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Integrated Approach for Sectoral Carbon Drawdown Solutions

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Sectoral contributions of greenhouse gas (GHG) emissions are at the heart of the climate debate. Carbon drawdown solutions from different sectors (e.g. energy, land, urban infrastructure, and industrial systems) will play significant roles in mitigating climate change in the coming decades. This work identifies the feasible carbon drawdown solutions to support GHG emissions reduction paths globally. These solutions should meet both economic constraints and carbon emissions targets. This work develops a novel approach that integrates Carbon Emission Pinch Analysis (CEPA), the Best-Worst Method (BWM), and Cost-Benefit Analysis (CBA). For each sector, BWM is used to evaluate the performance of reduction solutions and identify their priority weights. Then, CBA is used to rank the options further. Finally, CEPA combines with the Marginal Emission Reduction Cost Curve to find the final mix to meet carbon reduction targets and investment costs. The results prioritize global carbon drawdown potentials for the power (186.4 Gt CO_2-eq), construction (97.9 Gt CO_2-eq), industry (23.8 Gt CO_2-eq), transportation (20.2 Gt CO_2-eq), food, agriculture, and land use (2.5 Gt CO_2-eq) sectors. Based on these results, this work presents an optimal path for carbon drawdown.

1. Introduction

Nowadays, global climate change has become one of the most concerning environmental issues in the contemporary world (Steffen et al., 2015). The impacts of global warming on the natural ecological system and the human system have attracted more attention because of the increasing frequency and intensity of extreme climate events. According to the Paris agreement, by the end of the century, global warming should be controlled to less than 2 °C compared with the pre-industrial level, and try to limit global temperature rise to within 1.5 °C (UNFCCC, 2016). The Paris Agreement recognizes that addressing climate change and ensuring sustainable development requires multisectoral and interdisciplinary approaches and actions (Foley et al., 2017). As a result, multiple sectors such as power, food, agriculture and land use, industry, transportation, and construction have important roles to play in meeting the global challenge of reducing GHG emissions. To understand the volatilization of these resources and technologies, it is necessary to understand the carbon emission potential, cost and technology level of these resources and technologies.

A systematic approach is necessary to achieve the 1.5 °C target. In the domain of process systems engineering, the effective method for energy optimization and integration in thermodynamic systems and processes is Pinch Analysis (PA) (Klemeš et al., 2013). PA has been successfully applied and developed Carbon Emission Pinch Analysis (CEPA) as the general method of resource minimization, carbon emission planning in energy planning (Tan and Foo, 2006). Tan et al. (2009) applied a graphic approach for carbon capture and storage transformation in the power generation industry. Munir et al. (2012) proposed a new process integration technology to achieve the overall minimum carbon target. This holistic approach in refinery applications shows the maximum potential CO_2 reduction rate as high as 95 %. Jia et al. (2016) proposed a multi-dimensional PA for China's power generation industry, i.e., carbon footprint, return on energy investment, water footprint, land footprint and human risk. Walmsley et al. (2015) applied CEPA to New Zealand's transport sector. Roychaudhuri et al. (2017) developed a graphical financial PA to select several independent projects from many energy-saving candidates.

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It provides a systematic approach to determine the financial feasibility of the projects under various financing schemes. Jia et al. (2018) extended this method to municipal solid waste management and adopted different treatment technologies to achieve emission reduction targets.
Climate change is both a huge challenge and a huge opportunity. Countries committed to saving the environment by reducing GHG emissions and utilizing more renewable energy resources. Eliminating energy poverty must maintain a positive attitude and mitigation measures will only be effective if nations work together. Therefore, through the analysis of various potential carbon emission reduction technologies, this paper selects the best feasible scheme to meet the economic constraints and reduce GHG emissions simultaneously. The rest of this paper is as follows: The second section presents the methodology. Section 3 is the case study and the discussions, and finally, the conclusion is presented.

2. Methodology

In this work, a novel integrated graphical approach is proposed to represent the decision-making process of carbon emission reduction technology projects, as shown in Figure 1. A total of four steps are proposed, i.e., Carbon Emission Pinch Analysis (CEPA), Best-Worst method (BWM), Cost-Benefit analysis (CBA), and Marginal Emission Reduction Cost Curve (MERCC). For a detailed description for these four tools please refers to the corresponding references.

- CEPA is used to screen out the optimal carbon emission reduction technology project portfolio under the assumption of financial resources (Tan and Foo, 2006).
- BWM will evaluate a variety of carbon emission reduction technology projects from multiple perspectives (Rezaei, 2015). A multiple criteria decision-making problem is formulated(Wang et al., 2020).
- CBA will get the priority order of each project implementation (Marchioni and Magni, 2018). Net Present Value (NPV) is used to measure the costs and potential benefits.
- MERCC will integrate the first three approaches to provide decision-makers with reasonable carbon reduction technology projects (Wang et al., 2021).

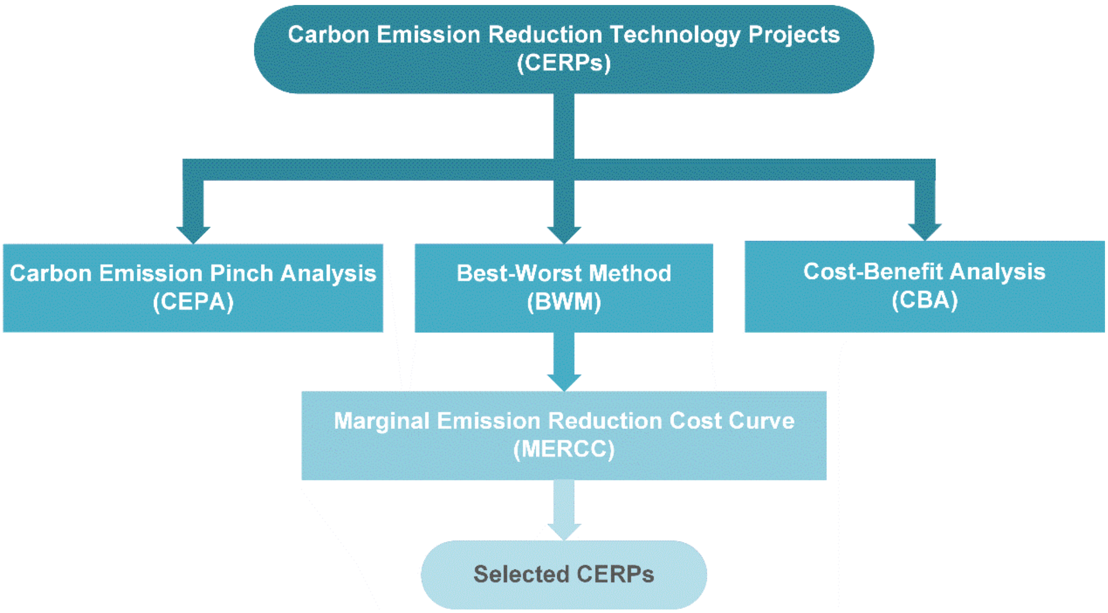

Figure 1: integrated graphical approach framework

3. Case Study

The top five sectoral sources of global GHG emissions are (1) power, (2) food, agriculture and land use (FAL), (3) industry, (4) transportation, and (5) construction. We select 82 carbon emission reduction technology projects (CERPs) from the Project drawdown report (2020). The CERPs for power industry are listed in Table 1. The detailed data for 82 CERPs, please refer to the reference (Zhou, 2020).

3.1 CEPA

According to Table 1, it is assumed that the power industry will achieve a 50 % reduction of the expected carbon emission and financial resources, which are determined as 143.8 Gt CO_2-eq and \$ 114×10[11].

Table 1: CERPs for the power industry (Project Drawdown team, 2020)

Industry division		Projects	CERP (Gt CO_2-eq)	Initial invest. cost (10^9 \$)	Net first cost (10^9 \$)
Power Industry	A1	Smart Thermostats	3.1	44.93	-808.70
	A2	Building Automation Systems	4.9	153.13	-1301.56
	A3	LED Lighting	16.1	-1,710.63	-4,528.13
	A4	Insulation	3.8	157.40	-4,879.29
	A5	Dynamic Glass	0.2	46.00	-65.33
	A6	High-Performance Glass	2.0	1,800.00	-660.00
	A7	Green & Cool Roofs	0.7	700.00	-350.00
	A8	District Heating	4.6	148.39	-1,112.90
	A9	High-Efficiency Heat Pumps	-1.7	-31.51	414.63
	A10	Solar Hot Water	0.8	160.00	-45.71
	A11	Low-Flow Fixtures	0.2	0.22	-88.89
	A12	Water Distribution Efficiency	0.7	17.00	-200.00
	A13	Building Retrofitting	N/A	-	-
	A14	Net-Zero Buildings	N/A	-	-
	A15	Concentrated Solar Power	18.6	400.00	800.00
	A16	Distributed Solar Photovoltaics	28.0	401.43	-7,827.96
	A17	Utility-Scale Solar Photovoltaics	42.3	-200.00	-12,900.00
	A18	Micro Wind Turbines	0.1	52.00	19.00
	A19	Onshore Wind Turbines	47.2	800.00	-3,800.00
	A20	Offshore Wind Turbines	10.4	600.00	-600.00
	A21	Geothermal Power	6.2	81.31	-813.11
	A22	Small Hydropower	1.7	52.06	-318.75
	A23	Ocean Power	1.4	215.38	1,076.92
	A24	Biomass Power	2.5	51.00	-200.00
	A25	Nuclear Power	2.7	103.85	-311.54
	A26	Waste-to-Energy	0.5	25.00	24.00
	A27	Landfill Methane Capture	0.2	-0.38	0.57
	A28	Methane Digesters	3.6	73.47	0.73

The carbon emission reduction intensity (CERI) of its financial resources is 12.6 kg CO_2-eq/ \$. Take financial resources as x-axis and carbon emission reduction as y-axis. All CERPs are arranged in ascending order of CERIs. The composite curve of CERPs is plotted according to the ascending order of CERIs. All financial resources are sorted in ascending order according to assumed CERIs.

Figure 2 shows CEPA for global wide scenario. As shown in Figure 2, when one financial resource is used for multiple CERPs, limited financial resources cannot fund all projects. Therefore, candidate projects from 82 projects were selected through CEPA. From the perspective of the cost-effectiveness, it is always recommended to subsidize CERPs with higher CERIs.

CERPs above the Pinch point are priorities. All the candidate projects were screened out and the corresponding cumulative initial investment costs will be \$ -2.34×1011. The cumulative carbon emission reduction of these projects will be 328 Gt CO_2-eq. Therefore, these projects will save financial resources of \$ 2.34×1011. The cumulative carbon emission reduction will be 328 Gt CO_2-eq, exceeding the expected carbon emission reduction by 214 Gt CO_2-eq in the next 30 y. The candidate projects that can not only save financial resources investment, but also meet or even exceed 50 % of the expected carbon emission reduction target.

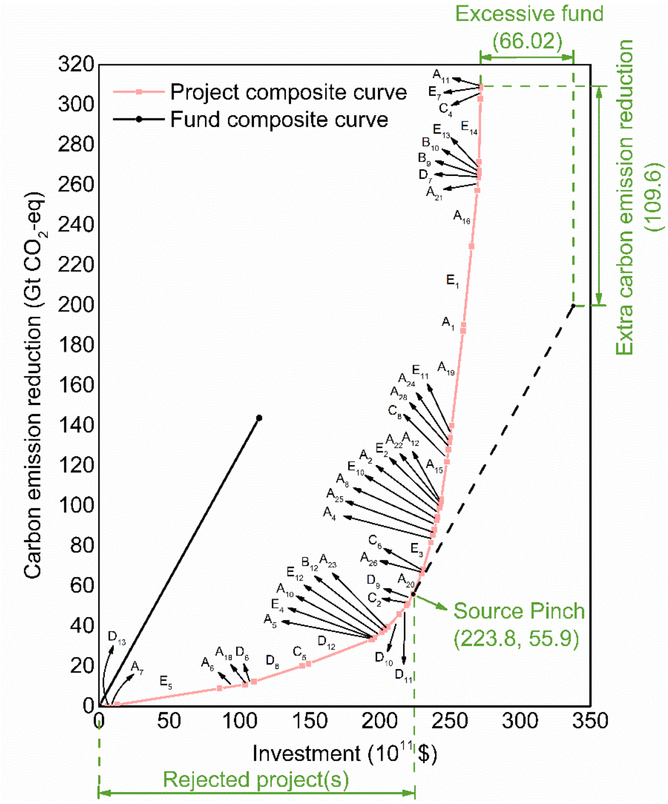

Figure 2: CEPA for global wide scenario

3.2 BWM

To make a more comprehensive evaluation of these 82 CERPs, the evaluation criteria will be conducted from four aspects, i.e., environmental, economic, social, and technology. Each criterion is assigned two indicators, as shown in Table 2.

Table 2: Selected criteria

criteria	indicator	
Environmental	Carbon dioxide reduction potential	K1
	Resource utilization	K2
Economic	Investment costs	K3
	Projects revenue	K4
Social	Employment	K5
	Government support	K6
Technical	Project maturity	K7
	Future development potential	K8

This hierarchical indicator system in this work enables the system analyst to perform a comprehensive assessment for each CERP. BWM is used to preliminarily evaluate the implementation priorities of CERPs (Zhou, 2020). This list is determined by decision-makers evaluation of the best and worst. The comprehensive score of each CERP refers to the sum of the optimal weight multiplied by the corresponding score of the project. The higher the comprehensive score, the better the technical project priority.

3.3 CBA

The NPV for each project is obtained by the CBA method. Based on the results of CBA, the marginal cost of mitigation for each technology project is arranged in ascending order. It can be seen from Figure 3 that, from left to right, the marginal emission reduction cost of the first half of the technology projects is negative. It indicate that the technical projects will make profits in the next 30 y, and the financial resources will be recovered quickly. The smaller the marginal emission reduction cost is, the more profits will be made. These projects include Sustainable Intensification for Smallholders (B8), Bicycle Infrastructure (D2), Small Hydropower (A22).

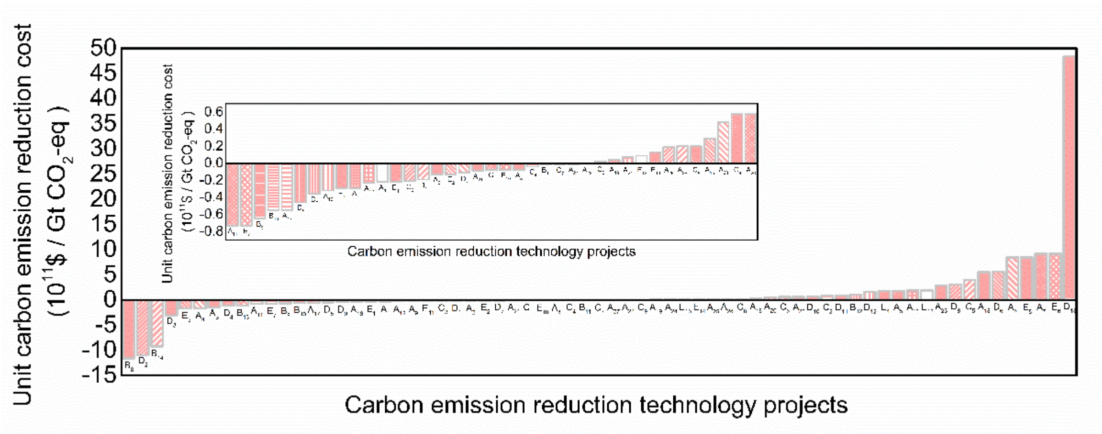

Figure 3: CBA for global wide scenario

On the contrary, if the marginal cost of emission reduction is positive, it indicates that the implementation of these projects cannot make profits. Marginal cost is positive projects include Refrigerant Management (C9), Onshore Wind Turbines (A19), Electric Trains (D13), etc. From left to right, Figure 3 shows that the priority order of project implementation is the most optimal to the least. This provides a cost-effective economic basis for decision-makers to develop reasonable carbon reduction projects.

3.4 MERCC

All the candidate projects selected by CEPA were first screened, according to the implementation priority order of the projects determined by cost-benefit analysis. Based on the ascending order of marginal emission reduction cost, their cumulative carbon emission reduction could be calculated. The x-axis is the cumulative carbon emission reduction, and the y-axis is the marginal cost of emission reduction, as shown in Figure 4. Frome the left to the right, the technical project implementation priorities are presented. The priorities from the optimal to the lowest is Bicycle Infrastructure (D2), Electric Bicycles (D3), Waste-to-Energy (A26), etc. The x-axis reflects the cumulative carbon emission reduction. The width of each small rectangle represents the carbon emission reduction potential of the technology project, and its area represents the cost-effectiveness of the project. The graphical approach reflects the cumulative total carbon emission reduction, the prioritization of project implementation, and the carbon emission reduction potential and cost-effectiveness of each project. It is convenient and intuitive to make a comparison and compare the advantages and disadvantages of two or more technical projects, to provide reasonable suggestions for decision-makers. Carbon source will accumulate to achieve carbon emission reduction by 328 Gt CO_2-eq.

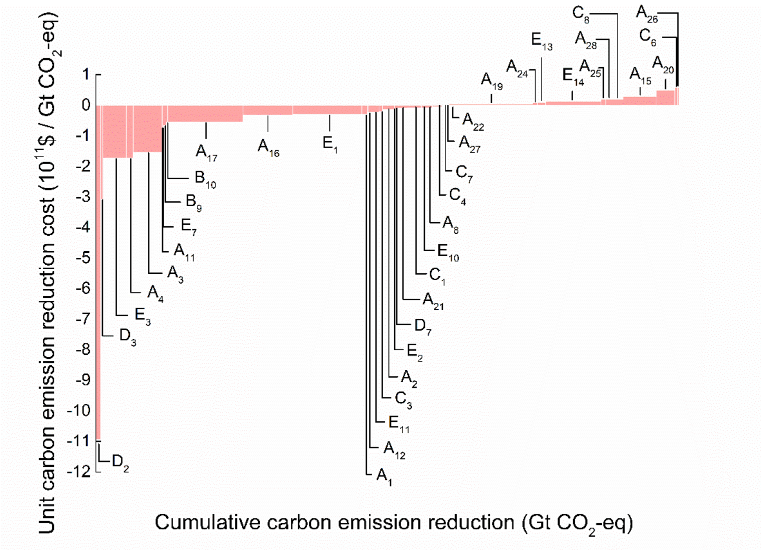

Figure 4: MERCC for global wide scenario

4. Conclusions

This work conducts an integrated framework for screening and evaluating CERPs. CEPA is used to determine the optimal project mix under the constraint of the fund and drawdown target. The benefit and cost of the project options are analysed based on the 82 existing climate solutions. The NPV per unit carbon emission reduction and marginal NPV diagram is selected to screen out the alternative projects for further analysis. BWM is used to evaluate the implementation priorities for all solutions. The MERCC roadmap for carbon drawdown is obtained. The proposed integrated framework can be used as a decision-making tool for selecting and ranking CERPs. All existing climate solutions could stem to reduce the excess of greenhouse gases. The carbon reduction potential of the five sectors, e.g. the power (186.4 Gt CO_2-eq), construction (97.9 Gt CO_2-eq), industry (23.8 Gt CO_2-eq), transportation (20.2 Gt CO_2-eq), food, agriculture, and land use (2.5 Gt CO_2-eq) over the next 30 y. In future work, carbon sinks to match the existing sources needs to be considered. Co-control analysis should urge authorities to investigate every possible solution to mitigate both carbon and air pollution emissions. Techno-economic uncertainties also need to investigate.

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