Decarbonisation of Construction Projects: A Review and Interpretive Structural Modelling of Carbon Reduction Drivers

Abstract

Purpose: Extant studies have discussed numerous carbon reduction drivers but there is a dearth of holistic review and understanding of the dynamic interrelationships between the drivers from a system perspective. Thus, this study aims to bridge that gap.

Design/methodology/approach: The study conducted a review using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and adopted interpretive structural modelling (ISM) to analyse and prioritise the drivers.

Findings: Eighteen drivers were identified and grouped into five namely; policy instruments, bid-related, cost and risk, education and training, and reward and penalty drivers. The ISM revealed two hierarchical levels of the drivers with only higher cost of electricity/fuel on the higher level, making it the most important driver that could influence others.

Practical implications: The study presents an overview of decarbonisation drivers in the literature and would be of benefit to the government and stakeholders towards achieving net zero emissions in the construction industry.

Originality/value: The findings of the study present drivers of carbon reduction, and prioritised and categorised them for tailored interventions within the construction sector. Also, it could serve as foundational knowledge for further study in the construction process decarbonisation research area.

Keywords: Carbon reduction drivers, interpretive structural modelling, construction projects, construction decarbonisation

1.0 Introduction

Global warming has become a matter of concern since the industrial revolution (Levy, 2023). Its effects are more pronounced these days and with a severe warning if the situation is left unabated (Jørgensen and Termansen, 2016). To avert major human and natural systems catastrophes, the world needs to limit global warming to 1.5^{o}C (Intergovernmental Panel on Climate Change (IPCC), 2018). In achieving this, the construction industry has been identified as a critical sector to devote attention to (Arogundade *et al.*, 2021b) since it is a major contributor to greenhouse gas (GHG) emissions (Giesekam *et al.*, 2018). To contextualise this, the consortium of the Global Alliance for Buildings and Construction (GABC), the International Energy Agency and the United Nations Environment Programme reported that globally in 2018, the building and construction sector emitted about 40% of the world's total carbon emission (GABC *et al*., 2019). While the United Kingdom Green Building Council (UKGBC) stated that in 2014, the built environment sector contributed around 42% of the UK's total carbon footprint (UKGBC, 2021) and the Environmental Audit Committee (EAC) of the UK parliament in 2022 warned that the sector needs to reduce its emission if the UK is to meet up with its net zero commitment by 2050 (EAC, 2022). This shows the significance of the construction sector in driving the ambition of net zero carbon globally. However, the sector is slow in adopting innovation and the move towards decarbonisation of projects is slow and bedevilled with challenges (Wuni and Shen, 2019). Hence, there is a need to examine the factors that would drive the construction stakeholders, especially contractors to adopt carbon reduction strategies in order to accelerate the decarbonisation of construction projects.

Against this backdrop, several researchers have identified numerous drivers that could aid construction carbon reduction (see Table 1). For instance, Mustaffa *et al*. (2022); Nishida *et al*. (2016) and Wong *et al*. (2013) highlighted the need to introduce stringent standards to achieve improved energy efficiency thereby lowering carbon emissions. Equally, the seminal work of Wong *et al.* (2013) identified and grouped carbon reduction drivers into penalty, reward, education and more stringent standard. However, the study of Wong *et al.* (2013) was conducted from an organisation perspective and did not consider the whole spectrum of construction projects. Also, the study did not utilise a systematic approach in identifying these drivers. They did not explore the interactions nor attempt to determine the key drivers that could make the most significant impact when trying to nudge stakeholders to minimise the carbon emission of construction projects. Moreover, due to the expected global growth in new construction (Arogundade et al., 2023b; UN Environment and International Energy Agency, 2017), the investigation of construction projects' carbon reduction drivers becomes vital in ensuring that sustainable practices are encouraged and incorporated into these anticipated developments. Due to the identified limitations, this study, therefore, aims to establish the drivers of carbon reduction for construction projects and investigate their interrelationship. In achieving this aim, the study was guided by three objectives: (1) to identify all drivers of carbon reduction in construction projects; (2) to evaluate the interrelationship between these drivers; and (3) to rank the drivers based on their interrelationship. To accomplish the objectives, a systematic review of literature was carried out to identify and group the drivers while interpretive structural modelling (ISM) approach was adopted to assess their interrelationship and prioritise the drivers. Based on the findings of the ISM analysis, the implications as it relates to construction projects are then discussed.

Authors and Year	Focus of study	Limitations relating to the current study
Mustaffa *et al*. (2022)	General inquiry on strategies and barriers affecting low carbon construction in Malaysia	The study adopted a case study, survey and structured interview approach in generating the barriers and drivers of low carbon transition. Hence, the resulting drivers highlighted in the study seems to be limited to participants' opinion.
Rissman *et al*. (2020)	This work examined decarbonisation drivers of the global industry from both the supply and demand side.	The study is broad and not specific to construction projects or industry.

Lai *et al*. (2017)	Investigation of low-carbon technology innovation drivers within the construction industry	No specific consideration of construction project decarbonisation.
Wong *et al.* (2013)	The study investigated the effect of some drivers on minimising the carbon footprint of construction projects	Detailed examination of the various drivers that could influence construction project decarbonisation was lacking as well as their interrelationship.

Table 1: Some previous studies on decarbonisation drivers and their limitations (Source: Created by authors)

2.0 Research Methods

The study employed a sequential two-stage approach – systematic review and interrelationship modelling - in achieving the objectives. A comprehensive review of the literature was conducted which provides an overview of the extant studies and theoretical support for the current study (Darko, 2019).

A systematic literature review approach is adopted because it employed auditable steps and provides a comprehensive report on subject matters (Charef *et al.*, 2018). For instance, Ershadi *et al.* (2020) used the systematic review approach to extract constructs, factors and established resilience measures from literature as it pertains to construction management graduates. Based on the wide usage of the systematic review approach in construction management research in deriving variables underlying a concept and its reliability in providing scientific value to a research study (Kitchenham and Charters, 2007), this study adopts the same approach in identifying factors driving carbon reduction in construction projects.

In conducting the systematic literature review, a four-step process adapted from Ershadi *et al.* (2020) was utilised. The process involves protocol development, searching and screening process, measurement variable extraction and in-depth review and discussion of identified variables.

The protocol development involves selecting an appropriate database, determining a search strategy and providing inclusion and exclusion criteria. There are different databases available to researchers in conducting reviews of literature, some of which include Web of Science, Science Direct, Scopus and EBSCOhost. However, for this study, Scopus was chosen because extant studies have highlighted that it has an enormous archive of management, business, engineering and construction management publications (Arogundade *et al.*, 2021a; Oliveros and Vaz-Serra, 2018). Having chosen a database, keywords were used to identify appropriate journals and papers related to the focus of this research (Deng and Smyth, 2013). Although, the selection of keywords was quite challenging and assumptions were made as required (Ershadi *et al.*, 2020; Dikert *et al.*, 2016). Such an assumption is permissible since Darko and Chan (2016) noted that no sole study can single-handedly address all the possible intricacies associated with research keywords in exploring a subject matter. It is worth noting that the number of relevant literature obtained for each keyword string might be influenced by the type of keywords adopted (Darko and Chan, 2016) and this might be a limitation as there might be a level of subjectivity which could be based on the general knowledge of the subject matter by the researcher. However, this was minimised in this study as as in-depth literature review was conducted and consultations were made with relevant professionals before commencing the systematic review. These professionals are from built environment contracting organisations with numerous years of experience relating to construction carbon reduction. Also, an initial search of the database was conducted to understand appropriate and related keywords associated with the drivers as practised by Charef *et al.* (2018). The final keyword utilised for the search which was conducted on the 11th July 2023 is as follows:

i. "*driv**" OR *"motivat*"* OR *"enabl*"* OR *"induc*"*

ii. *"reduc* carbon"* OR *"carbon reduction"* OR *"carbon emission*reduction"* OR *"co2 reduction"* OR *"co2 emission* reduction"* OR *"GHG reduction"* OR *"greenhouse gas emission* reduction"* OR *"GHG emission* reduction"* OR *"emission** *reduc*"* OR *"low carbon"* OR *"low-carbon"* OR *"embodied carbon reduc*"* OR *"reduc* embodied carbon"*

iii. *"contractor*"* OR *"behavio* change"* OR *"chang* behavio*"*

In terms of exclusion and inclusion criteria used during the search, the study of Charef *et al.* (2018) and Ershadi *et al.* (2020) was used as a guide with some modifications and this is depicted in Table 2. Also, both conference and review papers were included due to the limited number of studies associated with this research area as evidenced in the review study done by Arogundade *et al.* (2021a) to map researches that have been conducted on carbon minimisation during the execution of building construction projects within construction journals.

No.	Inclusion criteria	Exclusion criteria
1	Peer-reviewed studies	Studies published in books and book chapters
2	Studies focused on energy and carbon reduction	Studies without full text
3	Studies with findings or discussions related to the objectives of the current study	Studies published in other languages
4	Studies published in English	
5	No time boundary restriction on studies drawn from the utilised database	

Table 2: Inclusion and exclusion criteria for the study (Source: Created by authors)

The articles obtained through the use of the keywords and inclusion and exclusion criteria were screened for in-depth text review to generate the carbon reduction drivers' variables. During the in-depth text review, a snowballing method through the review of the reference list of the included articles was used to check if relevant articles could be found to improve the number of relevant papers to be included in the study but none was found. In general, twenty studies were found to be eligible for the study (Figure 1, Table 3). This number of articles is considered adequate for the study as it is comparable to the 22 papers used in the systematic review research carried out by Cheng *et al*. (2022) and almost similar in quantity to the 26 papers utilised in the study of Arogundade *et al*. (2023).

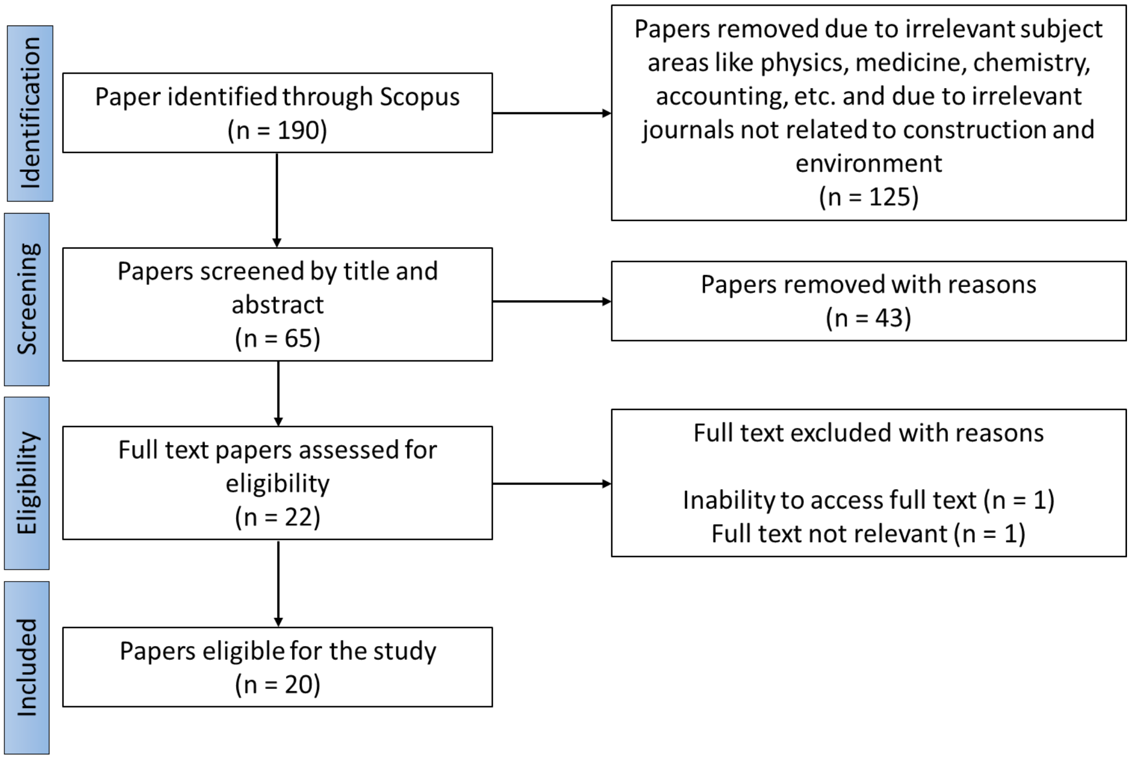

Figure 1: Flowchart for the Systematic Review (Source: Created by authors)

Source title	Authors and publication year	No. of Article
Building Research and Information	Berry *et al.* (2014); Mustaffa *et al*. (2022); Nishida *et al.* (2016)	3
Climate Policy	Grubb *et al.* (2020); Hamdi-Cherif *et al.* (2021)	2
Energy Research and Social Science	Niamir *et al.* (2020)	1
Energy Efficiency	Mundaca *et al.* (2019); Nolden & Sorrell (2016)	2
Nature Climate Change	Beckage *et al.* (2018); Bolderdijk *et al.* (2013)	2
Journal of Cleaner Production	Liu *et al.* (2017)	1
Energy Procedia	Al-Marri *et al.* (2017)	1
Smart and Sustainable Built Environment	Sanchez *et al.* (2014); Hayles *et al.* (2013)	2
Energy Policy	Mohareb and Kennedy (2014)	1
Transportation Research Part A: Policy and Practice	Marsden and Docherty (2013); Skippon *et al.* (2012)	2
International Journal of Project Management	Wong *et al.* (2013)	1
Transportation Research Record	Hickman *et al.* (2009); Millard-Ball (2008)	2
Total		20

Table 3: Summary of search result with publication source (Source: Created by authors)

2.1 *Interpretive Structural Modelling (ISM)*

ISM was adopted in this study to establish the relationship between the different sets of drivers obtained from literature and authors' brainstorming sessions as well as transform the drivers into a lucid structured system (Sushil, 2012). According to Saka and Chan (2020) and Sushil (2012), ISM has been used widely within construction-related research in examining complex systems and giving insight into the interrelationship among various elements. ISM disintegrates a system into numerous components by hatching up a multilevel hierarchy-based structural model utilising groups' judgement or expert opinion (Sushil, 2012; Tariq and Zhang, 2021). ISM becomes useful when logical and systematic thinking is desired to approach the complex issue of interaction amongst different elements to communicate their relationship (Iyer and Sagheer, 2010). ISM was utilised in this study due to its transformative nature and ability to convert abysmally articulated mental models into clear models that are easy to interpret. ISM interprets representation systems or embedded objects through the application of a systematic iterative graph theory, resulting in a digraph (directed graph) for the complex system for a particular contextual association between a set of elements (Sushil, 2012). The general methodology for conducting ISM as adapted from Saka and Chan (2020) and Mandal and Deshmukh (1994) is depicted in Figure 2 with the two major steps being:

- Establishment of a hierarchical structure between the drivers
- Analysing the dependence power and driving power of the drivers

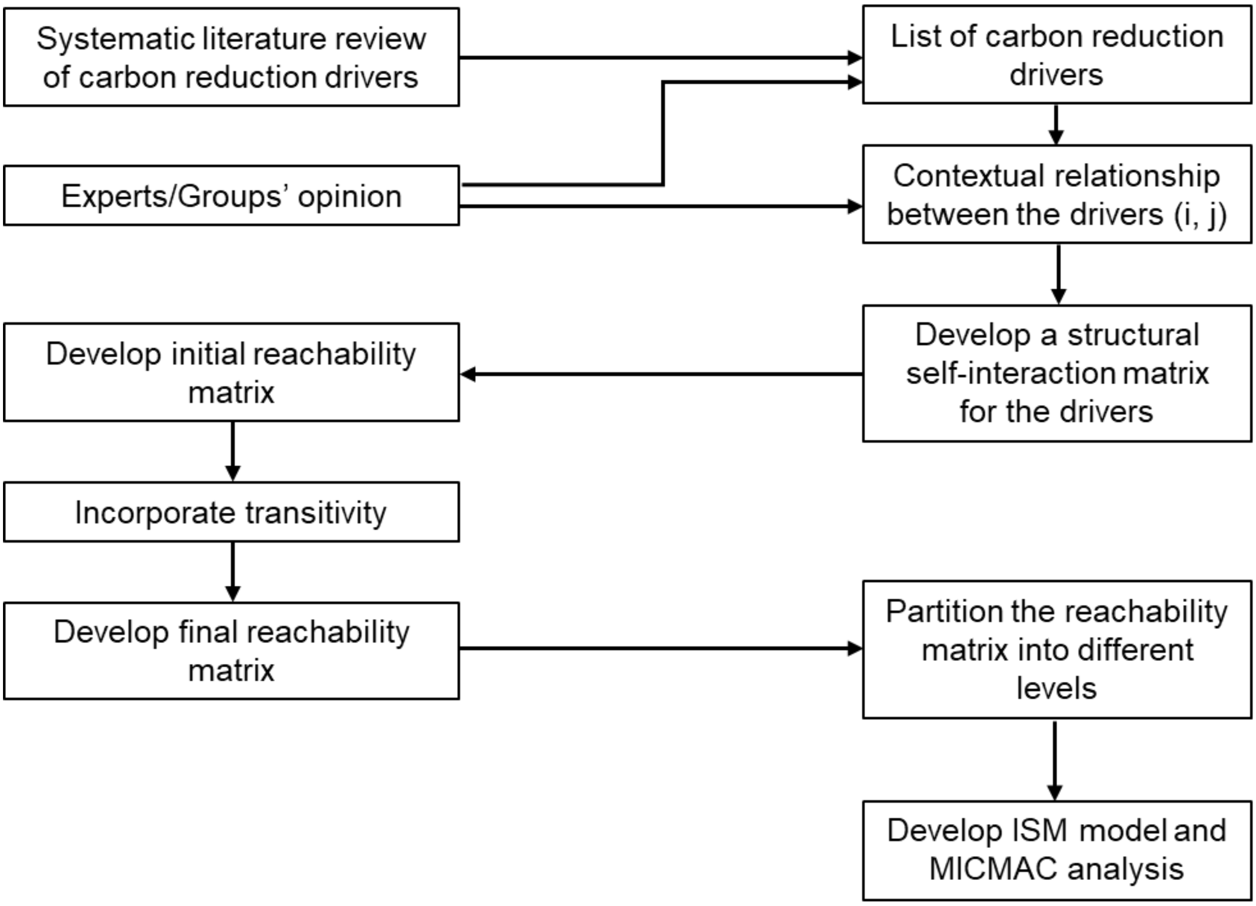

Figure 2: ISM Methodology (Adapted from Mandal and Deshmukh (1994) and Saka and Chan (2020))

The hierarchical structure (ISM model) between the identified drivers will be created using the systemic iterative process while *Matrice d'Impacts Croises-Multiplication Appliqué a un Classement* (MICMAC) technique will be used to analyse the dependence power and driving power of the drivers. MICMAC is used to classify the drivers into four distinct categories: autonomous, linkage, independent and dependent. The classification is done by plotting the driving power against the dependence power. The dependence power is obtained through the vertical summation (column-wise) of the relationship to and from a specific driver 'j'. The driving power is derived by summing the relationship horizontally (row-wise) to and from a specific driver 'i' (Saka and Chan, 2020).

3.0 Results and Discussion

3.1 Drivers of Carbon Reduction in Construction Projects

Extant studies have identified multiple factors that can aid the reduction of carbon emissions within the construction industry and associated sectors. For instance, Mundaca *et al*. (2019) identified the need for a policy initiative that will serve as a 'command-and-control' system in driving decarbonisation in the building sector in China. Likewise, Grubb *et al*. (2020) highlighted various policy instruments that can influence carbon minimisation during the production and consumption of different construction materials. Nishida *et al*. (2016) and Wong *et al.* (2013) discussed the need for the introduction of 'more stringent standard' in achieving better energy efficiency and performance in buildings. In line with this, researchers seem to agree unanimously that a single policy is inadequate in achieving a decarbonisation goal (Hamdi-Cherif *et al*., 2021; Niamir *et al*., 2020). Therefore, other measures such as incentives (Sanchez *et al*., 2014), rewards (Wong *et al.,* 2013), education (Berry *et al*., 2014; Hayles *et al*., 2013), cap and trade programme (Millard-Ball, 2008; Nishida *et al*., 2016), penalty (Wong *et al*., 2013) to mention but a few are equally important in attaining carbon reduction.

During the review of literature in exploring the drivers that can motivate construction stakeholders to reduce the carbon emission of construction projects, the study conducted by Wong *et al*. (2013) stood out. The authors seem to have done a similar study but within an organisational culture perspective and highlighted reward, penalty, more stringent standards and education as the required drivers that can nudge contractors to adopt carbon reduction measures. However, it is worth noting that this present study expands on that by conducting a more extensive literature review while equally considering carbon reduction drivers covering all aspects of construction projects, including interaction with clients and suppliers. This is necessary since it has been noted that to solve construction carbon reduction, there is a need for collaboration among all stakeholders (Manidaki *et al*., 2016a). Furthermore, in line with the objective of this research, other drivers not found in the literature, but which could nudge contractors to reduce carbon emissions were introduced. All identified drivers of carbon reduction are listed in Table 4.

3.1.1 Classification of Carbon Reduction Drivers

As shown in Table 4, a total of 18 drivers that can motivate construction stakeholders to reduce construction carbon emissions have been identified. However, to better understand these carbon reduction drivers, it is important to 'classify and differentiate between them' (Darko *et al.*, 2017, p.37). In doing this and after careful examination of previous studies utilised in the identification of carbon reduction drivers, Wong *et al.* (2013) categorisation of carbon reduction drivers into four – reward, penalty, more stringent standard and education – seem to be the only study that has made such broad classification. Hence, this current research adopted and modified this grouping while also introducing new categories based on the expanded review of literature carried out. The classification is illustrated in Figure 3 and discussed below.

3.1.1.1 Policy Instruments Drivers

Policy instruments are laws, regulations or standards that are utilised by the government in generating, evaluating and implementing policy options within a society (Capano and Howlett, 2020). For instance, when the European Union (EU) is considering policy options in tackling activities that could potentially harm the environment or economy, they might utilise a 'hard legally binding rule' as a policy instrument to specify the behaviour expected from individuals or organisations (Bennett, 2019 p.107). Relating to GHG emissions reduction, Grubb *et al.* (2020) in their study on utilising consumption-oriented policy instruments to encourage low-carbon behaviour within the EU context, suggested that policy instruments have been utilised in this regard.

Code	Drivers	References
D1	The introduction of standards such as PAS2080	Beckage *et al.* (2018); Grubb *et al.* (2020); Hamdi-Cherif *et al.* (2021); Hickman *et al.* (2009); Marsden and Docherty (2013); Mohareb and Kennedy (2014); Mundaca *et al.* (2019); Niamir *et al.* (2020); Skippon *et al.* (2012); Wong *et al.* (2013); Nolden & Sorrell (2016)
D2	Integrate carbon emission management into the assessment criteria of contractors	
D3	The introduction of a carbon reduction policy by the government targeting the adoption of low-carbon technology during construction projects	
D4	The infusion of carbon reduction requirements into the bid evaluation process	Liu *et al.* (2017)
D5	Higher cost of electricity/fuel	Al-Marri *et al.* (2017)
D6	Carbon trading programmes/emission trading schemes that bring about cost for carbon emission	Millard-Ball (2008); Nishida *et al.* (2016)
D7	Incentives for contractors within the bidding process to have a plan for reducing carbon	Sanchez *et al.* (2014)
D8	Exposure to carbon reduction training	Berry *et al.* (2014); Hayles *et al.* (2013); Wong *et al.* (2013), Mustaffa *et al*. (2022)
D9	Sharing knowledge and best practice related to carbon footprint reduction	
D10	The education and training support on carbon reduction from different stakeholders such as the government, clients, professional institutes and building authorities	
D11	Having the intention/willingness to preserve the environment	Bolderdijk *et al.* (2013)
D12	Employment of carbon tax once carbon emission surpasses a certain threshold during construction projects	Wong *et al.* (2013)
D13	Introduction of tax rebates and subsidy schemes	Wong *et al.* (2013)
D14	The willingness of the client to allow contractors to adopt low-carbon experimental products[a]	Authors
D15	Having a carbon simulation system (a platform that helps to visualise, estimate and optimise embodied carbon)[a]	Authors
D16	Reducing landfill tax for segregated waste and increasing fees for mixed waste[a]	Authors
D17	Work recognition by clients/professional associations/government through awards presentations[a]	Authors
D18	Carbon reduction bonus for contractors from their clients[a]	Expert

NOTE: [a]Drivers were added based on research objectives and validated.

Table 4: Carbon Reduction Drivers (Source: Created by authors)

Mundaca *et al.* (2019) alluded to the fact that having a wide-reaching policy tool is important to achieve a high carbon reduction.

In Australia, the national building codes board instituted a policy instrument to rate energy efficiency in buildings and some states like Victoria, have even taken it a step further by disapproving new construction works which fall below the national 5-star rating (Wong *et al*., 2013). Likewise, the EU introduced a much stricter standard for buildings to ensure that new buildings are near zero-energy as much as possible (Wong *et al.*, 2013). All of these efforts are geared towards ensuring that the carbon footprint of new construction or renovation is reduced significantly (Wachsmuth and Duscha, 2019).

Although, previous studies have pointed out that a single policy instrument might not be sufficient in achieving the desired emission cut (Grubb *et al.*, 2020, Niamir *et al.*, 2020). This therefore necessitates the need to have a complementary instrument or tool to reinforce one another. Such a complementary tool was highlighted by Niamir *et al.* (2020), where the authors stated that a mix of policies focusing on behavioural factors and subsidies could be mixed with education to drive the transition towards green energy. Consequently, policy instrument drivers would require other sets of drivers to be effective in realising carbon reduction goals.

3.1.1.2 Cost and Risk Drivers

In recent times, the cost of energy has continued to rise. This is partly due to the constraint in global supply and the opening up of economies worldwide post-covid 19 lockdown, leading to more demand than supply could fulfil (Bolton and Stewart, 2022). This increase impacts individuals and businesses, albeit differently depending on the regulation in effect in a particular country. In the UK, for example, the government puts a cap on electricity and gas prices used by domestic households which is now reviewed every three months due to the global increase in energy prices (Bolton and Stewart, 2022; Office of Gas and Electricity Market (Ofgem), 2022). However, businesses which are categorised as non-domestic energy users do not get a price cap on their energy usage (Bolton and Stewart, 2022). Hence, an increase in energy prices could lead to an increase in running costs for the businesses.

Although, there is the argument that this running cost increase could be transferred to clients. While this is possible and might not be totally disregarded, the energy cost increase could also induce organisations to seek alternatives to either change their energy supply source, type of equipment/machinery being used or monitor their usage generally to reduce it and become more energy efficient. This is because if an organisation succeeds in this effort, it makes them more competitive in the marketplace and other competitors not seeking alternatives might lose clients.

Contrary to the UK, the government of Qatar generally subsidises energy for everyone, including businesses and even allows its citizen to use energy for free (Al-Marri *et al.*, 2017; Meier *et al.*, 2013). In such circumstances, scholars have argued that this leads to wanton environmental consequences, including upping global carbon emission as a result of unrestricted usage due to low energy cost (Hamaizia and Moerenhout, 2022; Vernon *et al.*, 2021) except if there is a desire by individuals to preserve the environment (Bolderdijk *et al.*, 2013). Therefore, Al-Marri *et al.* (2017) suggested that having a higher cost of electricity and fuel could lead to reduced consumption, thereby positively affecting the associated carbon emission. This aligns with the observation of Kok *et al.* (2011) who noted that policymakers tend to utilise financial incentives as a major tool in influencing behaviour towards energy conservation. Although Bolderdijk *et al.* (2013) tend to disagree with this claim as the authors reported that in the field experiment carried out to explore people’s appeal to economic and biospheric messaging regarding tyre-check, it was discovered that more compliance was achieved with the biospheric messaging than that with the economic wording.

As regards risk, since most construction projects have cost and time constraints (Bentil *et al.*, 2017) and contractors always want to do their best to finish projects within these constraints, the possibility of a contractor trialling new experimental or novel construction products that could potentially reduce carbon is slim. This is because sometimes, the full effect of such new products on the quality of the construction might not be known, and if utilisation of such product does not meet the intended purpose necessitating its reversal or adjustment thereby extending the project completion timeline with an increasing cost, the contractor would want to know if the client would be willing to absorb such risk or at least if there will be no penalty for such default if it arises (Preston and Lehne, 2018). Although, contractors have also been urged to take leadership when it comes to carbon reduction efforts relating to construction projects (Manidaki *et al*., 2016b) but when it leads to cost increase, they might be reluctant due to the argument that profits made on construction projects are low (Moffat, 2020). Therefore, there might be a need for collaboration between clients and contractors in mitigating the risk of a novel product being trialled or used.

3.1.1.3 Reward and Penalty Drivers

Scholars have argued for and against the utilisation of reward and penalty mechanisms in changing behaviour relating to reducing carbon emissions (Wong *et al*., 2013). The difference in opinion especially regarding whether certain policies will effect a positive change in behaviour and serve as a reward or penalty tool sometimes lies in how the policy instrument is constructed. For instance, a report by Deloitte (2014) classified landfill tax as a penalty. However, suppose the landfill tax is varied based on whether wastes are segregated or not and beyond the quantity due for disposal. In that case, landfill tax could be classified as some reward for the organisation which separated its construction waste.

On the other hand, some policy tools seem to be clear-cut in their function as to whether they serve as a reward or penalty mechanism. Such instruments include; the employment of carbon tax once carbon emission surpasses a certain threshold during construction projects (penalty) and the introduction of tax rebates and subsidy schemes, carbon reduction bonuses for contractors from their clients, etcetera (reward). Whether these reward and penalty instruments will evoke the desired carbon reduction behaviour in targeted organisations is debatable. Hence, further research might be carried out with industry practitioners with good knowledge of carbon reduction within the construction sector to establish the efficacy of the listed reward and penalty drivers.

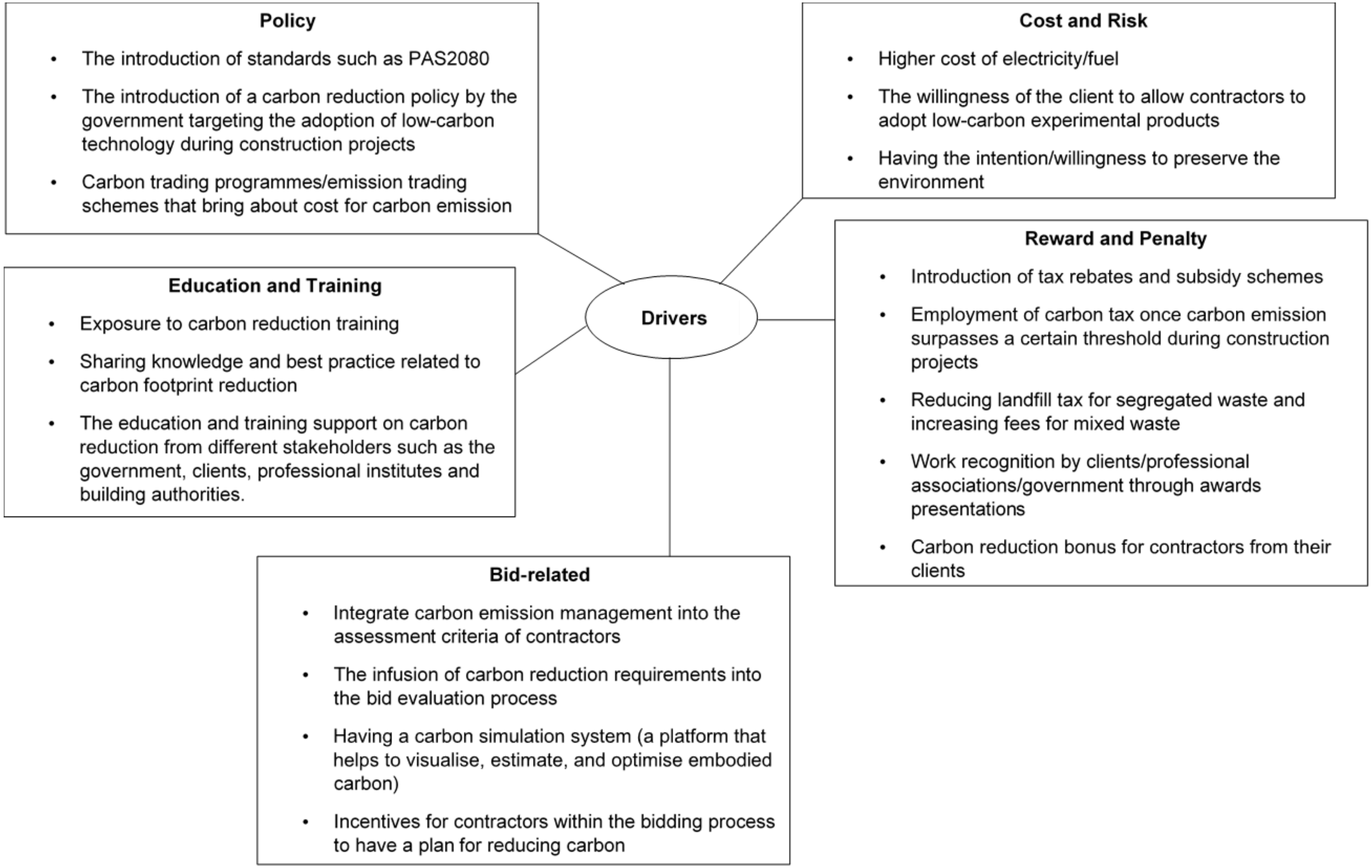

Figure 3: Thematic classification of carbon reduction drivers (Source: Created by authors)

3.1.1.4 Education and Training Drivers

Education and training have been identified as important drivers that can be paired with other carbon reduction drivers in achieving the desired behavioural change to minimise carbon emissions. In the research conducted by Niamir *et al.* (2020) to investigate the bottom-up drivers that could facilitate change in the energy behaviour of households in Spain and the Netherlands, the researchers noted that combining education to create awareness with other policies such as subsidies will strengthen the effectiveness of such policy. Likewise, Al-Marri *et al.* (2017) found out in their study on the connection between the cost of energy and its consumption behaviour amongst Qatari students in the UK that the awareness gained by the students through the study of sustainability issues combined with high energy cost motivated them to reduce their energy usage while in the UK and even when they got back to Qatar where their usage of energy is free of cost.

It is worth noting that training and education can be in different forms as evidenced in the study of Berry *et al.* (2014), which considered primary and secondary data from eco-home open events in Australia and the UK. The authors discovered that attending such events raised the level of consciousness of attendees and prompted them to adopt low-energy lifestyles and install low-energy technologies (such as energy-efficient lighting, 'double- or triple-glazing' windows, etcetera) in their homes. Such findings from the literature depict the importance of training and how it can enable change in behaviour relating to carbon emission reduction (Wong *et al.*, 2013).

3.1.1.5 Bid-related Drivers

Liu *et al.* (2017 p. 812) noted that although the bid evaluation process can be a 'complex multi-attribute group decision-making problem', infusing carbon emissions minimisation as an integral indicator is crucial to guide contractors ab-initio to improve their construction process and make it green and sustainable. This is especially important for publicly funded large projects where one of the major goals of governments lately is to achieve considerable carbon reduction (Liu *et al.*, 2017) in meeting their Nationally Determined Contributions under the

Paris Agreement. For instance, when procuring public projects in the Netherlands, the government utilises a sustainable construction tool (DuboCalc) to understand the ‘environmental cost of procurement’ and apply a price reduction for bids with low environmental impacts (Preston and Lehne, 2018; Rijkswaterstraat, 2022). Therefore, in ensuring that their bid is competitive, contractors could try to ensure that they integrate carbon emission management plans into their proposals (Grubb *et al.*, 2020). They could also utilise a carbon simulation tool for estimation and visualisation to understand the impact of the carbon management plan being proposed. While such incentives for carbon reduction during the bidding process have been highlighted in the literature (Preston and Lehne, 2018; Sanchez *et al.*, 2014), few empirical studies were found in determining its impact on the behaviour of contractors in reducing carbon during the execution of construction projects. Hence, there is a need for further research to establish the efficacy of such drivers in driving carbon minimisation during construction project implementation.

After a thorough review of the drivers thematically, this study suggests that carbon reduction drivers that could affect the ability of construction stakeholders, most especially contractors, to reduce carbon while implementing a construction project can be broadly grouped into five: policy instruments, cost and risk, reward and penalty, education and training, and bid-related drivers.

3.2 ISM Analysis of the Drivers of Carbon Reduction in Construction Projects

3.2.1 Structural Self-interaction Matrix (SSIM)

In conducting the ISM analysis, a SSIM is the foremost modelling step to be carried out and this is achieved by establishing the contextual relationship between the variables (drivers in this case) based on the unanimous opinion of experts (Mandal and Deshmukh, 1994; Wuni and Shen, 2019). However, some of the authors performed a brainstorming session to establish the relationship and consensus was achieved by soliciting justification when opinions differ. This is in tandem with the approach adopted by Wuni and Shen (2019) while developing SSIM in establishing the relationship between the drivers of offsite construction. The aggregated response after the session is depicted in Table 5. The dynamic relationship of the drivers (i and j) was determined by utilising the symbols (X, V, A, O) according to the below principle:

i. X – Driver i influences j and j also influences i.
ii. V – Driver i influences j and j does not influence i.
iii. A – Driver j influences i and i does not influence j.
iv. O – Driver i and j have no links.

3.2.2 Initial Reachability Matrix (IRM)

Following the establishment of the contextual relationship between the drivers, the resulting SSIM is transmogrified into an IRM, as shown in Table 6, through the use of binary digits by following the below criteria:

- If the cell (i, j) is X, then the cell (i, j) entry is 1 and the cell (j, i) entry is 1.
- If the cell (i, j) is V, then the cell (i, j) entry is 1 and the cell (j, i) entry is 0.
- If the cell (i, j) is A, then the cell (i, j) entry is 0 and the cell (j, i) entry is 1.
- If the cell (i, j) is O, then the cell (i, j) entry is 0 and the cell (j, i) entry is 0.

Drivers	**D*j***																	
D*i*	D18	D17	D16	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1
D1	V	V	V	V	V	V	V	V	V	A	V	V	V	O	V	X	V	X
D2	V	V	O	V	X	A	O	V	X	V	V	X	O	A	X	A	X	
D3	O	V	V	V	V	X	X	V	X	V	V	O	O	O	O	X		
D4	V	V	O	V	X	O	O	V	X	V	V	X	O	O	X			
D5	O	O	O	V	O	O	O	O	O	V	O	V	O	X				
D6	O	O	O	V	V	X	X	V	V	V	V	O	X					
D7	V	V	O	V	V	O	O	V	V	V	V	X						
D8	A	X	A	X	A	A	A	X	A	X	X							
D9	A	A	A	V	O	A	A	X	X	X								
D10	V	X	X	V	X	X	X	V	X									
D11	X	X	A	X	A	A	A	X										
D12	O	O	O	V	V	X	X											
D13	O	O	X	V	O	X												
D14	A	A	O	V	X													
D15	A	V	O	X														
D16	O	O	X															
D17	X	X																
D18	X																	

Table 5: SSIM for Drivers of Carbon Reduction in Construction Projects (Source: Created by authors)

Drivers	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18
D1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	1	1	1
D2	0	1	0	1	0	0	1	1	1	1	1	0	0	1	1	0	1	1
D3	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0
D4	0	1	0	1	0	0	1	1	1	1	1	0	0	1	1	0	1	1
D5	0	1	0	0	1	0	1	0	1	0	0	0	0	0	1	0	0	0
D6	0	0	0	0	0	1	0	1	1	1	1	1	1	1	1	0	0	0
D7	0	1	0	1	0	0	1	1	1	1	1	0	0	1	1	0	1	1
D8	0	0	0	0	0	0	0	1	1	0	1	0	0	0	1	0	1	0
D9	1	0	0	0	0	0	0	1	1	1	1	0	0	0	1	0	0	0
D10	0	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1
D11	0	0	0	0	0	0	0	1	1	0	1	0	0	0	1	0	1	0
D12	0	0	1	0	0	1	0	1	1	1	1	1	1	1	1	0	0	0
D13	0	1	1	0	0	1	0	1	1	1	1	1	1	0	1	1	0	0
D14	0	1	0	1	0	0	0	1	0	1	1	0	0	1	1	0	0	0
D15	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	1	0
D16	0	0	0	0	0	0	0	1	1	1	1	0	1	0	0	1	0	0
D17	0	0	0	0	0	0	0	1	1	1	1	0	0	1	0	0	1	1
D18	0	0	0	0	0	0	0	1	1	0	1	0	0	1	1	0	1	1

Table 6: IRM for Drivers of Carbon Reduction in Construction Projects (Source: Created by authors)

3.4.3 Final Reachability Matrix (FRM)

In developing the FRM, a transitivity check was conducted on the initial IRM by assuming that if driver P is linked to Q and Q is linked to R, then P is linked to R (Mandal and Deshmukh, 1994; Saka and Chan, 2020). The transitivity check was performed by utilising a Python function (see below) (Xiang, 2013) to ensure that accuracy is maintained.

```
def transitivity (matrix):

        result = ""

        length = len(matrix)

        for i in range (0, length):

                for row in range (0, length):

                for col in range (0, length):

                matrix [row] [col] = matrix [row] [col] or (matrix [row] [i] and matrix[i] [col])

            result += ("\nW" + str(i) +" is: \n" + str(matrix) .replace ("], " , "] \n") + "\n")

        result += ("\n FinalReachabilityMatrix is \n" + str(matrix). replace ("], " , "]\n"))

        print (result)

        return result
```

The FRM obtained from the initial matrix after incorporating transitivity through the usage of the Python function is presented in Table 7.

Drivers	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	*Drp*
D1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	17
D2	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	17
D3	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	17
D4	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	17
D5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	18
D6	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	17
D7	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	17
D8	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	17
D9	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	17
D10	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	17
D11	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	17
D12	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	17
D13	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	17
D14	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	17
D15	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	17
D16	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	17
D17	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	17
D18	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	17
Dpp	18	18	18	18	1	18	18	18	18	18	18	18	18	18	18	18	18	18	

NOTE: *Dpp* – Dependence power; *Drp* – Driving power

Table 7: FRM for Drivers of Carbon Reduction in Construction Projects (Source: Created by authors)

3.4.4 Hierarchical Partition of the Drivers of Carbon Reduction

The hierarchical level partitioning of the carbon reduction drivers was implemented by first determining the reachability, antecedent and intersection sets of each driver by using the FRM. The reachability set for a driver is the driver itself and other drivers with the value of 1 in its row on the FRM, while the antecedent set for a driver is the driver itself and other drivers with a value of 1 in its column on the FRM. The intersection set of a driver is then obtained by identifying the drivers that are common in both its antecedent and reachability sets. Once the reachability, antecedent and intersection sets of each driver have been determined, then the driver with similar reachability and intersection set will be identified. Such drivers whose reachability and intersection set are the same are partitioned to the same level in the ISM hierarchical structure. Once this is done, such drivers will be removed from the partitioning sets and another iteration of the above will be carried out to determine the next hierarchy level. This iteration will continue until all drivers are positioned in the ISM model. In this study, only two iterations were done to obtain the ISM model. All drivers fell into level I during the first iteration process except D5 (higher cost of electricity/fuel). Therefore, upon removing all those drivers, D5 automatically became the only driver left for the second iteration, making it the driver in level II and completing the partitioning process. The hierarchical level of the drivers was used to develop the ISM model presented in Figure 4.

According to the ISM principle, the driver in level II which is D5 (higher cost of electricity/fuel) in this case, is the most critical and it will influence all the other drivers in the model. Hence, stakeholders within the construction industry must be conscious of this and consider it during bidding negotiations and when lobbying the government for policies that can impact energy production and pricing.

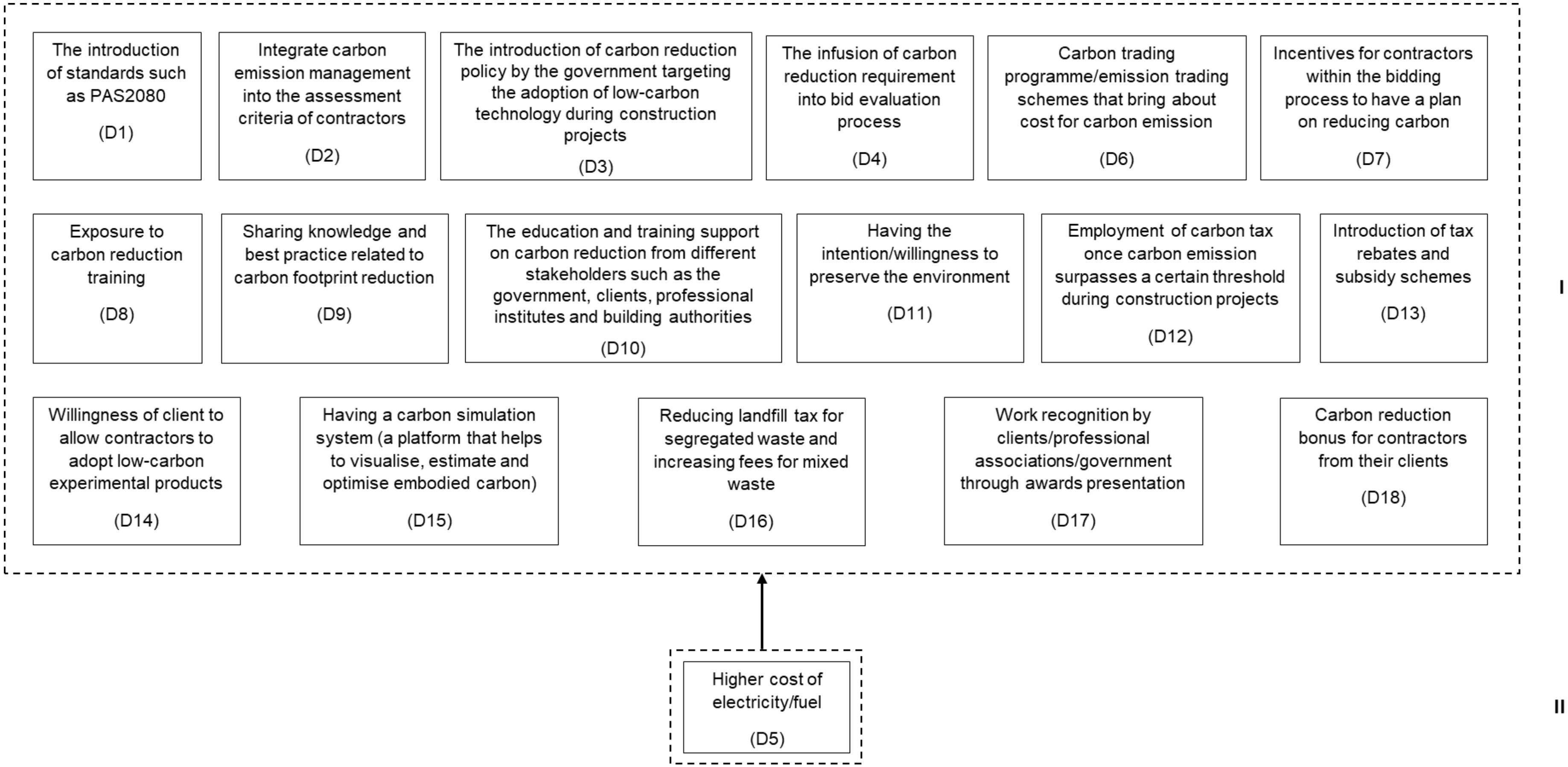

Figure 4: ISM Model for the Drivers of Carbon Reduction in Construction Projects (Source: Created by authors)

3.4.5 MICMAC Analysis

The MICMAC analysis essentially categorises the drivers into independent, linkage, autonomous and dependent variables based on the value of the driving and dependence power (Figure 5) calculated by using the FRM and as described in the research methods section. The driving and dependence power were plotted against one another, as shown in Figure 5, and the drivers of carbon reduction in construction projects broadly fall into two categories independent and linkage drivers. The driver 'higher cost of electricity/fuel' is the driver in the independent category depicting that it has high driving power but weak dependence power, and it is considered as the most important driver while others belong to the linkage category, that is, they have both strong dependence and driving power. This suggests that these drivers affect one another and equally have an impact on themselves. No driver fell into the autonomous and dependent category suggesting that all the carbon reduction drivers identified in the literature are somewhat vital in the effort to decarbonise construction carbon footprint since the autonomous and dependent categories are associated with weak driving power and are either dissociated from the main system (autonomous category) or mostly rely on others (dependent category).

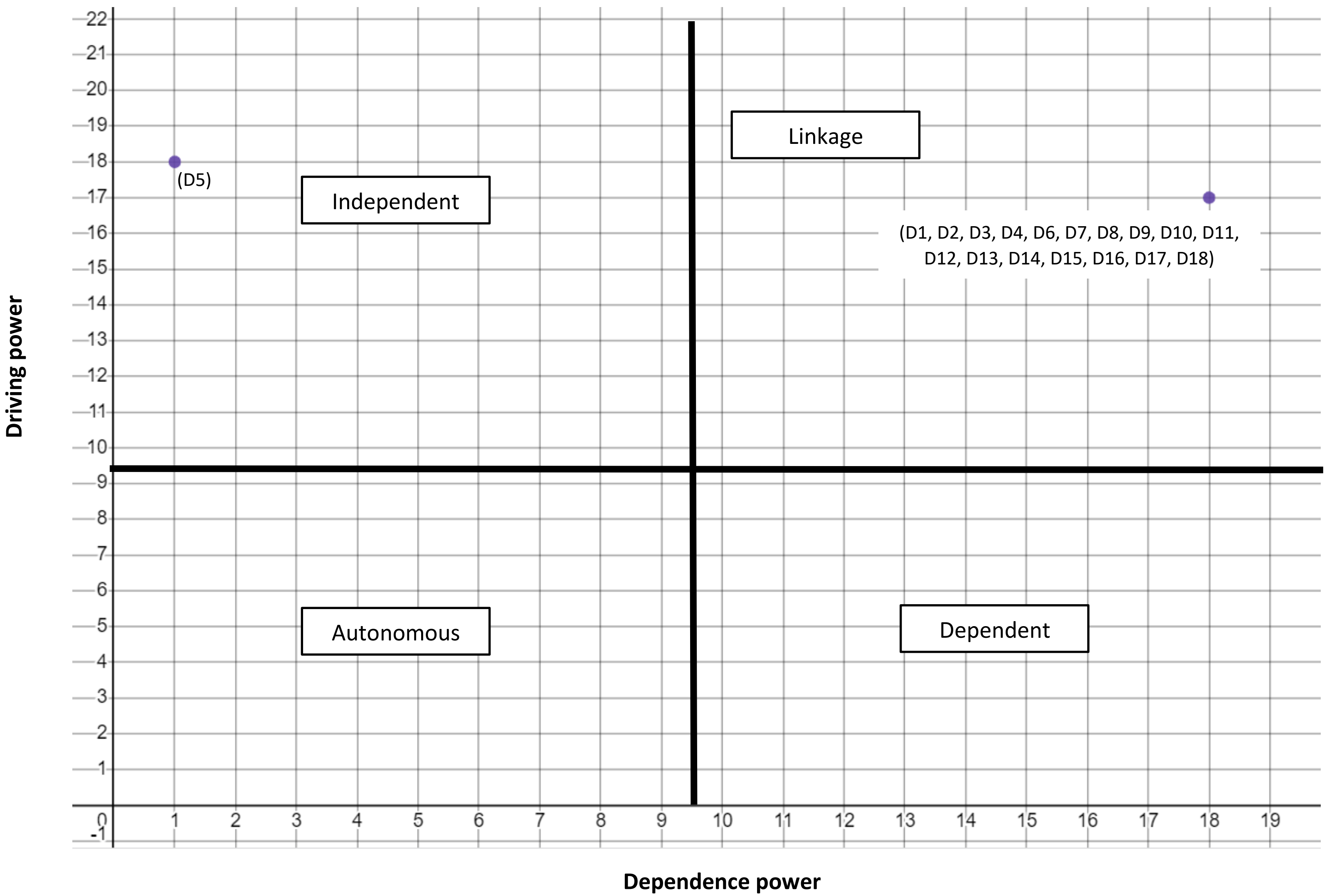

Figure 5: MICMAC Analysis for the Carbon Reduction Drivers in Construction Projects (Source: Created by authors)

3.4.6 Discussion of the ISM Analysis of the Drivers of Carbon Reduction

Based on the ISM model, it was discovered that D5 (higher cost of electricity/fuel) is the most important driver of carbon reduction in construction projects and could influence other drivers. Ironically, the high cost of electricity/fuel might not seem to be a crucial driver in reducing carbon, at least from a carbon emission perspective. However, from a cost perspective, the increase in the cost of electricity and fuel could erode the profit of contractors who are the stakeholders responsible for the construction process. Hence, there is a possibility that contractors might seek ways to reduce this rising cost associated with electricity and fuel either by utilising construction approaches that could lower their usage or look for an alternative source of energy supply that will have a reduced cost. A case in point is the recent energy crisis affecting some nations like the UK with the rising energy cost causing some organisations to close their business as they could not afford the increased cost of energy. According to experts, these consequences of the energy crisis result from over-reliance on fossil fuels for energy generation which means that sustainable alternatives are required to cushion such effects. Although, these tactics might be directed at cost, but any approach targeted at reducing the quantity of fuel/electricity utilised or finding sustainable substitutes will invariably reduce the carbon emission linked to energy usage. Also, according to Hamaizia and Moerenhout (2022) and Vernon *et al.* (2021), low energy cost causes unrestrained use, thereby leading to increased carbon emission. Consequently, the higher the energy cost, the higher the likelihood of regulating or minimising its usage by contractors which could lead to lessened carbon emissions linked to construction projects. Furthermore, it could be a bit surprising that policy-related drivers such as the introduction of standards and carbon reduction policy by the government did not fall in level II on the ISM model as part of drivers that could influence others. Especially since some scholars suggested that policy instruments can have a far-reaching effect on minimising carbon emissions (Grubb *et al.*, 2020; Mundaca *et al.*, 2019). Having said this, the MICMAC analysis showed a linkage between these policy drivers and other drivers except D5, as they all have strong driving and dependence power. This indicates that the policy drivers have an effect on other drivers as well as on themselves.

This is similar to the observation by Niamir *et al.* (2020) who stated that a mix of policies and education could assist carbon reduction efforts. Lastly, the fact that all the drivers including D5 have high driving power suggests that they are significant in driving carbon reduction in construction projects. Thus, stakeholders involved in managing the carbon footprints related to construction projects can decide to adopt a handful of the drivers as they strive to achieve their decarbonisation agenda.

4.0 Conclusion

The global agenda to decarbonise the construction sector and achieve net zero carbon by 2050 presents a challenge. The industry has been identified to be impervious to change and this might hinder the adoption of the necessary innovation and technology needed to realise decarbonisation. Therefore, it was important to identify and categorise essential drivers that could nudge construction stakeholders toward reducing the carbon footprints of construction projects in a bid to contribute to the net zero carbon agenda. The study identified 18 drivers from a comprehensive review of the literature and expert opinion and grouped them into policy instruments; bid-related; cost and risk; education and training; and reward and penalty drivers. Also, the drivers identified from literature were mostly from studies conducted in the developed countries. Additionally, the ISM approach was adopted to categorise the drivers to understand the interaction between them and to establish the most critical drivers that could influence the others, thereby ensuring that stakeholders know what to focus attention on when it comes to the decarbonisation efforts in reducing the carbon footprint of construction projects. Upon completing the ISM model, it was established that higher cost of electricity/fuel is the most critical driver. According to the MICMAC analysis, all the identified drivers have high driving power indicating that they are all significant in driving carbon reduction efforts during the implementation of construction projects. Furthermore, higher cost of electricity/fuel (D5) falls in the independent variable category in the digraph with high driving power and meagre dependence power thereby highlighting its unique ability to influence other drivers without necessarily relying on any of them to make an impact. This study has theoretical and practical implications. Firstly, it contributes to the few studies on carbon reduction in construction projects and can serve as foundational knowledge for researchers interested in understanding the motivating factors that could lead to construction project decarbonisation. Secondly, the findings of the study will be beneficial for stakeholders seeking ways to implore contractors to reduce the carbon footprint of construction projects. Moreover, policymakers could draw valuable insight from this study by ensuring that decarbonisation policies targeted to the built environment encompasses the identified categories especially education and training since Arogundade et al. (2023a) noted that it is one of the main challenges that could impede decarbonisation goal.

The findings of this study should be considered bearing in mind the following limitation. The 18 drivers identified from the literature and brainstorming session have been gathered irrespective of their geospatial distribution and construction project context. Their analysis followed the same approach. Therefore, to domesticate the findings to a particular geographical context, further empirical research could be conducted to establish the significance of the drivers that is applicable in reducing the carbon footprints of construction projects within that region. Likewise, empirical studies examining the specific drivers that could motivate carbon minimisation during the delivery of different types of construction projects can be carried out by scholars. Lastly, most of the eligible studies used in this paper were conducted in the developed countries. Hence, more research can be performed in developing countries to ensure that the benefits of decarbonisation permeates both side of the hemisphere.

Disclosure statement

No potential conflict of interest was reported by the authors.

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