NAMAe scenarios can also be observed.

$$\hat{y} - t_{\alpha/2,n-2}\sqrt{\sigma^2\left[1+\frac{1}{n}+\frac{(x_0-\bar{x})^2}{S_{xx}}\right]} \le y_0 \le \hat{y} + t_{\alpha/2,n-2}\sqrt{\sigma^2\left[1+\frac{1}{n}+\frac{(x_0-\bar{x})^2}{S_{xx}}\right]} \tag{4}$$

3.2 Energy demand

In the BAU scenario, total energy demand in 2005 is 9,066 ktoe and would rise to 19,810 ktoe in 2020. Cumulatively, the demand is 216.34 Mtoe in 15 years.

For the NAMA pathways, with only CO_2 reduction targets, the adoption of the NAMA-M scenario would result in the greatest amount of energy demand reduction of 9.37% in 2020. The NAMA-L and NAMA-H scenario would provide 8.89% and 8.87% in energy demand reductions accordingly. To move from the NAMA-L to the NAMA-M target, the optimized solution is to adopt more efficient technologies; thus, saving more energy demand. In the case of the NAMA-H scenario, the emission target is much higher; therefore, adopting more efficient

The reductions in energy demand are 10.04%, 10.44% and 9.93%, respectively, in the NAMAe-L, NAMAe-M and NAMAe-H scenario in 2020. Again the median mitigation level scenario will provide the greatest amount of energy saving. For each mitigation level, the NAMAe pathway shows a 1% higher reduction than the NAMA pathway because of the consumption cap imposed on charcoal and wood demand.

Figure 1 shows a comparison of energy demand in each scenario by fuel type. For electricity and solar energy, their demands are dictated by the allowable technology share previously discussed. For LPG, wood, and charcoal, their demands not only depend on the allowable share, but also on each other since they all provide the same output service.

The demand of wood reaches the maximum allowable limit in all scenarios as it is the cheapest mitigation option with no CO_2 emission. In the NAMA scenarios, the demand of wood is limited by the allowable technology share, and in the NAMAe scenarios, by the consumption cap. The LPG demand is limited by the CO_2 emission targets and the rest of the cooking demand is matched by charcoal.

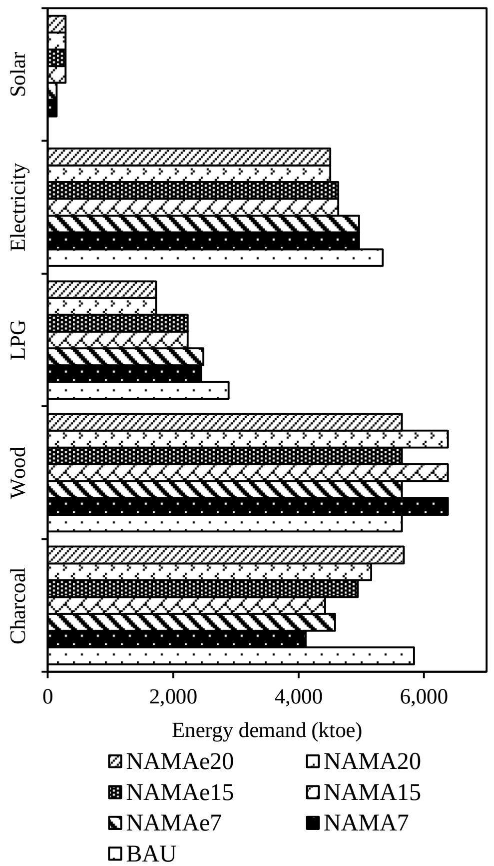

Figure 1. Energy demand in 2020 by fuel type.

Due to the wood demand cap in NAMAe scenarios, their charcoal demands are higher than their NAMA counterparts. All in all, the demand caps imposed on these biomass fuels result in more efficient traditional biomass stove to be selected which contributes to the lower energy demand in the NAMAe pathway.

3.3 CO_2 emissions

The CO_2 emissions in Thai residential sector are 19.18 Mt-CO_2 in 2005. This figure would more than double and reach 43.96 Mt-CO_2 in 2020. For the current technology availability constraints, the CO_2 emission reductions by each energy efficient scenario are shown in Figure 2. Results indicate that the reductions of the median and high mitigation scenarios are on par with the specified targets of 15% and 20% in 2020 below the BAU scenario.

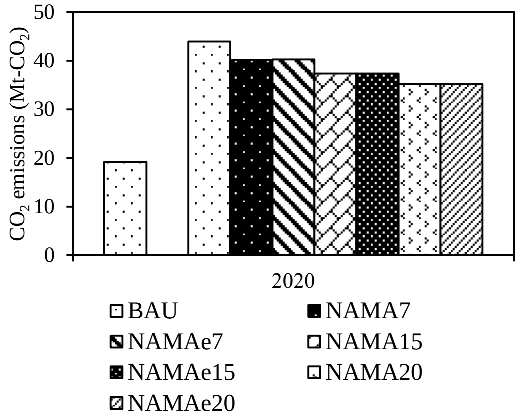

Figure 2. CO_2 emissions in 2020 in all scenarios.

In the scenarios with low reduction target levels, the NAMA-L scenario would provide a reduction of 8.6%, which is 1.6% more than the target. With the additional biomass energy demand constraint in NAMAe-L, the reduction in 2020 will be 8.4%. These two scenarios differ in the cooking energy demand. In the NAMA-L, wood and charcoal are consumed more, as seen in Figure 1, because there is no constraint on the amount of biomass demand. On the other hand, more LPG is demanded for cooking in the NAMAe-L scenario in order to compensate for the biomass consumption cap. Since LPG is not carbon neutral, the CO_2 emissions in the NAMAe-L scenario are higher.

In other scenarios, the optimization results show no difference in the two pathways to CO_2 emission mitigation and all scenarios can achieve their reduction targets.

3.4 Average abatement cost (AAC)

The AACs are negative for all energy efficient scenarios. This indicates that implementing CO_2 mitigation actions will result in both investment and energy cost savings as shown in Table 5. The NAMAe-L scenario would provide the most savings per ton of CO_2 abated. The scenario with the highest AAC is the NAMA-H scenario.

Results show that on average the investment cost is the lowest in the BAU scenario followed by the low, median and high mitigation scenario. Conversely, the energy cost is the lowest in the high mitigation level scenario followed by the median and low mitigation scenario and the BAU scenario. However, the savings in the investment cost offset the savings in the energy cost making the NAMAe7 scenario the minimum cost scenario in this study.

Table 5. Average abatement cost of energy efficient scenarios.

Case	AAC (USD/t-CO_2)
NAMA-L	-12.50
NAMAe-L	-13.13
NAMA-M	-4.29
NAMAe-M	-4.66
NAMA-H	-3.83
NAMAe-H	-4.09

3.5 Social development

The regression process was repeated three times and the outliers were eliminated twice. The normal probability plot of the initial data of human development index (HDI) vs biomass consumption in the residential consumption (BFM) is shown in Figure 3. The plot is approximately linear; thus, the normal distribution assumption is verified.

The final regression model is

$$\hat{HDI} = -0.534\,BFM^2 + 0.115\,BFM + 0.797\ , \quad (5)$$

where R^2 is 0.758; and the standard deviation, σ^2, is 0.0813. Thus, the model has a medium high fit to the data set. The scatter plot and the best-fit line are shown together in Figure 4. From Figure 4, as the BFM decreases, the HDI increases and peaks at the vertex, (0.108, 0.803). After the vertex, the HDI decreases as the BFM decreases to zero. Figure 4 also shows that many countries with zero biomass consumption do not actually score the highest on the HDI scale as expected. In fact, the highest HDI score belongs to Norway in 2011 where the BFM is 0.953.

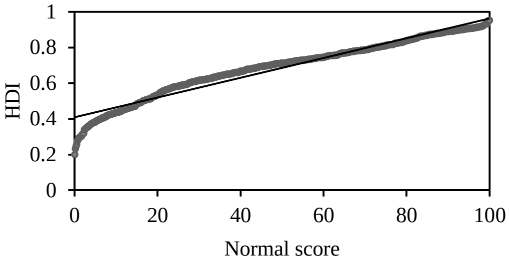

Figure 3. Normal probability plot of the HDI data.

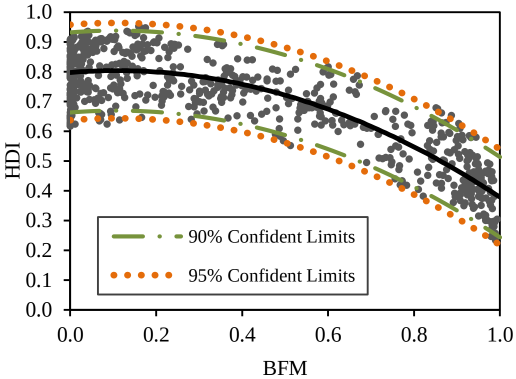

Figure 4. Final regression model and confidence limits of HDI vs. BFM.

Countries with zero and low level of biomass consumption can mostly be categorized as oil-rich countries, such as Qatar, Iran, and the United Arab Emirate [23], and advanced economy countries, such as Switzerland, Iceland and Singapore, as defined by [24]. These countries generally have high Gross Domestic Product (GDP) which is one of the components of the HDI; and their GDP would have substantially more influence on their HDI scores than any other factors. This diminishing influence of biomass is captured by the upside-down parabolic shape of (5), in which the trend changes on the left-hand side of the vertex.

There is a total of 51 outliers resulted from the two rounds of elimination. In the first round, the outliers correspond to Algeria, Egypt, Haiti, Iran, Iraq, Kyrgyzstan, Mongolia, Morocco, Mozambique, Namibia, Senegal, Sri Lanka, Syria and Tajikistan. Eliminating these outliers improves the R^2 by 10%; thus, a second round of elimination is carried out; and data corresponding to Algeria, Brazil, Egypt, Gabon, Jordan, Morocco, Sudan and Tunisia are eliminated. The stop criterion is met in this round as the R^2 is improved by 4%. All of the outlier countries, except for Sri Lanka and Namibia, have HDI scores which are lower than the predictions by (5). This is because other influences such as geopolitical conflict in the case of Iraq (2003-2010) and natural disaster in the case of Haiti (2010) are more significant to the HDI score than the use of biomass. For Sri Lanka, the HDI score is higher than other countries with comparable level of biomass consumptions because the country has high life expectancy and educational attainment [19] which is due to its universal health care and free education policy. The 90 and 95% confident intervals are also shown in Figure 4. The regression model, (5), is applied to the energy demand results of each scenario. The calculated BFM and the predicted HDI scores in 2020 are shown in Table 6. The scenario with the highest HDI score in 2020 is NAMAe-L (0.687). Only the low mitigation level scenarios would result in a higher HDI score than the BAU scenario. Scenarios with median and high mitigation level have higher biomass demand, thus, lower HDI scores.

Table 6. HDI score in 2020 in all scenarios.

Scenario	BFM	HDI	95% confident interval	
			Lower	Upper
BAU/2005	0.600	0.674	0.51	0.83
BAU/2020	0.584	0.682	0.52	0.84
NAMA-L	0.582	0.684	0.52	0.84
NAMAe-L	0.574	0.687	0.53	0.85
NAMA-M	0.602	0.673	0.51	0.83
NAMAe-M	0.597	0.675	0.52	0.84
NAMA-H	0.639	0.653	0.49	0.81
NAMAe-H	0.635	0.655	0.49	0.82

In general, scenarios in the NAMAe pathway show a higher HDI score than their NAMA counterparts in the final year. The consumption cap has helped in reducing the traditional biomass demand. However, the differences in the HDI score between the two pathways are small.

This analysis is not to suggest that the use of traditional biomass fuel is to be entirely eliminated. Nonetheless, access to modern energy is an undeniable driving force for positive human development. This study shows that making modern efficient appliances available to the rural population can be a part of the CO_2 mitigation effort. The promotion of other non-biomass fuel such as biogas could also be considered as a part of the mitigation plan. Biogas would result in reduction of biomass demand and a more affordable gas stove system.

For other energy sectors, the same HDI and biomass demand analysis may not apply as the ways that biomass are used varies across sectors. For example, in the transport sector, biomass is used to produce ethanol; and in the power sector, biomass is used as an alternative to coal and lignite. These types of consumption will have different effects on the population.

4. Conclusions

Six scenarios were constructed to evaluate the socio-economic benefits of different CO_2 mitigation pathways to NAMAs in the Thai residential sector. The social benefits were evaluated by (5) which was developed through the least squares regression method. Using the optimization model, the AIM/Enduse, the NAMAe-L scenario is the most cost effective with the lowest AAC (-13.13 USD/t-CO_2). Moreover, the NAMAe-L scenario would score 0.687 on the HDI scale in 2020, which is the highest among the energy efficient scenarios. At the same CO_2 reduction target, the NAMAe pathway would provide more energy and financial savings than the NAMA pathway. This was consequential of the higher adoption rate of efficient technologies. However, the imposed energy demand cap had no effect on the amount of CO_2 reductions as the quantities in both pathways were the same.

5. Acknowledgements

The author would like to thank the National Institute for Environmental Studies (NIES) Japan for generously providing the AIM/Enduse model at no cost. The author would also like to acknowledge Dr. Kamphol Promjiraprawat and Dr. Sujeetha Selvakkumaran for the training on the AIM/Enduse.

6. References

[1] UNFCCC, Decisions adopted by the Conference of the Parties, in *Report of the Conference of the Parties on Its Thirteenth Session, Held in Bali from 3 to 15 December 2007*, pp. 3 2007.

[2] S. Sharma and D. Desgain, *Understanding the Concept of Nationally Appropriate Mitigation Action*, Riso: UNEP Riso Center, 2013.

[3] UNFCCC, Decisions Adopted by the Conference of the Parties, in *Report of the Conference of the Parties on Its Sixteenth Session, Held in Cancun from 29 November to 10 December 2010*, pp. 3, 2010.

[4] Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. (2013, October), *Nationally Appropriate Mitigation Action (NAMA)*. Available at: http://mitigationpartnership.net/sites/default/files/giz2013-en-climate-nama.pdf, July 1, 2014.

[5] Department of Alternative Energy Development and Efficiency, Thailand Energy Situation 2011 Annual Report, Ministry of Energy. Bangkok, 2011.

[6] United Nations Development Program, Human Development Report 1990, New York: Oxford University Press, pp.9-16, 109, 1990.

[7] C. Torres-Duque, D. Maldonado, R. Peres-Padilla, M. Ezzati and G. Viegi, Biomass Fuels and Respiratory Diseases, in *Proc*. American Thoracic Society, pp. 577-590, 2008.

[8] M. A. Desai, S. Mehta and K. R. Smith, Indoor Smoke from Solid Fuels: Assessing the Environmental Burden of Disease at National and Local Levels, WHO, Geneva, 2004.

[9] K. Danielsen, Gender Equality, Women's Rights and Access to Energy Services, Ministry of Foreign Affairs of Denmark, pp.1-2, 2012.

[10] M. Kainuma, Y. Matsuoka and T. Morita, AIM Modeling: Overview and Major Findings, in *Climate Policy Assessment Asia-Pacific Integrated Modeling*, Tokyo: Springer, pp. 3-13, 2003.

[11] *AIM/Enduse Model Manual Ver3*, AIM Project Team, 2010, pp. 1-5.

[12] Department of Alternative Energy Development and Efficiency, Thailand Energy Situation 2005, Ministry of Energy, Bangkok, 2005.

[13] Electricity Generating Authority of Thailand, Thailand Power Development Plan 2008-2021 (PDP2007), 2009.

[14] Department of Alternative Energy Development and Efficiency, Electric Power in Thailand 2006, Ministry of Energy, Bangkok, 2006.

[15] Department of Alternative Energy Development and Efficiency, Electric Power in Thailand 2007, Ministry of Energy, Bangkok, 2007.

[16] Department of Alternative Energy Development and Efficiency, Electric Power in Thailand 2008, Ministry of Energy, Bangkok, 2008.

[17] Department of Alternative Energy Development and Efficiency, Electric Power in Thailand 2009, Ministry of Energy, Bangkok, 2009.

[18] Department of Alternative Energy Development and Efficiency, Electric Power in Thailand 2010, Ministry of Energy, Bangkok, 2010.

[19] United Nations Development Programme. *Human Development Report 2013 - The Rise of the South: Human Progress in a Diverse World*. Gilmore Printing Services Inc., pp. 148-151, 2013.

[20] International Energy Agency. Statistics, Available at: http://www.iea.org/statistics/, June 16, 2014.

[21] D. C. Montgomery and G. C. Runger, Simple Linear Regression and Correlation, in *Applied Statistics and Probability for Engineers*, John Wiley & Sons, Inc., pp. 391-419, 2007.

[22] B. B. Gerstman, t-table, Available at: http://www.sjsu.edu/faculty/gerstman/StatPrimer/t-table.pdf, July 07, 2007, September 2, 2014.

[23] Central Intelligence Agency, The World Factbook, Available at: https://www.cia.gov/library/publications/the-world-factbook/rankorder/2241rank.html, January 16, 2015.

[24] International Monetary Fund. (2014, April). *World Economic Outlook: Recovery Strengthens, Remains Uneven.* Available at: http://www.imf.org/external/Pubs/ft/weo/2014/01/, November 10, 2014.