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Verifying the sustainability factors of mega transportation infrastructure: Sydney Metro's commissioning through the "significance matrix" methodology

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Abstract

Purpose – Through the significance matrix, this paper aims to investigate and explore the main sustainability factors of mega transportation infrastructure projects. Sydney's Metro mega transportation infrastructure is used as a case study. Sydney's Metro was selected because of its sustainability challenges faced because of the areas' diverse ecological zones. Sydney's Metro is thus examined as the basis of best practice for the determination of the sustainability factors of transportation infrastructures.

Design/methodology/approach – Using the significance matrix as a methodology, this research evaluates the environmental impact assessment and environmental assessment processes, to alleviate the problems of the mega transportation infrastructure.

Findings – This research found that a more comprehensive determination is needed to further analyse the sustainability factors of mega transportation infrastructures, use of a significance matrix would further assess the environmental complexities of mega transportation infrastructures and the sustainability factors of mega transportation infrastructures should include a nonlinear and asymmetrical scheme highlighting its components and carefully outlining its integration and consolidation.

Originality/value – Although there is concurrent research into sustainability factors of mega transportation, this paper undertakes a new methodology for such infrastructure. While the significance matrix is not a new

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concept, it has never been used specifically for mega transportation infrastructure. Subsequently, using the significance matrix as a methodology, this research undertakes such environmental analysis and assessment and thus produces a qualitative risk analysis matrix. The findings from this research will ultimately assist the key stakeholders of mega transportation infrastructures to better plan, monitor and support similar projects.

Keywords Significance matrix, Environmental impact assessment (EIA), Environmental assessment process (EAP), Sydney Metro, Infrastructure sustainability

Paper type Research paper

1. Introduction and research aim

While environmental sustainability refers to ecological situations such as the condition and deterioration of nature and its related settings, environmental impact assessment (EIA) on the other hand is a plan of action about a premeditated development and its effects on the environment and the immediate surroundings. Consequently, in determining an effective EIA for a development, careful attention needs to be given to the protection, enhancement and augmentation of nature and wildlife. For mega transportation infrastructure sustainability considerations are vital (Elliott, 2014; Anastassiou, 2016; Gharehbaghi *et al.*, 2019). On the other hand, Li *et al.* (2015) argued that, as a part of a holistic sustainability consideration, EIA usually incorporates environmental assessment process (EAP). Subsequently, the main aim of this paper is to investigate, explore and scrutinize the crucial sustainability factors of mega transportation infrastructure. In doing so, the Sydney Metro development is to be investigated in depth. Sydney Metro is Australia's largest and most expensive rail transportation project. Sydney Metro was carefully selected not only because of its complex sustainability measures but also because it runs through some diverse ecological zones, thereby providing an excellent case study to examine the sustainability factors, the sustainability measurement process, the integrated EIA-EAP scheme and ultimately the entire ecological influence appraisal of such mega infrastructure projects.

2. Literature review

Vezzoli *et al.* (2018); Sladkowski and Pamula (2015), Koivurova and Lesser (2016); Gharehbaghi *et al.* (2020a); and Abdujabbar *et al.* (2021) among others, highlighted that the inclusion of sustainability factors for mega transportation infrastructure particularly aligns the EIA and EAP integration and consolidation. Subsequently, these two areas require much closer examination and therefore are covered in this section.

2.1 Environmental assessment process

The effectiveness of the EAP for the Sydney Metro may be compromised as often, the only access a local community has with respect to influencing the development of transport infrastructure is through an EAP. Sadler (1996, p. 37) defined the effectiveness of environmental assessment (EA) as "how well something works or whether it works as intended and meets the purposes for which it is designed." The community's ability to participate can be impacted by a multitude of variables that combine to effectively restrict the community's access to the EAP. When there may be a lack of community resources, cultural and language barriers, brief public review periods, community concerns about land acquisition and the need to understand the complex technical terminologies, the community may find it difficult to effectively participate in the EAP (Baker and McLelland, 2003).

The effectiveness of an EAP can be assessed by three generic criteria (procedural, substantive and transactive) that measure the planning and implementation of an EA. Procedurally effectiveness means to meet accepted principles and provisions, whereas to be substantively effective is the achievement of established purposes and objectives and transactive effectiveness is the extent to which the procedural principles deliver the substantive objectives with respect to the cost and time (Sadler, 1996; Todd, 2001).

Commonly, an effective approach for confronting environmental issues is to formulate a precise conservation strategy and action plan (Casparian and Sirokman, 2016; Gharehbaghi *et al.*, 2020c; Fageda, 2021), this is achieved through the development of a strategic environmental assessment and the identification of specific environmental indicators to provide a high level of environmental protection and to integrate environmental considerations into the planning processes. The environmental indicators may be used to demonstrate the changes in environmental quality resulting from the works associated with the Sydney Metro (Donnelly *et al.*, 2007). For sizable metropolitan areas, this will necessitate a city-specific design focusing on agreed environmental considerations (Faiza *et al.*, 2016; Centobelli *et al.*, 2017; Fageda, 2021). Furthermore, a strategic approach to effective environmental planning and management requires the developer's commitment and a choice of effective policy interventions (Abdujabbar *et al.*, 2021). The EAP enables a conclusive approach by including the integration of strategic ecological planning, comprehensive EIA and the incorporation of all necessary regulations.

The EAP is a collection of steps and procedures, which are premeditated to protect the environment and its associated surroundings (Byrne *et al.*, 2014; Elliott, 2014). These measures are strictly integrated with the relevant acts, regulations and enforcing authorities, for example, the New South Wales (NSW) government's Environmental Protection Authority (EPA). This integration is necessary to allow environment and heritage protection together with biodiversity conservation (Tyler and Spoolman, 2015). The overall framework of the EAP is shown in Figure 1.

The overall EAP framework consists of four main stages: determinants, analysis, decision-making and an action plan. In the determinants stage, the relevant environmental legislation and legal requirements are defined and established, in addition the enforcing authorities are identified, for example, the NSW EPA (Ghosh and Lee, 2012). During the analysis stage the examination and scrutiny of the environmental requirements are carried out via carefully validated and authenticated biophysical and socioeconomic information and facts (Casparian and Sirokman, 2016). The third stage consists of decision-making in which various environmental factors and issues of concern are highlighted. The environmental factors and issues are used to clarify different environmental dynamics and features, whether general or specific. To make appropriate decisions a decentralization of the decision-making process is required to ensure that decisions capture the needs of all stakeholders including those at the local and community levels. In the final stage, a forward action plan is shaped. The action plan involves the documentation of the EAP, followed by the proposed controlling and monitoring requirements that make up the environmental observation regimes.

Nonetheless, the sustainability factors of mega transportation infrastructure include a holistic approach that also incorporates a comprehensive EIA as a part of the complete environmental integration and consolidation.

2.2 Environmental impact assessment

The EIA is a process of evaluating the likely environmental impacts of a proposed project or development such as the Sydney Metro, considering the inter-related socio-economic, cultural and human-health impacts. Universally, the EIA could be referred to as a set of legal requirements as well as processes established to attain and measure specific environmental information concerning a certain development (Alexandre and Rui Costa, 2013; Mouratidis *et al.*, 2021). Gharehbaghi and Scott-Young (2018) noted that such requirements and processes typically capture the needs of a diverse group of stakeholders, including the general public and the relevant authorities. Furthermore, the EIA ought to consider both

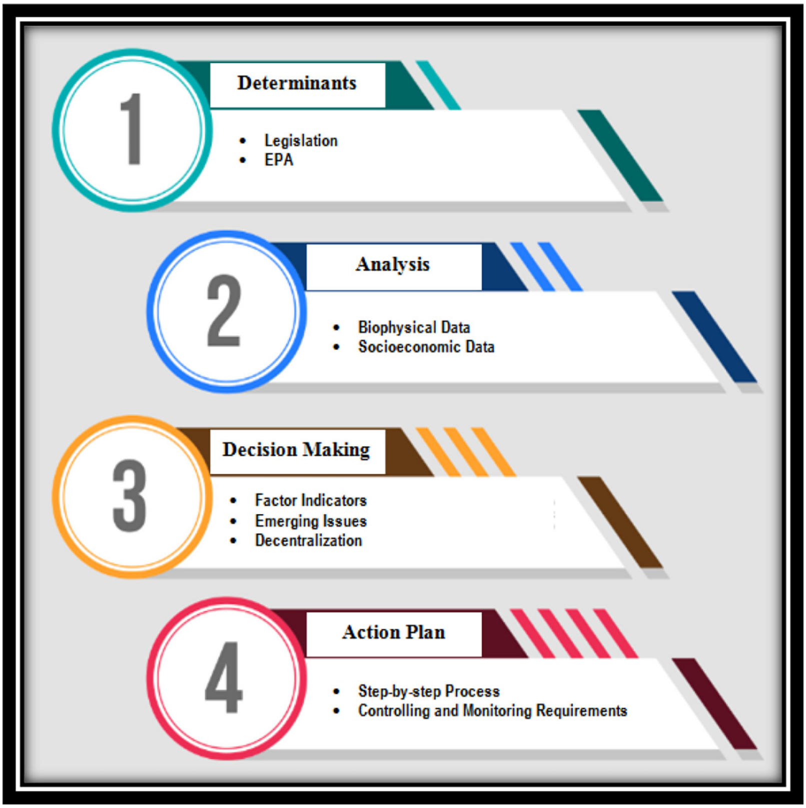

Figure 1.
EAP framework

negative and positive impacts, whether natural, social or economic (Rao *et al.*, 2015; Fageda, 2021). These impacts are usually assessed in terms of both the short-term and the long-term outcomes. By using EIA both environmental and economic benefits such as reduced cost and time of project implementation and design, treatment/clean-up costs avoided and impacts of laws and regulations can be achieved.

Importantly, both Cao and Orrù (2014) and Nakamura (2012) highlighted that EIA needs to carefully consider/study the health and condition status of the current and post-project ecosystems. Examining the status before and post man-made development is a vital component of the EIA to protect the sustainability of the various ecosystems in place. In particular, it is crucial to pursue a strategic approach which adopts a sustainable attitude and outlook into the future (Anastassiou, 2016).

The following two steps identified by Vezzoli *et al.* (2018) and Tyler and Spoolman (2015) facilitate the implementation of a sustainable approach. In the first step, the description of the site (including the existing environment, habitats and so on) and the proposed development is documented. This information must not only be current but also instigate a proper examination of both the short- and long-term impacts. Although some may view that only information concerning the short-term environmental effects is necessary; in fact, it is the long-term impacts that may bear much more influence when considering a comprehensive EIA process (Zeng *et al.*, 2007). The second step includes identifying and evaluating all of the environmental impacts. Once again, this step is in the context of short-term (immediate) and long-term (prolonged) impacts and effects. One key element of environmental safeguarding is to develop and use an efficient EAP. The EAP is an integral part of environmental impacts assessment and thus an important aspect of infrastructure sustainability. Besides the more technical environmental and ecosystem identification and assessment, which are part of a comprehensive EAP; in this stage, it is the inclusion of post-completion impacts that need to be integrated. This integration is shown in Figure 2 below.

It can be observed in Figure 2 that the overall environmental system needs to fully integrate the EIA and the mitigation processes. Gharehbaghi and Myers (2019) argued that a sound environmental system integration involves the inclusion of a comprehensive EIA and a step-by-step risk mitigation process. This in fact highlights the importance of the vigilant implementation of EAP as part of a step-by-step sustainability assessment.

The three prime steps in the sustainability assessment include the involvement of all the concerned stakeholders. Not only do the important key stakeholders need to be consulted, but more indistinct participants, for example, community groups and rural communities also need to be involved. This is essential, especially for mega projects, because such large-scale endeavours have considerably more outreaching impacts (Gharehbaghi *et al.*, 2019). The second step includes the consideration and determination of the project outcome. Once the previous two steps have been completed and documented, the final step of a sustainable development approach requires the inclusion of any interventions necessary to address the unresolved considerations and their subsequent environmental impacts. This may involve the inclusion of some minor but still rather important environmental frameworks and actions.

Further, to carefully align the EIA strategic approach, the four steps described by Young (2016) need to be comprehensively explored and scrutinized. As Glasson *et al.* (2012) argued, EIA includes the collection and analysis process of the data, together with the determination of the outcome for a specific project or development. Although EIA has a universal

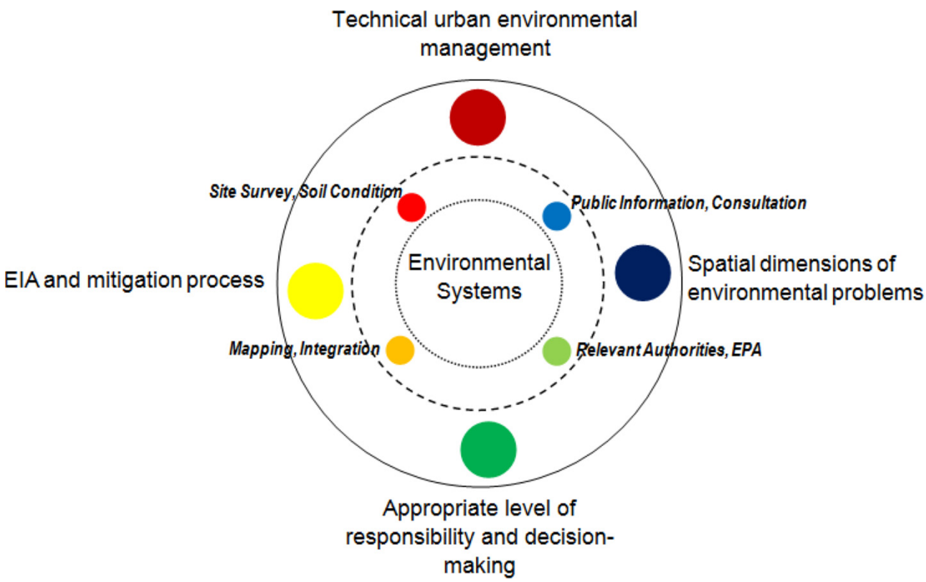

Figure 2.
Environmental system integration (Gharehbaghi *et al.*, 2028)

approach, it is a constraint to specific local regulations (Mouratidis *et al.*, 2021). These local regulations may be derived from the requirements of state or local government and relevant agencies. Although these regulations may have specific requirements for each area and zones of concern, they are part of the Federal government's holistic strategies (Jullien *et al.*, 2014; Gharehbaghi *et al.*, 2020b). Young (2016) argued, the primary and essential environmental subjects of EIA must include:

- an outline of the main substitute environmental studies as per feasibility studies' recommendations;
- a consideration of the direct and indirect effects to all the existing inhabitants, including wildlife;
- various capabilities and tools to measure, avert, downgrade and offset significant adverse effects for short- and long-term environmental issues; and
- a non-technical summary to represent to all key stakeholders the global environmental finding and recommendations.

With that said, EIA may also include historical *land information* data to further determine the prolonged status of the project or development (Gharehbaghi *et al.*, 2022). Figure 3 represents the overall framework of EIA.

The overall EIA framework consists of the following four main components:

(1) Identify parameters. The first component of the EIA framework concerns the establishment of parameters of interest. These parameters are: environmental, which encloses ecological, biological and natural considerations; economic, which

Figure 3.
EIA framework

comprises fiscal and financial deliberations; as well as social, which covers public and communal concerns. Although all three types of parameters are essential for the success of EIA, their ranking, i.e. relative importance, is case-specific and depends on each situation (Mouratidis *et al.*, 2021).

(2) Collect and analyse information. The second component, which concerns information, maintains particular significance in determining the success of EIA. Conversely, information is collected and analysed once the actual parameters have been properly premeditated. This component of the EIA framework includes:
   - Site and project description: This information is of particular importance within the terms of reference documents;
   - EIA studies and impact assessment: recording specific environmental predicaments and their subsequent ecological impact; and
   - Evaluate EIA studies and impact appraisal: to determine individual and specific environmental influences and consequent measurements.

(3) Manage and monitor EIA. This component involves the EIA being consolidated together with the EAP.

(4) Government proposition. The final component of the framework includes the government's (at all levels) review and final resolution of the EIA. The government proposition sets up guidelines not only for the short-term but also for the long-term environmental monitoring and controlling regimes.

As previously observed, an important aspect of the EIA is its successful integration with the EAP. This integration is represented in Figure 4.

As it can be noted, the overall EIA and EAP integration seems to be an uncomplicated undertaking and highlights the inclusive sustainability factors. This task utterly depends on the effectiveness and efficiency of undertaking both the EIA and the EAP (Mostafavi *et al.*, 2015). While the EIA encompasses the overall environmental necessities and application requirements, the EAP, on the other hand, will include the improvement obligations together with the concluding examination and determination. The successful integration of EIA and EAP involves the careful determination of the relevant sustainability factors

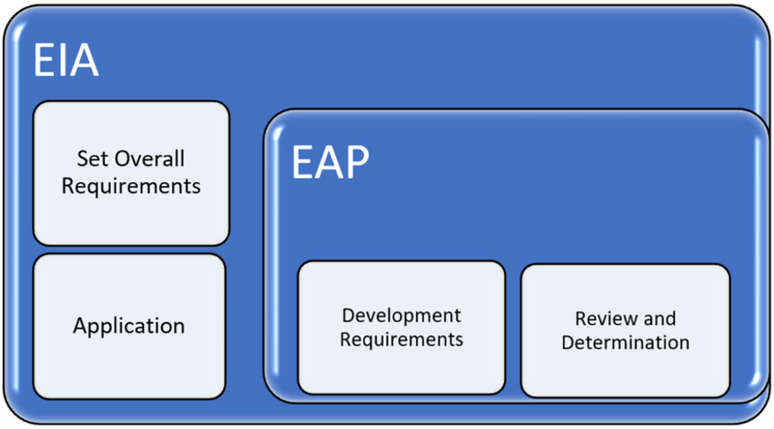

Figure 4.
Generic EIA and EAP integration

(Carroll and Turpin, 2009). Indeed, this effective integration of EIA and EAP was the last environmental springboard for the Sydney Metro mega transport project.

3. Research methodology

This empirical study was undertaken using a qualitative approach which commenced with an extensive literature review and collected data to develop a multi-criteria decision analysis (MCDA) simulation model that was used as a descriptive approach to decision-making along the interpretivist paradigm to aid in the analysis of the complex environmental factors. By using Sydney's metro project as the case study, the aim was to investigate and explore the crucial sustainability factors of mega transportation infrastructure projects.

3.1 Data collection and analysis

The duration of the data gathering in this empirical study was approximately 15 months which was followed by an additional six months for the analysis of the data. The collected data was obtained by direct observation through site visits and access to various project materials including project reports, plans and design schematics.

3.2 Data analysis approach

Initially, a careful comparative analysis of the current mega transportation development practices was conducted, and the results were contrasted with accepted best practices including environmental threat and opportunity profile (ETOP); political, economic, social and technological (PEST), quick environmental scanning technique (QUEST) and strengths weaknesses opportunity and threats (SWOT) analysis. Then the sustainability measures for mega transportation infrastructures were identified through a rigorous review of the current relevant literature. The identified crucial sustainability factors for the EIA and the EAP were integrated to form a consolidated set of sustainability factors that were applied to the significance matrix (Table 1).

MDCA is a suitable tool for the appraisal of policy options and other decisions, including but not limited to those having implications for the environment that do not necessarily rely on monetary valuations. It is a complementary tool to the cost-effectiveness analysis (CEA) and cost-benefit analysis (CBA) methods that are traditionally applied in decision- and policymaking. Both CEA and CBA are analytical ways of comparing different forms of input or output by giving them money values, and they might also be regarded as examples of multi-criteria analysis, whereas MCDA is an alternative when defining monetary values is impractical. The advantage of MCDA is the ability to deal with the difficulties that human decision-makers have in handling large amounts of complex information in a consistent way.

Traffic and transport	Landscape character and visual amenity
Noise and vibration	Groundwater and geology
Land use and property	Soils, contamination and water quality
Business impacts	Social impacts and community infrastructure
Non-aboriginal heritage	Biodiversity
Aboriginal heritage	Flooding and hydrology
Air quality	Waste management
Hazard and risk	Flora and fauna

Table 1. List of sustainability factors

A feature of the MCDA is the performance matrix or consequence table, in which each row describes an option and each column describes the performance of the options against each criterion. The performance matrix is shown in Figure 9 as the significance matrix, it can be used as a standardized tool in all EIAs for transport infrastructure projects. The value scaling functions (high, medium, low and negligible) of the matrix emphasise the impact of the "nature of effect" and the "receptor." It is a visual presentation of the significance impacts that is easy to understand and communicate. Despite the clear advantages of using this matrix, several weaknesses or short comings were identified, they include making comparisons with other projects difficult because of the qualitative scales, it would be problematic to aggregate impacts of several projects of differing magnitude and the matrix is sensitive to subjectivity in assessment of both "value and extent." An overview of the research process is presented in Figure 5.

4. Case study: Sydney Metro

Sydney Metro is Australia's largest and most expensive rail transportation project. This project was selected not only because of its complex technicality but also because this mega infrastructure project runs through diverse ecological zones. Accordingly, it provides an excellent case study to examine the sustainability factors, the sustainability measurement process, the integrated EIA-EAP scheme and ultimately the entire ecological influence appraisal of such a mega infrastructure project.

4.1 Introduction to Sydney Metro

The demand for transportation services in Sydney has increased exponentially, resulting in considerable overcrowding within the main transportation infrastructure services (Gharehbaghi and McManus, 2019). The fundamental challenges for optimizing infrastructure within Sydney include the ability to manage and sustain proper maintenance of the transport infrastructure; the provision of an acceptable level of service required by the community; and the delivering of efficient, effective and economic solutions that mutually benefit all key stakeholders (Gharehbaghi *et al.*, 2019). The Sydney Metro mega project currently consists of two stages. The Sydney Metro's Northwest is the first stage, whereas the Metro City and Southwest constitute the second stage. The Metro West Line will introduce the third stage. The overall map of the Sydney Metro (rail network) is shown in Figure 6.

The Sydney Metro project is part of Sydney's overall rail network system, including the Northwest link. Sydney's new generation of fast, safe and reliable metro trains were initially

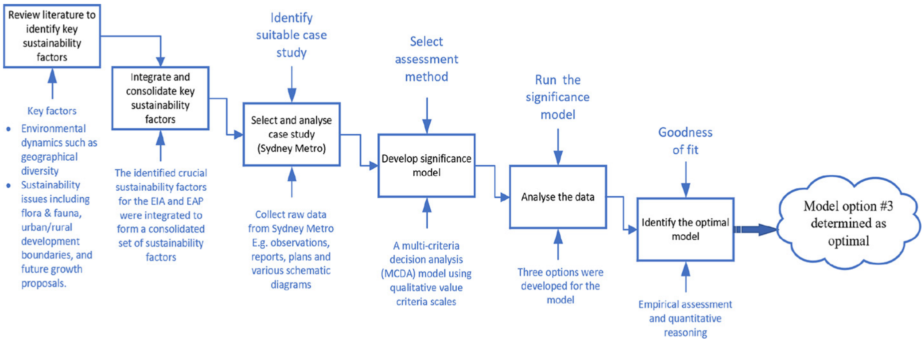

Figure 5.
An overview of the research process

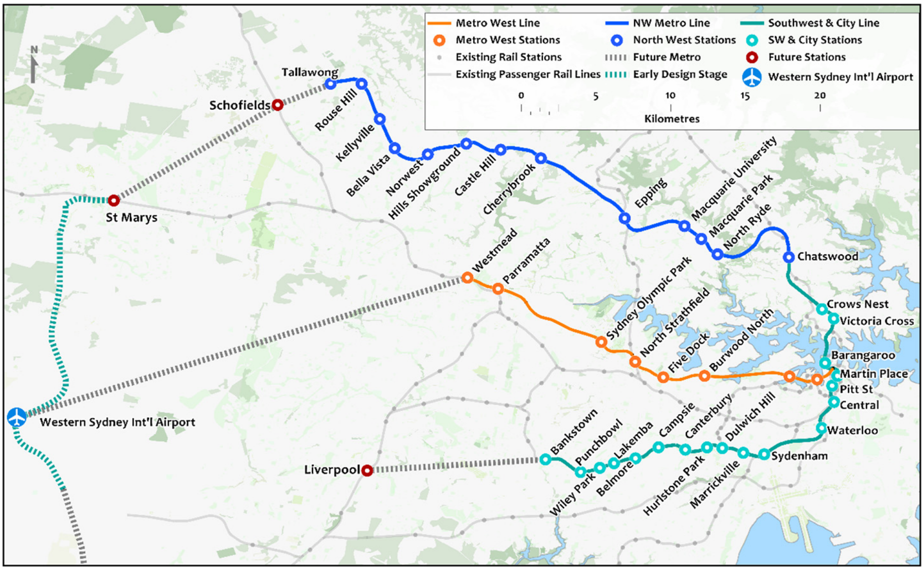

Figure 6.
Chart of the Sydney Metro – rail network

rolled out on Sydney Metro Northwest. This mega project includes the construction of twin 15 km tunnels from Bella Vista to Epping, which will be Australia's longest rail tunnels. The tunnel contract was awarded in late June 2013, and four tunnel boring machines are now in the ground. An integral part of Sydney Metro is the EAP which was initiated at the planning stage of this mega project.

For this mega transportation infrastructure, the challenge to sustainable development requires the adoption of a holistic approach to ensure that the future needs of ever-expanding cities such as Sydney are sustained. Hence, the Sydney Metro project was considered and approved under the *Environmental Planning and Assessment Act 1979* in New South Wales (NSW) before major construction works could commence. According to the Department of Transport for NSW (2020), the Sydenham to Bankstown component of the Project was subject to a separate EAP. Also, the NSW Department of Planning and Environment is the authority responsible for the EAI of the Sydney Metro.

4.2 Sustainability factors of Sydney Metro

The Environmental Impact Statement (EIS) for the Sydney Metro project incorporates EA of noise and vibration; groundwater and geology; soils, contamination and water quality; as well as sustainability. Environmental strategies to avoid, mitigate and manage potential impacts also need to be identified and developed as part of this EIS. As described by the Department of Transport for NSW, the entire Sydney Metro project has a clear vision for sustainable infrastructure delivery. This means Sydney Metro as a mega transportation project is delivering environmental, social and economic improvements throughout its lifecycle. Sustainable ecological measures such as biodiversity conservation have been established to reduce environmental impacts.

For the Sydney Metro, these impacts were holistically integrated to represent both *environmental dynamics* and *sustainability issues*, which in turn carefully considered the overall ecological outcomes, including:

- conservation conditions including any deterioration of the existing flora and fauna;
- essential requirements to examine the necessary infrastructure and their associated services;
- intensification alteration to scrutinize the degree of conversion within the demography and particular communities; and
- social circumstances including any urban and rural developments, expansion, boundaries and future growth proposals.

Figure 7 below shows the geological soil diversity affecting the metro lines.

The Northwest Line is built in areas that are primarily erosional soils with some colluvial and residual soils. Erosional soils are "soil landscapes that have been sculpted primarily by the erosive action of running water. Streams are well-defined and capable of transporting their sediment load," and "landscapes usually consist of steep to undulating hillslopes and may include tors, benches and areas of rock outcrop." Collovial is soil and rock transported by gravity and generally prevalent in moderate to steep landscapes. Residual soils are generally level to undulating areas and have deeper soils.

The Southwest and City Lines north of the bay has similar soils as the Northwest Line; however, as it heads south it encounters aeolian (soils transported by wind) residual soils. The proposed Metro West Line will have numerous soils and geography as it crosses under the bay several times before heading west to Westmead. Further, for Sydney Metro, the soil factors were carefully incorporated with the overall EIA and EAP integration and subsequent amalgamation of sustainability factors of EIA. Figure 8 represents the inclusion of sustainability factors within the EIA of Sydney Metro.

As it can be observed, the EIA and EAP integration for the Sydney Metro was an extremely comprehensive process. Figure 8 captures the various theories and suppositions previously discussed in Sections 2 and 3 of this paper. It is important to note that the integration of the EIA and EAP took approximately over two years to plan and outline. A key aspect to account for was the challenge of environmental vulnerability. Accordingly, the

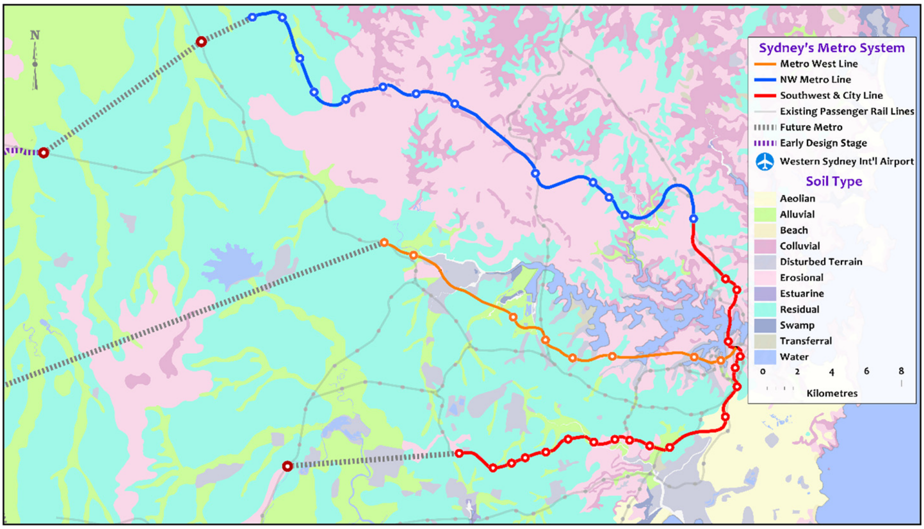

Figure 7.
Geological diversity (data sourced from the NSW Office of Environment and Heritage – NSW Government)

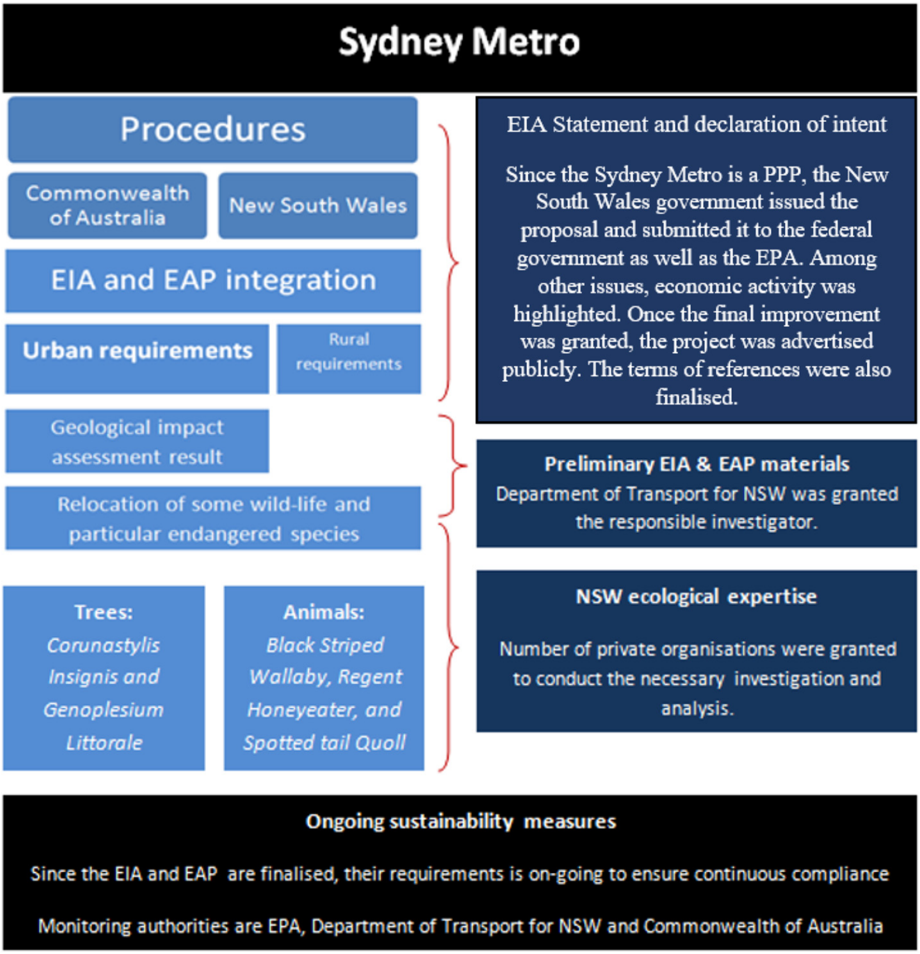

Figure 8.
Sydney Metro EIA and EAP integration

nature and severity of environmental problems together with the characteristics of potential intervention strategies led to investigating the following issues:

- The unique natural features of Greater Sydney have magnified some of the environmental concerns/problems. This included the unique ecosystem characteristics of the Greater Sydney area, which consisted of low-to-mild variation of habitation and environment of the surrounding regions and districts.
- The diverse spatial dimensions of Greater Sydney, together with its various environmental concerns/problems, created difficulties in determining the severity of impact, and the appropriate level of responsibility and decision-making needed to solve these problems.
- For the Sydney Metro, the roles of local authorities were of utmost importance. This required creating a responsive interaction with numerous public, private and

household actors who had either direct or indirect environmental effects along with subsequent problems and shortfalls.

As it can be observed from the above, the sustainability factors of Sydney Metro are complex and multifaceted and therefore required further evaluation. A key tool that was used to consolidate the sustainability factors of the Sydney Metro was the significance matrix.

4.3 Significance matrix

MCDA is a valuable tool that can apply to many complex decisions. It is most applicable to solving problems that are characterized as a choice among alternatives has been recognized as an important tool in environmental decision-making for formalizing and addressing the problem of competing environmental decision objectives (Janssen *et al.*, 2005; Regan *et al.*, 2007).

To scrutinize the sustainability factors within the Sydney Metro, a MCDA significance matrix was developed and further used as an investigation tool. Traditionally, the significance matrix is an environmental analysis and assessment tool that resembles a qualitative risk analysis matrix. For the Sydney Metro, the significance matrix carefully aligned the main sustainability factors with the relevant indicators. This specialized tool was used to determine the overall environmental impacts of the Sydney Metro. The significance matrix for the Sydney Metro is shown in Figure 9.

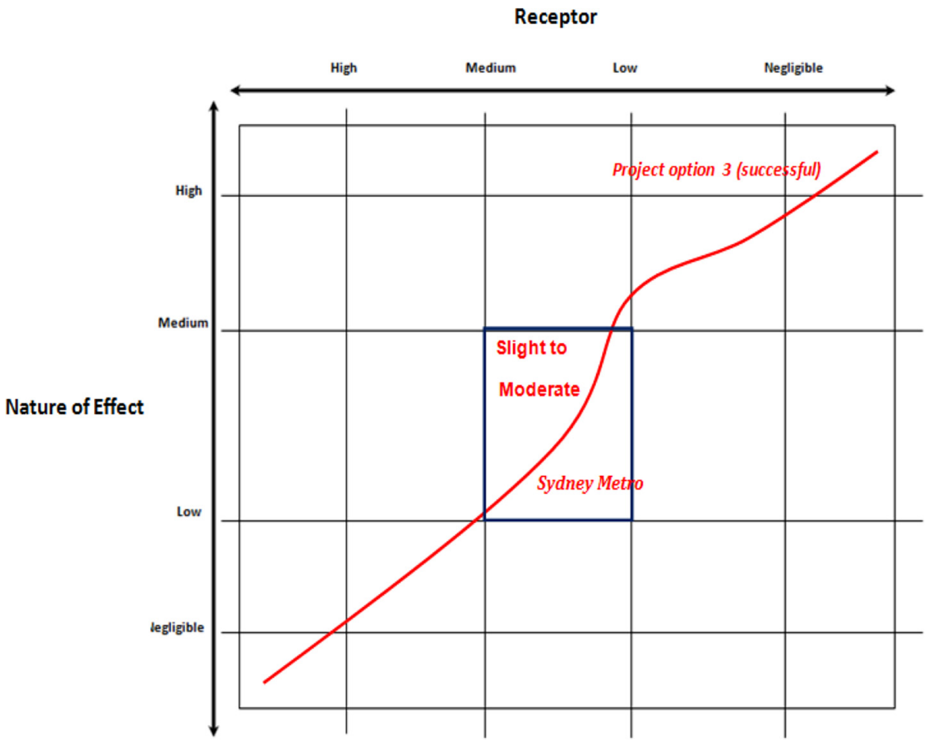

Figure 9.
Sydney Metro's significance matrix

Figure 9 represents the output of the Sydney Metro's significance matrix, where the receptors are based on sensitivity, value and importance; while the nature of effect is representative of magnitude, probability and reversibility. The successful significance matrix for Sydney Metro was the proposed "Option 3." This significance matrix highlights the magnitude and significance of this mega transportation project. It is observable that this project (at its centre) has a slight-to-moderate sustainability effect. While there were another two options, their subsequent significance matrices provided unbalanced approaches to sustainability. The resulting curve for Option 1 was an exponential growth for both the nature of effect and the receptor resulting in a higher risk outcome while Option 2 demonstrated a low growth curve for both axes with a low-to-medium nature of effect. With Option 3, careful project programming was aligned to ensure a stable and balanced sustainability approach. The significance matrix further validated the EIA and EAP integration for the mega project. Moreover, the significance matrix authenticated the importance of the *geological impact assessment* result. It was because of this particular assessment that the significance matrix produced a relatively high level for the dimension "nature of effect" together with a high level for the other dimension "receptors." Therefore, because of the geological impact assessment result, both ends of the nonlinear line exhibited high levels.

Accordingly, with the appropriate response to the geological impact assessment result, for example, the relocation of wildlife, in particular the endangered species, the significance matrix shows the centre of this line falls into the slight-to-moderate levels for both axes.

During the significance matrix exercise, final processes and policies for the Sydney Metro sustainability approach were confirmed. These included:

- closing the knowledge gap, which emphasizes routine collection, assessment, use and dissemination of critical information;

Sydney Metro stages	Sustainability indicators	Main sustainability factors
Metro Northwest	Environmental	• Comprehensive and on-going screening that is closely aligned with the published Sydney Metro EIA report • Existing wildlife with particular significance as well as some endangered species needed to be relocated to protected areas • Relocation of Corunastylis Insignis and Spotted-tailed Quoll • Significant impact on the existing wildlife
	Social	• Significant improvement to the public's standard of living • Existing social conditions are considered to be low
	Economic	• Improved fiscal situation for the Northwest growth corridor
	Transport engineering	• Medium traffic congestion reduction
Metro City and Southwest	Environmental	• Comprehensive and on-going screening that is closely aligned with the published Sydney Metro EIA report • Medium level of geological impact • Relocation of Genoplesium Littorale, Black Striped Wallaby and Regent Honeyeater • Minor impact on the existing wildlife
	Social	• Considerable enhancement of the existing standard of living • Existing social conditions are considered to be moderate
	Economic	• Enhanced fiscal circumstances for the existing population within the Sydney CDB and Southwestern suburbs
	Transport engineering	• Substantial traffic congestion reduction • Removing many hazardous railroad crossings

Table 2.
Sustainability factors of the Sydney Metro

- improving policy interventions through enhancing the overall quality control within the local, state and federal's plans; and
- strengthening service delivery, which involves upgrading the environmental management of local infrastructure and services for cities directly responsible.

As a best practice, the utilization of the significance matrix was in addition to the traditional environmental examination tools including ETOP, PEST, QUEST and SWOT analysis. Because of Sydney Metro's size and complex nature, it was determined that the significance matrix would further examine this mega transportation's sustainability integration and consolidation. Importantly, the significance matrix also drew attention to maintaining the integrity and productivity of the greater Sydney's unique natural and agricultural system. This was achieved via pre-estimation of such system components and their subsequent interactions.

Predominantly, for the Sydney Metro, the natural and agricultural system consisted of the nonlinear and asymmetrical scheme which not only highlighted its components but also carefully outlined its hierarchy together with the inclusion of the surrounding land-use mapping as a part of the overall natural, social and economic environment. The development and approval of the Sydney Metro's significance matrix was an essential precondition for its commencement. Also, the significance matrix ensured that sustainability factors were highlighted and perceived. This was achieved by giving appropriate attention to maintaining the ecosystem functions, life-support systems and representative forms of all other living natural assets.

The final sustainability progression was the careful integration and consolidation of the developed significance matrix and EIA and EAP. This integration and consolidation required the reaffirmation of Option 3 discussed above, as the most appropriate alternative for the Sydney Metro. Finally, this successful adaptation provided the necessary sustainability benefits to the relevant stakeholders. These stakeholders included the local authority planners, regulators, authorized bodies, other interested parties and the general public.

5. Research findings

As already discussed, the main aim of this research was to investigate, explore and scrutinize the crucial sustainability factors of mega transportation infrastructure. With that said, Sydney Metro was used as the basis of the transportation infrastructure case study. This research found that for this mega transportation infrastructure, a nonlinear and asymmetrical scheme was used. As a part of its sustainability measures, this project explicitly integrated the overall social, economic and environmental factors together with transport engineering indicators. Further, in support of the discussed significance matrix as the basis of a methodology, a careful examination of the Sydney Metro's sustainability factors was undertaken which is presented in Table 1.

As it can be noted from Table 1, the general sustainability factors of Sydney Metro were classified according to four indicators. For each of these four indicators, careful study and analysis was carried out to further investigate their possible outcomes. The overall summary is provided in Table 1; however, because of confidentiality constraints the explicit data and information cannot be supplied. Another key outcome of studying the sustainability factors of Sydney Metro was to promote its key environmental strategies. The overall environmental strategies for the Sydney Metro were as follows:

- vigilantly considering the worldwide sustainability themes with a special focus on environmental conditions through cumulative local actions;

- cautiously using successful urban environmental management schemes. This involved carefully examining the urban growth of the greater Sydney and its environmental problems in terms of short-term (<12 months) and long-term (>12 months). This involved using GIS mapping like Figure 6 to determine possible knock-on effects of such risks; and
- technical urban environmental management contemplation via the utilization of various codes and standards as a part of State of New South Wales and the Commonwealth of Australia's requirements, including AS/NZS ISO 14042, 2001 (Environmental Management - Life Cycle Assessment).

Further, once the environmental strategies for the Sydney Metro were in place, certain *environmental sustainability processes* were subsequently executed. The processes in reference included the following:

- Informed consultation during which rapid EA were conducted and issues were clarified including the relocation procedures for the endangered species.
- Key actors were drawn-in, a political commitment was achieved and priorities were set through informal meetings and formal consultations. This included the involvement of the Greater Sydney communities.
- Long-term goals (such as the on-going compliance with EPA), phased targets for meeting these goals (such as milestones for the rezoning of areas to protect the existing ecosystem) as well as agreements on issues-oriented action plans for achieving the targets were determined and finalized.
- On-going follow-up and consolidation during which agreed programs and projects were initiated. This was followed by Greater Sydney's community-based meetings to further explain the on-going conservational protection systems. Vigorous and systematic monitoring and evaluation procedures were put in place for supplementary use.

The above findings highlight the best practices for the sustainability factors of transportation infrastructure. These findings align with specific sustainability measures including environmental, social, economic and transport engineering considerations. Sustainability integration and consolidation is a fundamental part of the sustainability factors of mega transportation infrastructure and thus provide the best practice to plan and manage such complex projects.

5.1 Observations

This study has demonstrated that the inclusion of a MCDA significance matrix is a valuable tool in the EA arsenal, especially in situations where there are non-monetary attributes, and it brings a degree of structure, analysis and openness into classes of decision that lie beyond the practical reach of the traditional approach of CEA and CBA. The MCDA significance matrix enables a fine balance between the needs of the project, the community and the environment; it complements the concepts of sustainable development. The inclusion of the matrix enabled the voice of the stakeholders to be actively considered thereby increasing community capital by building stronger community values through engagement with the project and commitment to the outcomes. The use of the MCDA significance matrix facilitated a clearer understanding of the various legislative requirements enabling the project to meet its compliance obligations regarding the biodiversity of the fauna and flora within the local environs.

Despite the clear advantages of using the MCDA significance matrix approach, several weaknesses or short comings were identified, they include making comparisons with other projects difficult because of the qualitative scales, it would be problematic to aggregate impacts of several projects of differing magnitude and the matrix is sensitive to subjectivity in assessment of both "value" and extent." The value scaling functions (high, medium, low and negligible) of the matrix emphasize the impact of the "nature of effect" and the "receptor."

While the MCDA significance matrix is shown to be a valuable tool in the EA arsenal, the outcomes from the MCDA present some implications for the Sydney Metro in terms of potential changes in location choices and land uses to meet sustainability objectives which may have flow-on implications for travel behaviour by altering modal shares, travel distances, trip purposes and trip frequencies in addition to potential compromises regarding the impacts on the fauna and flora within the local environs.

6. Conclusion

By investigating, exploring and scrutinizing the crucial sustainability factors of mega transportation infrastructure, this paper highlighted that the successful integration of EIA together with EAP is a crucial task in developing a holistic sustainability approach to carefully consider the protection, enhancements and augmentation of nature and wildlife within the envelope of the transportation infrastructure project. Further, to validate the consolidation of EIA and EAP as a best practice, the Sydney Metro was used as a case study to carefully evaluate the main environmental implications of the Sydney Metro. This was achieved via a detailed EIA and EAP integration and consolidation ensuring that this mega project meets its environmental, economic and social sustainability goals. Successfully meeting the environmental concerns ensures that the overall apprehensions of the public, interested stakeholders and government agencies were appropriately considered.

To further scrutinize the sustainability factors under study, a significance matrix methodology was also used. The MCDA significance matrix was vindicated as a successful approach for the Sydney Metro's environmental strategies and has been shown to be a valuable tool in the EA arsenal. A key factor in this success is the proper handling of vulnerability in sustainability problems, which was addressed in this paper together with the key processes of EIA and EAP integration and consolidation. The findings presented in this paper will ultimately assist the key stakeholders of mega transportation infrastructure, to better plan, monitor and commission future mega infrastructure projects.

Finally, it was noted that despite the clear advantages of using the MCDA matrix, several weaknesses were identified, including the difficulty in making comparisons with other projects because of the qualitative scales and that it would be problematic to aggregate impacts of several projects of differing magnitude.

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