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The role of engineers in addressing climate action

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ABSTRACT

Climate change is an important problem that needs to be addressed in this present time. In late 2015, the United Nations held the Sustainable Development summit where 193 countries came together to develop and afterwards agree to uphold the 17 Sustainable Development Goals. The objective of this research is to critically analyse what engineers are able to do within their profession to achieve SDG 13 Climate action.

This paper is one part of a broader project investigating the following three research questions:

1. *What progress has Australia made against the indicators for SDG 13: Climate action?*
2. *What role **has** the Australian engineering sector played in contributing to and mitigating climate change?*
3. *What role **can** the Australian engineering sector play in addressing climate change?*

These questions will be explored by reviewing:

- *Statistical measures against the SDG13 targets and indicators*
- *Research literature on different technologies and approaches the Australian engineering sector can pursue to further contribute to climate action*

This paper focuses on the latter point, by reporting a systematic review of the research literature using search terms such as 'climat', 'engineer*' and 'Australia*' to comprehensively identify relevant publications.*

In this paper, we describe our methodology, final set of research papers, and preliminary analysis. We will report the key findings and recommendations for different strategies that the engineering sector can use to effectively address climate change at the conference in November.

INTRODUCTION

Climate change can be described as the atmospheric and environmental changes that affect the planet. These effects increase the risk of the event of disasters that could put ecosystems in disarray and affect the quality of life of their inhabitants within ecosystems (UNESCO 2021). Climate change is an important problem that needs to be addressed in this present time.

In late 2015, the United Nations held the Sustainable Development summit where 193 countries came together to develop and afterwards agree to uphold the 17 Sustainable Development Goals (SDGs). These 17 goals address many broad goals that affect all countries including but not limited to ending poverty, reach gender equality, end hunger, and climate action. In comparison to the predecessor to the current 17 Sustainable Development Goals (SDGs), the Millennium Development Goals were agreed by 189 countries in a promise to collaborate in reducing poverty and human deprivation over the years 2000-2015. The shifting focus between these two sets of goals can be seen by the outcomes of the MDGs and the progress of the SDGs. MDGs had a deeper focus on ending poverty, malnourishment of children in developing countries whilst the focus today expands further on people's livelihoods, the climate and the environment. This is symbolised in how of the eight MDGs, only one related to sustainability (MDG7: Ensure environmental sustainability), while of the 17 SDGs more than a third related to the environment or climate (see Table 1).

Table 1: The 17 SDGs, highlighting those related to climate and environment

1	No poverty
2	Zero hunger
3	Good health and well-being
4	Quality education
5	Gender equality
6	**Clean water and sanitation**
7	**Affordable and clean energy**
8	Decent work and economic growth
9	Industry, innovation and infrastructure

10	Reduced inequalities
11	**Sustainable cities and communities**
12	Responsible consumption and production
13	**Climate action**
14	**Life below water**
15	**Life on land**
16	Peace, justice and strong institutions
17	Partnerships for the goals

As engineers are the world leaders of innovation and design, it is imperative to address engineers' crucial role in achieving the Sustainable Development Goals (SDGs). The SDGs can be implemented into practices and bodies within the engineering industry with the goal of providing a sustainable and better future (UNESCO, 2021).

This study focuses on the period from 2015 over which the SDGs have been the guiding development framework. Future work is planned to compare and contrast this with the literature on how the Australian engineering sector contributed to climate action over the period 2000-2014, when the MDGs were the guiding framework.

METHODOLOGY

This paper reports on our systematic literature review of peer-reviewed research that was undertaken with the aim of identifying strategies that the Australian engineering sector has and potentially could use for mitigating the effects of climate change. Systematic literature reviews are a set of related methodologies for synthesising research on a given topic. Although there is some variation in how they can be conducted, and for what purpose, there are key commonalities of a systematic search technique (typically using some Boolean search string with a research database) and rounds of screening the results using inclusion and exclusion criteria (Grant & Booth 2009). The database SCOPUS was chosen as the source of information for this systematic review of research literature. Three rounds of screening were then conducted: title, abstract, and finally full-paper screens. Initially, all titles were screened. Of the remaining papers, the abstracts were screened, and then the full texts of the remaining paper were screened. In each round, both authors independently screened all papers and if papers were excluded, assigned the most relevant exclusion criteria. We would then meet to discuss our differences and reach consensus.

Search String

SCOPUS is known for being the largest peer-reviewed database. We used the following search string:

"TITLE-ABS-KEY (*climat**) AND TITLE-ABS-KEY (*engineer**) AND TITLE-ABS-KEY (*australia**) AND PUBYEAR > *2014* AND (DOCTYPE (*ar*) OR DOCTYPE (*cp*)) "

With this advanced search, the search term TITLE-ABS-KEY, returns results for any or all of the three criteria title, abstract and keywords. Furthermore through the asterisk key, we do not limit the search engine to the exact word given. This can be seen above with *engineer**. SCOPUS will not only look for engineer but any words that start with engineer, such as engineers, engineered, engineering, etc. As a result of the research pertaining to the SDGs, relevant papers were limited to 2015 and to the present.

Inclusion and Exclusion Criteria

The inclusion criteria specify which peer reviewed papers will be included and which will be excluded from the review (Meline 2006). These criteria may be subjected to change in the initial stages of the systematic review, but by freely specifying the inclusion criteria, relevant studies are less likely to be missed in the process. The exclusion criteria clearly exclude papers that meet at least one of these criteria (Meline 2006). By developing inclusion and exclusion criteria, answering the research questions becomes an easier task to accomplish. The following inclusion and exclusion criteria were developed.

Inclusion Criteria

IC1. Reports on the roles the Australian engineering sector has played (or could play) in addressing climate change.

IC2. Published peer-review conference or journal papers. This allows the researcher to sift through high-quality research and empirical evidence.

IC3. Published since the year 2015. Not only is this aligned with when the SDGs have been in effect, it keeps the scope manageable.

Exclusion Criteria – first version

EC1. Not peer-reviewed journal or conference paper

EC2. Not focused on Australia

EC3. Not focused on engineering

EC4. Not focused on climate change

EC5. Not written in English

Through collaborative discussion, further constraints on the criteria were placed to clearly identify papers that meet the answers to the research questions and refine the scope. The following revisions were made to the criteria that were then used for all screening rounds.

For IC1, three levels of "addressing climate change" were identified:

- Adaptation
- Indirect mitigation
- Direct mitigation

Clarke (2019, quoted in Russell (2019)) has argued that:

> *If you keep adapting without mitigating, what you are doing is compounding the effects on the poor. The world becomes a more unequal place. Adaptation without the reduction of carbon emissions is immoral, and it's stupid.*

In following this argument, only the two levels of mitigation were subsequently included:

- Indirect mitigation is a solution strategy without the explicit intent of climate action. An example of indirect mitigation is using new materials that are cost-efficient for manufacturing or infrastructure that also happen to reduce greenhouse gases in comparison to established, standard materials used in industry.
- Direct mitigation is a solution strategy with the intent to combat climate change. Examples of direct mitigation include the various types of geoengineering that can be implemented throughout the planet.

The exclusion criteria were updated (as follows) to be consistent with this, along with additional exclusion for duplicate papers (EC6) or those for which the full paper could not be found online or through a library request (EC7).

Exclusion Criteria – final version

EC1. Not peer-reviewed journal or conference paper

EC2. Not focused on Australia

EC3. Not focused on engineering to mitigate climate change:

EC4. Not focused on climate change

EC5. Not written in English

EC6. Duplicate

EC7. Full paper not available

RESULTS

The search string was used in late June 2021 to identify 209 papers. With two researchers on this project, three rounds were taken place where each individual completed a content analysis on the titles, remaining abstracts, and then remaining full papers. After each screening round, a meeting was organised to weed out any discrepancies to make a full consensus of each research paper section before proceeding to the next. Two rounds of reference list screening were then conducted, in which the reference lists of the kept full papers were reviewed by each author to shortlist additional titles, which were then screened by abstract and then the full text. This process is summarised in Figure 1 and discussed further below.

Screening results for database search

Title Screening

In the first round of title screening the papers identified from the SCOPUS search, each researcher screened all the titles independently using the inclusion and exclusion criteria described earlier.

As a result, an initial agreement of 62 percent on titles was made on whether the titles met the inclusion or exclusion criteria. After a discussion to reach consensus, 72 titles out of 209 were accepted to continue on to the abstract screening process.

Abstract Screening

The screening process was repeated with the abstracts. As a result, an initial agreement of 63 percent on abstracts was made on whether the abstracts met the inclusion or exclusion criteria. After a discussion to reach consensus, 46 abstracts out of 72 were accepted to continue on to the full paper screening process.

Full paper Screening

Both authors then read the papers in full, and reached an initial agreement of 70 percent on whether the full paper met the inclusion or exclusion criteria. After a discussion to reach consensus, 31 final papers were selected.

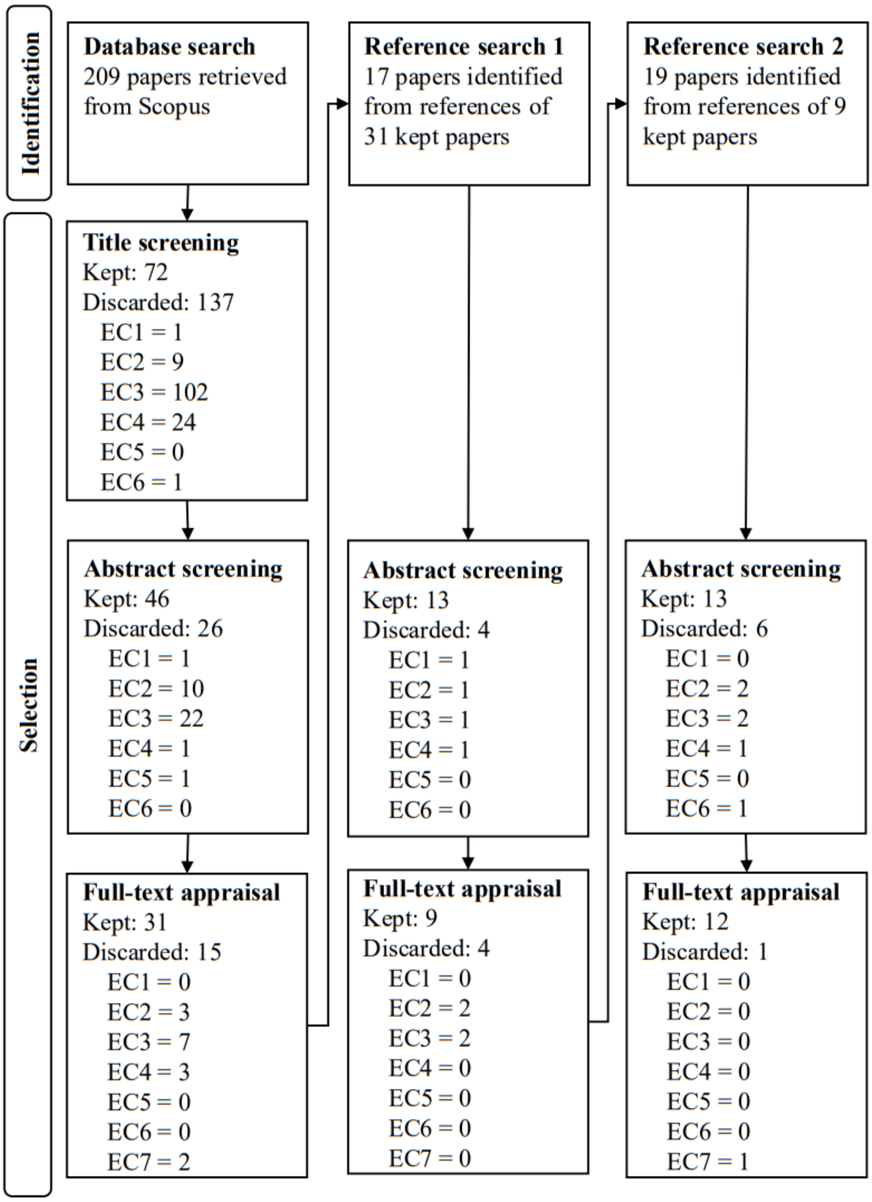

Figure 1. PRISMA diagram of identification and selection, adapted from Mazzurco et al. (2020)

Screening results for reference search 1

Title Screening

The title screening of references from papers identified by the authors underwent a more informal approach to selecting relevant titles. Both authors independently read references and selected titles based off the inclusion and exclusion criteria used for the database search. Instead of reaching a consensus, both agreed that all papers found in this screening would go through to the abstract screening round, where the papers go through the same processes of systematic review as the database searched papers. This will be the case for all reference list iteration screenings.

During the round of reference search, each researcher independently reviewed the titles using the previously specified inclusion and exclusion criteria. As a result, after brief discussion, 17 papers were selected in total by the authors.

Abstract Screening

The abstracts were subjected to the same screening procedure. As a result, an initial 82 percent agreement was reached on whether the abstracts fulfilled the inclusion or exclusion criteria. After a discussion to reach consensus, 13 abstracts out of 17 were accepted to continue on to the full paper screening process.

Full paper Screening

Both authors then read the papers in full and reached an initial agreement of 69 percent on whether the full paper met the inclusion or exclusion criteria. After a discussion to reach consensus, 9 final papers were selected.

Screening results for reference search 2

Title Screening

The second reference search goes through the same methodologies as its predecessor. During this round of reference search, each researcher independently reviewed the titles using the previously specified inclusion and exclusion criteria. As a result from brief discussion, 19 papers were selected in total by both the authors.

Abstract Screening

The abstracts were subjected to the same screening procedure. As a result, an initial 74 percent agreement was reached on whether the abstracts fulfilled the inclusion or exclusion criteria. After a discussion to reach consensus, 13 abstracts out of 19 were accepted to continue on to the full paper screening process.

Full paper Screening

Both authors then read the papers in full and reached an initial agreement of 77 percent on whether the full paper met the inclusion or exclusion criteria. After a discussion to reach consensus, 12 final papers were selected. The final set of papers are listed in Table 2, with full details in the reference section of this paper.

Table 2: Final set of screened full papers

Authors	Year	Title
Allinson et al.	2017	Best Practice for Transitioning from Carbon Dioxide (CO2) Enhanced Oil Recovery EOR to CO2 Storage
Alterman et al.	2015	The influence of thermal resistance and thermal mass on the seasonal performance of walling systems in Australia
Biswas & Yek	2016	Improving the carbon footprint of water- a Western Australian case study.
Carlisle et al.	2020	The public remain uninformed and wary of climate engineering
Chau et al.	2015	A review on Life Cycle Assessment, Life Cycle Energy Assessment and Life Cycle Carbon Emissions Assessment on buildings
De Andrés et al.	2015	Location targeting for wave energy deployment from an operation & maintenance perspective
Doan et al.	2017	A critical comparison of green building rating systems
Evison et al.	2018	Mass timber construction in Australia and New Zealand-status and economic and environmental influences on adoption
Feng et al.	2016	Could artificial ocean alkalinization protect tropical coral ecosystems from ocean acidification?
Hahnel et al.	2021	A comparative life cycle assessment of structural flooring systems in Western Australia
Islam et al.	2015	Life cycle assessment and life cycle cost implication of residential buildings—A review
Jayalath et al.	2016	Effects of phase change material roof layers on thermal performance of a residential building in Melbourne and Sydney
Jayalath et al.	2020	Life cycle performance of Cross Laminated Timber mid-rise residential buildings in Australia
Khalilpour & Zafaranloo	2020	Generic techno-economic optimization methodology for concurrent design and operation of solvent-based PCC processes
Kremer & Symmons	2015	Mass timber construction as an alternative to concrete and steel in the Australia building industry: a PESTEL evaluation of the potential
Kuller et al.	2018	What drives the location choice for water sensitive infrastructure in Melbourne, Australia?
Lawania & Biswas	2016	Achieving environmentally friendly building envelope for Western Australia's housing sector: a life cycle assessment approach
Le et al.	2019	Life-cycle greenhouse gas emission analyses for Green Star's concrete credits in Australia

Le et al.	2018	Life-cycle greenhouse-gas emissions assessment: An Australian commercial building perspective
Li et al.	2019	Feasibility study to estimate the environmental benefits of utilising timber to construct high-rise buildings in Australia
Lockyer & Symons	2019	The national security implications of solar geoengineering: an Australian perspective
Lu et al.	2017	A comparative life cycle study of alternative materials for Australian multi-storey apartment building frame constructions: Environmental and economic perspective
Maraseni et al.	2021	Carbon smart agriculture: An integrated regional approach offers significant potential to increase profit and resource use efficiency, and reduce emissions
McDonald et al.	2019	Governing geoengineering research for the Great Barrier Reef Research for the Great Barrier Reef
McGee et al.	2018	Geoengineering the oceans: An emerging frontier in international climate change governance
Mushtaq et al.	2015	Integrated assessment of water–energy–GHG emissions tradeoffs in an irrigated lucerne production system in eastern Australia
Muurmans et al.	2016	Communicating beach management: Educators; Coastal engineers and local governments collaborating to create successful education programs
Roach et al.	2017	Optimum Facade Design for Minimization of Heating and Cooling Demand in Commercial Office Buildings in Australian Cities
Robati et al.	2017	Impact of structural design solutions on the energy and thermal performance of an Australian office building
Schmidt & Crawford	2017	Developing an Integrated Framework for Assessing the Life Cycle Greenhouse Gas Emissions and Life Cycle Cost of Buildings
Sergiienko et al.	2020	Design optimisation of a multi-mode wave energy converter
Serrano et al.	2020	Impact of seagrass establishment, industrialization and coastal infrastructure on seagrass biogeochemical sinks
Sharma et al.	2017	The Australian South West Hub Project: Developing a Storage Project in Unconventional Geology
Siller et al.	2016	Creating international experiences for first-year engineers through the EWB Australia challenge project
Simms et al.	2017	Carbon footprint assessment of Western Australian Groundwater Recycling Scheme
Spence et al.	2021	Exploring cross-national public support for the use of enhanced weathering as a land-based carbon dioxide removal strategy
Stringer et al.	2020	Consumer-led transition: Australia's World-Leading Distributed Energy Resource Integration Efforts
Sugiyama et al.	2020	The North–South Divide on Public Perceptions of Stratospheric Aerosol Geoengineering?: A Survey in Six Asia-Pacific Countries
Talberg et al.	2018	A scenario process to inform Australian geoengineering policy
Tam et al.	2018	Optimizing Life-Cycle Carbon Emissions for Achieving Concrete Credits in Australia
Tanesab et al.	2016	Dust Effect and its Economic Analysis on PV Modules Deployed in a Temperate Climate Zone
Teh et al.	2015	Integrated carbon metrics and assessment for the built environment
Thorpe	2018	Meeting the challenges of engineering a sustainable future
Tushar et al.	2018	Correlation of Building Parameters with Energy Reduction
Van Le et al.	2020	Dynamic increase factors for Radiata pine CLT panels subjected to simulated out-of-plane blast loading
Vera et al.	2017	Influence of vegetation, substrate, and thermal insulation of an extensive vegetated roof on the thermal performance of retail stores in semiarid and marine climates
Wilkinson et al.	2021	Towards smart green wall maintenance and Wallbot technology
Willand et al.	2019	Addressing health and equity in residential low carbon transitions – Insights from a pragmatic retrofit evaluation in Australia
Wong et al.	2017	Modelling and analysis of practical options to improve the hosting capacity of low voltage networks for embedded photo-voltaic generation
Wong et al.	2015	Generation modeling of residential rooftop photo-voltaic systems and its applications in practical electricity distribution networks
Yap et al.	2015	Qualitative analysis of thin-film CIGS and c-Si technologies in tropical environments
Yigitcanlar et al.	2019	The making of smart cities: Are Songdo, Masdar, Amsterdam, San Francisco and Brisbane the best we could build?
Yu et al.	2017	The carbon footprint of Australia’s construction sector

ANALYSIS

Analysis is still underway and the final analysis will be presented at the conference. Some initial analysis is presented here.

Themes of excluded papers

Some of the common themes that were excluded from the final set of papers was work that just modelled climate change and its effects, or that investigated different adaptations to minimise the effects and consequences of climate change.

Modelling

Statistical modelling and simulation modelling was a common theme throughout the title screening of the reference list. Although useful in understanding the effects of climate change, it does not address any solutions that may proceed with these findings.

Climate adaptation

Many papers focused on adaptations to climate change, such as changing building practices or materials in coastal infrastructure to be more resilient against rising seas and storms. Adaptation does not mitigate the root causes of climate change and may in fact, as discussed above, further exacerbate social inequality. Adaptation measures were excluded from this study.

Themes of included papers

Mitigation measures that were included were grouped into several main categories:

- education & policy
- using materials or processes to reduce carbon emissions
- carbon capture and storage
- renewable energy technologies
- geoengineering

Education and policy

Further or initial education within the public community and the engineering industry is a potential strategy in mitigating climate change. Working in policy or education to make climate considerations more salient in engineering practice or decision-making can mitigate the effects of climate change. For example, Muurmans, Leahy & Richards (2016) evaluated how coastal engineers could become involved in outreach programs about climate change.

Using materials or processes to reduce carbon emissions

Some papers looked at how different materials can be used to reduce carbon emissions, such as Teh et al. (2015) who compared the embodied emissions of different construction materials to make recommendations for how to reduce emissions in the construction industry. Similarly, some papers also sought to reduce carbon emissions through adapting different processes. For example, Willand, Maller & Ridley (2019) investigated how to re-design heating and cooling systems to be more efficient while also taking in to account usage patterns and preferences of end-users.

Carbon capture and storage

Some papers described different approaches to carbon sequestration. For example, Serrano et al. (2020) investigated how different coastal infrastructures could promote the growth of seagrasses which act as a natural carbon sink.

Renewable energy technologies

Many papers explored renewable technologies, testing and simulating different situations to improve energy efficiency, or developing new technologies. For example, Sergiienko et al. (2020) investigated how to optimise wave-energy conversion.

Geoengineering

Some papers tackled climate change directly, by investigating interventions to cool the planet on a massive scale. For example, Sugiyama, Asayama & Kosugi (2020) researched attitudes towards spreading aerosols in the stratosphere to reflect some sunlight back to space.

Boundary Cases

The paper from Kuller et al. (2018) "What drives the location choice for water sensitive infrastructure in Melbourne, Australia?" is useful to consider as a boundary case that was eventually included within the final set of papers. The two researchers percieved the paper differently where one researcher made the initial decision to discard the paper due to the paper's focus on adaptation to risk of flooding. However, the second researcher initially accepted it as water sensitive urban design can mitigate urban heat island effects, and offer an opportunity to educate communities about sustainability. The researchers came to a consensus to keep the paper in although it sits very close the boundary line of what's in and what's out to answer the research questions. This paper was added in with the argument that water sensitive urban design provides multiple positive outcomes that both entails flood risk management and mitigation to climate change.

Moore's 2016 paper "The economic value of trees in the urban forest as climate changes" is another boundary case, that in this case was excluded. It provides a good strategy to combating climate change in the form of increased planting of flora within urban environments. This paper makes an interesting boundary case encountered during the full paper screening. It was excluded because engineers were not directly a focus of the research. Nevertheless, it was noted that when engineers are in the position to make budgetary decisions, including the economic costs and benefits of different climate change strategies, can contribute to climate action.

LIMITATIONS

In this paper we took a systematic approach to reviewing the literature on how the Australian engineering sector can contribute to climate action. Such systematic approaches, with defined inclusion and exclusion criteria, can exclude publications that may nevertheless be relevant. In our study, we limited the publications to peer-reviewed conference or journal articles, published since 2015, that explicitly make mention of the Australian context. It is almost certainly the case that other types of publications (such as books or other non-peer-reviewed articles), articles published prior to 2015, or articles based on similar contexts to Australia (but that do not mention Australia specifically), may yet still be relevant to climate action by the Australian engineering sector. Additionally, there may be publications regarding disciplines adjacent to engineering, such as construction, architecture, or applied science, that although relevant may have been overlooked in our review. Finally, there may have been some publications that would meet our criteria but that without specifically mentioning the word 'engineering' did not appear in our search, such as potentially those from manufacturing or medical science.

There is an additional limitation due to the innate complexity and diversity of the topic. Both engineering, climate change, and their conjunction in how engineering can contribute to climate action, have multiple dimensions. This made it challenging to identify search terms that would comprehensively identify all relevant publications. This is evident in how a sizeable fraction of papers were identified in the reference list screening stages, rather than the original database search.

One opportunity for further research in this area could be to pursue additional stages of reference list screening to then refine the search criteria to better target papers in the area. Alternatively, the scope could be broadened to look at papers from international contexts, publications prior to 2015, or those from neighbouring but related disciplines.

CONCLUSION

Through our systematic review of peer-reviewed research, we were able to briefly analyse trends from the search string used to identify strategies that the Australian engineering sector has and potentially could use for mitigating the effects of climate change. Of the 209 papers from the database search, 31 papers were accepted as the final set of references. Of the 17 papers identified from the final set of references, 9 papers were accepted. In the second iteration of reference search, of the 19 papers identified, 12 papers were accepted by the end of the selection process. The final 52 papers were grouped into five categories, which represent different domains in which engineers can contribute to climate action:

- education & policy
- using materials or processes to reduce carbon emissions
- carbon capture and storage
- renewable energy technologies
- geoengineering

Although we redacted the majority of papers, much can also be analysed from rejected papers along with multiple boundary cases that were hard to distinguish using inclusion and exclusion criteria.

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