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Original research article

The Mechanism to Drive Carbon Neutrality Policy and Net-Zero Emissions for the Building Sector in Thailand

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ABSTRACT

Carbon neutrality and net-zero emissions (NZE) are the commitments made at the Conference of the Parties (COP). Many countries have committed to this operation, while the statistics on electricity usage are continuously increasing, mainly from fossil fuel power plants. This paper proposes the Carbon-Dioxide-Reducing Portfolio Standards (CO_2RPS) policy for consumers. The policy has two parts. Firstly, to boost the percentage of electricity usage from renewable energy resources for buildings and, secondly, to boost the number of electric vehicles charging stations (EVCSs) required for buildings larger than 2,000 square metres (1@1 policy). This study paints a picture of the situation after this policy is applied and can be a guideline for developing the infrastructure for electric vehicle (EV) penetration and controlling CO_2 emissions. This novel policy focuses on carbon neutrality by linking buildings and transportation sectors. The policy can fill the gap in the existing Building Energy Code (BEC) policy to help steer the countries toward their carbon neutrality and net-zero emissions goals.

Keywords: Carbon neutrality; Net-zero emissions; Energy policy; Carbon-dioxide emission Portfolio Standard (CO_2ePS);

1. Introduction

With a rise in carbon emissions (CO_2e) due to the gradual energy usage in buildings, multiple studies have forecast that, by 2060, CO_2e and the number of buildings will increase by 50% and 100%, respectively. This situation is one of the causes of climate change and leads to global warming. The Conference of the Parties (COP) aims to lower the global temperature by 1.5 °C and lead the world toward carbon neutrality and net-zero emissions [1-3]. COP26 was a conference where many countries presented their plans to reduce greenhouse gas (GHG) emissions. Since January 2021, 28 countries have taken

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action via legislation, mandatory law announcements, and policies. Thailand is one of the countries that has announced its goals to be carbon neutral by 2050 [4] and net zero by 2065 [5]. In order to achieve carbon neutrality, it is necessary to control the incremental CO_2 content and compensation.

Therefore, this article proposes two policies. Firstly, the Carbon-Dioxide-Reducing Portfolio Standards (CO_2RPS) policy applies to all electricity consumers and aims to reduce CO_2e produced by the electricity consumption of every type of building. Secondly, the one station per building (1@1) policy to boost the number of EVCS to support incremental EV usage in the future requires all new buildings larger than 2,000 m2 [6] to install at least one EVCS. Moreover, this paper also analyses the amount of CO_2e generated by on-grid charging stations used to charge EVs based on the technical data of four battery electric vehicles (BEVs) sold in 2022 [7-9]. The organization of this paper consists of three parts: (i) the details of the conceptual framework, (ii) the method for calculating CO2e reductions from monthly electricity bills, and (iii) an analysis of the impact of CO2e from charging EV batteries with electricity from the grid.

2. Literature Review and Methods

2.1 Thailand's Nationally Determined Contribution (NDC) roadmap and action plans

Thailand has developed a plan to reduce greenhouse gas emissions, i.e., Thailand's Nationally Determined Contribution (NDC), which has a time frame from 2021 to 2030. The goal is to reduce GHG emissions by at least 20%, equivalent to 115.6 million tons of carbon dioxide (MtCO_2e) [10, 11]. The action plan includes four areas:

1) The energy sector should reduce GHG emissions by at least 117.66 MtCO_2e by 2030 [12].

2) The transportation sector should reduce GHG emissions by 35.42 MtCO_2e [13].

3) The industrial processes, production, and wastewater sector should reduce greenhouse gas emissions by 0.6 MtCO_2e [14].

4) The municipal waste management sector should reduce GHG emissions by 2 MtCO_2e [15].

In addition, there are also plans to encourage the production and use of EVs in the country. The goal is to make 30% of the country's total vehicle production consist of zero-emission vehicle (ZEV) electric vehicles by 2030. This production will include 725,000 cars and pickups and 675,000 electric motorcycles. The goal is also to promote the use of 440,000 cars and pickups and 650,000 electric motorcycles. Lastly, it aims to construct 12,000 fast EVCS and 1,450 battery charging stations by determining the locations and number of public charging stations. The three main concepts designed for EVCS to facilitate access are the following: 1) maximum accessibility; 2) maximum utilization – the location must be in an area of high demand; and 3) minimal costs – the charging station's operating costs, rental costs, and electricity costs must be considered [16].

However, from Thailand's NDC plan, the GHG reduction targets need to be elevated more to meet the goals of the Paris Agreement signed in 2015. These goals include raising the NDC targets to a higher level, expanding clean energy transportation systems, achieving zero GHG emissions through legislation, and reducing the use of fossil fuels [17]. Because Thailand drafted the NDC before the COP26 meeting, it implies that the plans for GHG emission reduction in Thailand are already made. However, a plan to achieve carbon neutrality and net-zero emissions (NZE), as promised at the COP26 meeting, is still in progress.

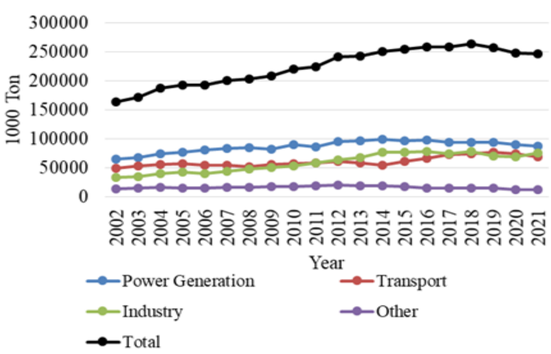
2.2 Carbon neutrality and net-zero emissions

Carbon neutrality is the reduction of carbon emissions to achieve equilibrium. There are two methods that can be used to achieve this goal. First, carbon-dioxide emissions and greenhouse gases produced by human activities can be reduced by using renewable energy technologies such as solar energy and wind energy.

Second, emissions can be reduced by carbon credit trading. NZE differs from carbon-neutral emissions, as it is the sum of all greenhouse gases that need to be reduced and offset to achieve a net effect of zero emissions [18].

2.3 Carbon-dioxide emissions in Thailand

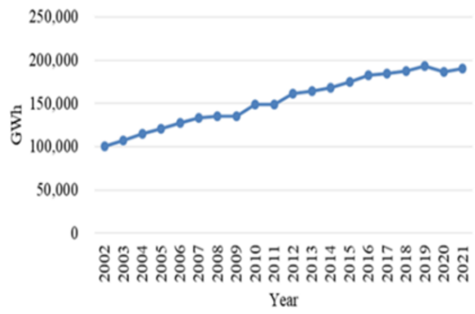
The Energy Policy and Planning Office (EPPO) statistics on CO_2e emissions from 2002-2021 show a steady increase in CO_2e emissions, mainly due to electricity generation. This is because electricity generation uses fossil fuels such as natural gas, coal, and oil, respectively. The electricity sector is followed by the industrial sector, as a result of the use of coal/lignite fuels in the production process, and the transport sector, mainly due to the consumption of refined fuels, as shown in Fig. 1 [19].



Data source: Table 9.1-2, Energy Policy and Planning Office [19]

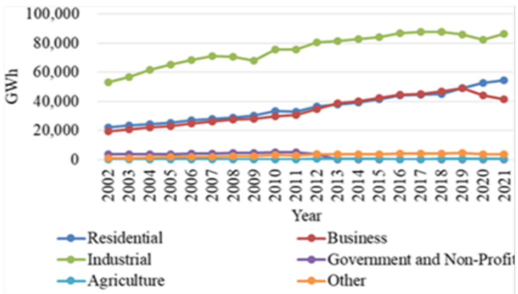
Fig. 1. CO_2 emissions from energy consumption by sector from 2002-2021.

Fig. 2 [20] shows that the overall statistics of electricity demand for the whole country from 2002-2021 has continuously increased. Most electricity consumers are in the industrial, residential, and business sectors, as shown in Fig. 3 [20].



Data source : Table 5.3-4, Energy Policy and Planning Office [20]

Fig. 2. Electricity consumption for the whole country from 2002-2021.



Data source : Table 5.3-4, Energy Policy and Planning Office [20]

Fig. 3. Electricity Consumption for the Whole Country (Classified by Sector) from 2002-2021.

The increase of CO_2 from fossil fuel combustion in the energy, industry, and transport sectors, an increase in electricity production from renewable energy resources, and EV usage are the key factors for carbon neutrality and Net Zero Emissions.

3. Methods

Rising CO_2e levels due to the electricity demand and the use of refined oil in the transportation sector make it very challenging to achieve the goals of carbon-neutral propulsion and net-zero greenhouse gas emissions. Therefore, this paper presents a policy framework for Carbon-Dioxide-Reducing Portfolio Standards (CO_2RPS) and charging station portfolio standards for buildings. The charging station policy is a methodology for determining the number of charging stations for a building; it is known as the one station per building policy (1@1 policy). The details are discussed in the following subsections.

3.1 Carbon-Dioxide-Reducing Portfolio Standards (CO2RPS) policy framework

The CO_2RPS policy is a novel policy that sets a carbon-dioxide reduction ratio for the monthly electricity consumption of building owners or other consumers. The goal of this ratio is to measure and control the amount of CO_2e to reduce CO_2e from the consumers electricity use. After applying this policy, we forecast that we will be able to monitor and control the amount of CO_2e from buildings. Additionally, this reduction and its compensation will come from the increase in the renewable energy usage rate, e.g., from solar photovoltaics (solar PVs) or wind energy. We, therefore, designed the policy implementation process for building owners to follow the CO_2RPS policy. The process has four stages as follows:

1) Government or business owners set and announce the goal of reducing the percentage of CO_2 emissions from electricity consumption for all electricity consumers. For example, an announcement could be made requiring electricity consumers to reduce CO_2e from monthly electricity consumption by 5%, based on the monthly electricity consumption indicated by the electricity bill.

2) The amount of CO_2 reduction that electricity consumers or building owners can achieve is determined by performing calculations using the electricity bill.

3) The amount of electricity generated by renewable energy to compensate for the reduction in or to offset the CO_2 generated from monthly electricity consumption is determined.

4) The CO_2 reduction performance of the building owners or electricity consumers is monitored. Suppose that a consumer cannot achieve their reduction goal. In this case, offsetting can be done by other means, e.g., buying and selling carbon credits.

3.2 One station per building (1@1) policy framework

One Station per Building (1@1) is a policy to expand EVCS across the country; we propose to take advantage of the increase in the number of buildings, which usually grows annually. This policy focuses on buildings with a total area of 2,000 square metres or more because, at the moment, these buildings already fall under the Building Energy Code [6]. This means that we can increase the number of EVCSs with the number of buildings. The following procedures are used to determine the number of charging stations (Charging Station Portfolio Standard):

1) Define the number of EVCSs appropriate for the building, e.g., one station per building.

2) Determine the number of EV chargers at each charging station for electric vehicles, e.g., one EV charger per station or three EV chargers per station.

3.3 Methodology

3.3.1 The Carbon-Dioxide-Reducing Portfolio Standards (CO_2RPS) policy

The methodology for CO_2RPS consists of the following four steps:

1) CO_2 emissions (CO_2e) from the monthly electricity consumption of the consumers are estimated by using individual electricity bills:

$$CO_2 \text{ emissions} = EC \times EFE_{lec}, \tag{3.1}$$

where CO_2 emissions represent the carbon dioxide produced by the electricity consumption of building owners in kilograms (kgCO_2e). EC is the amount of electricity consumed (electricity consumption), which appears on the monthly electricity bill (kWh). EFE_{lec} is the greenhouse gas emission coefficient for electricity use (emission factor for electricity, grid mix). Its value is 0.5986 kgCO_2/kWh, according to March 2021 data from the Thailand Greenhouse Gas Management Organization (public organization) [21].

2) The amount of CO_2 emission reduction according to the announcement in subsection 3.1 is determined

$$CO_2eR = CO_2e \times \text{Target of } CO_2RPS, \quad (3.2)$$

where CO_2 emission reduction (CO_2eR) represents the amount of CO_2e that a building owner or consumer has to reduce their emissions by, according to the announcement of the government or an organization. The CO_2RPS target is a target (percentage) given by the government or an organization to reduce CO_2e from the building sector.

3) The number of power generation units the building owner or electricity users can produce from renewable energy sources such as solar PVs or wind turbines is determined.

This activity aims to compensate for the monthly electricity consumption to bring the CO_2e closer to the target:

$$EPVR = CO2eR / EF_{Elec}, \quad (3.3)$$

where the electricity produced from a solar photovoltaic rooftop (EPVR) is the amount of electricity generated by the solar power system installed in the building to reduce CO_2e according to announcement from the government or an organization owner.

4) Building owners consider solar PV installation guidance and the EPVR.

3.3.2 One station per building (1@1) policy

Regarding the second objective of the policy, which focuses on EVCS penetration, the following methodologies are used to help policymakers to determine the number of stations and the number of EV chargers per station in the policy:

$$\text{Target number of EVCSs} = \text{Number of buildings} \times \text{Number of EVCSs at each building}, \quad (3.4)$$

$$\text{Target EV chargers} = \text{Number of EVCSs} \times \text{Number of EVCS chargers per station}. \quad (3.5)$$

The CO_2 emissions from electric vehicles, when they are charged from the distribution system, can be calculated as follows:

$$CO_2e\,EV = (BEVC / EVR) \times EF_{Elec}, \quad (3.6)$$

where CO_2e from EVCSs (CO_2eEV) represents the CO_2 emissions created by the power plant when it produces the electricity needed to charge an EV to travel for one kilometer ($kgCO_2e/km$). The battery electric vehicle capacity (BEVC) is the capacity of an electric vehicle battery (kWh). The electric vehicle range (EVR) is the distance an electric vehicle can travel after being fully charged, expressed in kilometers (km).

3.4 Data source to validate the proposed policy

The data we use to demonstrate the validity of the CO_2RPS policy framework are statistical data (on electricity consumption) published on the Office of Energy Planning and Policy website [19]. According to the NDC plan discussed in subsection 2.1, the CO_2RPS target in the study will be 20-25% [10, 11]. The coefficient (EF_{Elec}) in this study is from the latest revised announcement for 2021, which was published by the Thailand Greenhouse Gas Organization [21]. The data for the monthly electricity used by consumers was obtained from the following sources**:**

3.4.1 Residential houses

We obtained data from the electricity bills of users who registered for meter type 1.2 from Suphanburi's Provincial Electricity Authority and indicated that they lived in general residential houses with no commercial space.

3.4.2 Commercial buildings

We also obtained data from the electricity bills of users who registered for meter type 2.1 in Nonthaburi Province and engaged in daytime industrial or commercial business.

For the one station per building policy (1@1 policy), we obtained information from a report from Thailand's National Statistics Office from 2020 [22], which reports statistics on the number of buildings approved for construction across the country.

In the study, we selected only the data of condominiums larger than 2,000 square meters because we believe they can provide access to electric vehicle charging stations for people living in the condominiums. In general, we used the concept based on the principle in [22] to determine the locations and number of charging stations for the public. Table 1 illustrates the details of the data we used in our simulation for both CO_2RPS and the 1@1 policy.

Table 1. Input data for CO_2RPS and 1@1 policy for the simulation.

Key component	CO_2RPS
Target of CO_2RPS [10-11].	20%
Interim schedule [10-11].	2021–2030
Electricity bill	Electricity consumption (kWh), residential type 1.2, and business type 2.1
Condominium area from 2,000–9,999 m^2 22]	177 units
Condominium area greater than 10,000 m^2 [22]	58 units
Emission factor of electricity, grid mix [21]	0.5986 $kgCO_2$/kWh

For the simulation on battery charging using electricity from the electricity distribution system, we obtained data for four car models from the technical characteristics published on the websites of three car companies. Table 2 illustrates the technical details of our simulation.

Table 2. Technical input data of EVs for the simulation.

EV model	Specifications	
	BEVC (kWh)	EVR (km)
EV01	40	311
EV02	50.3	380
EV03	47.788	400
EV04	63.139	500

4. Results and Discussion

The simulation results consist of four parts: 1) the results of the application of the CO_2RPS policy; 2) the results of the application of the CO_2RPS policy for residential buildings and commercial buildings, where the aim is to test the calculation method of CO_2RPS using data from the electricity bills of electricity consumers; 3) the impacts of applying the 1@1 policy; and 4) the impacts of CO_2 emissions from EV charging activity. Sections 4.1 to 4.4 discuss the details of each simulation result, respectively.

4.1 Results of CO_2RPS

After applying the CO_2RPS policy to residential, commercial, and industrial electricity consumers, the results show significant differences before and after the application of the policy.

For the residential sector, the annual CO_2e generated from electricity use before the application of the policy (non-CO_2RPS policy) in 2021 is 32,498,280,037 $kgCO_2$e. With the policy, the reduction target (CO_2RPS target) is 20%, which is equal to 6,499,656,007.36 $kgCO_2$e annually. The policy reduces the annual CO_2 emissions to 25,998,624.03 $kgCO_2$e (CO_2eR). Table 3 illustrates the details of this simulation.

For the business sector, the detailed results are shown in Table 4. The annual CO_2e generated from electricity use before the application of the policy (non-CO_2RPS policy) in 2021 is 24,859,180,383 $kgCO_2$. With the policy, the reduction target (CO_2RPS target) is 20%, which is equal to 4,971,836,076.59 $kgCO_2$ annually. The policy reduces the annual CO_2 emissions to 19,887.344.31 $kgCO_2$ (CO_2eR).

For the industrial sector, the annual CO_2e generated from electricity use before the application of the policy (non-CO_2RPS policy) in 2021 is 51,735,271,043.96 $kgCO_2$. With the policy, the reduction target (CO_2RPS target) is 20%, which is equal to 10,347,054,208.79 $kgCO_2$ annually. The policy reduces the annual CO_2 emissions to 41,388,216,835.17 $kgCO_2$e (CO_2eR). Table 5 illustrates the details of this simulation.

Table 3. Results of CO_2RPS policy for residential buildings.

Date	EC (GWh)	CO_2e ($kgCO_2e$)	Target of CO_2RPS ($kgCO_2e$)	CO_2eR ($kgCO_2e$)
JAN	3481.64	2084110823	416822164.68	1667288658.71
FEB	3571.31	2137785382	427557076.37	1710228305.47
MAR	4508.14	2698572677	539714535.41	2158858141.62
APR	4858.16	2908091649	581618329.77	2326473319.08
MAY	5319.71	3184378098	636875619.54	2547502478.18
JUN	5246.04	3140278865	628055773.04	2512223092.15
JUL	5090.29	3047044740	609408948.09	2437635792.38
AUG	5045.99	3020527951	604105590.22	2416422360.87
SEP	4572.10	2736856497	547371299.36	2189485197.44
OCT	4578.19	2740503537	548100707.47	2192402829.86
NOV	4247.71	2542679465	508535892.92	2034143571.68
DEC	3771.22	2257450353	451490070.51	1805960282.03
YTD	54290.48	32498280037	6499656007.36	25998624029.46

Table 4. Results of CO_2RPS policy for business buildings.

Date	EC (GWh)	CO_2e ($kgCO_2e$)	Target of CO_2RPS ($kgCO_2e$)	CO_2eR ($kgCO_2e$)
JAN	2977.03	1782050177	356410035.37	1425640141.49
FEB	3109.93	1861601741	372320348.16	1489281392.62
MAR	3916.95	2344687438	468937487.65	1875749950.59
APR	3607.31	2159333415	431866682.99	1727466731.94
MAY	3659.11	2190345437	438069087.45	1752276349.79
JUN	3672.99	2198652117	439730423.48	1758921693.92
JUL	3494.76	2091963059	418392611.73	1673570446.92
AUG	3386.15	2026946979	405389395.87	1621557583.47
SEP	3347.96	2004087210	400817442.10	1603269768.39
OCT	3538.18	2117953402	423590680.46	1694362721.82
NOV	3506.42	2098943210	419788642.00	1679154568.00
DEC	3312.09	1982616197	396523239.34	1586092957.38
YTD	41528.87	24859180383	4971836076.59	19887344306.34

Table 5. Results of CO_2RPS policy for industrial buildings.

Date	EC (GWh)	CO_2e ($kgCO_2e$)	Target of CO_2RPS ($kgCO_2e$)	CO_2eR ($kgCO_2e$)
JAN	6828.61	4087603580.87	817520716.17	3270082864.70
FEB	6586.13	3942455478.47	788491095.69	3153964382.78
MAR	7742.98	4634946610.28	926989322.06	3707957288.22
APR	6998.31	4189188588.04	837837717.61	3351350870.43
MAY	7585.83	4540877016.16	908175403.23	3632701612.93
JUN	7340.00	4393725300.97	878745060.19	3514980240.77
JUL	7240.32	4334053929.94	866810785.99	3467243143.95
AUG	7159.45	4285645405.61	857129081.12	3428516324.49
SEP	7175.09	4295009491.70	859001898.34	3436007593.36
OCT	7457.08	4463811055.59	892762211.12	3571048844.47
NOV	7345.84	4397222191.88	879444438.38	3517777753.51
DEC	6967.48	4170732394.45	834146478.89	3336585915.56
YTD	86427.12	51735271043.96	10347054208.79	41388216835.17

Fig. 4 shows the results of the CO_2RPS policy. We can see that the increase or decrease in CO_2e varies according to the amount of electricity consumption.

The distance between CO_2e and CO_2eR is constantly at 20%. Policymakers can adjust this percentage according to their CO_2 reduction targets. We also calculate the amount of electricity from the EPVR that is used to compensate for the reduction of CO2e by the CO_2RPS policy.

Table 6 lists the EPVR electricity production in every sector. The results show that the CO_2e reduction goal requires the electricity generated by the EPVR to be 10,858.10 GWh in the residential sector, 8,305.77 GWh in the business sector, and 17,285.42 GWh in the industrial sector annually.

Table 6. The quantity of electricity to be produced from the EPVR.

Date	EPVR(GWh)		
	Residential	Business	Industrial
JAN	696.33	595.41	1,365.72
FEB	714.26	621.99	1,317.23
MAR	901.63	783.39	1,548.60
APR	971.63	721.46	1,399.66
MAY	1063.94	731.82	1,517.17
JUN	1049.21	734.60	1,468.00
JUL	1018.06	698.95	1,448.06
AUG	1009.20	677.23	1,431.89
SEP	914.42	669.59	1,435.02
OCT	915.64	707.64	1,491.42
NOV	849.54	701.28	1,469.17
DEC	754.24	662.42	1,393.50
YTD	10858.10	8305.77	17,285.42
YTD (100%)	47	30	23

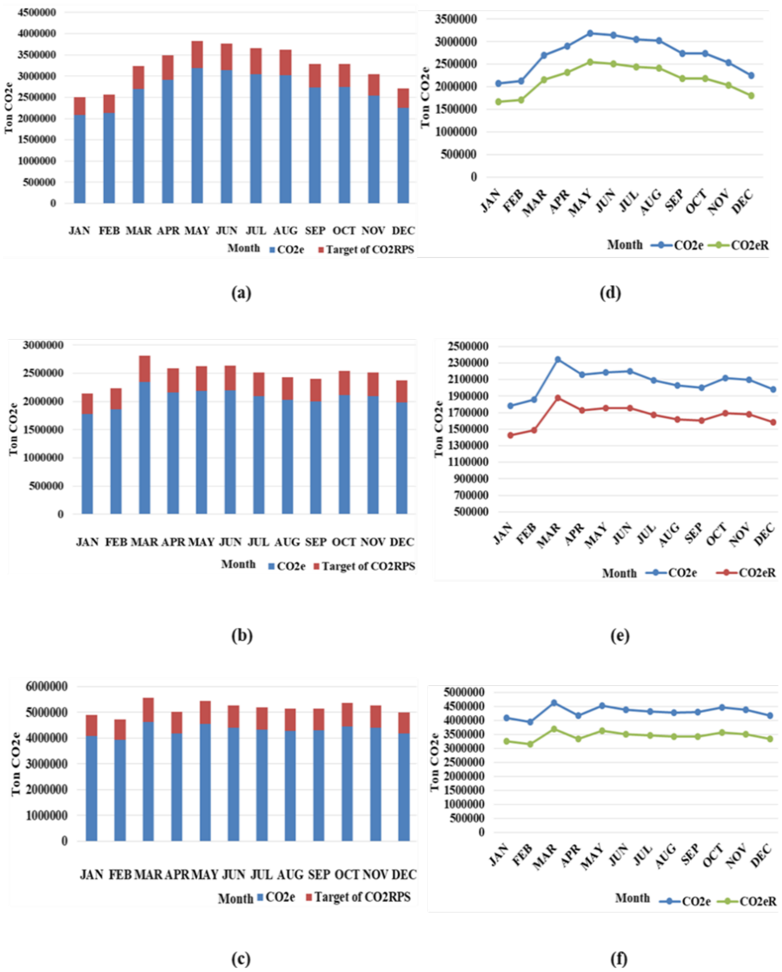
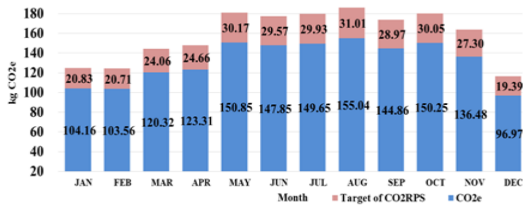


Fig. 4. CO_2e targets and the results of CO_2RPS policy application of the tree sector buildings (a and d) residential, (b and e) business and (c and f) industrial.

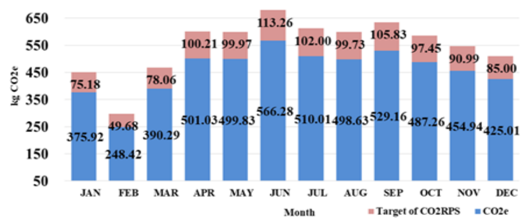
4.2 Results of CO_2RPS in case study of residential and business buildings

Table 7 illustrates the results of using CO_2RPS in a case study of residential buildings based on the monthly electricity bills of electricity users after simulating the implementation of the CO_2RPS policy. After applying the policy, the amount of CO_2e from electricity consumption in 2021 was reduced from 1,583.30 kgCO_2 to 1,266.64 kgCO_2. This is the target amount of CO2e reduction (20% or 316.66 kgCO_2), and it requires electricity generation from a solar PV system or EPVR to compensate for the reduction at 530.60 kWh.

Table 8 illustrates the results for business buildings. It shows that the total amount of CO_2e emissions from electricity use in 2021 was reduced from 5,486.77 kgCO_2 to 4,389.41 kgCO_2 after applying the policy. This is from the target amount of CO_2e reduction (20% or 1,9097.35 kgCO_2), and it requires electricity generation from a solar PV system or EPVR to compensate for the reduction at 1,838.73 kWh.



(a)



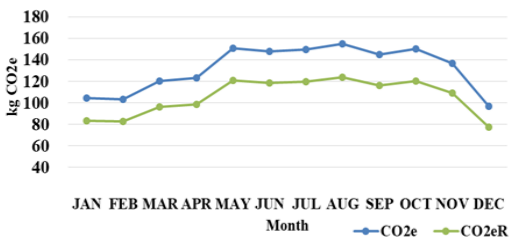
(b)

Fig. 5. CO_2e and CO_2eR values of (a) residential and (b) business buildings.

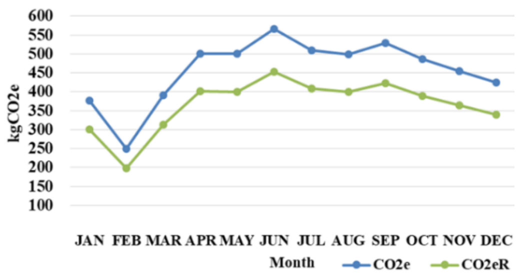
Fig. 5 illustrates the results of the application of the policy for CO_2e and CO_2eR from monthly residential and commercial electricity bills. The difference between the CO_2e and CO_2eR values is constant at 20% (the CO_2e reduction target). Fig. 6 shows the amount of CO_2e reduction caused by the implementation of the CO_2RPS policy. Finally, Fig. 7 illustrates the amount of EPVR generation needed to compensate for the reduction for each month.

From the results of this case study, we found that the CO_2RPS policy can be applied to electricity consumers with monthly electricity bills. The proposed calculation process is practical. Additionally, it allows the policymakers to adjust the target values (%) of CO_2RPS according to their own plans.

Furthermore, by knowing the number of units (kWh) of electricity that must be generated by the EPVR, it is possible to plan or set targets to promote the use of electricity from renewable sources in a building.



(a)



(b)

Fig. 6. Results of CO_2RPS policy application of electricity users (a) residential and (b) business building.

Table 7. Results of using CO_2RPS in the case study of residential building.

Date	EC (kWh)	CO_2e ($kgCO_2e$)	Target of CO_2RPS ($kgCO_2e$)	CO_2eR ($kgCO_2e$)	EPVR (kWh)
JAN	174	104.16	20.83	83.33	34.90
FEB	173	103.56	20.71	82.85	34.70
MAR	201	120.32	24.06	96.25	40.32
APR	206	123.31	24.66	98.65	41.32
MAY	252	150.85	30.17	120.68	50.55
JUN	247	147.85	29.57	118.28	49.55
JUL	250	149.65	29.93	119.72	50.15
AUG	259	155.04	31.01	124.03	51.96
SEP	242	144.86	28.97	115.89	48.55
OCT	251	150.25	30.05	120.20	50.35
NOV	228	136.48	27.30	109.18	45.74
DEC	162	96.97	19.39	77.58	32.50
YTD	2,645	1,583.30	316.66	1,266.64	530.60

Table 8. Results of using CO_2RPS in the case study of business buildings.

Date	EC (GWh)	CO_2e ($kgCO_2e$)	Target of CO_2RPS ($kgCO_2e$)	CO_2eR ($kgCO_2e$)	EPVR (kWh)
JAN	628	375.92	75.18	300.74	125.98
FEB	415	248.42	49.68	198.74	83.25
MAR	652	390.29	78.06	312.23	130.79
APR	837	501.03	100.21	400.82	167.90
MAY	835	499.83	99.97	399.86	167.50
JUN	946	566.28	113.26	453.02	189.77
JUL	852	510.01	102.00	408.01	170.91
AUG	833	498.63	99.73	398.91	167.10
SEP	884	529.16	105.83	423.33	177.33
OCT	814	487.26	97.45	389.81	163.29
NOV	760	454.94	90.99	363.95	152.46
DEC	710	425.01	85.00	340.00	142.43
YTD	9,166	5,486.77	1,097.35	4,389.41	1,838.73

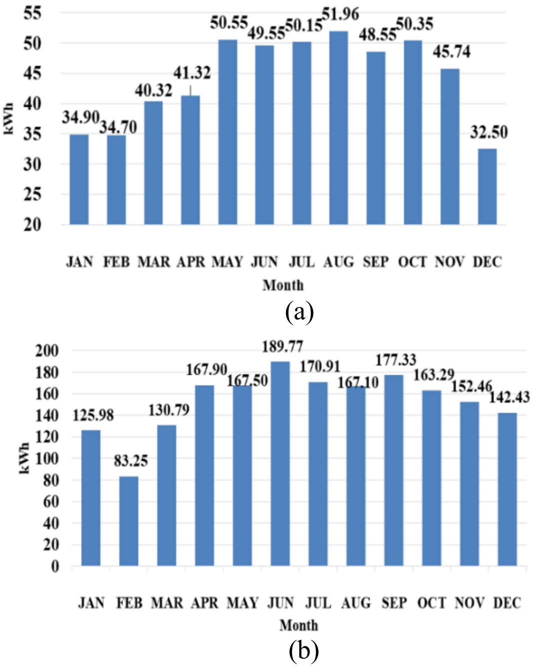


Fig. 7. The amount of EPVR in the (a) residential and (b) business buildings.

4.3 Results of one station per building (1@1) policy

In this study, the 1@1 policy is based on the number of condominium buildings larger than 2,000 square meters in 2020. The total number of buildings considered is 235; there were 177 buildings from 2,000 to 9,999 square meters and 58 buildings larger than 10,000 square meters. Therefore, implementing the 1@1 policy will result in 235 charging stations.

This paper has yet to consider the number of charging stations for each building size. Initially, the policy indicates that a building of 2,000 to 9,999 square meters must have at least one charging station. This will result in an additional 177 chargers and the building of 10,000 square meters must have five chargers per station. This will result in an additional 290 chargers.

Therefore, there will be 467 chargers at 235 stations. This way, the distribution of charging stations for electric vehicles can be increased and spread over different areas according to the increase in the number of condominiums and EVCSs.

4.4 Results of CO_2 emissions from electric vehicle batteries when charging with electricity from the grid

Table 9 illustrates the results of this simulation. We selected four EV models [7-9] with different battery capacities and distances, i.e., from 311-500 km per full charge (100%). The amount of CO_2e from battery charging using electricity generated by a power plant (CO_2ekm) is 0.07-0.08 kg CO_2e/km.

As shown in Table 10, we selected three models of plug-in hybrid vehicles (PHEVs) for comparison and found that, on average, the selected PHEVs that use only pure gasoline have CO_2e per kilometre of driving of 0.036 kgCO_2/km [23]; for the PHEVs that used a gasohol E20 oil, the CO_2e will be about 0.042 kgCO_2/km [24]. In addition, e-Power vehicles use the gasohol E20 fuel; they have a battery but no external charge. Therefore, unlike the PHEVs, their average CO_2e is 0.1 kgCO_2/km [25].

Table 9. Simulation results of the CO_2 emissions from EVs when they are charged using the electricity distribution system [7-9].

EV model	BEVC (kWh)	EVR (km)	CO_2ekm (kgCO_2/km)	$CO_2eCycle$ (kgCO_2/Cycle)
EV01	40	311	0.08	23.94
EV02	50.3	380	0.08	30.11
EV03	47.788	400	0.07	28.61
EV04	63.139	500	0.08	37.80

Table 10. Simulation results of the CO_2 emissions from other car technologies when they are charged using the electricity distribution system [23-25].

Car technology	BEVC (kWh)	EVR (km)	CO_2ekm (specifications of the car) (kgCO_2/km)	$CO2_ekm$ (charging from a distribution system) (kgCO_2/km)	Total (kgCO_2/km)
PHEV (3 models) with gasoline oil	16.6	67	0.036	0.148	0.18
PHEV (2 models) with gasohol E20	13.8	55	0.042	0.150	0.19
Not external charging	(specifications of the car)				
e-Power	2.06	-	0.1	-	0.1

The results show that the EV is a promising vehicle that can reduce CO_2e, even though it could cause some emissions while charging from the grid. The CO_2e while charging EVs from the grid is still lower than those of PHEVs and internal combustion vehicles. We can infer that the CO_2e will eventually reduce after the continuous increment of EV usage.

5. Conclusion

The CO2RPS and 1@1 policy is a new novel mechanism that can be used to drive the country toward its carbon neutrality and net-zero emissions goals. This mechanism is meant to control and reduce CO_2e from electricity users in the building sector and increase the number of EVCS to support EV users in the future. This research applied CO2RPS in a case study of residential, business, and industrial electricity users and applied 1@1 policies in a case study of condominium buildings. The impacts of CO_2 emissions from EVs when charged from the electricity grid were also analyzed. The results show that this mechanism can help control and decrease CO_2e. Increased usage of electricity produced from rooftop solar photovoltaics in buildings and the number of EVCS can drive the country toward the goals of carbon neutrality and net-zero emissions in the future.

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