ESTIMATION OF GREENHOUSE GASES EMISSION FROM HOUSEHOLD ENERGY CONSUMPTION OF A RURAL COMMUNITY IN THAILAND

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Abstract- According to current environmental degradation, it was stemmed from several significant causes such as energy production and consumption for different activities as well as climate change. These reasons seemed to be more severe until they become global environment issues. However, Thailand participated in Kyoto Protocol to proceed Clean Development Mechanism (CDM) to reduce greenhouse gas emission. Therefore, the researcher aimed to investigate amount of each kind of energy consumption and activities stemmed from average energy consumption per household. The study was conducted in Lam Nam Nan Self Supporting Settlement, Uttaradit Province, Thailand. Then the data were calculated to figure out the amount of greenhouse gas emission from the average energy consumption per household including carbon dioxide, methane and nitrous oxide. The amount of greenhouse gas emission was processed from emission factor obtained from combustion of each kind of energy, except electricity. It was because the value was calculated and adjusted regarding the ratio of fuel consumption of power generation of Thailand. Moreover, expenses caused by environmental effects were also estimated to adjust the proportion of greenhouse gas emission into tCO_{2eq}. After that, it was computed with carbon tax to reflect the social cost of climate change due to the greenhouse gas emission in the atmosphere. The results found that the most energy consumption included diesel oil, followed by electricity and charcoal at 247, 171, 131 kgoe/year, respectively, and the total energy consumption per household was at 805 kgoe/year. When calculating the amount of greenhouse gas emission per household as tCO_{2eq}, it found that the quantity of greenhouse gas in tCO_{2eq} was mostly came from the consumption of electricity and diesel oil at 1,203 and 786 kg/year, respectively. Moreover, the amount of greenhouse gas emission per household as tCO_{2eq} was 3,455 kg/year and the environmental cost per household was 1,669 Baht/year. When considering each activity consuming the energy, the result showed that the amount of energy consumption, the greenhouse gas emission and the expenses caused by environmental effect was mostly stemmed from cooking, transportation. Consequently, there should be a campaign to decrease the consumption of electricity and oil that would be helpful to alleviate the effects of greenhouse gas emission and environmental cost which might be collected as the carbon tax in the future.

Keywords- Energy Consumption, Greenhouse Gas Emission, Global Warming, Carbon Tax.

I. INTRODUCTION

Energy and environmental issues are considered as global concerns. The tendency of main energy supply is constantly decreasing worldwide, especially oil, natural gas and coal, while the energy consumption seems to increase. It can be said that there will be no more energy for our world in the near future, which may cause a large impact on everyone. This is because the energy is a factor that facilitates human life and reinforces industrial, economic and political securities. Nowadays, use of renewable energy or alternative energy; for instance, solar energy, wind energy, biomass, hydropower energy and energy from wastes, is promoted as a resolution to solve current issues. However, another way to sustainably solve the problems is everybody must help save or reduce the energy consumption.

According to the decrease in energy consumption, it is helpful to maintain the world's energy resources and diminish environment effects stemmed from the energy consumption. Every kind of energy production and energy consumption causes pollutions, air pollution leading to global warming. The process of energy production emits carbon dioxide, carbon monoxide, and sulphur dioxide. Moreover, the energy consumption, especially from incomplete combustion, causes some toxic gases as well. Carbon dioxide is one of six primary greenhouse gases controlled by Kyoto Protocal (there are 6 types of anthropogenic greenhouse gases; carbon dioxide, methane, nitrous oxide, hydro fluorocarbon, perfluorocarbon, and sulfur hexafluoride [1]). The increase of greenhouse gases traps more heat in the atmosphere and then temperature of earth and sea level will rise with them. These results greatly affect ecology, biodiversity, human health, living things, and several natural disasters.

Therefore, this research aimed to examine quantity of greenhouse gas emission from energy consumption in Lam Nam Nan Self Supporting Settlement, Uttaradit Province, Thailand. The findings of this case study were applicable to define a plan to adjust or reduce the energy consumption. They were also useful to alleviate the environmental impact caused by the energy consumption. In the future, carbon tax might be applied in Thailand to reflect true cost that

affected society due to climate change and greenhouse gas emission or called social cost of carbon (SCC). The shown figure might encourage people's participation in the energy consumption reduction as well.

II. METHODOLOGY

This research investigated the quantity of energy consumption of the selected community, divided by 9 types of energy and 6 activities resulted from energy consumption. The 9 types of energy included electricity, LPG, diesel oil, gasoline 91, gasohol 91, gasohol 95, charcoal, firewood, and biogas. Besides, the 6 activites stemmed from the energy consumption consisted of cooking, lighting, electrical appliances, agricultural work, industrial equipment, and transportation. The population were the number of households in the community. Then Taro Yamane's formula [2] was applied to calculate the sample size and probability theory was utilized to randomize the households. Moreover, stratified random sampling [2] was conducted to figure out the samples including 393 households.

After that, the data on the quantity of energy consumption were assessed to find out the quantity of greenhouse gas emission caused by the energy consumption. These greenhouse gases comprised of carbon dioxdie, methane, and nitrous oxide obtained from coefficients of greenhouse gas emission from combustion of each type of energy. The coefficients were provided in Greenhouse Gas Emission Inventory of Intergovernmental Panel on Climate Change (IPCC) [1]. However, the coefficient of electricity was excluded because it was estimated and adjusted following the various proportions of energy consumption of electricity generation of Thailand. Then it was prepared by Thailand Greenhouse Gas Management Organization (Public Organization) (TGO) and other relevant agencies [3]. The coefficients of greenhouse gas emission from the energy consumption were shown in Table 1.

Table 1: The coefficients of greenhouse gas emission from the energy consumption (kg_{ghg}/GJ)

Greenhouse gas / Energy types	carbon dioxdie (CO_2)	methane (CH_4)	nitrous oxide (N_2O)
Electricity	166.5136	0.0008	0.0004
LPG	63.1000	0.0050	0.0001
Diesel oil	74.1000	0.0100[a]/0.0039[b]	0.0006[a]/0.0039[b]
Gasoline 91	69.3000	0.0330	0.0032
Gasohol 91	69.3000	0.0330	0.0032
Gasohol 95	69.3000	0.0330	0.0032
Charcoal	112.0000	0.2000	0.0010
Firewood	112.0000	0.3000	0.0040
Biogas	54.6000	0.0050	0.0001

Remarks: [a] = This value was used for agricultural work activities.
[b] = This value was used for transportation activities.

In the last stage, additionally, the environmental cost was figured out by adjusting the calculation ratio of greenhouse gas emission into tCO_{2eq}. Then it was calculated with the carbon tax which was regarded as an economic tool to define the price. The carbon tax was associated with environmental tax that reflected the social cost stemmed from the climate change and the greenhouse gas emission to the atmosphere or called the social cost of carbon (SCC). The rate of carbon tax should not be less than the value of SCC to avoid taking on the damage of the society. According to the estimate of previous carbon tax [4, 5], it found that the acceptable rate of carbon tax was between 192 -3,133 baht per tCO_{2eq}., the average price was 483 baht per tCO_{2eq}. Currently, a feasibility study has been conducted in Thailand to establish a carbon tax system and determine suitable rate of carbon tax.

III. RESULTS

3.1. The quantity of energy consumption

According to the survey of average energy consumption per household, divided by types of energy and activities, it found that there were 6 types of commercial energy used in the community as follows; (1) electricity used for cooking appliances, facilities, bulbs, agricultural machinery, and equipment for household industry, (2) LPG used as cooking gas, (3) diesel oil used for pickup truck, farm tractor, and agricultural pump, (4) gasoline 91, (5) gasohol 91 used for motorcycle, and (6) gasohol 95 used for cars. Additionally, there were 3 types of renewable energy consumed in the community including (1) charcoal, (2) firewood, and (3) biogas used for cooking.

Regarding Table 2 presenting the average energy consumption per household, the most consumed energy was diesel oil, followed by electricity and charcoal at 247.40, 170.93, 131.15 kgoe/year, respectively. When divided by the activities, it illustrated that the transportation consumed the most energy, followed by cooking at 317.17 and 280.03 kgoe/year. Thus, the total energy consumption per household was 804.92 kgoe/year.

Table 2: Total energy consumption per household classified by activities and energy types (kgoe/year)

Activities \ Energy types	Electricity	LPG	Diesel oil	Gasoline 91	Gasohol 91	Gasohol 95	Charcoal	Firewood	Biogas	Total energy consumption
Cooking	15.57	91.94	-	-	-	-	131.15	38.74	2.63	280.03
Lighting	22.54	-	-	-	-	-	-	-	-	22.54
Electrical appliances	117.88	-	-	-	-	-	-	-	-	117.88
Agricultural work	2.08	-	52.36	-	-	-	-	-	-	54.44
Industrial equipment	12.87	-	-	-	-	-	-	-	-	12.87
Transportation	-	-	195.04	102.42	14.43	5.28	-	-	-	317.17
Total energy consumption	170.93	91.94	247.40	102.42	14.43	5.28	131.15	38.74	2.63	804.92

3.2. The quantity of greenhouse gas emission from energy consumption

The average energy consumption per household was used to estimate the quantity of greenhouse gas emission including 3 significant types; carbon dioxide, methane, and nitrous oxide as shown in Table 3. According to Table 3, the quantity of carbon dioxide was at the highest level at 774.43 and 620.53 kg/year due to the use of diesel oil and charcoal. The total carbon dioxide from the energy consumption per household was at 3,389.30 kg/year. When divided by the activities, most of carbon dioxide was stemmed from cooking, followed by the transportation at 1,164.49 and 968.07 kg/year. Beside, Table 3 represented that the methane was mostly caused by the use of charcoal and firewood at 1.1081 and 0.4910 g/year. The total methane from the energy consumption per household was at 1.8493 g/year. When divided by the activities, it found that most of methane was obtained from cooking, followed by the transportation at 1.6196 and 0.2024 g/year. In addition, Table 3 demonstrated that the nitrous oxide was stemmed from the use of diesel oil and gasoline 91 at 0.0335 and 0.0138 g/year. The total nitrous oxide from the energy consumption per household was at 0.0653 g/year. When divided by the activities, it showed that most of nitrous oxide was gained from the transportation, followed by cooking at 0.0468 and 0.0127 g/year.

Then the quantity of greenhouse gas from the 3 types of energy consumption was adjusted into tCO_{2eq} as presented in Table 3 (to estimate the expenses from environment impact). The quantity of greenhouse gas was represented as tCO_{2eq} and mosted caused by the use of electricity and diesel oil at 1,203.36 and 785.76 kg/year. When divided by the activities, the quantity of greenhouse gas in tCO_{2eq} was mostly obtained from cooking and transportation at 1,208.78 and 987.62 kg/year. The total greenhouse gas in tCO_{2eq} per household was at 3,455.01 kg/year

Table 3: The quantity of carbon dioxide (kg/year), methane (g/year), nitrous oxide (g/year), and greenhouse gas adjusted into tCO_{2eq} (kg/year) from energy consumption per household classified by activities and energy types

Activities \ Energy types	Greenhouse gas	Electricity	LPG	Diesel oil	Gasoline 91	Gasohol 91	Gasohol 95	Charcoal	Firewood	Biogas	Total energy consumption
	CO_2	109.52	245.08	-	-	-	-	620.53	183.30	6.06	1,164.49
Cooking	CH_4	0.0005	0.0194	-	-	-	-	1.1081	0.4910	0.0006	1.6196
	N_2O	0.0003	0.0004	-	-	-	-	0.0055	0.0065	<0.0001	0.0127
	CO_{2eq}	109.61	245.68	-	-	-	-	649.89	197.53	6.07	1,208.78
	CO_2	158.52	-	-	-	-	-	-	-	-	158.52
Lighting	CH_4	0.0008	-	-	-	-	-	-	-	-	0.0008
	N_2O	0.0004	-	-	-	-	-	-	-	-	0.0004
	CO_{2eq}	158.65	-	-	-	-	-	-	-	-	158.65
Electrical	CO_2	829.16	-	-	-	-	-	-	-	-	829.16
	CH_4	0.0040	-	-	-	-	-	-	-	-	0.0040
appliances	N_2O	0.0020	-	-	-	-	-	-	-	-	0.0020
	CO_{2eq}	829.85	-	-	-	-	-	-	-	-	829.85
Agricultural	CO_2	14.65	-	163.90	-	-	-	-	-	-	178.56
	CH_4	<0.0001	-	0.0222	-	-	-	-	-	-	0.0222
work	N_2O	<0.0001	-	0.0013	-	-	-	-	-	-	0.0014
	CO_{2eq}	14.66	-	164.85	-	-	-	-	-	-	179.52
Industrial	CO_2	90.50	-	-	-	-	-	-	-	-	90.50
	CH_4	0.0004	-	-	-	-	-	-	-	-	0.0004
equipment	N_2O	0.0002	-	-	-	-	-	-	-	-	0.0002
	CO_{2eq}	90.58	-	-	-	-	-	-	-	-	90.58
	CO_2	-	-	610.53	299.83	42.25	15.46	-	-	-	968.07
Transportation	CH_4	-	-	0.0321	0.1428	0.0201	0.0074	-	-	-	0.2024
	N_2O	-	-	0.0321	0.0138	0.0020	0.0007	-	-	-	0.0486
	CO_{2eq}	-	-	620.91	307.53	43.33	15.85	-	-	-	987.62
Total energy	CO_2	102.36	245.08	774.43	299.83	42.25	15.46	620.53	183.30	6.06	3,389.30
	CH_4	0.0058	0.0194	0.0543	0.1428	0.0201	0.0074	1.1081	0.4910	0.0006	1.8493
consumption	N_2O	0.0029	0.0004	0.0335	0.0138	0.0020	0.0007	0.0055	0.0065	<0.0001	0.0653
	CO_{2eq}	1,203.36	245.68	785.76	307.53	43.33	15.85	649.89	197.53	6.07	3,455.01

Table 4: The expenses from environmental impact per household classified by activities and energy types (Baht/year)

Activities \ Energy types	Electricity	LPG	Diesel oil	Gasoline 91	Gasohol 91	Gasohol 95	Charcoal	Firewood	Biogas	Total energy consumption
Cooking	53	119	-	-	-	-	314	95	3	584
Lighting	77	-	-	-	-	-	-	-	-	77
Electrical appliances	401	-	-	-	-	-	-	-	-	401
Agricultural work	7	-	80	-	-	-	-	-	-	87
Industrial equipment	44	-	-	-	-	-	-	-	-	44
Transportation	-	-	300	149	21	8	-	-	-	477
Total energy consumption	581	119	380	149	21	8	314	95	3	1,669

3.3. The expenses from environmental impact

According to the estimation of the quantity of greenhouse gas caused by 3 types of energy consumption and the carbon tax, it found that the expenses from environmental impact in table 4. were mostly stemmed from the electricity and diesel oil about 581 and 380 Baht/year. When divided by the activities, it demonstrated that most expenses were related to cooking and transportation about 584 and 477 Baht/year. The total expenses from environmental impact per household were 1,669 Baht/year.

IV. DISCUSSION AND RECOMMENDATIONS

According to the survey on average energy consumption per household, there were 2 types of energy used in the community; commercial energy and renewable energy. The first type was most consumed which included diesel oil for pickup truck, followed by electricity for electrical appliances. The latter consisted of 3 types of renewable energy; charcoal, firewood, and biogas. This kind of energy was widely used for cooking, especially charcoal and firewood. It was because the surveyed community was located in rural area and over 80% of this district was utilized for agriculture [6]. Consequently, farming was a major occupation for local people and they could find the biomass for their own use. To the biogas consumption, there were only some households using it because the biogas from pig manure was promoted by government agency. Regarding the above 4 types of energy consumption, when divided by the activities (diesel oil, electricity, charcoal, and firewood), the energy was most consumed for the transportation as well as cooking.

The estimation of greenhouse gas emission obtained from the average energy consumption per household; including the quantity of carbon dioxide, methane, nitrous oxide, or tCO_{2eq}; revealed that there was a direct variation with the quantity of energy use. Besides, there were only 3 main kinds of greenhouse gas emission (CO_2, CH_4 and N_2O) from the energy consumption [7], particularly in the household sector [8]. Nevertheless, another 3 types of greenhouse gases (HFC, PFC and SF_6) were not calculated in this paper because there was only a little quantity of them and they were also mostly found in factory. The carbon dioxide was usually released from several types of energy production such as electricity generation, consumption and production of different kinds of oil, and biomass combustion. Even though the carbon dioxide was not the highest global warming potential gas compared to methane and nitrous oxide, it was a significant cause of increase in the earth's temperature [9].

When considering both types and activities of the energy consumption, it found that the greenhouse gas was most emitted from cooking, particularly the use of charcoal and firewood. This was because the people in rural area usually found the energy by themselves, especially the biomass, which affected higher level of greenhouse gas emission [10]. Moreover, the oil was mainly consumed for vehicles used for the transportation while the electricity was widely utilized for the facilities.

Thus, a measurement on the control of greenhouse gas emission and the energy efficiency should be defined. Furthermore, the alternative energy should be more developed to replace the traditional energy which emitted high levels of greenhouse gases [8]. The solar energy, wind energy or hydropower could be applied to enhance the electricity generation because they were clean energy with low levels of greenhouse gas emission [11]. Besides, the electricity could be used for cooking instead of the biomass as well. The greenhouse gas emission from oil consumption could be reduced by improving the efficiency of vehicles and planning routes to save more energy [12]. Additionally, the speed rate of vehicles had a direct variation which affected the

quantity of fuel consumption and increasing carbon dioxide emission [13].

Although Thailand did not provide any obligation on the control of greenhouse gas emission regarding international agreement, it tended to place more emphasis on this matter in the future. Consequently, tax measurement was considered as one of effective solutions to decrease the greenhouse gas emission from the energy use [14]. In this paper, the expenses from environmental impact; climate change caused by the greenhouse gas emission, were calculated with the carbon tax to figure out the true cost regarding 'Polluter Pays Principle' (PPP). In addition, the direct variation was also found between the quantity of energy consumption and the greenhouse gas emission.

CONCLUSION

According to the study on the quantity of energy consumption and the estimation of greenhouse gas emission and the expenses from environmental impact, it demonstrated that the renewable energy was consumed in the rural community, especially the biomass energy for cooking. Regarding commercial energy use, furthermore, the electricity was consumed for the electrical appliances while the oil was consumed for the transportation. The greenhouse gas emission from the production process and the energy consumption was at high level due to the quantity of energy consumption. Hence, energy management should be initiated to improve the energy use and energy efficiency or consume the alternative energy. The cooperation between public and private sectors should be promoted to generate more people's participation in concrete development of sustainable energy use and to stimulate social awareness. This could be investigated from the figures showing the quantity of greenhouse gas emission from the energy consumption and the environmental cost collected as the carbon tax in the near future.

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REFERENCES

[1] S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe, "2006 IPCC Guidelines for National Greenhouse Gas Inventories", The National Greenhouse Gas Inventories Programme, IGES, pp. 2.15-2.22, 3.11, 3.15, 2006.

[2] B. Kijpredaborisuthi, "Research methodology in social sciences", pp.99-126, 2008.

[3] Thailand greenhouse gas management organization (Public organization), "Report of coefficient emissions. from the electricity 2011", pp.3-7, 2011.

[4] P. Khowkachaporn, "Environmental tax", The Secretariat of the senate, pp.12-17, 2014.

[5] A. Wattanakuljarus, and K. Wongsa, "Carbon tax : CO_2 emissions control and the impacts on the Thai economy", National institute of development administration and Chiang Mai university, pp.1-2, 2012.

[6] Department of Social Development and Welfare, "Full report on the production of food crops in the area of Lam Nam Nan Self Supporting Settlement", pp.30-46, 2010.

[7] A. Kolasa-Wiecek, "Stepwise multiple regression method of greenhouse gas emission modeling in the energy sector in Poland", Journal of environmental sciences, vol. 30, pp.47-54, 2015

[8] P. Nejat, F. Jomehzadeh, M. M. Taheri, M. Gohari, M. Z. and A. Majid, "A global review of energy consumption, CO_2 emissions and policy in the residential sector (with an overview of the top ten CO_2 emitting countries)", Renewable and sustainable energy reviews, vol. 43, pp.843-862, 2015.

[9] Thailand greenhouse gas management organization (Public organization), "Greenhouse Gas", http://www.tgo.or.th/2015/thai/content.php?s1=7&s2=16

[10] H. Niu, Y. He, U. Desideri, P. Zhang, H. Qin, and S. Wang, "Rural household energy consumption and its implications for eco-environments in NW China: A case study", Renewable Energy, vol. 65 , pp.137-145, 2014.

[11] C. Li, L. He, Y. Cao, G. Xiao, W. Zhang, X. Liu, Z. Yu, Y., Tan, and J. Zhou, "Carbon emission reduction potential of rural energy in China", Renewable and sustainable energy reviews, vol. 29, pp.254-262, 2014.

[12] V. Ratanavaraha, and S. Jomnonkwao, "Trends in Thailand CO_2 emissions in the transportation sector and Policy Mitigation", Transport policy, Article in press.

[13] H. Chowdhury, F. Alam, I. Khan, V. Djamovski, and S. Watkins, "Impact of vehicle add-ons on energy consumption and greenhouse gas emissions", Procedia Engineering, vol. 49, pp.294-302, 2012.

[14] L. X. Zhang, C. B. Wang, and A. S. Bahaj, "Carbon emissions by rural energy in China", Renewable Energy, vol. 66, pp.641-649, 2014.

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