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Research article

Integrated approach for the estimation of regional low carbon potential: Application for Ho Chi Minh City, Viet Nam

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ABSTRACT

Currently, multidisciplinary integrated and quantitative methodologies are necessary for policymakers in deciding a reasonable and acceptable target of greenhouse gas (GHG) reduction as well as realization of mitigation actions. Therefore, this study aims to develop an integrated methodology to harmonize the top-down and bottom-up approaches to support the development of low carbon actions at the regional or city level based on their energy-saving programs and technology status. This integrated approach is necessary to bridge the theoretical and empirical frontiers of modeling in quantifying and analyzing the feasibility of the local police framework and international cooperation in terms of climate mitigation projects. The top-down approach uses the Extended Snapshot (ExSS) tool to estimate GHG emissions and reduction potential based on macro socioeconomic information. Meanwhile, the technology-based bottom-up approach is a method to estimate the reduction potential of GHG emissions by accumulating specific energy-saving projects. Parameters related to energy service demand, energy efficiency, energy share, and dispersed power generation are harmonized in the integration process via a set of equations. Under the assumption of socioeconomic growth of Ho Chi Minh City (HCMC), which is a 1.37 times increase for population and a 4.41 times increase for GDP growth in 2030 compared to 2013, the total energy consumption will increase 3.73 times compared to 2013, which is nearly 26 million toe (Mtoe) in 2030. The total GHG emissions will also increase 4.02 times, reaching nearly 117.2 $MtCO_2eq$ if HCMC does not consider any climate change mitigation actions. However, if HCMC successfully implements the mitigation projects discussed and quantified in this study, the total GHG emissions might be lower, approximately 85.6 $MtCO_2eq$. Analysis of the results from the two scenarios (BaU and CCAP) shows that the energy saving potential is approximately 15.0% and that the total GHG emissions reduction potential of HCMC (excluding the potential from grid power, which is outside the effort of HCMC) is 20.7% of BaU's emissions, which is between the 8-25% reduction target of Vietnam intended nationally determined contribution. By looking at the disaggregation of reduction potential by each sector and project, policymakers can prioritize mitigation measures to meet the GHG emissions reduction target or to maximize GHG emissions reduction potential. The integrated approach requires the consistency between classifications in top-down (driving force based) and bottom-up (technology based) approaches as well as the modification and bridging of the top-down sectors and the bottom-up categories with detailed data. This method is very applicable for cities or regions that are developing climate change action plans with precise technological information.

Key words: Top-down approach, bottom-up approach, energy savings, technology-based, low carbon actions, extended Snapshot model

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INTRODUCTION

As a low-carbon society is commonly recognized and has become the national goal[1], many countries are developing their low-carbon action plans[2], especially the importance of low-carbon action plans at the regional or city level[3–7]. Recently, the Plan-Do-Check-Act (PDCA) cycle has been considered one of the most effective tools to continuously improve the quality of low carbon action management and implementation[8]. At the Plan stage of the PDCA cycle, an overarching GHG emissions reduction target will be set. However, to decide a reasonable and acceptable target, policymakers must ensure that their planning stage considers the strong and complex relationship of low carbon policy with all socioeconomic activities and other sectoral policies. Furthermore, the climate change policy must be downscaled into projects that can be implemented at local or sectoral levels.

The important aspect of low carbon development studies is that the planning and realization of a low carbon society cannot be conducted successfully without multidisciplinary, integrated and quantitative methodologies[9–11]. The ExSS tool has been applied for the development of low-carbon scenarios for many cities and countries in Asia, such as Kyoto-

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Japan[12], China[13], Thailand[14], Malaysia[15], and Cambodia[16]. However, those studies have not considered the actual requirements of policymakers in developing and implementing action plans against climate change[17]. Moreover, the review shows that many applications of integrated approaches are for climate change adaptation[18–22].

As a result, this research aims to develop a methodology for an integrated approach where a top-down approach will be harmonized with a technology-based approach, especially those energy-saving projects that are being implemented and planned to be implemented in emerged cities for climate change mitigation. The method is applied for HCMC to quantify the GHG mitigation potential of the city based on its climate change action plan. Following this section, this paper is structured with Section 2, which describes the top-down approach and technology-based approach in climate change mitigation, especially the method for the integration of these two approaches. The results from applying this method to the case of HCMC, Vietnam, are written in Section 3, followed by the discussion and conclusions in Section 4 and Section 5, respectively.

MATERIALS AND METHODS

Top-down approach

In low-carbon scenario planning, the top-down approach is a method to estimate GHG emissions and reduction potential in a future changing society based on macro socioeconomic information. Two scenarios are assumed for the future based on socioeconomic and energy development plans. One is the business as usual (BaU) scenario, where there is no target for the reduction of GHG emissions. The other scenario is the climate change action plan (CCAP) scenario, where mitigation measures or projects are assumed to be implemented to meet a specific GHG emissions reduction target. GHG emissions in each scenario are calculated based on current data and future changes in macro socioeconomic and energy data. Then, the reduction potential of GHG emissions is calculated by comparing the two scenarios.

In the top-down approach, we can ensure the consistency between macro socioeconomic and energy indicators (calibration based on the data from the input–output table and energy balance table) and thus retain the development vision of policymakers. Moreover, there would be no duplication or overcounting of the GHG emissions reduction potential. However, policymakers can face difficulties in understanding the method and then reflecting it into the policy. This can be considered the weak point of the top-down approach.

In this study, the ExSS tool[12] is used to calculate energy consumption and CO_2 emissions according to equations (1) to (3). where *eds* stands for end use sector; *esv* stands for energy service; *e* stands for fuel; $ESDF_{eds,esv}$ stands for driving force; $\underline{Esvg_{eds,esv}}$ stands for energy service demand per driving force; $ED_{eds,esv,e}$ stands for energy demand; $ESVD_{eds,esv}$ stands for energy service demand; $Es_{eds,esv,e}$ stands for fuel share in energy service in end use sector *eds* and energy service *esv*; and $Ee_{eds,esv,e}$ stands for energy efficiency. Moreover, $CO2_{eds,esv,e}$ stands for CO_2 emissions; $Ttl\_Co2ef_{eds,e}$ stands for the CO_2 emission factor, including both dispersed power generation and central power supply.

$$ESVD_{eds,esv,e} = ESDF_{eds,esv} \times \underline{Esvg_{eds,esv}} \tag{1}$$

$$ED_{eds,esv,e} = ESVD_{eds,esv} \times ESVD_{eds,esv,e}/Ee_{eds,esv,e} \tag{2}$$

$$CO2_{eds,esv,e} = ED_{eds,esv,e} \times Ttl\_Co2ef_{eds,e} \tag{3}$$

$Es_{eds,esv,e}$ and $Ee_{eds,esv,e}$ are calculated based on energy device data, as shown in equations (4) and (5). where $Es_{eds,esv,e}$ stands for the total number of energy devices; $Ee_{eds,esv,e}$ stands for the average number of energy devices; *device* stands for the energy device; $\underline{Ts_{eds,esv,e,device}}$ stands for the share of energy devices in the end use sector *eds* and energy service *esv*; and $\underline{Te_{eds,esv,e,device}}$ stands for the energy efficiency of the energy device.

$$Es_{eds,esv,e} = \Sigma device \underline{Ts_{eds,esv,e,device}} \tag{4}$$

$$Ee_{eds,esv,e} = \frac{\Sigma device \left(\underline{Ts_{eds,esv,e,device}} \times \underline{Te_{eds,esv,e,device}} \right)}{\Sigma device \underline{Ts_{eds,esv,e,device}}} \tag{5}$$

$Ttl\_Co2ef_{eds,e}$ is calculated in equation (6). where *ele* stands for electricity (element of *e*, ele ∈ e); $\underline{DPG_{eds,e}}$ stands for dispersed power generation; $\underline{Co2ef_{"ele"}}$ stands for the CO_2 emission factor of electricity (excluding dispersed power generation); and $\underline{Dpg\_Co2ef_e}$ stands for the CO_2 emission factor of dispersed power generation.

$$Ttl\_Co2ef_{eds,e} = [\underline{Co2ef_{"ele"}} \times (\Sigma_{esv} ED_{eds,esv,"ele"} - \Sigma_e DPG_{eds,e}) + \Sigma_e \left(\underline{DPG_{eds,e}} \times \underline{Dpg\_Co2ef_e} \right)] / \Sigma_{esv} ED_{eds,esv,"ele"} \tag{6}$$

Technology-based approach

In low-carbon scenario planning, the list of mitigation projects with detailed measures and technology information[23] is the output, and these projects will be implemented in practice. Thus, the technology-based approach is a method to estimate the reduction potential of GHG emissions in the future by accumulating specific technological-based projects. First, we list up as many projects that can reduce GHG emissions as possible. Energy-saving technology projects have the highest potential and the highest feasibility to be implemented. The selection of the project needs to be consulted with policymakers and local experts. Then, it is required to make equations to calculate the GHG emissions reduction by each project and assign values of each parameter in the equations (for example, assuming the technological information). Finally, the total technology-based reduction potential in a region is acquired by summing the reductions by all projects. The technology-based approach provides the convenience and acceptance for policymakers to check the reliability of the reduction potential and then allocate these mitigation projects to related departments or authorities. However, since one project can contribute to reducing GHG emissions in not only one sector, the calculation of reduction potential might be duplicated. Thus, the integrated approach will bridge the merits of the mentioned individual approaches and overcome their limitations.

Integration between the top-down approach and the technology-based approach

Parameters for estimation of the CCAP case in ExSS, such as energy efficiency, are calculated backward from CO_2 reduction by projects and BaU data calculated by ExSS to reflect technology-based calculations (as illustrated in Figure 1). Projects can intervene in the CO_2 calculation of ExSS through three aspects and four parameters: energy service demand $(Esvg_{eds,esv})$; energy efficiency and share in energy service ($Es_{eds,esv,e}$ and $Ee_{eds,esv,e}$); and dispersed power generation ($DPG_{eds,e}$).

To integrate the top-down sectors with bottom-up categories, the ten technology-based categories are sorted into the ExSS's sectors. Since the ExSS tool only estimates the CO_2 emissions from energy-related activities (as shown in Figure 2), the GHG emissions from other nonenergy-related activities of technology-based categories might be estimated by applying IPCC guideline 2006 for GHG inventory[24]. The integration is also based on the characteristics of sectors in the top-down approach (Table 1) and categories in the bottom-up approach (Table 2).

Energy service demand

Projects related to energy service demand are reflected to ExSS through $Esvg_{eds,esv}$ by equation (7). where $Esvg\_BaU_{eds,esv}$ is the energy service demand per driving force in the BaU case; $CO2\_BaU_{eds,esv,e}$ is the CO_2 emissions in the BaU case; and $d\_CO2\_Esvg_{eds,esv,pj}$ is the reduction in CO_2 emissions by project *pj*.

$$Esvg_{eds,esv} = Esvg\_BaU_{eds,esv} \times \frac{\Sigma_e CO2\_BaU_{eds,esv,e} - \Sigma_{pj} d\_CO2\_Esvg_{eds,esv,pj}}{\Sigma_e \; CO2\_BaU_{eds,esv,e}} \tag{7}$$

Moreover, the energy intensity can be calculated by dividing the final energy consumption over the driving forces to show the change in energy consumption over the growth. For instance, if the driving force is population change, then the energy intensity will be final energy consumption per total population; and if the driving force is gross domestic product (GDP) growth, then the energy intensity will be final energy consumption per total GDP (as the energy intensity result shows in Table 4).

Energy efficiency and share in energy service

Projects related to energy efficiency and share in energy service are reflected to ExSS through $Es_{eds,esv,e}$ and $Ee_{eds,esv,e}$ by equations (8) and (9), in which each project is dealt with as a virtual device. In which, *pj* is project (subset of *device*, $pj \subset device$); $d\_CO2\_device_{eds,esv,e,pj}$ is reduction of CO2 emissions by project pj; $ESVD\_BaU_{eds,esv}$ is energy service demand in BaU case; $Ts_{eds,esv,e,pj}$ is share of project in enduse sector *eds* and energy service *esv*; $Ee\_BaU_{eds,esv,e}$ is energy efficiency in BaU case; $Te_{eds,esv,e,pj}$ is energy efficiency by project; $Ttl\_Co2ef\_BaU_{eds,e}$ is CO2 emission factor including both dispersed power generation and central power supply in BaU case.

$$d\_CO2\_device_{eds,esv,e,pj} = ESVD\_BaU_{eds,evs} \times Ts_{eds,esv,e,pj} \times \left(\frac{1}{Ea\_BaU_{eds,esv,e}} - \frac{1}{Te_{eds,esv,e,pj}}\right) \times Ttl\_Co2ef\_BaU_{eds,e} \tag{8}$$

$$\frac{1}{Te_{eds,esv,e,pj}} = \frac{1}{Ee\_BaU_{eds,esv,e}} - \frac{d\_CO2\_device_{eds,esv,e,pj}}{ESVD\_BaU_{eds,esv,e} \times Ts_{eds,esv,e,pj} \times Ttl\_Co2ef\_BaU_{eds,e}} \tag{9}$$

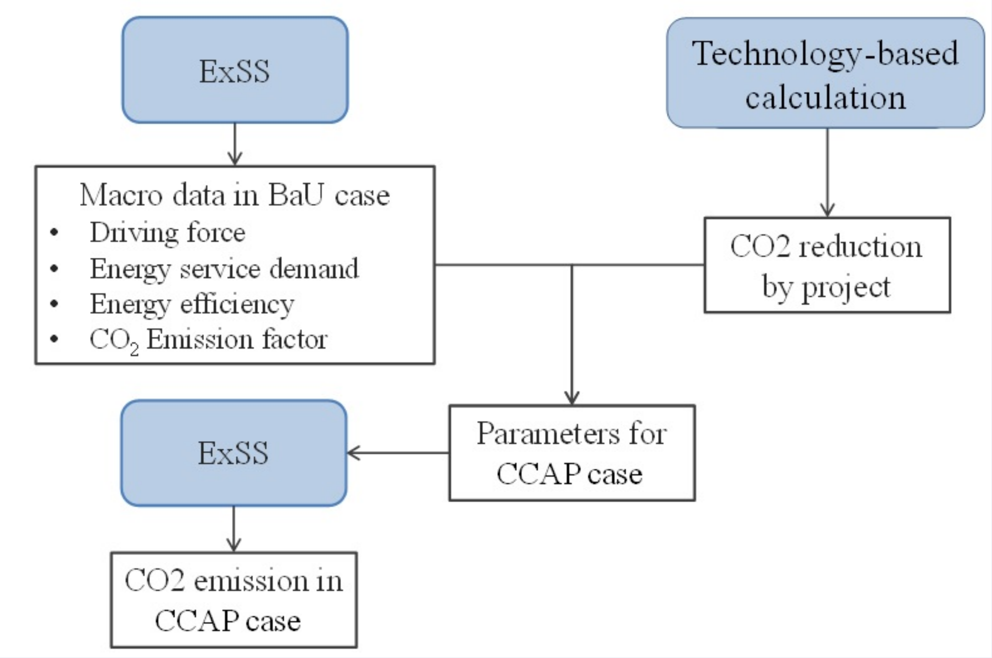

Figure 1: Flow of connection between technology-based projects and ExSS

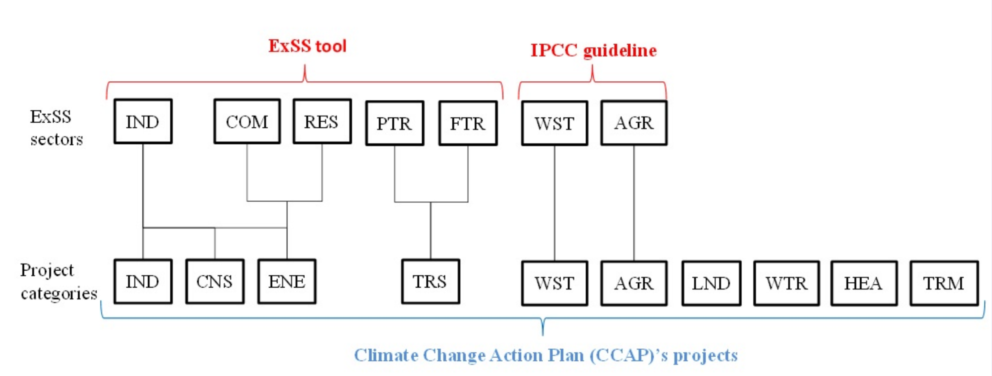

Figure 2: Integration of ExSS sectors and project categories

The remaining shares other than projects are occupied by representative technology in the BaU case, as calculated in equations (10) and (11). where *bau* is a representative technology in the BaU case (element of *pj*, $bau \in pj$) and *pj_ccap* stands for projects in the CCAP case (subset of *pj*, $pj\_ccap \subset pj$). Then, $Es_{eds,esv,e}$ and $Ee_{eds,esv,e}$ are calculated by using equations (12) and (13).

$$Ts_{eds,esv,e,"bau"} = Es\_Bau_{eds,esv,e} \times \left(1 - \Sigma_e \Sigma_{pj} Ts_{eds,esv,e,pj\_ccap}\right) \tag{10}$$

$$Te_{eds,esv,e,"bau"} = Ee\_BaU_{eds,esv,e} \tag{11}$$

$$Es_{eds,esv,e} = \Sigma_{pj} Ts_{eds,esv,e,pj} \tag{12}$$

$$Ee_{eds,esv,e} = \frac{\Sigma_{pj}(Te_{eds,esv,e,pj} \times Ts_{eds,esv,e,pj})}{\Sigma_{pj} Ts_{eds,esv,e,pj}} \tag{13}$$

Dispersed power generation

Projects related to dispersed power generation are reflected to ExSS through $DPG_{eds,e}$ in equation (14). where $d\_CO2\_DPG_{eds,e,pj}$ stands for the reduction of

Table 1: Characteristics of sectors in the top-down approach (ExSS tool)

Sector	Driving force	Energy service	Reduction measure
Agriculture (AGR)	Agricultural production activities/outputs	Motor, lighting, other agricultural energy service	Energy efficiency Fuel shift
Industry (IND)	Industrial production activities/outputs	Lighting, direct heating, steam boiler, motor, other industrial energy service, steel, cement	Energy efficiency Fuel shift
Commercial (COM)	Population, floor area	Lighting, space heating, cooking, cooling, water heating, electric appliance	Energy efficiency Fuel shift Renewable energies Improvement of energy service intensity (behavior change)
Residential (RES)	Population, floor area	Lighting, space heating, cooking, cooling, water heating, electric appliance	Energy efficiency Fuel shift Renewable energies Improvement of energy service intensity (behavior change)
Passenger transport (PTR)	Population, income, trip per person, trip distance, modal share	Waterway, car, bus, train, motorbike, aviation	Energy efficiency Modal shift
Freight transport (FTR)	Volume of freight, GDP (freight generation per output, transport distance, modal share)	Train, ship, truck, aviation	Energy efficiency Modal shift

CO_2 emissions by project *pj*.

$$DPG_{eds,e} = \frac{\Sigma_{pj} d\_CO2\_DPG_{eds,e,pj}}{Ttl\_Co2ef\_BaU_{eds,\text{"}ele\text{"}}} \qquad (14)$$

Table 3 summarizes the supplementary information for the endogenous variables in all 14 equations.

RESULTS

Driving forces of energy consumption and GHG emissions in Ho Chi Minh City, Vietnam

At the national level, some analyses are conducted to realize Vietnam's Intended Nationally Determined Contributions (INDCs) (Tran et al., 2016, 2011)[25,26]. At the city level, HCMC is chosen to apply the methodology discussed in this paper since HCMC is one of the most vulnerable cities due to climate change[27]. Moreover, in Vietnam, HCMC is the leading city in developing climate change mitigation and adaptation plans for other cities in Vietnam to follow. The estimation of social and economic growth is based on the targets in the master development plan[28]. Table 4 shows the results of the main socioeconomic driving forces for base year 2013 and target year 2030, in which data for 2013 are from the statistical yearbook and data for 2030 are estimated based on the HCMC Master Plan for socioeconomic development (Vietnam-PrimeMinister, 2013)[28]. The registered population (night-time population) in HCMC increases 1.37 times compared to 2013, reaching nearly 10.87 million people in 2030. By assuming that the household size in 2030 is 5 persons per household (smaller than the calculated value for 2013, which is 6.2), the total number of households increases 2.13 times, reaching more than 2.72 million households in 2030. Meanwhile, it is estimated that the GDP of HCMC in 2030 will increase 4.41 times compared to 2013. In 2013, the commercial sector dominates the GDP share with 59.5%, followed by the industrial sector with 39.5%. In 2030, due to the rapid growth rate in commercial compared to other sectors, the share of commercial in total GDP increases to 63.7%, while the share of industry reduces to 35.8%, with a small share of less than 1% of total GDP from agriculture. This economic structure follows the current trend and future vision of Vietnam toward the tertiary industrial economy. The main socioeconomic

Table 2: Characteristics of categories in the bottom-up approach (technology-based)

Category	Driving force	Energy service	Reduction measure
Land-use planning (LND)	Land use change		Greenery, regulation ponds
Energy (ENE)	Population, floor area	Lighting, space heating, cooking, cooling, water heating, electric appliance	Energy efficiency Energy shift Renewable energies Improvement of energy service intensity (behavior change)
Transport (TRS)	Trip per person/volume, trip distance, modal share	Waterway/ship, car/truck, bus, train, motorbike, aviation	Energy efficiency Modal shift
Industry (IND)	Industrial production activities/outputs	Lighting, direct heating, steam boiler, motor, other industrial energy service, steel, cement	Energy efficiency Energy shift Renewable energies Improvement of energy service intensity (behavior change)
Water management (WTR)	Water usage and management	Motor, chemical use	Energy efficiency Reduction of chemical use
Waste management (WST)	Waste generation and management	Landfill, incineration, combustion	Energy efficiency Waste-to-energy
Agriculture (AGR)	Agricultural production activities/outputs	Motor, lighting, other agricultural energy service	Energy efficiency Fuel shift
Construction (CNS)	Floor area	Building, lighting	Energy efficiency
Health care (HEA)	-	Nonenergy related activities	Indirect mitigation reduction
Tourism (TRM)	-	Nonenergy related activities	Indirect mitigation reduction

driving forces shown in Table 4 are assumed to be the same for both scenarios (2030BaU and 2030CCAP).

Due to the increasing population and industrial activities, the transport demand in 2030 also increases rapidly, with 1.83 times the passenger transport demand and 3.97 times the freight transport demand compared to 2013 (Table 4). In passenger transport, there is a rapid increase in demand on cars (including taxis) to 5.06 times, and even motorbikes still dominate. The share of public transport increases from 4.94% in 2013 to 30.01% in 2030BaU and reaches 37.01% in 2030CCAP due to the contribution of bus rapid transport (BRT) and the mass rapid transport (MRT) system, as mentioned in the urban transport development plan. In freight transport, the demand increases mainly in trucks and waterways. Since we have no information about the plan for freight transport, we assume that the shares of freight transport modes in 2030 are the same as those in 2013, in which trucks contribute more than 66.6%, followed by waterways with a 33.1% contribution, and a very small part is from trains.

Energy consumption in Ho Chi Minh City

In 2030BaU, the total energy consumption is 3.73 times higher than that in 2013 (Table 5), increasing from 6,972 ktoe to 25,973 ktoe. Industry is still the main energy consumer, with 65.6% (4.34 times increase), followed by the transport sector, with 14.8%. Commercial has the highest speed of energy consumption, with a 5.60-fold increase, and its share is 12.1%. In terms of the energy consumption mix, there is a switch from coal and oil consumption to natural gas and electricity. However, coal and gas are still the main energy sources, with the share of coal and oil consumption from 68.2% in 2013 to 66.0% in 2030BaU, especially for industrial activities. A small share of the total final energy consumption is

Table 3: **Supplementary information for endogenous variables**

Variable	Value	Unit	Source	Description
$ESDF_{eds,esv}$	Energy service driving forces	vary	assumed based on socioeconomic development plan	see Table 2 for detail information of driving forces. The unit is vary depending on the driving forces and sectors - calibrated based on the input–output table (for base year 2013)
$ESVD_{eds,esv}$	Energy service demand	ktoe	calculated based on energy service per driving force (Eq.1)	- calibrated based on the energy balance table and input–output table (for base year 2013) - harmonized with reduction of CO2 emissions by project and energy service demand in BaU (Eq.7)
$Es_{eds,esv,e}$	Fuel share in energy service	%	calculated based on share of energy device (Eq.4)	harmonized with share of project/technology in enduse sector (Eq.12) and BaU's results (Eq.10)
$Ee_{eds,esv,e}$	Energy efficiency	%	calculated based on energy efficiency of energy device (Eq.5)	harmonized with energy efficiency by project/technology (Eq.13) and BaU's results (Eq.11)
$ED_{eds,esv,e}$	Energy demand	ktoe	calculated based on energy service demand and energy efficiency (Eq.2)	calibrated based on the energy balance table (for base year 2013)
Ttl_Co2ef_{ec}	Total CO2 emission factor	tCO2/ toe	calculated based on IPCC's emission factor (Eq.6)	depends on the share of energy for each technology to meet the service demand
$CO2_{eds,esv,e}$	CO2 emissions	ktCO2	calculated based on energy demand and total emission factor (Eq.3)	- depends on the share of energy in the final energy demand - emissions from projects related with dispersed power generation are calculated using Eq.14
d_CO2_Esv	reduction of CO2 emissions by project pj	ktCO2	calculated based on technology information and BaU's results (Eq.8)	the mitigation of projects depends on the diffusion rate of the technology
$Ts_{eds,esv,e,pj}$	share of project/technolo in enduse sector	%	assumed based on the technology information	depends on the availability of technology for each service demand
$Te_{eds,esv,e,pj}$	energy efficiency by project/technolo in enduse sector	%	calculated based on technology information (Eq.9)	depends on the availability of technology for each service demand

Table 4: **Main socioeconomic indicators in HCMC**

	Unit	2013	2030	2030/2013	CAGR
Population	persons	7,939,752	10,869,565	1.37	1.9%
No. of households	household	1,277,338	2,717,391	2.13	4.5%
GDP per capita	million Dongs	96	310	3.22	7.1%
GDP	billion Dongs	764,560	3,373,415	4.41	9.1%
Passenger transport demand	milion.person.km	75,357	138,204	1.83	3.6%
Freight transport demand	million.ton.km	57,434	227,903	3.97	8.4%

CAGR: Calculated Annual Growth Rate

Table 5: **Final energy consumption by sector (ktoe)**

	2013		2030BaU		2030CCAP		2030BaU/2	CCAP/BaU
	ktoe	%	ktoe	%	ktoe	%		
Total	6,972	100.0	25,973	100.0	22,204	100.0	3.73	0.85
By sector								
Agriculture	8	0.1	19	0.1	18	0.1	2.52	0.95
Industry	3,921	56.2	17,031	65.6	15,727	70.8	4.34	0.92
Commercial	561	8.0	3,142	12.1	2,240	10.1	5.60	0.71
Residential	786	11.3	1,915	7.4	1,328	6.0	2.44	0.69
Transport	1,696	24.3	3,865	14.9	2,890	13.0	2.28	0.75
By energy type								
Coal	1,916	27.5	8,320	32.0	2,965	13.4	4.34	0.36
Oil	2,837	40.7	8,829	34.0	5,617	25.3	3.11	0.64
Gas	135	1.9	587	2.3	7,677	34.6	4.34	13.07
Solar					232	1.0		
Biomass	566	8.1	2,415	9.3	969	4.4	4.27	0.40
Electricity	1,518	21.8	5,821	22.4	4,743	21.4	3.84	0.81
Energy intensity (toe/billion Dongs)	9.1		7.7		6.6		0.84	0.85

from biomass for some purposes in the residential and commercial sectors.

The energy intensity by GDP decreases from 9.1 toe/billion Dongs in 2013 to 7.7 toe/billion Dongs in 2030BaU and 6,6 toe/billion Dongs in 2030CCAP due to the lower increasing rate of energy consumption compared to the rapid growth of GDP. This reduction follows the target to reduce 1% to 1.5% per year, as mentioned in the Vietnam national green growth strategy[29].

GHG emissions in Ho Chi Minh City

In 2030BaU, the total GHG emissions increase 4.02 times compared to 2013. The share of energy-related GHG emissions increases from 93.6% in 2013 to 96.3% in 2030BaU, and the remaining share is from nonenergy-related GHG emissions (Table 6).

In energy-related categories, the largest CO_2 emitter is still industry, with a 4.56-fold increase, contributing to 58.4% of total emissions. Residential and commercial sectors contribute to 15.9% (6.25 times of 2013)

Table 6: **GHG emissions by sector ($ktCO_2eq$)**

	2013		2030				2030	
			BaU		CCAP		BaU/2013	CCAP/BaU
GHG emissions		%		%		%		
Energy-related GHG emissions	28,094	93.6	112,851	96.3	82,810	96.7	4.02	0.73
Agricultural energy-related	26	0.1	66	0.1	58	0.1	2.59	0.87
Industry	15,001	50.0	68,407	58.4	54,623	63.8	4.56	0.80
Commercial	2,988	10.0	18,663	15.9	11,255	13.1	6.25	0.60
Residential	5,074	16.9	14,139	12.1	7,978	9.3	2.79	0.56
Transport	5,006	16.7	11,574	10	8,896	10.4	2.31	0.77
Nonenergy related GHG emissions	1,918	6.4	4,307	3.7	3,149	3.7	2.25	0.73
Agricultural nonenergy related	635	2.1	332	0.3	325	0.4	0.52	0.98
Solid waste management	1,283	4.3	3,975	3.4	2,824	3.3	3.10	0.71
Total GHG emissions	30,012	100.0	117,158	100.0	85,625	100.0	3.90	0.73
GHG emissions per GDP (tCO_2eq/billion Dongs)	39.3		34.7		25.4		0.88	0.73
GHG emissions per capita (tCO_2eq/person)	3.8		10.8		7.9		2.85	0.73

and 12.1% (2.79 times of 2013) of total emissions, respectively. Meanwhile, emissions from transport increased 2.31 times compared to 2013 (10.0% of the total emissions). Agricultural energy-related activity contributes 0.1% of total emissions.

As the main energy consumers in industrial subsectors, the group "Others" (mainly manufacturing, construction, machinery, etc.) shares 35.2% of emissions from industry. Moreover, emissions from nonmetallic mineral and paper production increased by 4.41 times compared to 2013, contributing to 26.9% and 10.4%, respectively. Textiles, food tobacco, and chemical production also contribute to 9.2%, 8.0%, and 7.8% of the emissions from industry, respectively. Meanwhile, iron and steel have the smallest amount of CO_2 emissions since this is not the main industrial activity in HCMC.

In nonenergy-related categories, solid waste is the main emitter, with a 3.10-fold increase, contributing to 3.4% of total emissions. Meanwhile, agricultural nonenergy-related activity contributes 0.3% of total emissions.

GHG emissions reduction potential in Ho Chi Minh City

In this paper, the estimation of low carbon potential for HCMC is based on the projects listed in the HCMC climate change action plan[30]. Among the ten categories, energy has the largest reduction potential, followed by waste management and transport (Table 7). The fourth reduction potential is from industry, even though this is the main source of GHG emissions. The fifth reduction potential is from land-use planning, since HCMC has several priority projects, such as the construction of regulation ponds and the increase in greenery. Construction is the sixth reduction potential, followed by water management and agricultural nonenergy-related activities. The total GHG emissions reduction potential of HCMC (excluding potential from grid power, which is outside the effort of HCMC) is 20.7% of BaU's emissions, which is between the 8-25% reduction target of Vietnam intended nationally determined contribution[31].

Table 7 shows the potential of GHG emissions reduction in HCMC by two groups of projects for all ten categories. This grouping of projects follows the classification of Vietnam's intended nationally determined contribution[31]. By its own effort (without international support), HCMC can reduce 11.7% of its total GHG emissions through internal projects. Additionally, a 9.0% reduction potential can be additionally achieved through external projects under international support. Moreover, the grid power has the

Table 7: GHG emissions reduction potential in HCMC by categories and project groups

				$ktCO_2eq$	%
1. GHG emissions in 2030BaU				117,158	100.0
2.GHG emissions reduction potential in 2030CCAP				31,532.5	26.9
a. Reduction by projects (in HCMC)		Effort		Total by category	Share by category
		Internal	External		
Category	Land-use planning	333.7	2.5	336.1	0.3
	Energy	8,054.6	9,956.2	18,010.8	15.4
	Transportation	2,256.9	243.0	2,499.8	2.1
	Industry	1,576.2	0.0	1,576.2	1.3
	Water management	81.7	56.3	138.0	0.1
	Solid waste management	1,150.7	0.0	1,150.7	1.0
	Construction	292.5	261.3	553.8	0.5
	Healthcare	0.0	0.0	0.0	0.0
	Agriculture	0.0	14.1	14.1	0.0
	Tourism	0.0	0.0	0.0	0.0
Total by effort		13,746.3	10,533.4	24,279.7	20.7
Share by effort (%)		11.7	9.0	20.7	
b. Reduction from grid power (outside HCMC)				7,252.8	6.2

potential to reduce total emissions by 6.2%, which is not counted in the above project groups.

DISCUSSION

In this paper, we mainly describe the integration method. For the detailed results of GHG reduction potential for each project, we distributed to the Ho Chi Minh City Climate Change Bureau (HCCB) for their consideration. All the assumptions related to the mitigation projects will be adjusted by HCCB's policymakers after consulting with relevant departments. Based on the estimated mitigation reduction potential for each project and the total reduction potential for Ho Chi Minh City proposed in this study, policymakers can prioritize the implementation of mitigation projects based on their reduction potential as well as the categories that have the highest reduction potential.

By reflecting these results into the CCAP, policymakers can easily identify the target of GHG emissions reduction based on the current projects or actions, and with the planned projects or actions, a city or region can achieve a more stringent reduction target. We expect this method to be useful for various cities and regions to develop low-carbon scenarios and efficiently implement low-carbon action plans. In the future, when bottom-up technological information is available in more detail, the sector-based mitigation potential of HCMC will be analyzed in more detail, and it can become a good lesson learned for other cities in developing countries.

However, to apply this methodology to other regions or cities, these regions or cities need to ensure the consistency between the classification in top-down (driving force based) and bottom-up (technology-based) approaches. Specifically, the integrated approach requires the modification and bridging of the top-down sectors and the technology-based categories with detailed data. This method is very applicable for cities or regions that are developing climate change action plans with detailed technological information. By looking at the reduction potential of each sector and each project, policymakers can prioritize the mitigation measures to meet the GHG emissions reduction target or to maximize the GHG emissions reduction potential. As a result, the technology will be recognized and implemented in real life, making the change to society.

CONCLUSIONS

Recognizing the importance of an efficient implementation and management of climate change action plans, we developed an integrated approach to bridge the top-down approach with a technology-based approach. Three aspects with four parameters, including energy service demand, energy efficiency and share in energy service, and dispersed power generation, are integrated with technology-based information to assess the actual potential of mitigation projects.

This method was applied to forecast the GHG emissions reduction potential for HCMC in 2030 based on its mitigation projects. The results show that the total reduction potential of HCMC is nearly 27.0%. Of these, 11.7% is from internal effort (without international support), 9.0% is from external effort (with international support), and 6.2% is the potential of grid power. Among the ten categories, energy has the largest reduction potential, followed by waste management, transport, industry, land-use planning, construction, water management and agricultural nonenergy-related activities. The remaining two categories, including healthcare and tourism, which have no direct reduction potential, are not estimated.

ABBREVIATION

BaU: Business as usual
CCAP: Climate Change Action Plan
ExSS: Extended Snapshot
GHG: Greenhouse gas
GDP: Gross Domestic Products
HCMC: Ho Chi Minh City
IPCC: Intergovernmental Panel on Climate Change
PDCA: Plan-Do-Check-Act
toe: ton of oil equivalent (ktoe = thousand toe, Mtoe = million toe)

COMPETING INTERESTS

The author(s) declare that they have no competing interests.

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