CHEMICAL ENGINEERING TRANSACTIONS
VOL. 122, 2025
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it
Guest Editors: Jeng Shiun Lim, Bohong Wang, Guo Ren Mong, Petar S. Varbanov

ISBN 979-12-81206-23-6; **ISSN** 2283-9216
DOI: 10.3303/CET25122001

DPSIR Framework for Carbon Pricing: a Systematic Review and DEMATEL Analysis of Cambodia Case

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Carbon pricing is a key instrument for climate change mitigation by introducing a financial incentive scheme to reduce carbon emissions. Without carbon pricing factoring into the products and services price, greenhouse gas is emitted at every production stage and at environmental costs. This carbon pricing scheme could also be a key driver for grassroots innovation and the deployment of green technologies while creating carbon trading opportunities. Moreover, revenue generated from carbon trading could fund both climate projects and green infrastructure, such as renewable energy and clean energy grid, toward net zero. Likewise, this study aims to systematically review the Drivers, Pressures, State, Impact, Response (DPSIR) framework for carbon pricing. A bibliometric DPSIR analysis of 47 articles is complemented by a Decision-Making Trial and Evaluation Laboratory (DEMATEL) based case study in Cambodia. Result shows that the success of carbon pricing in Cambodia largely depends on targeted policy interventions that address the most influential causal barriers: policy adjustment, environmental tax, and green finance. In addition, special attention should be given to carbon tariffs and market-oriented environmental regulation, which play key roles in shaping the long-term effective impacts of these interventions. Most importantly, the interdependency of the DPSIR factors provides practical insights for national carbon pricing strategies and supports broader ASEAN low-carbon initiatives.

1. Introduction

The urgency of climate change has intensified the global call for coordinated and effective climate policy instruments. Since 1990, scientific consensus on the anthropogenic causes of climate change has been led by successive assessment reports from the Intergovernmental Panel on Climate Change (IPCC, 2023). In response, the United Nations (UN) established the UN Framework Convention on Climate Change (UNFCCC) in 1992 to initiate negotiations on a multilateral climate framework. This process eventually formed the 1997 Kyoto Protocol and was subsequently replaced by the 2015 Paris Agreement. This allows each country to voluntarily submit its nationally determined contributions (NDCs) for the climate pledge (UNFCCC, 2024). A major challenge in implementing the NDCs in developing countries is the unfulfilled or low accessibility to climate finance, which constrains mitigation and adaptation investments. In response to this financing gap, carbon pricing has gained prominence as a strategic economic instrument for climate action. Built on the Pigouvian tax theory, the carbon pricing aims to alleviate the negative externalities through market dynamics, allowing the environmental costs to be internalised into the product and service pricing to act as a price signal. Instruments such as carbon taxes and emissions trading systems (ETS) generate dual benefits: incentivizing low-carbon innovation while mobilizing fiscal revenues for sustainable investment. Globally, more than 70 jurisdictions have adopted some form of carbon pricing, underscoring its rising importance in climate policy portfolios. Cambodia presents a unique case as the very first nation in the least developed country to submit the Long-term Strategy for Carbon Neutrality (LTS4CN) to the UNFCCC in 2021. However, Cambodia's implementation capacity remains challenged by the unfulfilled or low accessibility to climate finance to cover the cost of implementing its NDCs (Ministry of Environment, 2024). In the absence of predictable external funding, domestic sustainable financing options such as carbon pricing are crucial to finance Cambodia's climate commitments. Putting a price on carbon, nevertheless, requires numerous considerations on the policy design, timing, and effectiveness,

Paper Received: 21 September 2025; Revised: 17 October 2025; Accepted: 5 December 2025
Please cite this article as: Bou S., Sdok S., Kuok F., Promentilla M.A.B., 2025, DPSIR Framework for Carbon Pricing: A Systematic Review and DEMATEL Analysis of Cambodia Case, Chemical Engineering Transactions, 122, 1-6 DOI:10.3303/CET25122001

especially for a developing country like Cambodia. This paper applies the DPSIR framework to systematically review the dynamics of carbon pricing through a bibliometric analysis. DPSIR offers a structured lens for understanding systemic environmental factors (Carnohan et al., 2023), while DEMATEL analyses interdependencies and causal structures among those factors. Setyawati and Wibawa (2024) applied DPSIR and Causal Loop Diagram approaches to examine how carbon pricing mechanisms influence the development of carbon capture and storage across ASEAN countries, highlighting the importance of coordinated policy, carbon market development, and investment readiness that also emerged in this study's analysis of carbon pricing dynamics in Cambodia. DEMATEL has been widely used to identify priority barriers and inform policy strategies (Meas et al, 2022). This study is the first to integrate DPSIR and DEMATEL to review the carbon pricing adoption in the case of Cambodia, with implications for national and regional policy development.

2. Methodology

This study explores the global landscape of carbon pricing as a key economic instrument for reducing climate pollutants, with a particular focus on the factors influencing its implementation. A multi-step methodology was employed, beginning with a systematic analysis that informed the development of a DPSIR framework, which was then used to design expert interviews. Thirteen experts were consulted to evaluate key contextual factors related to drivers, pressures, state conditions, impacts, and policy responses. Participants were selected based on the strategic roles of their institutions in climate policy, sustainable development, economics, and public sector strategy, and included representatives from government agencies, non-profit organizations, and academia with expertise in carbon pricing systems. Their insights helped refine a list of barriers specific to Cambodia's context. Further analysis was conducted to investigate the interdependencies among influencing factors by applying the DEMATEL method, with a specific case study focused on Cambodia.

2.1 Systematic review using DPSIR

The Scopus database was queried using a Boolean search string targeting titles related to carbon pricing mechanisms, retrieving 181 articles published between 2022 and 2024. These search terms were entered using Boolean logic under the "TITLE" target to carbon pricing adoption mechanism. The query string included terms is TITLE (("carbon" OR "CO2" OR greenhouse* OR ghg OR emission* OR "climate pollutant") AND (pric* OR cost OR value* OR fee* OR tax* OR levy OR tariff* OR charge*) AND (factor OR driver OR determinant OR variable OR element OR influence OR parameter OR cause OR variation)) AND PUBYEAR>2021 AND PUBYEAR<2025. The final set of documents was critically reviewed to address the predefined research questions (see Table 1). After screening titles, abstracts, and keywords, and removing duplicates, 47 relevant articles were selected to capture generalizable patterns in carbon pricing, none of which covered Cambodia.

Table 1: Research questions

No.	Questions
RQ1	What are the drivers influencing carbon pricing?
RQ2	What are the pressures shaping the adoption of carbon pricing?
RQ3	What is the current state of carbon pricing?
RQ4	What are the impacts of and responses to carbon pricing?

2.2 Decision-Making Trial and Evaluation Laboratory (DEMATEL)

The DEMATEL method is well known for the analysis of interdependency of barriers and the elucidation of actionable policy interventions. The methodological procedure is presented (Meas et al., 2022). In Step 1, the direct-relation matrix X is constructed to quantify the intensity of influence exerted by one barrier over another. This is operationalized using a 5-point ordinal scale ranging from 0-4, with denotation of "no influence (0)," "low influence (1)," "medium influence (2)," "high influence (3)," and "very high influence (4)." The individual expert k is then rating X_{ij} based on the influence of barrier i on barrier j. The collective group direct-influence matrix is subsequently derived through the N experts' aggregated rating. Eq(1) generates the group direct-influence matrix while Eq(2) and Eq(3) provide the normalized direct-influence matrix Y:

$$X_{ij}=\frac{1}{N}\sum_{k=1}^{N} X_{ij}^{\ k}\ ,\ i,j=1,2,\ldots,n \tag{1}$$

$$Y=\frac{X}{s} \quad \text{where } Y=[\,Y_{ij}\,]_{n\times n} \tag{2}$$

$$s=\max\left(\max_{1\leq i\leq n}\sum_{j=1}^{n} X_{ij},\ \max_{1\leq i\leq n}\sum_{i=1}^{n} X_{ij}\right) \tag{3}$$

Step 2: Derive the total-influence matrix T from the normalized direct-influence matrix Y, $T=[\,Y_{ij}\,]_{n\times n}$ can be calculated by aggregating both the direct effects and all of the indirect effects in accordance with Eq(4). The problematic causal map is created using Eq(5) and Eq(6):

$$T=Y+Y^2+Y^3+...+Y^h=Y(1-Y)^{-1} \text{ where } h\rightarrow\infty \tag{4}$$

$$R=[r_i]_{n\times 1}=\left[\textstyle\sum_{j=1}^{n} t_{ij}\right]_{n\times 1},\ \text{i,j}=1,\ 2,\ldots,\ n \tag{5}$$

$$C=\left[c_j\right]_{n\times 1}=\left[\textstyle\sum_{i=1}^{n} t_{ij}\right]_{n\times 1},\ \text{i,j}=1,\ 2,...,\ n \tag{6}$$

The prominence, horizontal axis vector (R+C), indicates how strong the barrier influences and is influenced by others. Meanwhile, Net relation index, the vertical axis vector (R-C), reflects a factor's overall influence direction within the system. Note that the net influences of barriers on other barriers are calculated by ($r_i - c_j$). The positive value of ($r_i - c_j$) signifies that barrier B_j has a net influence on the other barriers and the negative value of ($r_i - c_j$) shows that the barrier B_j is affected by interactions from other factors in the system. Minor influences are excluded by applying a threshold based on the average of the total relation matrix, allowing only stronger connections to be plotted in the inner dependency matrix.

3. Result and discussion

3.1 DPSIR analysis of carbon pricing drivers

The carbon pricing is influenced by a range of interrelated factors that reflect both policy interventions and market dynamics. The first driver is energy prices, particularly those of fossil fuels like oil, coal, and natural gas, affecting the cost structure of emissions rights. This driving force is prominently observed in carbon markets such as China's Emissions Trading System and the European Union Emissions Trading System (Cao et al., 2023). In other words, when emissions levels rise, the growing demand for pollution permits can exceed available supply, thereby driving up carbon pricing (Alfakihuddin et al., 2024). The second driver is a macroeconomic factor, encompassing overall economic performance and key industrial activities, which directly shape carbon pricing. For instance, empirical evidence demonstrates a direct relationship between financial market indices such as the China Securities Index 300 and carbon pricing fluctuations, driven by firm-level operational characteristics (Min et al., 2022). The third driver involves a comprehensive policy framework, particularly carbon taxes and emissions allowance systems, which provide consistent market signals, enhance price stability, and strengthen institutional credibility (Zeng et al., 2023). Lastly, the fourth driver is carbon pricing stability, which is crucial for attracting investor participation and supporting the long-term viability of such markets (Tariq et al., 2023). These drivers create a complex interplay of policy, market, and societal pressures that reflect both global climate commitments and local regulatory dynamics.

3.2 Pressures shaping carbon pricing adoption

The first pressure is the emission reduction targets mandated by international agreements such as the Paris Agreement, which compel national governments to adopt concrete mitigation measures, including afforestation initiatives and reforms in the energy sector (Li et al., 2022b). The second pressure includes environmental taxes designed to penalize high-emission firms. However, these taxes can trigger unintended consequences, such as cost pass-through to consumers or the relocation of firms to countries with laxer environmental regulations (Cai et al., 2016). The third pressure involves competitive market demands, which intensifies the push for carbon pricing, as firms are increasingly required to meet international climate standards while seeking competitive advantages through early adoption of green technologies (Nesheim et al., 2022). Finally, the fourth pressure is the necessity of a robust long-term environmental regulation framework to bridge the gaps between policy and practice (Zou and Zhong, 2022). The framework shall address the risk of carbon leakage and rebound effects, where emissions reductions in one region are offset by increases in another (Chen et al., 2022). Therefore, to ensure carbon pricing contributes meaningfully to climate objectives, it must be integrated into coherent, transparent, and socially responsive policy architectures that balance environmental goals with economic and political feasibility (Mayol and Porcher, 2024).

3.3 Current state of carbon pricing: market and regulatory dynamics

In the current state, market-oriented environmental regulations and carbon tariffs significantly influence carbon pricing dynamics. Regional carbon market pilots such as those in Shanghai, Hubei, and Guangdong in China exhibit diverse maturity levels and market volatility driven by local economic contexts and energy dependence (Qu et al., 2024). These pilots are examples of market-oriented environmental regulation because while rising price on carbon initially create cost pressures for firms, over time they encourage investments in low-carbon technologies (Wu and Wang, 2022). Additionally, cross-border carbon tariffs are emerging as a complementary regulatory mechanism. Developed countries have introduced carbon border adjustment mechanisms to target carbon-intensive exports such as crude oil from developing countries. These tariffs can reduce trade volumes and raise domestic prices, creating deadweight loss in the importing country (Sheng and Wang, 2022). However, cross-border carbon pricing adjustment is often exempt if equivalent prices have already been applied in the country of origin. This reciprocity mechanism generates incentives for exporting countries to implement domestic carbon taxes, allowing them to retain the associated tax revenues and reinvest them in domestic emissions reduction programs.

3.4 Impacts and policy responses to carbon pricing

The impacts of carbon pricing are multifaceted, producing wide-ranging economic and structural transformations. The first impact is technological innovation and increasing total factor productivity (TFP) without increasing the pollution levels (Lv et al., 2024). For example, raising Chinese carbon pricing to EU levels could increase firm TFP by 22.7 % (Wu and Wang, 2022). To address this first impact, monetary tools such as green finance initiatives reinvest environmental tax revenues toward clean energy and technology development (Jiang and Qiu, 2023). The second impact involves the adjustments in supply chain design as firms seek to minimise carbon costs through their operations (Li et al., 2022a). Mitigation strategies like carbon allowance control through the limited availability of carbon allowance supply to the market through auctions can stabilize the fluctuation and volatility of carbon pricing in the markets (Cao et al., 2023). The third impact is the accelerated deployment of renewable energy. When a carbon tax is present in fossil fuels, the renewable energy supply is enhanced through public and private investment in the clean energy infrastructure (Przychodzen, 2024). In responses, for an oil-dependent country aiming for a carbon-neutral economy, oil rents, which refer to revenues from oil extractions, can play a significant transitional role to clean and affordable energy. The oil price control through collaboration among international organizations (e.g., OPEC) could serve as a mechanism to limit fossil fuel production and enforce cleaner energy alternatives (Ajayi, 2024). The fourth impact involves the changes in financial market behaviors, notably investors' trading frequencies on carbon markets, driven by carbon market dynamics (Wang et al., 2023). To address this impact, exchange rate interventions may help shield domestic carbon markets from currency-induced price shocks, ensuring predictability and investor confidence (Ajayi, 2024). Lastly, carbon pricing also impacts the export capacity, particularly when the trade-exposed countries face carbon border adjustment tariffs as the trade volumes could be simulated upon imposing the tariff (Sheng and Wang, 2022). These tensions are especially acute in developing countries balancing fossil fuel dependence with climate obligations, a dilemma described as "ecological poverty" (Yang et al., 2022). Policy adjustments, such as differentiation of carbon tariffs by pollution intensity, allow low-emission countries to maintain trade competitiveness while incentivizing high-emission exporters to reform (Gautier, 2022). Together, these responses reflect a shift toward dynamic, multi-level governance frameworks that balance environmental integrity with socio-economic and political realities.

3.5 DEMATEL analysis for case study of Cambodia

Through expert interviews, key factors were identified and analyzed to evaluate Cambodia's carbon pricing options (see Table 2).

Table 2: Influencing barriers of carbon pricing in Cambodia

Code	Barriers	Code	Barriers
B1	Energy price (crude oil, coal, natural gas)	B6	Carbon tariffs
B2	Carbon pricing stability	B7	Green total factor productivity (GTFP)
B3	Emission reduction target	B8	Supply chain network
B4	Environmental tax	B9	Policy adjustment
B5	Market-oriented environmental regulation	B10	Green finance

Figure 1a shows the heatmap of the influence between barriers based on the inner dependency matrix. The light grey colour indicates zero influence, while the dark blue colour shows the strongest influence. Note that weaker causal relationships between barriers were filtered out by using a threshold value of $\alpha=0.448$. The heatmap shows the light grey colour in rows B2 and B7, indicating zero influences of barriers, carbon pricing stability (B2) and green total factor productivity (B7) on other barriers, and suggesting that these barriers are independent barriers with low prominence and relation, followed by those of supply chain network (B8) and energy price (crude oil, coal, natural gas) (B1). A problematique causal map of the barriers is segmented into causes (Quadrants I and II) and effects (Quadrants III and IV), plotted by prominence (x-axis) and net relation index (y-axis) (See Figure 1b). Policy adjustment (B9) is situated at the highest value of net relation index and that of prominence, indicating the central and causal barrier, followed by environmental tax (B4), and green finance (B10). Market-oriented environmental regulation (B5) and carbon tariffs (B6) are located in quadrant II, suggesting that these barriers are the influential and determinant barriers that directly impact the outcome decision. On the other hand, the emission reduction target (B3) is the effect barrier, followed by B1, B8, B2, and B7. Similar to Setyawati and Wibawa (2024), this study finds that effective carbon pricing depends on strong policy design, investment support, and regulatory alignment within developing ASEAN economies. Therefore, the success of carbon pricing for the Cambodia case, depends highly on the policy interventions for the causal barriers B9, B4, and B10, while special attention should also be given to barriers B6 and B5 to ensure the expectation of the positive impact of the proposed policy interventions.

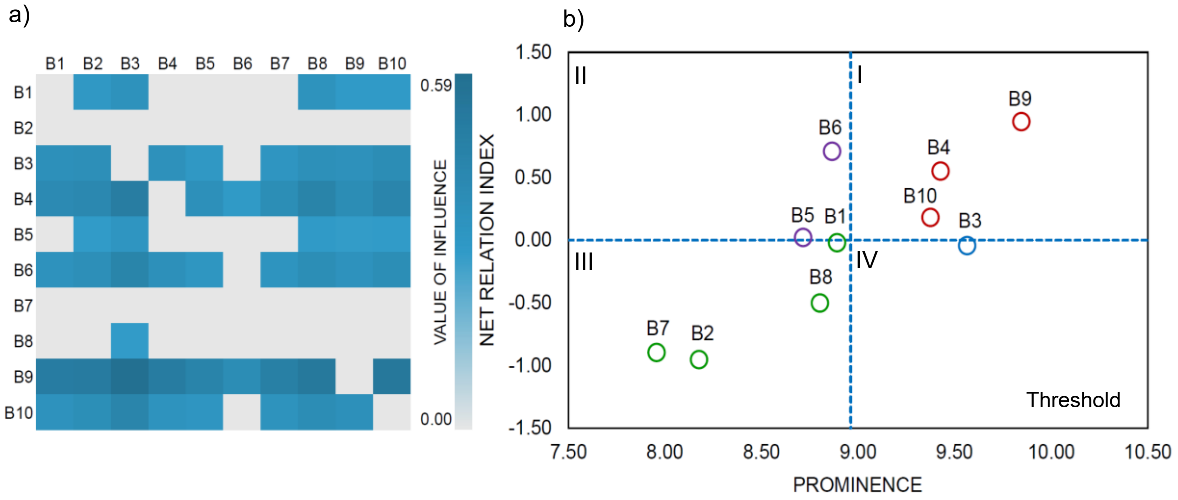

Figure 1: Interrelationship of the barriers to carbon pricing in Cambodia case (a) Heatmap of influences between barriers (b) Problematique causal map

4. Conclusion

This study provides a comprehensive analysis of the challenges associated with carbon pricing implementation in developing countries, with a particular focus on Cambodia. Utilizing the DPSIR framework and DEMATEL methodology, the study identifies and analyses the interrelated barriers influencing the success of carbon pricing as a climate mitigation strategy. Key findings reveal that policy adjustment, environmental tax reform, and access to green finance are the most influential factors, while elements such as carbon pricing stability and green productivity exhibit lower systemic impact. By mapping the causal relationships among these barriers, the study offers practical insights to inform policy decisions and enhance institutional readiness. The results highlight the importance of targeted interventions that strengthen regulatory frameworks and mobilize financial resources to support market-driven environmental initiatives. This research fills a critical knowledge gap by integrating structured analytical tools into policy design and advocating for a coordinated ASEAN response. Moving forward, the findings support the development of comprehensive national and regional strategies aimed at accelerating carbon pricing adoption. Through this approach, ASEAN countries can enhance their resilience to climate change and advance the transition to a low-carbon economy.

Acknowledgments

The authors acknowledge the financial support of Faculty of Social Sciences and Humanities, Royal University of Phnom Penh and the Association of Asian Studies for this study.

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