Scenario analysis for Green City model: Case study of Chiang Mai World Green City Model, Thailand

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Abstract

The principle of life cycle assessment, linear regression and trend analysis were applied to develop a Chiang Mai World Green City (CWGC) that could be used to estimate the CO_2 balance cycle at the Asian Development College for Community Economy and Technology (adiCET), Chiang Mai Rajabhat University, Thailand. From the CWGC model, scenario analysis was used as tool to determine the appropriate activities in terms of carbon neutral target. adiCET aims to be the first practical carbon neutral community in Thailand. adiCET could apply the result of CWGC model as a guideline of green city master plan. The data was observed and collected from the beginning of construction in 2011 to normal operation phase in the period of approximately 3.5 years. The CO_2 balance in CWGC model was calculated in terms of actual CO_2 and relative CO_2 value based on 15 years' simulation. The result of business as usual scenario showed the net accumulated CO_2 has gradually increased annually and the value is +2,001,834 $kgCO_2$ in the final year. For the best scenario, the net accumulated CO_2 is -7,505 $kgCO_2e$ in which the trend decreases to nearly zero as the ideal carbon neutral concept from the 4th year until the final year. The results of the best scenario revealed the potential that adiCET could achieve the carbon neutral goals as mentioned with the appropriate implementation of carbon mitigation activities.

Keywords: *scenario analysis, trend analysis, mathematical model, carbon neutral community, low carbon society, green city model*

1. Introduction

The industrial revolution caused a significant increase in greenhouse gases (GHG) which is the root cause of global warming. Carbon dioxide (CO_2) is one of the most concerned GHG in the atmosphere. From 1750 to 2005, global atmospheric concentrations of CO_2 increased from 280 to 379 ppmv [1]. Referring to IPCC study, the European council reached at political consensus that an increase of 2^{o}C above pre-industries levels is the maximum safe level, therefore, CO_2 concentrations must be less than 450 ppm in the atmosphere [1, 2]. The reduction of CO_2 emissions has become one of the most important issues in the Kyoto protocol. The countries must reduce their emissions by at least 5% below 1990 level [3]. To achieve this goal, many countries have implemented low carbon society concepts, such as the Japan government set a goal of 70% CO_2 reduction in 2050, namely, 2050 Japan Low Carbon Society [4]. The United Kingdom has committed to reduce the CO_2 emissions to 60% of 1990 levels by 2050 [5]. Thailand has established the agenda in the Tenth National Economic and Social Development Plan (2007-2011) to decrease 5% of CO_2 emissions per capita to be less than 3.5 tCO_2 per capita [6]. Moreover, guidelines of low carbon society vision 2030 of Thailand have been submitted by the SIIT, Thailand for approval. NIES, Japan concluded that CO_2 emissions per capita of Thailand will increase from 3.1 tCO_2/year in 2005 to 8.2 and 4.7 tCO_2/year in 2030, without and with counter measures, respectively [7].

In the context of international concern on climate change with the emission of GHG, Chiang Mai World Green City Model (CWGC) was established as a tool to demonstrate implementation activities to achieve carbon neutrality. CWGC has the goal of becoming the first carbon neutral community in Thailand. The Biggar village of Scotland [8] and Tianjin eco-city of China [9] aimed to be a carbon neutral community as well. Carbon neutral means that through a transparent process of calculating emissions, reducing those emissions and offsetting residual emissions-net carbon emissions equal zero [10]. CWGC model would be a carbon neutral tool of adiCET by analyzing and forecasting the dynamics of CO_2 emissions within the next 15 years (2013-2028), through the population growth which will interact with the carrying capacity of adiCET. From the Collapse book, the major factor contributing to the failures of group decision making is the failing to anticipate the problem [11]. Therefore, the forecasting of CO_2 emission is important to policy makers in order to set action plans and select the appropriate technologies. Zhang Hong Bo [12] has developed SPSS model for forecasting energy demand and propose measurement for energy restructuring which could contribute to energy policy of China.

CWGC model is a bottom-up model study which is designed to explore the interconnected behavior modes in a limited system as the prediction of the future carbon balance cycle [13]. The model composed of a group of mathematical equations which are the representative of activities at adiCET. The principle of trend analysis and life cycle assessment were employed as a main method of calculation. Trend analysis is a mathematical technique which used historical data to predict future. It is a simplified method and the projection is based on the available data which the other techniques are more complicated and require many parameters [14]. For example, in our study the electricity consumption, municipal waste generated and water consumption per day was collected for 120 days. Those data are classified as value per person. Then, the equations in the function of time and population are developed from the linear optimization and regression analysis which could simulate future projection. Life cycle assessment is defined as the computation and evaluation of input, output and potential environmental impacts of product system throughout its life cycle [15]. It is understandable that the relationship of CO_2 cycle is complex due to various sources and sinks in the part of dynamic system. A lot of systematic methodologies were applied to estimate the CO_2 balance in the local area. However, we have explored a simplified method and established a model by the intent of accessibility for others. Moreover, an understanding of CO_2 balance model would be a key success factor of sustainable development in the future. This is a new intent to combine a scenario analysis with CWGC model to determine the appropriate activities. Besides that, the relative abatement cost was evaluated to verify the possibility of each scenario in practical action to ensure the selected scenario was considered by comparing with BAU [16]. Ambiguous measuring and misunderstanding KPI of development from the past is the initiating point which lead to develop CWGC model as a tool for measuring and controlling CO_2 emissions. The model could provide a new indicator to monitor performance activity where the outcomes of all activities were converted into the equivalent number of $kgCO_2e$.

In this paper, the development of CWGC model is described in the first section which is composed of conceptual framework and mathematical model, and then we have applied scenario analysis for justifying the appropriate actions for adiCET. We hope that this paper will be useful to stimulate people to reconsider and become more informed about the principle of green city. Finally, the word of green city model will be a common phrase for Thai people.

2. Methodology

In this work, Asian Development College for Community Economy and Technology (adiCET) was chosen as the case study for the green city model. adiCET is located in Chiang Mai Rajabhat University, Amphur Mae Rim, Chiang Mai Province, Thailand. adiCET has the total area of 16 Hectares (ha) which comprised on developed land of 1.34 ha with 16 building units as smart community. The smart community has residential housings, green institute and an office and business zone. The community business area comprises on a convenient store, a restaurant, and a coffee shop. These businesses are the training center and outlets for agricultural and local community products from surrounding communities. Smart community is also the first community in the world with DC micro grid that installed 55 kWp PV power plant and 20 kW biomass gasification power plant. Green Institute is the zone for academics and research, and the location for ASEAN Regional Training and conference Center. All classrooms, conference, and seminar centers were constructed to be energy efficient and integrated with the environment. The populations of this study are separated in 4 groups which had the same concept with TGBI [17] including 10 permanent residents, 10 non-permanent residents, 30 students/month and 100 visitors/month at the first year. The number of occupants will increase every year until reach the carrying capacity in the 9^{th} year. Therefore, the populations in the simulation are based on actual population in the first year and increases at 10.8% per year by average. The picture of adiCET is shows in the Figure 1.

Figure 1 Top view of adiCET, Chiang-Mai Rajabhat University, Thailand

2.1 The conceptual framework of CWGC model

CWGC model was developed from the vision of adiCET to solve the global warming crisis. The CWGC model is a simplified mathematical model where the relationship of each activity was represented through a set of mathematical equations. While Shiwei Yu has proposed a hybrid algorithm PSO-GA EDE model to improve estimation efficiency for future projection with the more complicated method [18]. The operation data from construction to operation period was collected for approximately 3 years. The principle of LCA and trend analysis method was used to project the future model. CWGC model has been developed for estimating the dynamic CO_2 emissions of adiCET within the next 15 years. Currently, there are many studies about the simulation of CO_2 emissions. For example, global environmental model -

21P(GEM-21P) [19] and SIIT et al. (2010) has developed LCS 2030 for Thailand by simulated CO_2 emissions from 2005 to 2030. There are many factors that influenced the carbon balance of the model. The population growth is a driving force of the model and was applied as the driving variable of the model. In this paper, the population growth of adiCET was assumed as structurally capable of sigmoid curve [20]. Sigmoid growth curve is in the condition of the external factors which are instant and accurate or the population limits itself without needing signals from external limits [21]. The simulation of CWGC model could be a tool for adiCET to evaluate the degree of green city or carbon neutral community. The conceptual framework of study is described with diagram as shown in Figure 2.

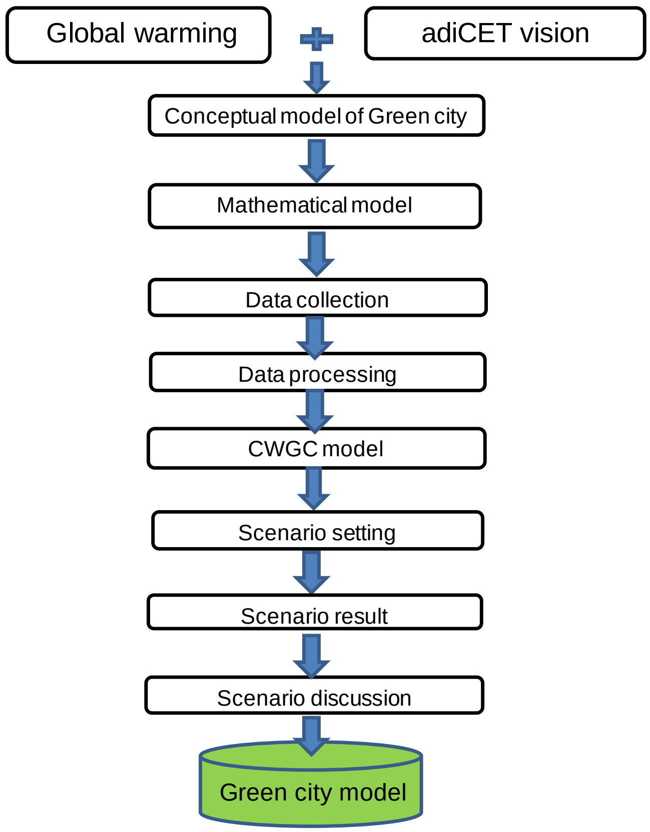

Figure 2 The conceptual framework diagram of CWGC model scenario analysis

Figure 2 states all steps for developing the CWGC model. Setting up conceptual model of green city is the first action of this study, with the question of "how to be carbon neutral community?" Secondly, mathematical model formation by using the principle of trend analysis, a set of mathematical equations, which represents dynamics of carbon balance of adiCET has been developed. Then, the process of data collection consisted of onsite survey, questionnaires, adiCET records, secondary data, and technical information. The data values of each variable are the rate of consumption per person with the consideration of population growth. The analysis consisted of 3 data groups: 1) Basic Infrastructures such as amount of green area, building number, size of building etc; 2) CO_2 emissions from construction period as the constant value; and 3) Rate of $kgCO_2$ per person and per month which is the dynamic part of equation in the function of time and population.

2.2 The development of CWGC model

From the conceptual framework and the principle of LCA and trend analysis, CWGC model was developed to estimate and evaluate the influence of different conditions. From Figure 3, there are 2 groups of the CWGC model consisting of CO_2 emissions, represented with positive (+) sign, and CO_2 sequestrations group, represented with negative (-) sign. From the diagram of CWGC model (Figure 3), the detail of variables' relationship is shown in Figure 4 which is composed of variable chains of cause and effect. The meaning of (+) and (-) sign are the relationship of variables and environment. In addition, the (+) sign is a direct variation while the (-) sign is an inverse variation for the cause and effect variables. Figure 4 lead to the process of data collection and on-site survey with variable determination and sample group. The scope of area was mathematically and statistically evaluated.

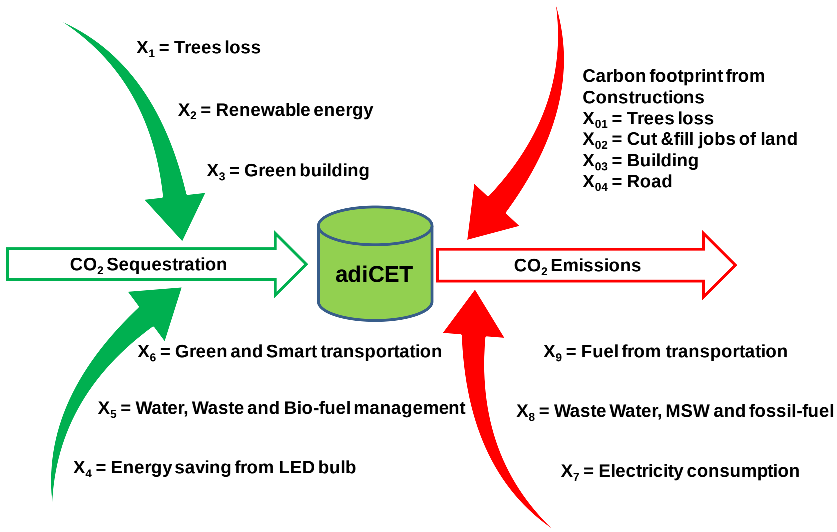

Figure 3 The diagram of CWGC model

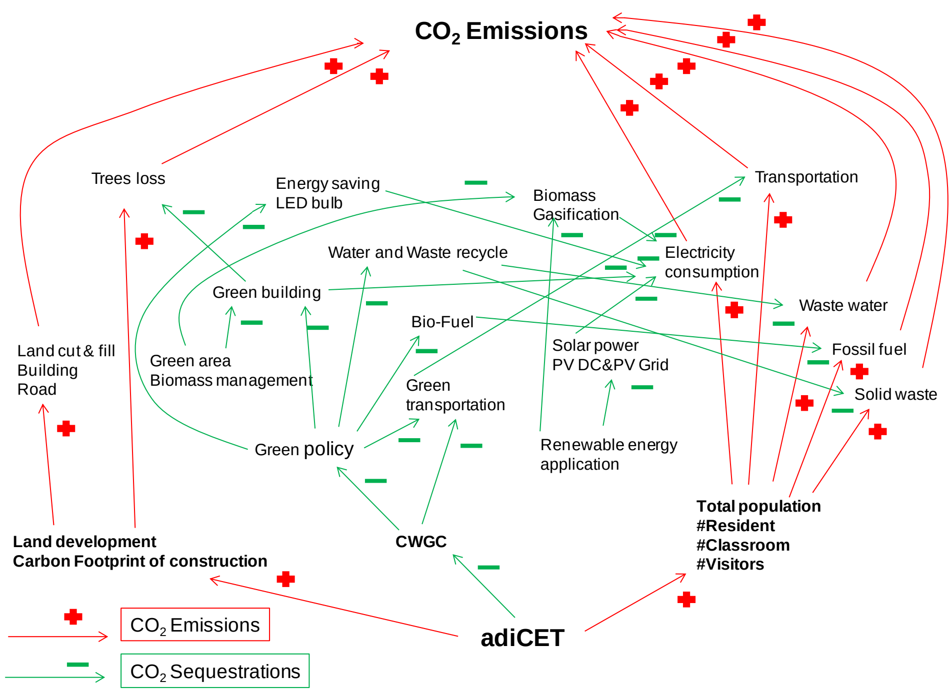

Figure 4 A chain of cause and effect of CWGC model

The data presented the relation between direct variation and inverse variation regarding the number of population at a given time. It could demonstrate in the form of equations that represented CWGC model as followed.

$$Yacc = \sum_{i=1}^{180} Yi + X_0 \quad (1)$$

$$X_0 = X_{01} + X_{02} + X_{03} + X_{04} + X_{05} \quad (2)$$

$$Y_i = X_{1i} + X_{2i} + X_{3i} + X_{4i} + X_{5i} + X_{6i} + X_{7i} + X_{8i} + X_{9i} \quad (3)$$

$$X_{1i} = NPP_r/k - (NPP/k \times e^{-ki}) \quad (4)$$

$$NPP = NPP_r \times A \quad (5)$$

$$k = NPP/ CO_2 \text{ outlet} \quad (6)$$

$$X_{2i} = ((X_{2iPVDC} + X_{2iPVPG)} \times EF_{PV} + (X_{2iG} \times EF_{G})) \quad (7)$$

$$X_{2iPVDC} = \text{average capacity} \times kWp \quad (8)$$

$$X_{2iPVDC} = X7i + \% \text{ of PVDC improvement} \quad (9)$$

$$X_{2iPVPG} = \text{average capacity} \times kWp \quad (10)$$

$$X_{2iG} = \text{Capacity} \times \text{operation time} \quad (11)$$

$$X_{3i} = (-0.000619755 \times N_i^2 + 1.490389657 \times N_i + 1.13 \times 10^{-12}) \times EF_3 \quad (12)$$

$$\text{kW heat} = \Delta OTTV \times \text{Total surface (Roof and wall)} \quad (13)$$

$$\Delta OTTV = \text{OTTV standard} - \text{OTTV actual} \quad (14)$$

$$\text{OTTV actual} = (Uw \times T_{deq} \times (1-WWR)) + (SF \times SC \times WWR) + (WWR \times U_f \times \Delta T) \quad (15)$$

$$3.5 \text{ kW heat} = 1 \text{ RT} \quad (16)$$

$$\text{kW saving} = \# \text{ RT} \times \text{efficiency of air conditioner} \times \# \text{ hrs of loading} \quad (17)$$

$$X_{4i} = (X_{7ikWh} \times 0.3) \times \% \text{ ES} \times EF_4 \quad (18)$$

$$X_{5i} = (X_{5iB1} \times EF_{B1}) + (X_{5iB2} \times EF_{B2}) + (X_{5iW} \times EF_{5W}) + (X_{5iH} \times EF_{5H}) \quad (19)$$

$$X_{5iB1} = (X_{8iW} \times 0.4) \times \% R_{51} \quad (20)$$

$$X_{5iB2} = (NPP \times 0.33) \times \% R_{52} \quad (21)$$

$$X_{5iW} = (X_{8iW} \times 0.6) \times \% R_{53} \quad (22)$$

$$X_{5iH} = X_{8iH} \times \% R_{54} \quad (23)$$

$$X_{6i} = -X_{9i} \times \% R_6 \quad (24)$$

$$X_{7i} = X_{7ikWh} \times EF_7 \quad (25)$$

$$X_{7ikWh} = (X'_{7i1} \times FTE_{1i} + X'_{7i2} \times FTE_{2i} + X'_{7i3} \times FTE_{3i} + X'_{7i4} \times FTE_{4i}) \times b + a \quad (26)$$

$$FTE_{1\_4i} = N_{1\_4i} \times \text{Frequency of visiting for } N_{1\_4} \quad (27)$$

$$X_{8i} = X_{8iW} \times EF_W + X_{8iH} \times EF_H + X_{8iE} \times EF_E \quad (28)$$

$$X_{8iW} = (X'_{8iW1} \times FTE_{1i} + X'_{8iW2} \times FTE_{2i} + X'_{8iW3} \times FTE_{3i} + X'_{8iW4} \times FTE_{4i}) \times b + a \quad (29)$$

$$X_{8iH} = ((X'_{8iH1} \times FTE_{1i} + X'_{8iH2} \times FTE_{2i} + X'_{8iH3} \times FTE_{3i} + X'_{8iH4} \times FTE_{4i}) \times b + a + X_{8iH5}) \times EF_H \quad (30)$$

$$X_{8iE} = X'_{8iE1} \times EF_E \quad (31)$$

$$X_{9i} = (X'_{9i1} \times FTE_{1i} + X'_{9i2} \times FTE_{2i} + X'_{9i3} \times FTE_{3i} + X'_{9i4} \times FTE_{4i}) \quad (33)$$

2.3 Scenario analysis

Scenario analysis is a process of analyzing possible future situation which can determine the consequences of activities under different conditions. It is not to identify the exact conditions of the future but rather to highlight central element of a possible future and draw attention to the key factors that will drive future development [22]. Scenario analysis, as a tool to support decision making for green city policy, have been reported and shown alternative activities which have high potential for action by many groups such as LCS 2050 [4] of Japan, LCS2030 of Thailand [7] and Biggar community of Scotland [8].

To formulate CWGC model, expected data was estimated under various scenarios with the intent of the potential ability of adiCET through the year 2028 and scenario setting is the first step by varying the degrees of contribution of driving forces parameters. With the same concept as Wang [23] with the case of Minhang District, the degrees of driving forces parameters were varied from minimum to maximum level. In this paper, the potential capacity for improvement of adiCET was assumed in the case of minimum, maximum and middle for each scenario. After that, the optimum conditions were selected with the intention of adiCET to be carbon neutral community. The selected variables and their assumption of improvement are presented in Table 1.

Table 1 The assumption and the range of degrees' contribution of driving force parameters

Parameters	Assumption	Minimum	Maximum
X_1	Increasing the area of green city as the existing area is 16 ha.	16 ha	32 ha
X_{2PVDC}	At present, the capacity of PV DC power system is more than the consumption of DC apparatus, therefore, the modification of that will increase CO_2 sequestration. The value is of % of electricity apparatus modify to cover maximum capacity PV DC system.	0 %	100 %
X_{2G}	Increased operation time of biomass gasifier will increase CO_2 sequestration. The normal operation is a 3 hrs/day and maximum is 24 hrs/day.	3 hrs	24 hrs
X_3	The green building can develop OTTV value by increase shading area of surrounding area for prospected buildings. Adjustment the Sc value (Shading coefficient) of mirror at prospected buildings from 0.73 to 0.65 will enhance energy saving 5%. 5% of energy saving is the maximum value.	0 %	5 %
X_4	The lighting system was assumed as 30% of total consumption. With the replacement of light bulb to LED, energy saving will decrease lighting loading 70% or 20% of total loading. Therefore, 20% is the maximum value [24].	0 %	20 %
X_{5B1}	Recycle organic waste to biochar will increase CO_2 sink. The percentage of organic waste recycle from the total organic waste will be the represented value of this activity [25].	0 %	100 %
X_{5B2}	Using residual biomass from green area for biomass gasifier will increase CO_2 sequestration. Using rate of residual biomass will calculate in term of percentage of total residual biomass. Residual biomass is a part of bark and leaf of tree which will decompose to the nature if we do nothing [26].	0 %	100 %
X_{5H}	Implementation of recycle water from household for watering green area to reduce irrigation water. 50% of water used at household was assumed to be recycled for that purpose. The 50% volume of household usage is 25% of total volume, then 25% will be a maximum value.	0 %	25 %
X_{5W}	Recycle of plastic wastes	0 %	100 %
*X_6	Emissions from transportation are the main portion of CO_2 emissions of the model. adiCET has developed green transportation and smart classroom projects for a year, however the energy saving have not been recorded officially. It was assumed that those projects could reduce CO_2 emissions for the maximum of 38% and 10% from the average of the total transportation emissions.	0 %	38 %

*Green transport is defined as walking, cycling, and riding public transport [9]. For adiCET, car pool and electric vehicle is also considered as green transport.

The degrees of contribution of driving forces parameters were calculated in terms of net accumulated CO_2. The result is shown in BAU or Scenario A as a baseline for the other scenarios. The results of BAU lead to setting up 3 scenarios corresponding to different degrees of contributions in the views of improvement. The scenario with minimum improvement is Scenario B, moderate improvement is Scenario C, and maximum improvement is Scenario D. The level of improvement was based on actual carrying capacity of adiCET. The details of 5 different scenarios are shows in Table 2.

Table 2 The degree of contributions for driving force parameters in each scenario

		Degree of contribution									
Scenarios	Assumptions	X_1	X_{2PVDC}	X_{2G}	X_3	X_4	X_{5B1}	X_{5B2}	X_{5W}	X_{5H}	X_6
		ha	%	hrs	%	%	%	%	%	%	%
A	BAU	16	0	3	0	0	0	0	0	0	0
B	Minimum improvement	16	10	3	0	5	10	10	10	5	0
C	Average improvement	24	50	8	5	10	50	50	50	15	10
D	Maximum improvement	32	100	24	10	20	100	100	100	25	30
E	Ideal condition#1	28	100	3-6	3-10	20	100	100	100	25	10
F	Ideal condition#2	16	100	3-6	3-10	20	100	100	100	25	10-38

The assumptions of each scenario are described as follows:

1. BAU (Business as Usual) or Scenario A is baseline of the CWGC model.
2. Scenario B is a worse condition or minimum improvement for X_{2PVDC}, X_{3G}, X_4, X_5 and X_9
3. Scenario C is a moderate improvement for X_1, X_{2PVDC}, X_{3G}, X_4, X_5 and X_9
4. Scenario D is a maximum improvement for X_1, X_{2PVDC}, X_{3G}, X_4, X_5 and X_9
5. Scenario E is ideal condition #1 which focusing on green area activity and the optimum value from the Scenario B, C and D
6. Scenario F is ideal condition #2 which focuses on green transportation activity and the optimum value from the Scenario B, C and D

3. Scenario result and discussion

The result of Scenario A or BAU in Figure 5 shows the simulation over the 15-year time period of 2013-2028. The graph composed of CO_2 sequestrations group (X_1, X_2, X_3, X_4, X_5, and X_6) and CO_2 emissions group (X_7, X_8, and X_9). The positive and negative values are represented for CO_2 sequestration and CO_2 emissions, respectively. Overall, the summation of sequestrations group is 33% and emissions group 67% of total CO_2 transferring in the system. For CO_2 sequestrations group, the percentage of X_1, X_2 & X_3 is 66.30%, 30% and 4.2%, respectively. In case of X_4, X_5 and X_6 is on the process of recording data officially so we have not included the results of that in this period. We found that green area and renewable energy will be the main contributors to offsetting CO_2 emissions. Unfortunately, the Biggar community has similar initiative by increasing green area and renewable energy with wind turbine to offsetting CO_2 emissions [8]. While the percentage of emissions group, X_7, X_8 and X_9 are 4.4% 15.8%

and 79.8%, respectively. The transportation activity or X_9 is the main CO_2 emissions which should be the main focus for the emission mitigation. Corresponding to the Biggar community, CO_2 emissions from transportation is 59 % of the total emissions [8]. For the overall of Thailand, the emission from transportation sector is 30% but lower than industrial sector which is 45% [7]. Anyhow, the study of Sawangphol on polices suggestion toward low carbon electricity development in Thailand have shown the emission reduction with nuclear scenario and without nuclear scenario at 9.43% and 7.18%, respectively [27]. While a CO_2 emission from transportation sector of Bangkok is the major part at 37.68% [28] which is close to adiCET. From the results, Figure 6 exhibited the summation of that as the net accumulation of CO_2.

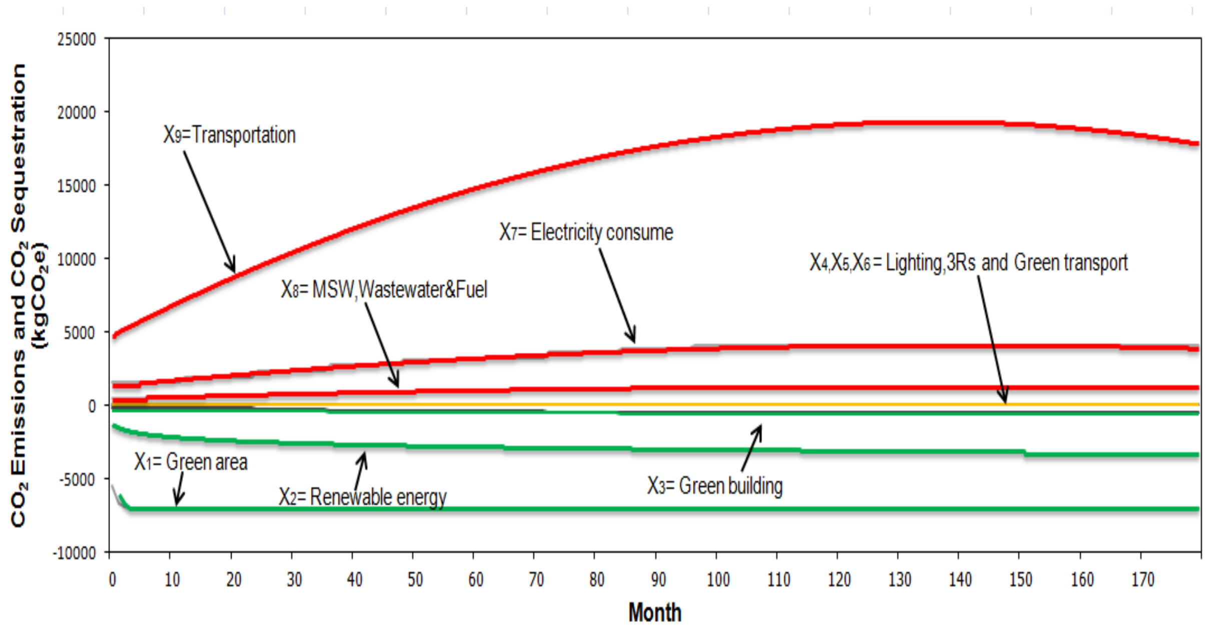

Figure 5 CO_2 emissions and CO_2 sequestrations of BAU

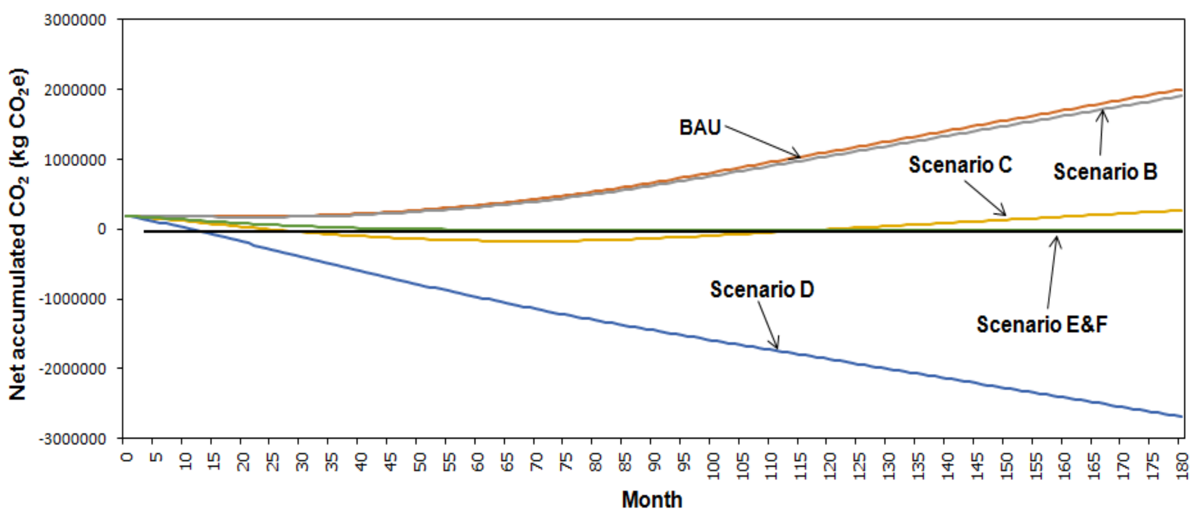

Figure 6 The net accumulated CO_2e graph of scenario A, B, C, D, E and F

At the first period of Scenario A (BAU), the net accumulated CO_2 balance will be constant at the value of 180,000 kgCO_2e until the 24th month. Then, the CO_2 emission has dramatically increased from the transportation sector at 133,455 kgCO_2e/year from the direct influence of the population growth in the simulation. The result of the net accumulated CO_2 (Yacc) of BAU was adjusted for the value of X_1, X_{2PVDC}, X_{2G}, X_3, X_4, X_{5B1}, X_{5B2}, X_{5W}, X_{5H} and X_9 in different conditions for Scenario B, C and D based on the assumption of minimum, moderate and maximum improvement, respectively. From that adjustment, the net accumulated CO_2 of Scenario B is the similar with Scenario A. The CO_2 emissions have been slightly mitigated by increasing the renewable energy usage and waste recycle programs. The net accumulated CO_2e has decreased from 2,001,834 to 1,907,245 kgCO_2e at the final year. Scenario C which is the moderate improvement of green area, renewable energy, waste recycle and green trip activities provided a positive result for the net accumulated CO_2e. The trend dropped rapidly from the beginning until 72nd months. After that, it has dramatically increased by the influence of transportation sector. From the existing resources, Scenario D has simulated with the maximum increase of green area, renewable energy, recycle projects and green transportation. The result has shown the maximum CO_2e offsetting by decreasing of the net accumulated CO_2 average of -417,694 kgCO_2e/year and the value is -2,392,562 kgCO_2e in the final year. The tendency results of Scenario B, C and D are the guideline for adjusting the degrees' contribution of potential parameters to determine the appropriate value for ideal scenarios. The carbon neutral community assumption, as the trend of the net accumulated CO_2, should be nearly zero or a slightly negative at the end of the model. The ultimate outcome of the ideal scenario, scenario E and F, showed the tendency mentioned above. The list of influencing factors for Scenario E, Scenario F and BAU are shown in the Table 3.

Table 3 List of influence factor for Scenario E, F and BAU

Item	Scenario E % of contribution	Scenario F %of contribution	BAU % of contribution
Transportation (X9)	37.94	39.94	51.21
Green area (X1)	23.9	23.9	16.0
Renewable energy (X2)	10.79	10.79	9.63
Green transportation (X6)	3.79	11.7	0
Environment M. (X5)	10.36	10.36	0
Waste, Water, Fuel (X8)	7.5	7.5	10.13
Construction (X0)	2.43	2.43	3.28
Electricity consume (X7)	2.07	2.07	2.8
Green building (X3)	1.06	1.06	1.06
Lighting bulb (X4)	0.12	0.12	0
Total	100	100	100

Scenario E and F were employed as ideal scenarios by focusing on the improvement of green area and green transportation, respectively. By adjusting the degrees of the parameter driving force, the expected net accumulated CO_2 should be nearly zero which is the sign for carbon neutral community. Scenario E and F has shown that tendency of net accumulated CO_2 near zero from 48th months until the 15th years. Therefore, Scenario E and F were represented as the best scenario which the trend line are most complied with the principle of green city or carbon neutral community. The scenarios could be described in details of activities in terms of the quantity of emissions and the percentage of contribution in Table 4.

Table 4 The descriptions of potential activities for scenario E and F

Item	Scenario E	Scenario F
1. Green area (X_1)	Expanding green area 1.76 hectares in 49th month 4.96 hectares in 73rd month 5.6 hectares in 85th month	No expanding plan.
2. DC power plant (X_{2PVDC})	Modify electricity apparatus to utilize 100% of electricity from DC power plant	Modify electricity apparatus to utilize 100% of electricity from DC power plant
3. Biomass gasification power plant (X_{2G})	Increasing operation time from 3 hrs/day to: 5 hrs/day in the 37th-60th month 10 hrs/day in the 61st-72nd month 9 hrs/day in the 73rd-84th month 7 hrs/day in the 85th-96th month 8 hrs/day in the 97th-180th month	Increasing operation time from 3 hrs/day to: 5 hrs/day in the 37th-60th month 10hrs/day in the 61st-72nd month 9hrs/day in the 73rd-84th month 7hrs/day in the 85th-96th month 8hrs/day in the 97th-180th month
4. Green building (X_3)	Improving shading and insulation of building 9 units to improve Sc value from 0.73 to 0.65 which could reduce 5% energy consumption.	Improving shading and insulation of building 9 units to improve Sc value from 0.73 to 0.65 which could reduce 5% energy consumption.
5. Energy saving from lighting (X_4)	Change lighting bulb by using LED bulb from 46, 60, 150 and 250 Watt to 5,7,18 and 36 Watt, respectively.	Change lighting bulb by using LED bulb from 46, 60, 150 and 250 Watt to 5,7,18 and 36 Watt, respectively.
6. Organic waste (X_{5B1})	100% Recycle organic waste to be bio-char as a soil conditioner	100% Recycle organic waste to be bio-char as a soil conditioner
7. Residual biomass (X_{5B2})	100% recycle the residual biomass to be fuel of biomass gasification	100% recycle the residual biomass to be fuel of biomass gasification
8. Plastic waste (X_{5W})	100% plastic waste as a renewable material for construction or other purpose. 25% of waste water for watering green area	100% plastic waste as a renewable material for construction or other purpose. 25% of waste water for watering green area
9. Green transportation (X_6)	No additional action	Implemented green transportation and smart classroom projects, we have assumed that the CO_2 emissions will decrease 10% and 38%

4. Conclusion

adiCET aims to become the first carbon neutral community in Thailand. Therefore, the CWGC model was developed to estimate the CO_2 balance in the future as the guideline for the adiCET carbon neutral strategic planning. From the simulation, the results revealed that it is possible to achieve that goal with action plans for practical implementation. The data collected for this work started from the construction periods of the Chiang Mai World Green City to the normal operation of almost 4 years. This paper is pioneer study for the green community with the purpose of developing a method for evaluating the green activities potentials with simple mathematical and statistical method. Mathematical model was established along with the principle of trend analysis. The data was collected to formulate the forecasting equation which could project the tendency of CO_2 balance in the future for 15 years. The tendency of CO_2 balance of BAU is steady in the beginning and gradually increases until 15^{th} years because of the influence of CO_2 emissions from transportation, municipal waste and electricity. Then, the data was simulated by using scenario analysis and assuming different conditions for each scenario. The results of BAU scenarios lead to determine the appropriate condition for the ideal scenario, namely Scenario E and F. The ideal scenarios have simulated appropriate activities to offset CO_2 emissions in the optimum range which made the tendency line of the CO_2 accumulated emissions nearly zero according to the target of adiCET as carbon neutral community. The accuracy of the CWGC model CO_2 balance projection is indicative of the influence of several factors which need to be collected for longer term. Moreover, achieving the green city model in real conditions will be challenging. The results of this research would be beneficial to policy making process of green city prototype and the model of sustainable community.

Reference

[1] Alley, R.B., Spencer, M.K., Anandakrishnan and S., "Ice-sheet mass balance: Assessment, attribution and prognosis," Ann. Glaciol, 46 (2007) 1-7.

[2] Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller and H.L., "Climate change 2007: The physical science basis," Contribution of working group 1 to the Fourth assessment report of the intergovernmental panel on climate change, Cambridge University Press, Cambridge, UK (2007).

[3] United Nation, "Kyoto protocol to the united nation framework convention on climate change," United Nation (1998).

[4] National Institute for Environmental Studies (NIES), Kyoto University, Ritsumeikan University, Mizuho Information and Research Institute, "2050 Japan low-carbon society," Tsukuba-City, Ibaraki, Japan (2007).

[5] Odenberger, M., Johnsson, F., "Achieving 60% CO_2 reductions within the UK energy system-implications for the electricity generation sector," Energ. Policy, 35 (2007) 2433-2452.

[6] National Economic and Social Development Plant Board (NESDB), "National economic development plan 10" (2006), WWW.IDD.go.th/Thai-html/05022007/pdf/pdf01/index.htm, accessed 10 Dec 2013.

[7] Sirindhorn International Institute of Technology, Thammasat University, Asian Institute of Technology, National Institute for Environmental Studies, Kyoto University, Mizuho Information & Research Institute (2010). "Low carbon society vision 2030 Thailand", https://www.siit.tu.ac.th/pdf/LCS_Thailand_2030.pdf, accessed 02 Feb 2013.

[8] Barthelmie, R.J., Morris, S.D., Schechter and P., "Carbon neutral Biggar: Calculating the community carbon footprint and renewable energy options for footprint reduction," Sustain Sci., 3 (2008) 267-282.

[9] Federico, C., "Critical research on eco-cities A walk through the Sino-Singapore Tianjin eco-city, China," Cities, 36 (2014) 10-17.

[10] Department of Energy and Climate Change (DECC), UK 2009. "The guidance on carbon neutrality," www.practicallaw.com/0-385-1549, accessed 03 Jun 2012.

[11] Diamond, J. 2005. "Collapse; How societies choose to fail or succeed," Penguin Group, New York, USA.

[12] Zhang, H. and Zhang, N., "Forecast of energy demand in the next decade," Energy Procedia, 5 (2011) 2536-2539.

[13] Nakata, T., Silva, D., Rodionov, M., "Application of energy system model for designing a low-carbon Society," Prog. Energy. Combust., 37 (2010) 462-502.

[14] Aylin, C.K., Tayfun, B., "Forecasting of CO_2 emissions from fuel combustion using trend

Analysis," Renew. Sust. Energy. Rev., 14 (2010) 2906-2915.
[15] Guinee, J.B., "Handbook on life cycle assessment operation guide to the ISO standard," Kluwer academic, New York (2004).
[16] Mckinsey & company, "Pathways to a low-carbon economy version 2 of the global green house gas abatement cost curve" (2009), http://www.mckinsey.com/~/media/mckinsey/dotcom/client _service/ sustainability/cost%20curve%20pdfs/pathways_lowcarbon_economy_version2.ashx, accessed 06 Apr 2011.
[17] Thai green building Institute (TGBI), "Thai's rating of energy and environmental sustainability for new construction and major renovation," Chulalongkorn University (2012).
[18] Shiwei, Y., Yi-Ming, W., Ke, W., "A PSO-GA optimal model to estimate primary energy demand of China," Energ. Policy, 42 (2012) 329-340.
[19] Baek, C., Park, S.H., Suzuki and M., "Life cycle carbon dioxide assessment tool for building in the schematic design phase," Energ. Buildings, 61 (2013) 275-287.
[20] Pinngarm, P., Setthapun, W., Pavasant, P., Jesdapipat and S., "Linear regression and forecasting analysis for green city model: Case study of Chiang Mai World Green City model, Thailand," Proceedings of World Biodiversity Congress, The Development Dimension of Thai Graduate to ASEAN Citizenship: dd-TGAC, Chiang Mai, Thailand, (2013) 42-52.
[21] Meadows, D., Randers, S., Meadows and D., "Limits to growth," Chelrea green publishing Company, USA (2004).
[22] Kosow, H., Gaβner and R., "Methods of future and scenario analysis, overview, assessment and selection criteria," German Development Institute (DIE), Bonn, Germany (2008).
[23] Wang, M., Che, Y., Yang, K., Wang, M., Xiong, L., Huang, Y., "A local scale low carbon plan base on the STIRPAT model and the scenario method: The case of Minhang District, Shanghai, China," Energ. Policy, 39 (2011) 6981-6990.
[24] Neto, A.H., Fiorelli and F.A.S., "Comparison between detailed model simulation and artificial neutral network for forecasting building energy consumption," Energ. Building, 40 (2008) 2169-2176.
[25] Lehmann, J., Gaunt, J., Rondon and M., "Bio-char sequestration in terrestrial ecosystem," Mitig. Adapt. Strat. Global Change, 11 (2006) 395-419.
[26] Gajaseni, J., Gajaseni, N., "Ecosystem ecology," Chulalongkorn University Press, Bangkok, Thailand (2009).
[27] Sawangphol, N., Pharino and C., "Status and outlook for Thailand's low carbon electricity development," Renew. Sust. Energ. Rev., 15 (2011) 564-573.
[28] Bangkok metropolitan Administration, "Greenhouse gas emissions: Baseline inventory and projections", (2007) 4-10. http://www.office.bangkok.go.th/environment.pdf, accessed 06 Aug 2012.