Carbon footprint reduction from Bangkok urban home vegetable garden

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Abstract

The objective of this work is to evaluate carbon footprint reduction from vegetables in the Bangkok Urban Home Vegetable Garden model (BUG) compared to commercial vegetables. The BUG model was developed based on appropriate home gardens in Bangkok and applied the concept of pesticide-free agriculture. The information on Bangkok home gardens was obtained from questionnaires by random sampling in Bangkok urban area customers of pesticide-free vegetable stores, who are interested in home gardening. Life cycle analysis was used to evaluate the environmental impact of CO_2 emissions of Chinese kale, Chinese cabbage, bird pepper, holy basil and sweet basil for the Bangkok area. The results revealed that vegetables from the BUG model emit 0.0753 $kgCO_2eq/kg$ of vegetable (37.8%) less than commercial vegetables. Total GHG emission of vegetable cultivation and raw material transportation in Bangkok is 6,542,700 $kgCO_2eq$. Total GHG emission reduction for Bangkok is approximately 2,446,655 $kgCO_2eq$ by changing from commercial vegetables cultivation and raw material transportation into BUG model for the 5 types of vegetables. One of the main GHG emission reductions is vegetables transportation from other provincial production sources to the selling points in Bangkok which account for 992,020 $kgCO_2eq$.

Keywords: *Home garden, carbon footprint, life cycle analysis*

1. Introduction

The world population is expected to increase to 9.7 billion people in 2050, up from 7.3 billion as of mid-2015 [1]. Therefore, the need to provide sufficient and healthy food will increase significantly. In which, Thailand aims to be the kitchen for the world. However, in Thailand the amount of greenhouse gas emissions from the agricultural sector (51.88 $TgCO_2eq$, 22.6%) is second after the energy sector (159.39 $TgCO_2eq$, 69.6%) [2]. Large commercial farming uses enormous amounts of chemical fertilizers and pesticides during cultivation which causes adverse effects on the environment as well as high energy usage. Land preparation and water management uses significant fossil fuel in the process. Therefore, the main CO_2 emission part for agriculture is production and energy usage in transportation of produce. For example, of green bean production in Nongsue and Pathumthani Provinces average CO_2 emission is 118.9 $kgCO_2eq/rai$ and the cultivation process has the most effect on emission [3]. A study from the United Kingdom on lettuce, apple and cherries revealed that lettuce grown in the UK and Spain had the least amount of CO_2 emission. Cherries were air transported from North America for 7,751 kilometers and therefore have 80 times the emission of the lettuce. The apples were transported by sea for over 8,000 kilometers and have 2.4 times the emission of lettuce [4]. Transportation of produce is one of the main reasons for high energy consumption and the emission of carbon for vegetable consumption. To mitigate the high transportation cost, home garden and urban horticulture is an alternative way to provide vegetable for urban consumption. Home gardens are the smallest food production system that uses small investments. Home gardens can be found both in the urban city areas and the rural areas. It is also considered as food source for vegetable and protein with high nutrition [5]. The factors affecting urban horticulture, especially in developing countries are geography, economy and culture; awareness in energy and environmental conservation; mindset for healthy living. For the home garden/urban horticulture development, these countries receive support from various organizations because urban horticulture will play a large part in helping to mitigate carbon emissions. The benefits of urban horticulture and home gardens are increasing food security, nutrition and household income as well as providing jobs, reducing poverty, developing the community and increasing the flexibility in household consumption [6, 7]. In addition, home gardens can also be a source of additional income for the household [7]. The local produce will also provide food security and reduce environmental impact. This will reduce food transportation (Food Miles) from the producer to the consumer [8]. The agriculture area will increase with the most efficient usage. For Thailand, urban home gardens were supported by the Sustainable Agriculture Foundation's Suan Khun Ta (Sukhumvit 62) and Nuanpan Mansion. An urban garden can also be found on the rooftop of Lak Si in Bangkok. Kamon Lerdrat and coworkers created an innovative home garden by planting vegetables and raising fish together. The interrelationship between fish and vegetables revealed that the organic matter from fish becomes nutrients to the vegetables, and in turn, the plants help treat the water for fish farming. The water can be recycled and the farmers do not need to change the water in the fish pond. Only a small space with low maintenance is needed for this process [9]. The goals of these projects are aim at healthy living and reducing environmental impact. However, the promotion of urban agriculture or home gardens could still cause water pollution from chemical fertilizers [7]. Therefore, there is a need for a home garden model with the criteria of lower pollution and energy consumption thus reducing CO_2 emission. Reduction of energy consumption can be achieved with energy efficiency measures and/or the usage of renewable energy.

With the issues stated above, the objective of this project is to evaluate people's behavior, study constraints, obstacles, and factors affecting people's decisions in order to develop a home garden in Bangkok and evaluate the environmental impact of the garden by using life cycle analysis and carbon emission standards. The analysis of environmental impacts at the household level were performed and the results were extended in scope to include the entire Bangkok area. The results from this study will portray the approach to reduce environmental impact from chemical fertilizer, pesticide, and agricultural transportation from farms to the consumers. Method of energy efficiency and renewable energy will be recommended to further reduce the environmental impact of the home garden. This is to demonstrate the tangible benefits if the patterns of home gardening derived from the research are used. The main aim is to help home gardeners become more self-reliant and healthy in a better environment. They will be able to reduce their expenses and have good and healthy relationships among family members and neighbors.

2. Methodology

2.1 Urban home garden model

The integrated method is used in this study. Information for the Bangkok urban home gardens were obtained by questionnaires from 400 samples. The number of samples were calculated based on Taro Yamane Sample Calculation at 5% margin of error for the Bangkok urban area population of 5.6 million. The samples were selected based on random sampling from people in the Bangkok urban area customers of the pesticide-free vegetable stores, and people who are interested in home gardening. The Bangkok urban home vegetable garden model (BUG) was determined by analyzing the existing successful home garden and the unsuccessful factors in the Bangkok home gardens. In addition, the pesticide-free concept was integrated into the model [10].

2.2 Life cycle assessment

Life Cycle Assessment (LCA) was used as the tool to evaluate the carbon footprint of the BUG model and commercial vegetables. The carbon footprints of the vegetables are determined according to the follow steps:

1) Determine goal and scope of the life cycle for production of vegetables
2) Create life cycle flow to compare cultivation processes of the BUG model and commercial vegetables
3) Conduct life cycle inventory.

4) Determine and collect the Emission Factor (EF) related to each component of the life cycle as standards to calculate the GHG emission.

5) Analyze and calculate carbon footprint based on Cradle-to-Gate concept from LCA focusing on getting the components of growing vegetables and the vegetable growing process. The calculation is based on LCA-GHG equation (Eq.1):

$$E_{x,i} = \sum_i (A_i \times EF_{x,i}) \quad (1)$$

$E_{x,i}$: Amount of GHG x in kg CO_2eq
A_i : Activity i that causes GHG
$EF_{x,i}$: Emission Factor of activity i

3. Results and discussion

3.1 Bangkok urban home vegetable garden model (BUG model)

The Bangkok Urban Home Vegetable Garden Model or BUG model was developed from the concept and criteria of the successful home garden model in Bangkok based on the results of questionnaires (Figure 1). The 400 questionnaires revealed that the general urban home garden had a limited area in the range of 1-2 sqm. The type of vegetables most grown are pesticide-free with the main interest of no residue, fresh/clean and good for their health and the environment. The results also revealed that home gardeners are mostly women. The reasons for failure in home gardening are no caretaker, lack of knowledge and lack of maintenance time. Therefore, from the results of the questionnaires, the concept of the BUG model was developed in Figure 1 and it is based on "Grow whatever you eat and eat whatever you grow".

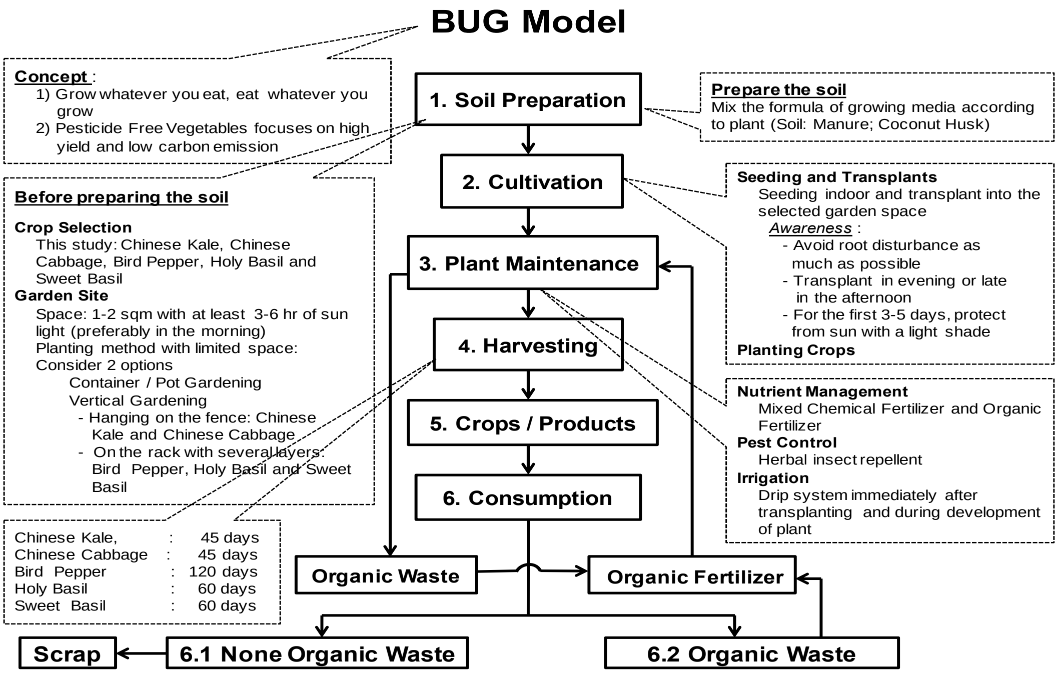

Figure 1 Bangkok urban home vegetable garden model concept and criteria

In the urban home setting, people do not have much time for garden maintenance. Therefore, the BUG model has low maintenance and components of the garden must be easily available in market. The area of the home garden should be 1-2 square meter per household base on the results of the questionnaire survey. With limited space, planting in pots, container or vertical gardens are preferred. The watering system should be a dripped irrigation system. The BUG model is based on pesticide free vegetable gardening because this type of gardening provides a higher yield than inorganic farming and is easier to maintain. The concept of low carbon gardening was integrated into the BUG model with the criteria of soil preparation, cultivation, and plant maintenance. For example, the BUG model would use a mixture of chemical fertilizer and organic fertilizer because it will provide higher crop yield, and lower carbon emissions. Using only manure or organic fertilizer will emit higher carbon than using those together with chemical fertilizer. Figure 1 provides the criteria of the BUG model for Chinese kale, Chinese cabbage, bird pepper, holy basil and sweet basil. These vegetables are chosen because they are main ingredients in Thai cooking and a popular consumption choice of participants. In addition, the chosen vegetables are selected according to vegetable types purchased and the results of the surveyed type of vegetable grown in home garden [10]. From the criteria of the BUG model in Figure 1, each of the detailed components will be used in determining the carbon emissions from the vegetables produced with the BUG model via Life Cycle Analysis method (LCA).

In this work, the LCA from the vegetables of the BUG model was compared with commercial vegetables from conventional methods of agriculture. Figure 2a and 2b provided the comparison of the structure and process in gardening for the BUG model and Commercial model, respectively. From Figure 2a, raw material components, that must be bought and transported to the home garden, are soil, manure, coconut husk, seed, herbicide, and chemical fertilizer. Compost could be produced from the organic wastes of garden. Irrigation is water from homes. For the second part of the model, production of vegetables consisted of land preparation and seeding, cultivation, nutrient management, pest control, irrigation, weed control and harvesting. Kitchen and garden organic wastes are turned into compost and used in cultivation. The scope of the LCA is only for the Raw Material and Production section. Figure 2b represented the LCA model of commercial vegetables from conventional methods of agriculture. The model was developed based on typical processes of agriculture cultivation for the 5 types of vegetables. Raw materials consisted of seeds, chemical fertilizer and pesticide that must be transported to the farms. Then irrigation is from diesel pumps. Production composed of land preparation, sowing, cultivation, nutrient management, pest control, irrigation, weed control, liming and then harvesting. The produced crop will then be transported to market. The wastes that occurred from this commercial model will not be reused. Similar to the BUG model, the scope of LCA is focused on the Raw material and Production section.

3.2 Life cycle inventory analysis

From the LCA of both the BUG and commercial vegetable model, the life cycle inventory is shown in Figure 3. The inputs are seed, nutrients, pesticide, herbicide, fungicide, irrigation, transportation, fossil fuel and electricity. The outputs are crops/products as well as other environmental impacts are represented in CO_2 equivalents such as CO_2 from liming; CH_4, N_2O from compost; and N_2O from manure and chemical fertilizers. These components will cover 4 activities of productions which are Land preparation/Sowing/Seeding, Cultivation, Plant treatment and Harvesting. The scope and boundary of this work focused on these 4 activities for carbon footprint evaluation.

The life cycle inventory in Figure 3 shows the cultivation process for growing vegetables. Each component of inventories was analyzed to determine the amount of inputs and outputs for growing 5 vegetables namely Chinese kale, Chinese cabbage, bird pepper, holy basil and sweet basil. Table 1 displays the measured amount of inputs and outputs for growing 5 types of vegetables with the BUG model vs. commercial vegetables. The amount of input and output are normalized based on 1 kilogram of each vegetable. Overall, vegetables from the BUG model have approximately, a 3 times higher total amount of input than commercial vegetables, while the total amount of output from both models are approximately the same. The amount of input comprises, land preparation, nutrient management, pest management, irrigation, transportation and fuel. Based on the inputs, in the BUG model land preparation is significantly higher because they were grown in pots and containers instead of cultivated land. The mass production of commercial vegetables provides higher yields and used less raw materials per kilogram of vegetables due to using more chemical fertilizer. However, the commercial vegetables require more transportation and irrigation than the BUG home garden vegetables. These values are a tradeoff between growing vegetable at home and purchasing them from the market. Another evaluation to be considered is the carbon footprint comparison of the 2 types of vegetables in the next section.

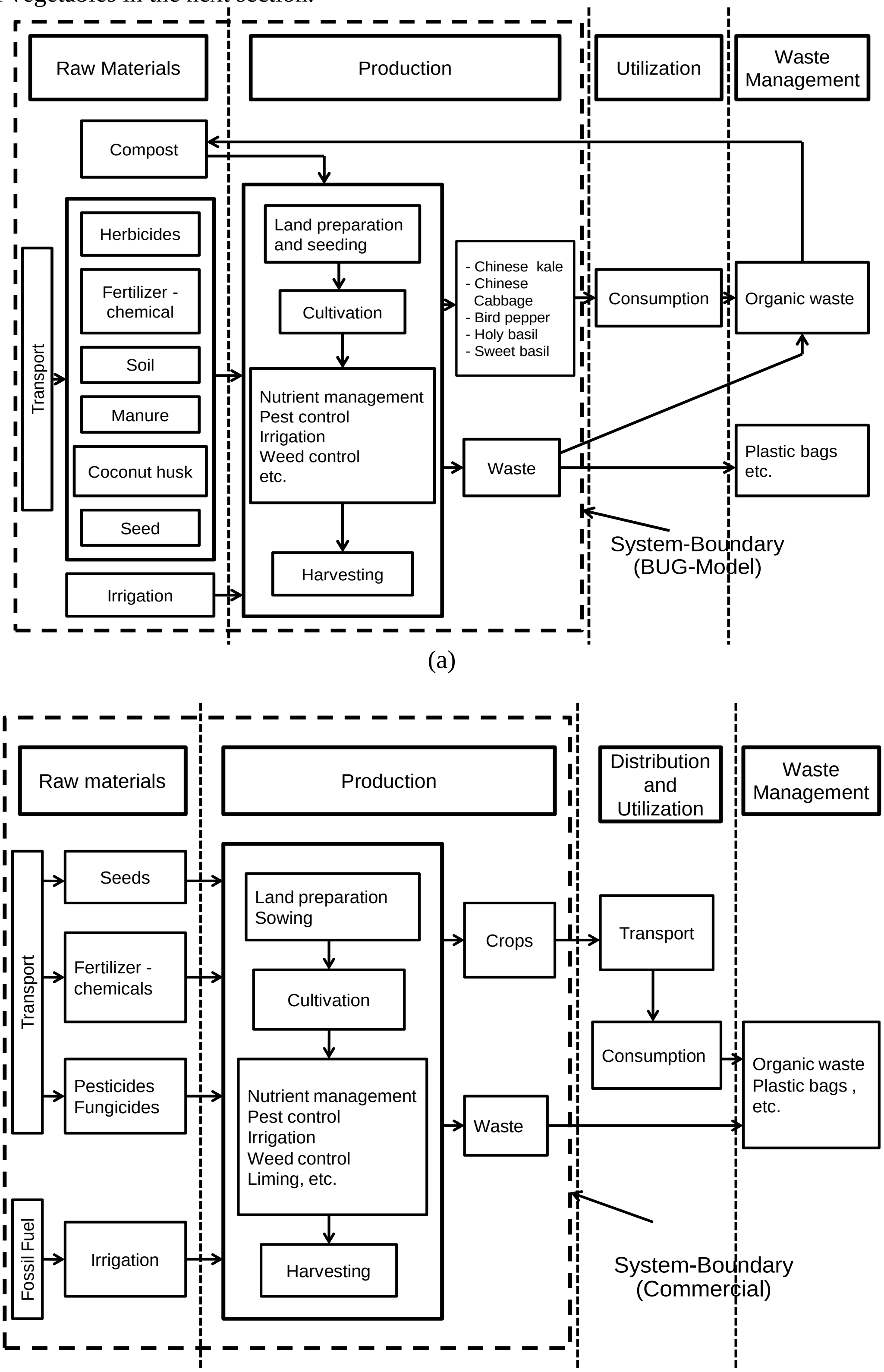

Figure 2 Life cycle analysis of vegetable from (a) BUG Model and (b) Commercial vegetables

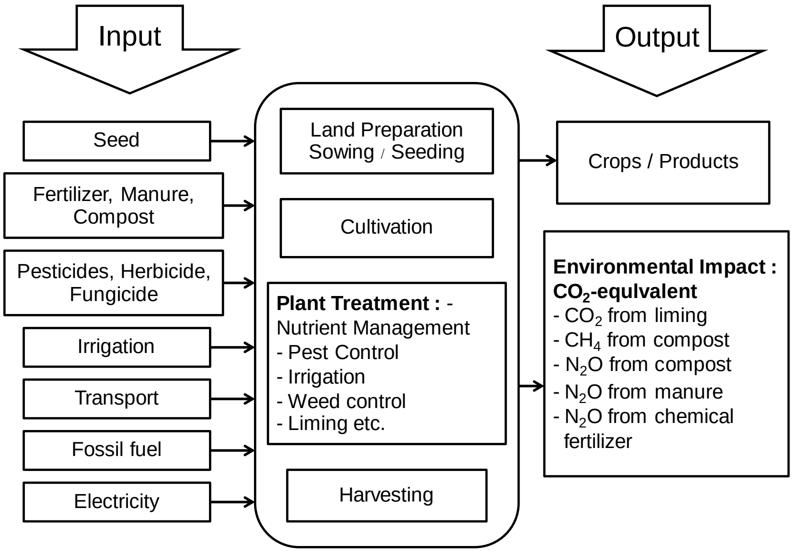

Figure 3 Life cycle inventory of the inputs and outputs of vegetable production

3.3 Greenhouse gas emissions

The Greenhouse Gas Emissions (GHG Emission) were calculated based on life cycle inventory from Table 1. Each component of GHG emission is represented as CO_2 equivalent per kilogram of vegetable (CO_2eq/kg) from a commercial market and the BUG model in Table 2. The average of vegetables from BUG model emitted 37.8% less CO_2eq than commercial vegetables. Commercial vegetables emitted 0.1993 CO_2eq/kg while the BUG vegetables emitted 0.2746 CO_2eq/kg on average for all 5 vegetables. Figure 4 showed the GHG emission comparison for commercial vegetables and BUG model. For the commercial vegetable GHG emission, the highest to lowest emission factors are nutrient, direct emissions and pesticides, respectively. This is because commercial vegetables need to produce the highest yield possible to maximize profit thus the high usage of nutrients and pest control products. However, for the BUG model vegetables, the highest emission factor is from irrigation while the second highest is nutrients. This is because watering vegetables in home gardens would use the municipal water supply which has been treated properly. Commercial vegetables typically use untreated water from canals, river, or underground wells, consequently lower GHG emissions. Therefore, if the BUG model uses rainwater or other natural sources, GHG emission would be reduced significantly. For the second rank emission of the BUG model, pesticide, herbicide or fungicide is minimally use because of health concern for home garden members when compared to commercial vegetables.

When ranking the vegetables according to their emission from lowest to highest, commercial vegetables resulted in Chinese kale, Chinese cabbage, bird pepper, holy basil and sweet basil, respectively (Figure 5). The results are similar in ranking for the BUG model but overall emission is lower than commercial vegetables. The similarity in ranking is because the growing procedures are similar to each other according to Figure 2. However, the BUG model resulted in lower emissions overall.

3.4 BUG Model emission implications to Bangkok

Based on primary and secondary data, the amount of vegetable consumption is determined by four factors. Firstly, vegetable sources data are provided by merchants at Si Moomuang Market and Talad Thai Market in September 2015. Secondly, Thailand and Bangkok population are provided by the Bureau of Registration Administration (BORA) in 31 December 2014 [13]. Thirdly, total output of the year for Chinese kale, Chinese cabbage, bird pepper, holy basil and sweet basil are provided by the Department of Agriculture Extension report of the crop status (RT.01) National Yearly Report of

2014 [14]. Fourthly, transport distance data are provided by Department of Highways in 9 September 2015 [15]. This data was used to analyze total emission of BUG vegetables. Up to now, there has been insufficient data on vegetable consumed and the amount of vegetables sold in Bangkok. The researcher has considered using the amount of vegetable consumption based on the ratio of Bangkok's population against the total population of Thailand and the above factors which are the base data for GHG emission calculation for BUG model.

Table 1 Amount of components in the steps for growing vegetables using the BUG model vs. Commercial Vegetables

Description	Unit	Usage per kilogram of vegetable											
		Chinese Kale		Chinese Cabbage		Bird Pepper		Holy Basil		Sweet Basil		Average	
		C	B	C	B	C	B	C	B	C	B	C	B
Input		**1.5958**	**6.6099**	**1.6160**	**8.0573**	**1.6898**	**3.6238**	**1.6527**	**3.2301**	**2.3530**	**4.0806**	**1.7815**	**5.1203**
1) Land preparation, Sowing, Seeding	kg, M^2	**0.8010**	**5.7076**	**0.6330**	**6.9574**	**0.6880**	**3.0339**	**0.4170**	**2.6335**	**1.0670**	**3.3668**	0.7212	4.3398
2) Fertilizer, Compost, Manure	kg	0.5146	0.7455	0.6830	0.9087	0.6690	0.3187	0.0880	0.3224	0.0920	0.3644	0.4093	0.5319
3) Pesticide, Herbicide, Fungicide	kg	0.0014	0.0004	0.0027	0.0005	0.0033	0.0016		0.0010	0.0012	0.0010	0.0017	0.0009
4) Irrigation	M^3	0.1300	0.0834	0.1030	0.1017	0.1290	0.2318	0.3072	0.2397	0.3200	0.3063	0.1978	0.1926
5) Transport	tkm	0.1411	0.0730	0.1845	0.0890	0.1526	0.0379	0.8052	0.0334	0.8500	0.0422	0.4267	0.4551
6) Fossil Fuel	tkm	0.0021		0.0098		0.0479		0.0353		0.0228		0.0236	
7) Electricity	kWh	0.0056										0.0011	
Output		**1.0003**	**1.0002**	**1.0003**	**1.0002**	**1.0214**	**1.0001**	**1.0005**	**1.0001**	**1.0005**	**1.0001**	**1.0046**	1.0001
1) Crops	kg	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2) CO_2 from liming	kg					0.0211						0.0042	
3) N_2O from fertilizer	kg	2.9E-4	1.9E-4	2.6E-4	1.6E-4	2.2E-4	6.0E-5	5.0E-4	7.0E-5	5.0E-4	7.0E-5	0.0003	0.0001
4) CH_4 from compost	kg	0.00003		0.00004		0.00002						0.00002	

Note : C = Commercial, data base on National Metal and Materials Technology Center [11] , B = BUG Model, data base on amount of actual usage and Laksi District Office [12]

Table 2 GHG Emission in components for growing vegetables of BUG model and Commercial Vegetable

Description	GHG Emission ($kgCO_2eq$ per kg of vegetable)												
	Chinese Kale		Chinese Cabbage		Bird Pepper		Holy Basil		Sweet Basil		Average		
	C	B	C	B	C	B	C	B	C	B	C	B	Var
Input	0.1277	0.1102	0.1433	0.1343	0.1984	0.1672	0.1843	0.2003	0.1897	0.2199	0.1687	0.1664	-1.4%
1) Land preparation, Sowing, Seeding			2.50E-4		0.0375						0.0076		-100%
2) Fertilizer, Compost, Manure	0.1053	0.0560	0.1119	0.0682	0.0911	0.0433	0.1635	0.0731	0.1628	0.0574	0.1269	0.0596	-113%
3) Pesticide, Herbicide, Fungicide	0.0160	1.26E-5	0.0192	1.54E-5	0.0507	4.67E-5		2.85E-5	0.0093	2.85E-5	0.0190	2.64E-5	-7.2E4%
4) Irrigation		0.0424		0.0517		0.1178		0.1218		0.1556		0.0979	+100%
5) Transport	0.0023	0.0118	0.0056	0.0144	0.0030	0.0061	0.0092	0.0054	0.0096	0.0068	0.0059	0.0089	33.4%
6) Fossil Fuel	0.0007		0.0064		0.0161		0.0116		0.0080		0.0086		-100%
7) Electricity	3.41E-3										6.82E-4		-100%
Output (Direct Emission)	0.0869	0.0553	0.0798	0.0485	0.0866	0.0183	0.1405	0.0208	0.1358	0.0216	0.1059	0.0329	-221.9%
1) CO_2 from liming					0.0211						0.0042		-100%
2) N_2O from fertilizer	0.0450	0.0182	0.0234	0.0033	0.0187	0.0040	0.1405	0.0084	0.1358	0.0058	0.0727	0.0079	-808%
3) CH_4 from compost	0.0008		0.0010		0.0006						0.0005		-100%
4) N_2O from compost	0.0180		0.0241		0.0144						0.0113		-100%
5) N_2O from manure	0.0232	0.0370	0.0313	0.0451	0.0317	0.0143		0.0124		0.0158	0.0172	0.0249	+30.9%
Total	**0.2146**	**0.1654**	**0.2231**	**0.1828**	**0.2850**	**0.1855**	**0.3248**	**0.2211**	**0.3255**	**0.2415**	**0.2746**	**0.1993**	-37.8%
Var	**-29.7%**		**-22.0%**		**-53.6%**		**-46.9%**		**-34.8%**				

Note : C = Commercial, B = BUG Model

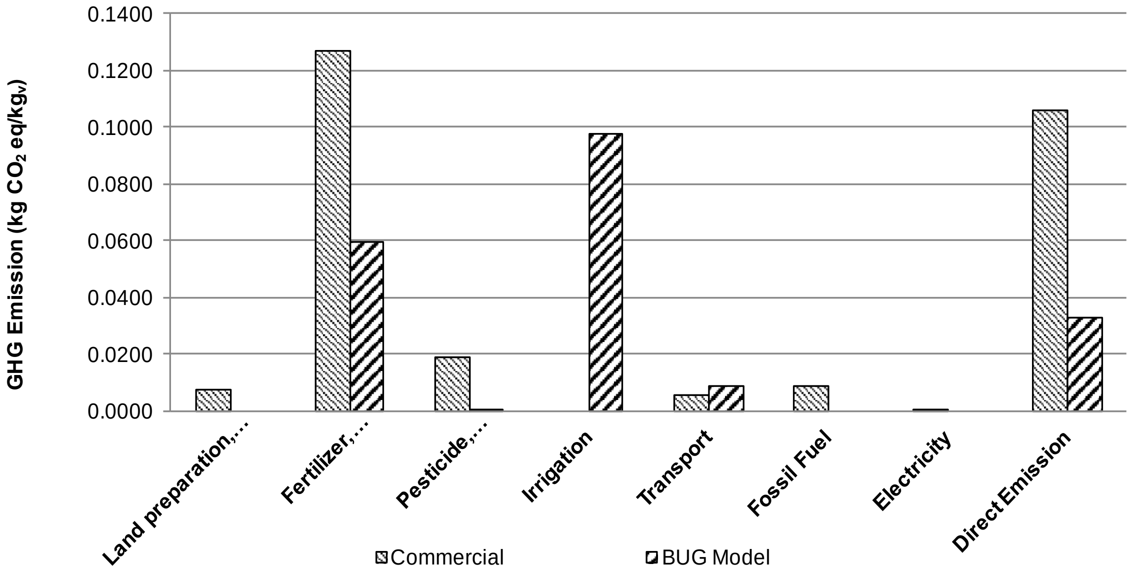

Figure 4 GHG Emissions of 5 sample vegetables from BUG model and commercial vegetable

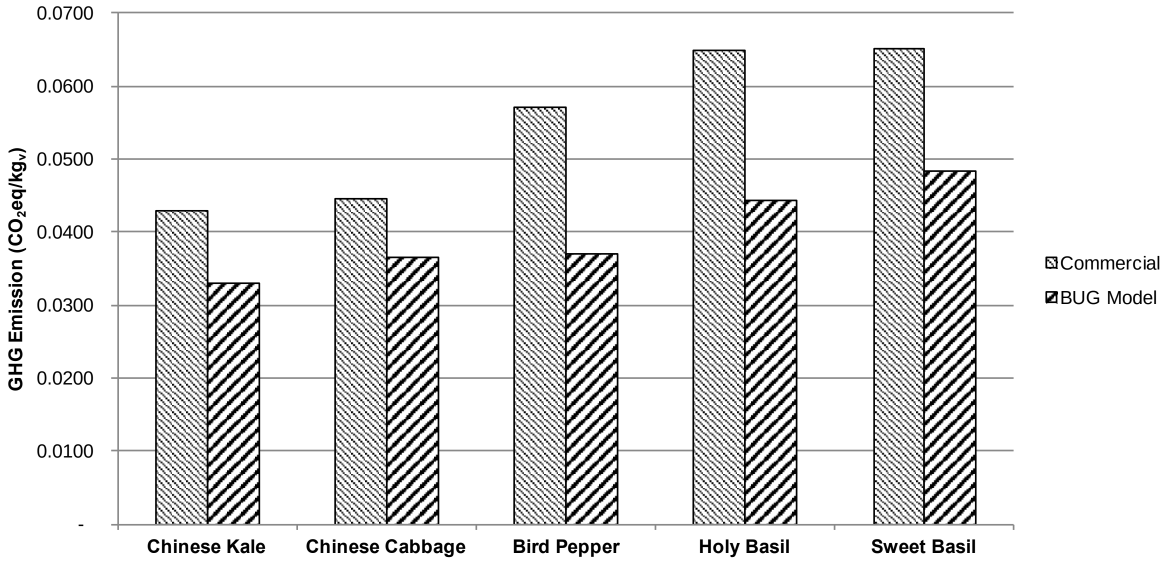

Figure 5 GHG Emissions of inputs and outputs components from BUG model and commercial vegetables

Table 3 GHG Emission of 5 vegetables from BUG and commercial model

Vegetable	Amount Sold in Bangkok (kg)	BUG Model ($kgCO_2eq$)		Commercial ($kgCO_2eq$)		Total GHG Reduction ($kgCO_2eq$) (1)-(2)
		GHG per kg vegetable	Total Emission in Bangkok (1)	GHG per kg vegetable	Total Emission in Bangkok (2)	
Chinese kale	14,487,675	0.1654	2,396,261	0.2146	3,109,055	- 712,794
Chinese cabbage	7,075,721	0.1828	1,293,442	0.2231	1,578,593	- 285,151
Bird pepper	12,164,717	0.1855	2,256,555	0.285	3,466,944	- 1,210,389
Holy basil	1,151,777	0.2211	254,658	0.3248	374,097	- 119,439
Sweet basil	1,415,252	0.2415	341,783	0.3255	460,665	- 118,882
Total			**6,542,699**		**8,989,354**	**- 2,446,655**
						- 27.2%

Table 4 GHG Emission from transportation of vegetable logistics

Description	Province	Production Quantity (kg)	Selling Quantity in Bangkok (kg)	GHG Emission of Transportation ($kgCO_2eq$)
Chinese Kale	Bangkok	3,119,423	3,119,423	-
	Other Provinces*	50,057,339	11,368,252	167,963.3
	Total	53,176,762	14,487,675	167,963.3
Chinese Cabbage	Bangkok	2,270,830	2,270,830	-
	Other Provinces*	30,599,837	4,804,891	56,011.8
	Total	32,870,667	7,075,721	56,011.8
Bird Pepper	Bangkok	14,850	14,850	-
	Other Provinces*	74,748,482	12,149,867	755,451.2
	Total	74,763,332	12,164,717	755,451.2
Holy Basil	Bangkok	487,300	487,300	-
	Other Provinces*	8,462,360	664,477	5,093.7
	Total	8,949,660	1,151,777	5,093.7
Sweet Basil	Bangkok	487,900	487,900	-
	Other Provinces*	8,237,722	927,352	7,500.0
	Total	8,725,622	1,415,252	7,500.0
	Grand Total			992,020.0

*Provinces in Table 5 except Bangkok

Table 5 Assumption of transport distance and production source of vegetables

Description	(1) Province	(2) Transport distance (km)
Chinese Kale	Bangkok	-
	Nonthaburi	20
	Pathumthani	28
	Saraburi	107
	Ratchaburi	100
	Kanchanaburi	129
	Suphanburi	107
	Nakhonpathom	56
Chinese Cabbage	Bangkok	-
	Nonthaburi	20
	Pathumthani	28
	Ratchaburi	100
	Kanchanaburi	129
	Suphanburi	107
	Nakhonpathom	56
	Samutsakhon	30
Bird Pepper	Bangkok	-
	Lopburi	153
	Nakhonratchasima	259
	Sisaket	531
	Ubonratchathani	592
	Chaiyaphum	342
	Nakhonsawan	240
	Kanchanaburi	129
	Nakhonpathom	56
Holy Basil	Bangkok	-
	Nonthaburi	20
	Pathumthani	28
	Nakhonpathom	56
Sweet Basil	Bangkok	-
	Nonthaburi	20
	Pathumthani	28
	Nakhonpathom	56

Note : (1) Data from merchants at Si Moomuang Market and Talad Thai Market in September 2015 and (2) data from Department of Highways [15]

The results in Table 3 reveal that total GHG emission from vegetable cultivation and raw material transportation in Bangkok is 6,542,700 kgCO_2eq. Total GHG emission in changing from commercial vegetable cultivation and raw material transportation into the BUG model in Bangkok for the 5 types of vegetables is reduced approximately 2,446,655 kgCO_2eq. In additional, GHG emission from the transportation could be reduced, mainly the transportation of vegetables from production source to selling points in Bangkok. According to the interview, the 5 sample vegetables are mostly grown upcountry and delivered to Bangkok. Mainly pickup trucks are used for transportation. Production quantities of each vegetable produced in Bangkok and other provinces are shown in Table 4 and the assumption of transport distance and production source of vegetables are shown in Table 5. The assumption was made that vegetables grown in the Bangkok area are sold in Bangkok. If there is more demand for vegetables, they are transported from upcountry. The results are indicated in Table 4, GHG emission reduction occurs by removing vegetables transportation from production source to the selling points in Bangkok, for a total of 992,020 kgCO_2eq. Bird pepper was the most consumed (12,164,717 kg/year) thus it emitted the most 755,451.2 kgCO_2eq from transportation. The bird pepper must be transported from various provinces, quite far from Bangkok. The second ranked emission is from Chinese kale (167,963.3 kgCO_2eq) and the consumption quantity (14,487,675 kg/year) is similar to bird pepper. But the emission of Chinese kale is significantly less than the bird pepper because Chinese kale is grown in an area closer to Bangkok. The Chinese cabbage GHG emission is 56,011.8 kgCO_2eq. The emission is lower because there is less consumption than Chinese kale and the growing area of the Chinese cabbage crop is similar to Chinese kale. Lastly, holy basil and sweet basil are not consumed as much as the other vegetables. The GHG emission values are 7,500.0 kgCO_2eq and 5,093.7 kgCO_2eq, respectively. The basil is also grown in provinces close to Bangkok. Therefore, based on the transportation emission values and consumption quantities, Bird Pepper should be first as a vegetable appropriate for urban home gardens. Chinese kale, Chinese cabbage, sweet basil and holy basil should be promoted in rank, respectively.

4. Conclusion

This study developed the urban home vegetable garden model for Bangkok. This low-carbon based model was developed from theory, literature, questionnaires and practical information about home vegetable cultivation and market. Based on this model, bird pepper, Chinese cabbage, Chinese kale, holy basil and sweet basil were selected as vegetables to be compared between the Bangkok Urban Home Vegetable Garden (BUG) and commercial vegetables. On average, GHG emission from the BUG is 0.0753 kgCO_2eq/kg of vegetables (37.8%) less than commercial vegetables. The average emission for commercial vegetables is 0.2746 kgCO_2eq/kg of vegetables while the BUG is 0.1993 kgCO_2eq/kg of vegetables. If the BUG is used instead of the commercial vegetables, the overall carbon reduction would be 2,446,655 kgCO_2eq/year for Bangkok. The main GHG emission factor from commercial vegetable production is from nutrients, while the main emission factor for the BUG is from usage of municipal water. Promoting the BUG for Bangkok urban homes will assist carbon reduction from the transportation of vegetables as well. Bangkok has limited agricultural areas, so the vegetables grown there are not sufficient for the population. Transportation of vegetables burns fossil fuels and causes GHG emissions. With the BUG, GHG emissions could be reduced by up to 992,020 kgCO_2eq/year due to elimination of vegetable transportation from the production source to selling points in Bangkok. These results are in agreement with the research of Hui (2011) on the environmental benefit and emission reduction of urban rooftop gardening [16]. Based on the selected vegetables, bird peppers should be promoted as the vegetable for urban home gardening because they account for 76% of the total reduction of transportation GHG emission in Bangkok. The secondary vegetables for promotion should be Chinese kale, Chinese cabbage, sweet basil and holy basil, respectively.

Home gardens could provide benefits to the consumers' health; reduce household expenses and save time by not going to the market. The home garden activities will reduce GHG emissions from vegetable production and usage of fossil fuel in transportation. To further reduce GHG emissions, home gardens could integrate natural water systems or small fish ponds with pumping and water circulation using Photovoltaic (PV) systems. Using renewable energy with water management has been widely implemented in rural areas with no access to electricity and is an alternative to diesel pumps. Since water management is a main part of maintaining home gardens, implementing renewable energy with the BUG model would produce even lower carbon emissions. The results from this study could have high impact for the environment in the form of government policy with the goal to promote urban home gardens.

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