Prioritising Investment Opportunities in Research and Development Using Multiple Criteria Decision Analysis

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Abstract

We demonstrate how multiple criteria decision analysis (MCDA) is applied to assist prioritisation of investment in research and development programs. We investigate a case study of research programs prioritisation towards the Renewable Energy Powerhouse Mission by CSIRO, Australia's national science agency. The data for MCDA was collected through a targeted survey, that reached over 200 internal and external stakeholders and received 53 responses. The results of MCDA demonstrate that the top alternative that outperformed others is focused on the direct routes to metals and chemicals. The second leader promotes the development of the natural graphite-to-anode industry, followed by revolutionizing the economics of battery recycling. The paper discusses the implementation of MCDA process in a cross-disciplinary area with multiple collaborators and interested parties, and when the results are highly uncertain. The results of this study fed into a re-articulation of the upcoming Mission strategy in a series of events in the first several months of 2021, which resulted in management endorsement of the new strategy and allocations of funding.

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Keywords: multiple criteria decision analysis; research and development; investment; critical energy metal; CSIRO mission

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Introduction

Decision-making in the area of research and development (R&D) is complex. To achieve impact and reach R&D goals organisations need to concentrate resources and often seek external funding and support. R&D projects are

associated with high risks of failure, they are hard to budget for and the impact of the R&D activities might not be visible in short-term. Investment decisions in R&D, hence, face conflicting objectives of short-term earning pressure versus long-term investment returns, potential impact versus risks of failure. Setting up priorities upfront, taking into account various objectives of R&D projects and the interests of different stakeholder groups, is critical for the R&D project success.

Multiple criteria decision analysis (MCDA), also referred to as multiple-criteria analysis, is a family of decision support techniques under the operations research discipline developed specifically to assist decision-makers with complex decisions that face multiple, conflicting objectives [1-3]. Since its introduction in 1960s it has been applied across public and private organisations[4] in sectors such as medicine and healthcare [5-10], energy and environmental studies [3,11-15], among numerous others [3]. However, MCDA applications for decision-making in research organisations for prioritisation of R&D investments are rare in the economic literature [16].

This paper demonstrates how MCDA is applied to assist prioritisation of investment opportunities in R&D. Specifically, we investigate a case study of MCDA application to help prioritise research programs towards the CSIRO's Renewable Energy Powerhouse Mission [17]. The Renewable Energy Powerhouse or at the time of research - Critical Energy Metals Mission (the Mission) is proposed as one of the CSIRO's Missions. Missions are aspirational research programs that CSIRO, the Australia's national science agency, is developing that will help to solve some Australia's toughest innovation challenges including climate change and energy security. Missions are complex, dynamic and collaborative programs that require effective allocation of resources and collaboration with government and industry leaders along with research organisations. because the challenges that missions try and solve are such that no single organisation can tackle them in solo [18].

Next section of this paper defines the decision problem that the leadership of the Mission faced followed by an overview of the methodology and setup for the analysis. We then provide analysis of the outcomes followed by discussion and conclusions.

Prioritising areas for research towards the Mission

The Mission aims to unlock greater economic potential of Australia's mineral resources by moving downstream toward manufactured goods [19]. The key opportunity in the field is related to the global energy transition. The investments in the key energy technologies such as wind turbines, solar photovoltaic (PV), and electric vehicles will drive substantial demand for metals like lithium, graphite and cobalt, which according to the World Bank, could increase by 500% by 2050 compared to 2020 [20].

Australia is well positioned to capitalise on this growth opportunity given its rich resource base, sustainable mining and production processes and research base. However, the even bigger opportunity for Australia could be realised by moving toward manufacturing end of the global value chain [21,22]. For example, Australia has the raw materials to produce lithium-ion batteries, however, the materials are exported as ores and concentrates with limited value-add. For example, in 2017 Australia was among the leading exporters of lithium globally but only earned 0.05% of a $200 billion global value chain [23,24].

At the time of research, the challenge for the Mission was to develop a compelling strategy and research agenda which carved out a piece of this broader challenge to pursue. The Mission commissioned a Critical Energy Minerals Roadmap [24] that evaluated the metal demand, and supply chain opportunities, around 5 key energy technologies: wind, solar PV, concentrated solar thermal, hydrogen (electrolysis and fuel cells), and EVs (lithium-ion batteries and traction motors) [24].

However, this is still a broad remit, offering many different potential research pathways that could be pursued, ranging from lithium mining all the way to the development of next generation battery technologies, and even recycling. The priority opportunities identified by the Mission in the battery segment were articulated in terms of four pillars or research areas that ranged from new mineral processing, all the way to battery recycling and next generation batteries. This remit was still perceived as too broad, and the Mission desired a more rigorous process to prioritise workstreams, and perhaps even further reduce the scope of the Mission.

The decision problem that the Mission leadership team faced in April-May 2021 was one of prioritisation of what would become the Mission's core R&D activities. The Mission has multiple objectives and performance indicators as well as a broad range of stakeholders. The stakeholder represented multiple sectors including mining, manufacturing, energy, and environment protection. This stakeholder heterogeneity meant a range of conflicting priorities, interests and levels of understanding of the problem from a big picture to the deep expertise and experience in particular fields. This made gaining consensus on a broad-based research agenda difficult. Another layer of complexity was associated with the novelty of the emerging technologies, at different stages of development, and with different commercialisation potentials. Prioritisation of an R&D agenda needed to take into consideration the conflicting interests of stakeholder groups as well as risks associated with the implementation of each project.

The Mission also has multiple objectives, some of which are conflicting, such as short-term attractiveness of research projects for investors who want near-term returns, versus the longer-term potential from investing in breakthrough innovations that are at an earlier stage of development. We further demonstrate how we applied MCDA to discover a right balance between the objectives of the Mission, stakeholder preferences, and to determine the priorities for R&D investment into few large initiatives within the Mission.

Method

Multiple-criteria analysis (MCDA) is a family of decision support techniques designed specifically to assist with complex decision problems with multiple, conflicting objecting and involving various stakeholder groups [16]. In this case study, MCDA was selected as a decision support tool to assist in development of priority areas for R&D investment within the Mission. MCDA application included three phases (see Figure 1).

1. Decision structure

The first stage was focused on problem structure and identification of decision options and decision criteria.

The problem was defined through a goal to '*establish a competitive lithium-ion battery industry in Australia by 2030. High-purity metals and chemicals are the missing link between Australia's minerals and a viable domestic lithium-ion battery industry. This mission will focus on closing that gap, while creating a viable industry of its own: economical, low-carbon footprint battery commodities that can be sold on the international market that can serve as the stepping stone to develop our own vertically integrated battery manufacturing industry*'.

The following four options were defined as pillars and provided with short and long descriptions for stakeholders (see Appendix for full descriptions).

- Pillar 1: Direct routes to metals and chemicals.
- Pillar 2: Developing the natural graphite-to-anode industry.
- Pillar 3: Revolutionising the economics of battery recycling.
- Pillar 4: Next generation batteries

Decision criteria are factors and conditions that are deemed important for to reach the goal of the Mission. Seven criteria were selected as critical for the Mission's goal (see for full description of criteria):

- Criterion 1: Alignment with Government priorities
- Criterion 2: Ability to make large-scale market impact
- Criterion 3: Alignment with industry needs
- Criterion 4: Strength of CSIRO's science capabilities
- Criterion 5: Timeframes to commercial impact
- Criterion 6: Attracting industrial collaborators
- Criterion 7: Australia's current competitive position

The set of options and criteria were identified in consultation with the Mission's leadership team and internal stakeholders. It took several iterations to refine the definitions and reach agreement over the final set of options and criteria for the Mission.

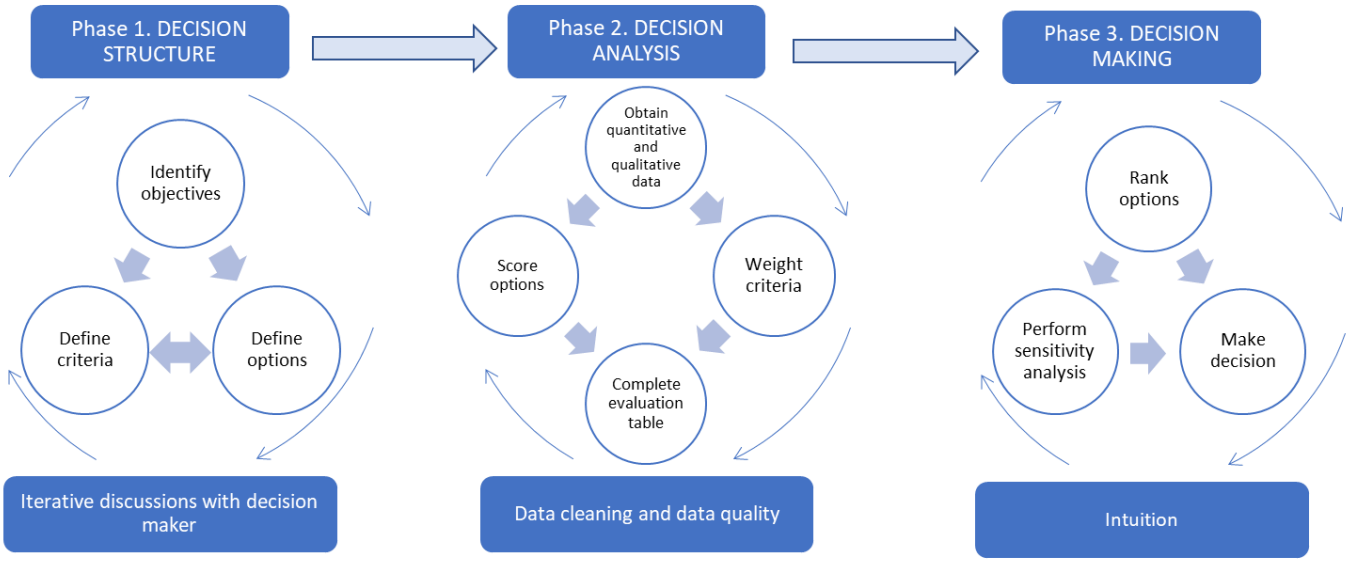

Figure 1 The multiple criteria analysis decision process

Source: adapted from S.Hajkowicz [25]

2. Decision analysis

To collect the data for analysis we conducted a survey in April-May 2021. Survey was distributed among industry groups and partnering organisations – external stakeholders, and actively promoted at the Mission's workshops and events. A targeted list of 125 external stakeholders sourced from the Missions' outreach activities were invited via to partake in the survey in April 2021 and left in the field for two weeks. At the Internal CSIRO stakeholders were also encouraged to take the survey and a snowball effort was utilised internally by advertising the survey on company-wide Yammer channels, and an MS Teams message board targeting a more engaged cohort totalling approximately 110 staff. The survey was conducted online via SurveyMonkey platform. Survey questions in full are provided in the Appendix.

The survey included 12 questions, the Mission's goal, description of 7 decision criteria and 4 pillars (options). The opinions of external stakeholders were collected on the following:

- Performance of options against criteria,
- Weights of criteria.

Weights of criteria reflect the relative importance of criteria for the Mission's goal. The higher the weight allocated to certain criterion the higher is its deemed importance.

In total research team received 53 survey responses of which 34 were complete and hence included in the analysis. Survey results were combined into evaluation matrices and analysed separately for individual respondents and for industry groups. For transparency, MCDA was undertaken using linear additive model [1]. As a result of MCDA we received ranking of pillars.

3. Decision making

At the final phase of analysis, the MCDA results were tested in several rounds of sensitivity analysis. The obtained final ranking of pillars was discussed with the Mission leadership team and internal stakeholders. Discussion was important to sense-check the analysis results, acknowledge limitations and define steps forward.

Analysis and discussion

Groups of respondents

In total, we received 53 survey responses, of which 34 were complete and hence included in the analysis. Out of 34 responses, 13 respondents self-identified as belonging to CSIRO (38%), 7 experts (21%) represented mineral, explorations, mining and processing industry group. Non-CSIRO researchers and academics included 5 respondents (15%) and 4 people (12%) represented government organisations (excluding CSIRO).

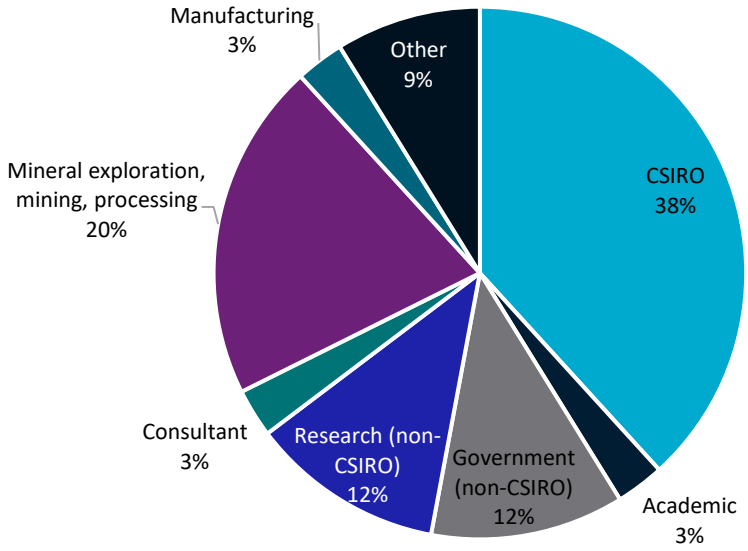

Figure 2 Survey respondents by the type of organisation

Source: MCDA results

Weighting of decision criteria

Question 3 of the survey asked participants to weight the criteria according to their understanding of what are the most important factors that should be considered when building a research program for the Mission.

Survey respondents scored *Alignment with industry needs* as the most important criterion for selection of pillars within the Mission. Second highest weighed criterion was *Ability to make large-scale market impact*. *Alignment with Government priorities* scored the last on average. Although in few individual responses it was among the most important criteria. Criteria weighting results ae summarised in Figure 3.

Of particular interest are three major groups of respondents – representatives from CSIRO, Mineral exploration, mining, processing; and Government (Non-CSIRO) (see Figure 4). Some of the decision criteria are particularly aligned with the functions and aims of industry and government sector. Specifically, we expected that through criteria weights representatives could express vested interest in better performance of certain criteria. Our hypothesis was that the group of stakeholders that defined themselves as belonging to the Government could put a larger weight on criterion 1 '*Alignment with government priorities*' while industry representatives from Mineral exploration, mining, processing would value criterion 3 '*Alignment with industry needs*' more than total average.

Analysis of criteria weighting by industry groups showed that the hypothesis was not correct. All three groups of interest put the largest weight on criterion 3 emphasizing that alignment with industry needs is key for the Mission's research program to succeed. Interestingly, the Government group weighted this criterion the highest (average weight 27.5 out of 100) – contrary to our expectations. Related criteria on attraction of industry collaborators and large-scale market impact (criterion 2 and criterion 6) were also weighted highly by the Government respondent group.

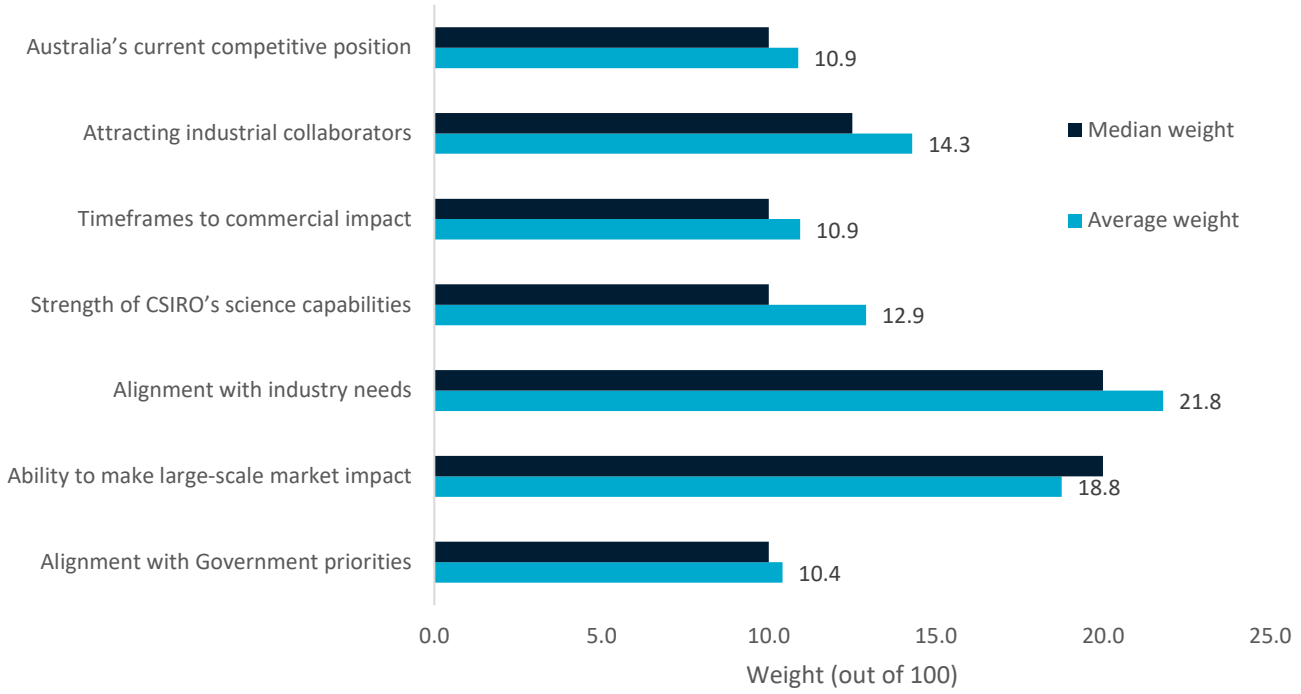

Figure 3 Weighting of decision criteria

Source: MCDA results

Similar distribution of weights was done by the largest industry group (Mineral, exploration, mining and processing). Industry needs and ability to make large-scale impact got the highest weights. Interestingly, this group emphasized an importance of Australia's current competitive position by giving the criterion 1 a weight of 14.3 out of 100 – ahead of the average weights for two other groups of interest (see Figure 4).

For CSIRO representatives the two most important criteria were industry – associated (criteria 5 and 6). However, the third most important criterion for CSIRO respondents was the strength of CSIRO's science capabilities. Interestingly alignment with government priorities was marked above-average by CSIRO respondents (see Figure 4). Since this group was the most represented in the survey, it clearly affected (increased) the total average weight for criterion 6.

Later in the paper we will provide results of the sensitivity analysis that would test and check the robustness of the obtained weights distribution by normalizing the groups responses by the number of representatives.

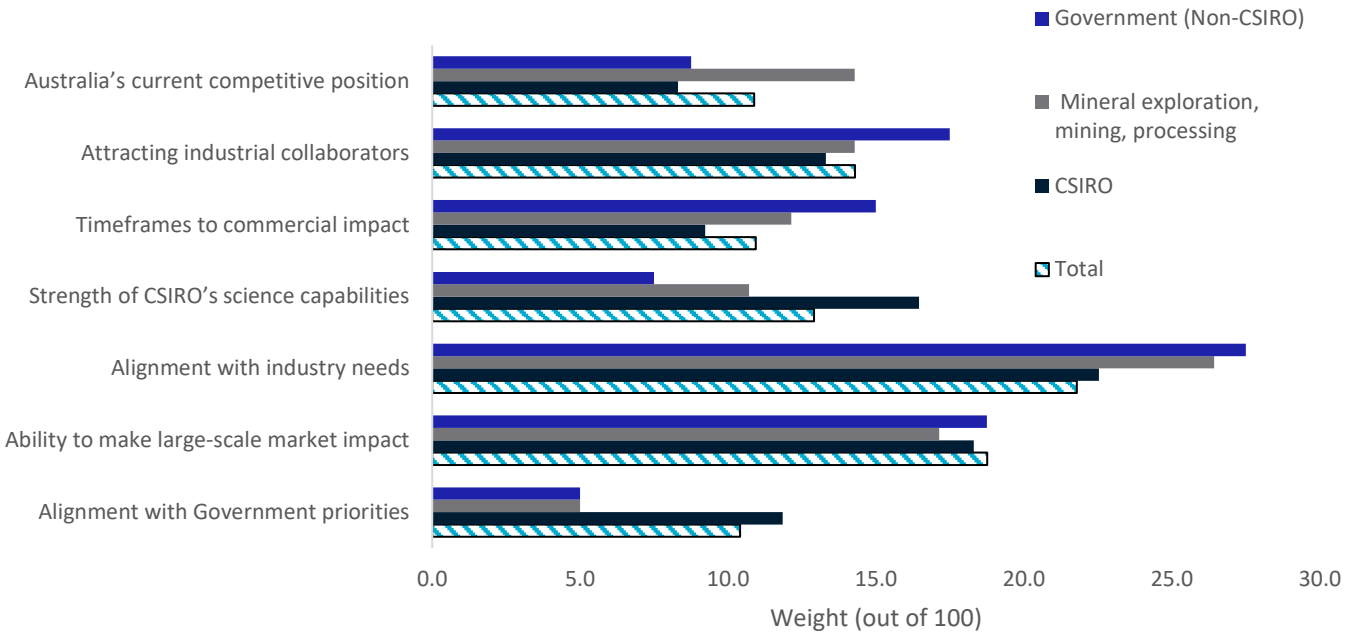

Figure 4 Criteria weighting by industry groups

Source: MCDA results

Ranking of the Mission pillars

Multiple Criteria Analysis of the performance matrices across the respondent groups resulted in the following final ranking of the decision options – the Mission's pillars (Figure 5):

1. Pillar 1 *Direct routes to metals and chemicals* is the top ranked research opportunity.
2. Pillar 2 *Developing the natural graphite-to-anode industry* and Pillar 3 *Revolutionising the economics of battery recycling* are close in ranking, although Pillar 2 slightly outperforms Pillar 3
3. Pillar 4 *Next generation batteries* received the lowest score overall.

The final ranking therefore coincided with the numbering of pillars.

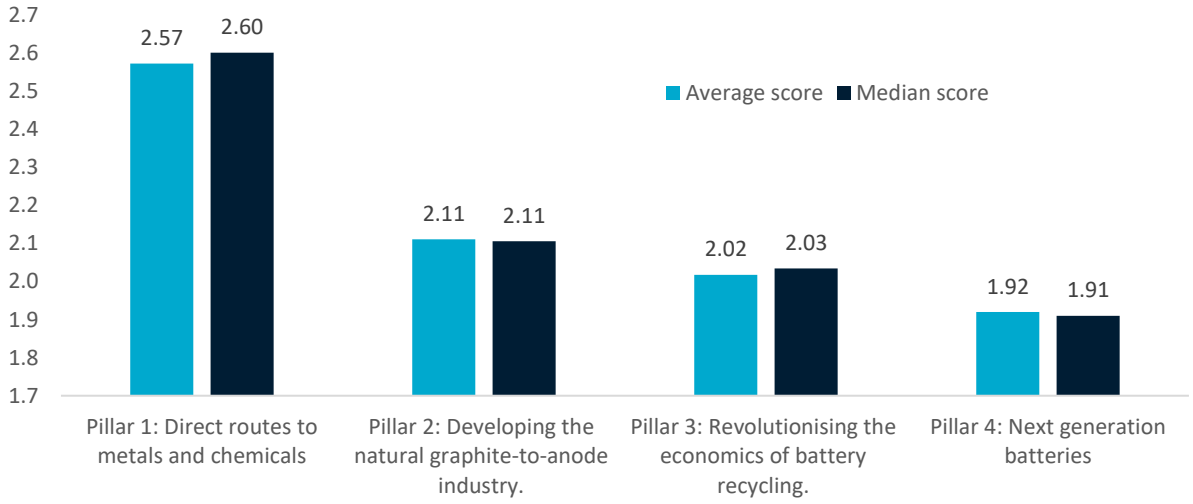

Figure 5 Final ranking of the Mission pillars

Source: MCDA results

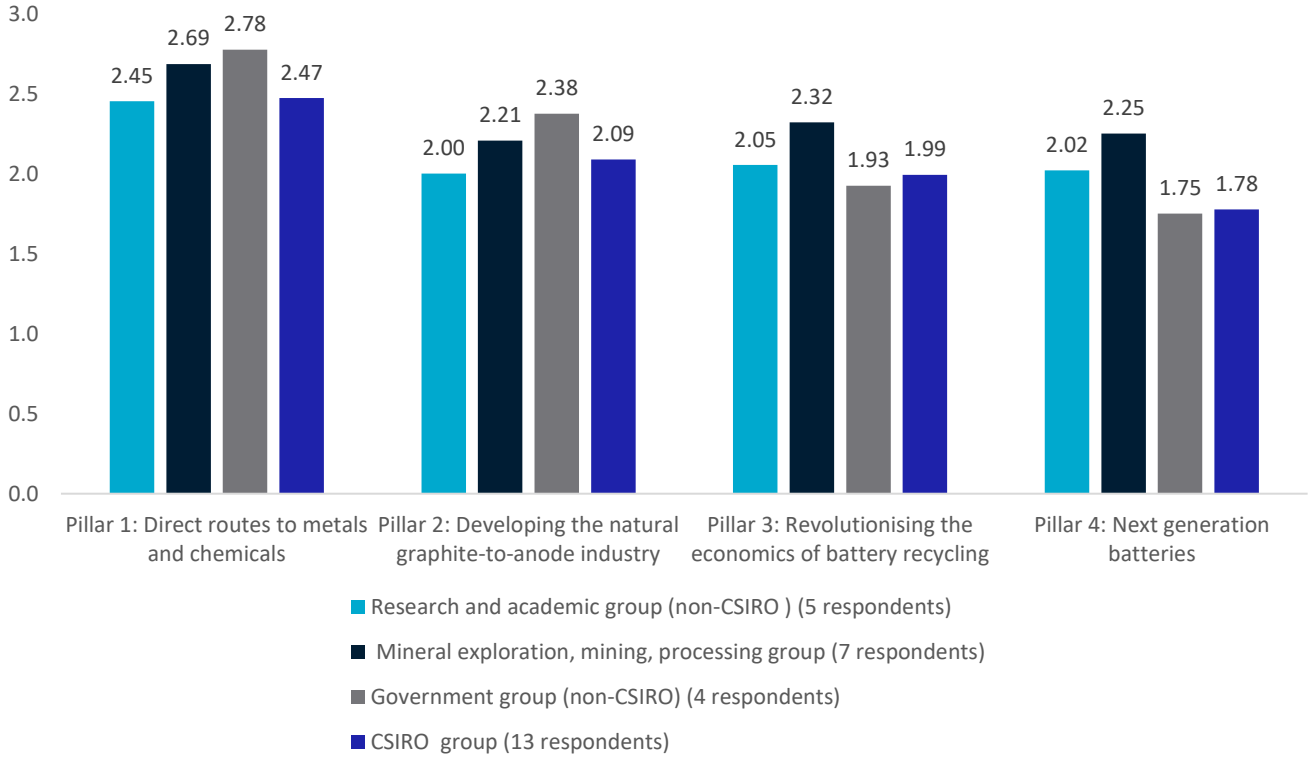

Figure 6 The Mission pillars ranking by industry groups

Source: MCDA results

Analysis of the survey results by stakeholder groups shows interesting results (see Figure 6). CSIRO, the most represented stakeholder group with 13 survey respondents, ranked the pillars in line with the average rankings from Pillar 1 as a leader over to Pillar 4 as the least preferred alternative. Representative of government organisations ranked the pillars in the same order. For the research and academic stakeholder group, Pillar 1 was also ranked top. However, three other pillars got almost the same score with Pillar 3 slightly outperforming the remaining two pillars. Ranking from the mineral exploration, mining, processing industry group also confirms the leading position of Pillar 1. It is followed by Pillar 3 and closely scored Pillar 4 and Pillar 2.

Overall analysis of ranking by separate stakeholder groups shows a clear preference towards Pillar 1 and some discrepancies in ranking among other pillars. Second pillar appears to host the second place for most of respondents, while Pillars 3 and 4 are very close in ranking. Pillar 3 outperforms the latter for most of respondents.

Sensitivity analysis and Imitations of the study

One of the concerns raised during the analysis is unequal representation of stakeholder groups among the survey respondents. Indeed, the CSIRO group is the largely represented with 13 survey respondents while manufacturing is clearly under-represented with only one respondent from this industry. While true, it might as well be a reflection of the true distribution of the groups interested in the development and implementation of the Mission.

To test the robustness of the results and their sensitivity to the split of group representation, we normalized the stakeholder groups by the number of respondents. Groups with over 1 representative were normalized to 1 such that all groups are equally represented in the sample (1 CSIRO, 1 Research (non-CSIRO), 1 Mineral exploration, mining, processing etc.). The criteria weighting result for normalized group representation is demonstrated in Figure 7.

Under the normalized representation criteria weights are allocated more equally. Two leading criteria retain their top two positions – criteria 3 and 2, both focused on industry engagement. This sensitivity test confirms that the MCDA results are sensitive to the distribution of respondents across stakeholder groups. However, in general the weighting has not substantially changed with the normalization.

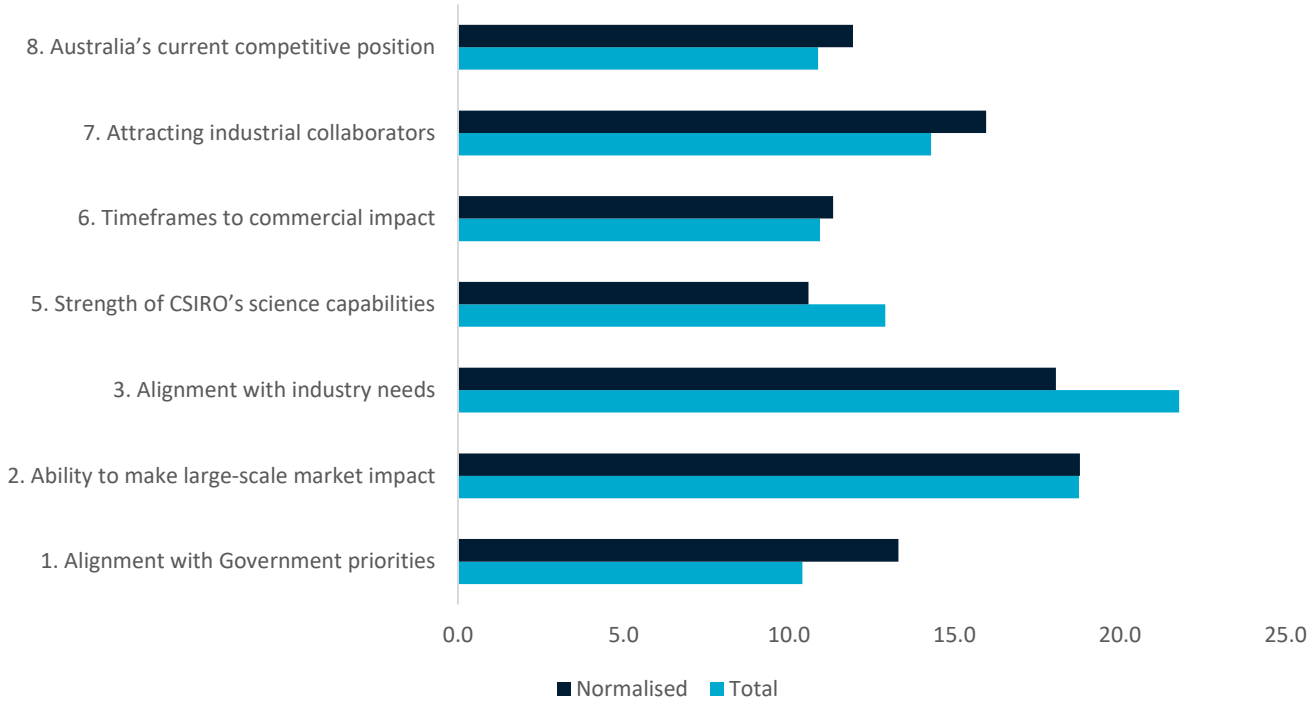

Figure 7 Original (total) and normalised average criteria weights

Source: MCDA results

Another concern raised at the discussion of the MCDA results is the role of weights in the final rankings of the Mission pillars. Sensitivity has been tested with respect to weights allocations across criteria. The sensitivity test was conducted with all criteria weights set equal. These results show direct scoring without an impact of criteria weights allocations (see Figure 8). As a result, we obtained the same ranking as before with the top average score achieved by Pillar 1, followed by Pillar 2, Pillar 3 and finally Pillar 4. Similarly, with the median scores, Pillar 1 is a clear leader, Pillars 2 and 3 are ranked the same and the least preferred option is Pillar 4. This sensitivity test proves robustness of the MCDA results. Criteria weights allocations act in the same way as scoring and reinforce the scoring results.

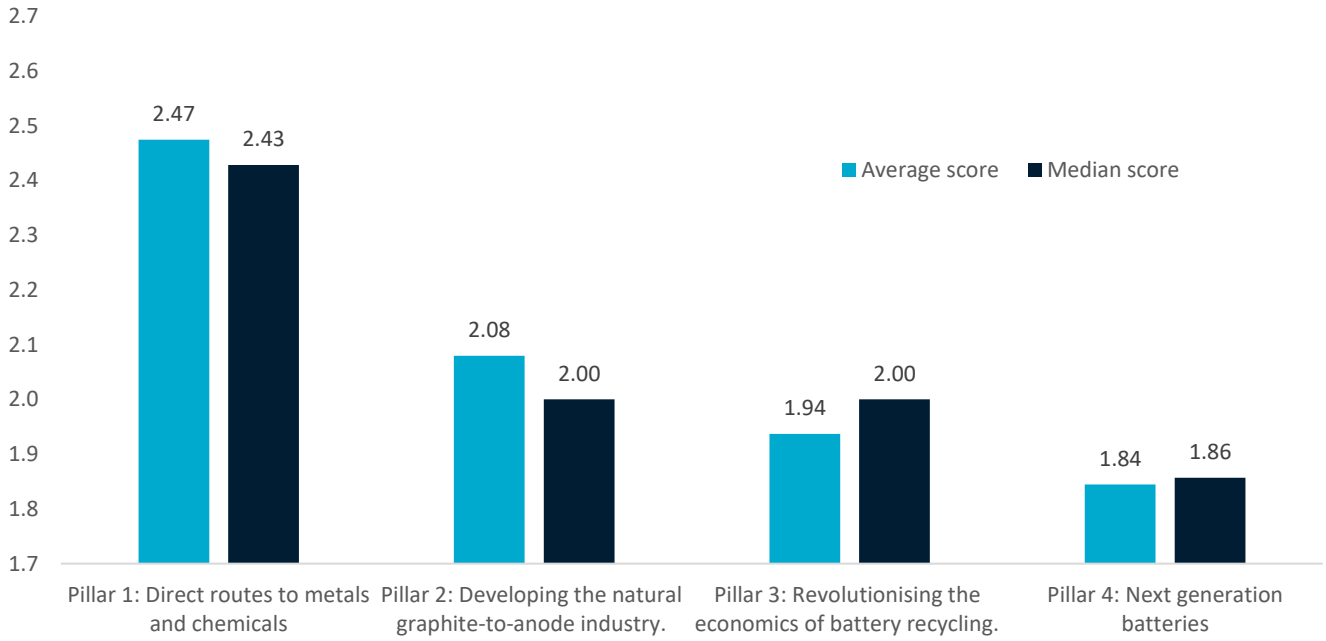

Figure 8 Sensitivity analysis: final scoring with equal criteria weights

Source: MCDA results

There are several limitations of this study that require acknowledgement and determine future research directions.

- Time sensitivity of the analysis results.

The results are valid at the time and in the general setting of the survey. Pillars and criteria should be read in the context of this decision for the Mission research science program. Outside this context, criteria and pillars might be interpreted differently. Also, should the survey be undertaken at different point in time we would likely get different results. This is due to the rapidly changing environment of during/post-covid economic recovery. Now many organisations are re-inventing the ways they operate and revisiting their strategies. These results were particularly important for the Mission at the time of this research as they helped the decision makers navigate through the changing and turbulent environment and set up priorities that are future-focused.

- Portfolio analysis

This MCDA was set up as a prioritization exercise with an assumption that activities within pillars are to be implemented separately. Survey participants were asked to choose one option over the other assuming investment in one pillar would mean lack of investment in others. In reality, implementation of activities under separate pillars can happen simultaneously. It might be worth considering an additional piece of analysis (portfolio analysis) that would evaluate the possible benefits of combining pillars in parts or spreading investment resources across several pillars.

- Biases and vested interest

We acknowledge that survey respondents were likely responding according to their personal experiences in the field and might have also responded with a vested interest. This could have created biases in the responses. To control for biases, we included in the survey self-ranking of expertise levels, provided participants with explicit and easy-to-read information on the Mission (decision problem), pillars (decision options) and criteria in a neutral form with sufficient detail. That helped control for biases by ensuring experts are on the same page in understanding the policy options (pillars) criteria and the objectives of the survey. We further conducted sensitivity test to identify any clear biases from under/over representation of particular stakeholder groups in the

survey. However, we acknowledge that biases are still likely to have affected the MCDA results. The biases reflect natural behaviors of people and decision makers.

- Independence of options and criteria

Criteria are not completely independent, and options are not completely mutually exclusive. Adding quantitative estimates to options performance against criteria was not possible at eth time of this study. However, it could have enhanced the results and defined options better. This sets up a possible direction for future research.

Conclusions

Transparent and insightful process of definition and prioritisation of R&D activities is especially important today when R&D funding is highly competitive. Concentration of resources on fewer larger things with aspirational goals is required to achieve the goals and to make a difference. However, a move towards fewer bigger projects in R&D field compared to more smaller projects, implies less diversification, high stakes, and potentially high cost of failure. Setting clear priorities upright, taking into account data, evidence and perspectives of various stakeholder groups is critical in mitigating these risks [26,27].

For CSIRO, Australia's national science agency, missions are the aspirational research programs that require substantial resources and long-term commitments. Prioritisation of investment activities at the start of each mission is therefore very important for the success of missions along with the performance of the organisation as a whole. In this project applied MCDA to help determine and prioritise R&D pathways and activities for the proposed CSIRO's Renewable Energy Powerhouse Mission (at the time of research - Critical Energy Metals Mission). MCDA is a well-regarded decision support mechanism, that has been successfully applied around the world to enhance decision making for the problems with multiple conflicting objectives and diverse stakeholders.

The results of MCDA demonstrate that the top alternative that outperformed others is the Pillar 1 that focuses on the direct routes to metals and chemicals. The second leader is Pillar 2 that promotes development of the natural graphite-to-anode industry. Third alternative in overall ranking is Pillar 3 that looks at revolutionizing the economics of battery recycling followed by the least preferred Pillar 4 with the activities focused on new generation batteries. Pillars 3 and 4 are very close in ranking and for individual industry groups Pillar 3 appeared to be a better alternative to Pillar 4.

The MCDA results fed into a rearticulation of the Mission strategy in a series of events in the first several months of 2021, that resulted in management endorsement of the new strategy and allocations of funding. Firstly, the fourth pillar of the Mission was dropped from the strategy all together. A business plan was written to this effect and shared and endorsed by the Missions steering committee, the business unit leadership forum, and by the Mission office. This refocused strategy was compelling and unlocked another 6 months of additional investment. Secondly, this funding was directed in an accelerated fashion toward pillar one 'direct routes to metals and chemicals.' For example, new subcontracts were issued to assess carbon footprint and costs of nickel-based battery chemical manufacturing. Funding to conduct an open innovation challenge was unlocked and focused on the same area of nickel processing. And finally, applications from the Australian university system were sought for new metal processing concepts as part of CSIRO's early-stage technology accelerator called, On Prime.

Choosing a strategic direction for the future is not easy. It is especially difficult in the time of change, in cross disciplinary areas with multiple collaborators, interested parties and when the results (return on the investment) is highly unknown. This is a case for most of R&D projects today. Application of robust, transparent decision support tools such as MCDA provides decision makers with a leverage to enhance decisions, reach consensus and act with confidence.

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Appendix

Metals Mission Market Survey

Basics

CSIRO, Australia's national science agency, is working with the government, universities, and industry on a new missions program to bolster Australia's COVID-19 recovery and build long-term resilience.

This survey is about the '**critical energy metals' mission**, and our refreshed goal to **'Establish a competitive lithium-ion battery precursor industry by 2030.'**

This survey will help us **prioritise the research pillars** that will help us to achieve this goal.

It should take you about 5 minutes to complete.

We do not ask for personal data and all responses will remain confidential. The survey is being conducting under CSIRO human ethics approval number **047/21.** Contact csshrec@csiro.au with questions.

Q1. In your current role, please choose the most appropriate organisation type

- CSIRO
- Academic
- Government (Non-CSIRO)
- Research (Non-CSIRO)
- Consultant
- Mineral exploration, mining, processing
- Manufacturing
- Peak body
- Other (fill in)

Q2. Lithium-ion battery value chain

Please indicate your expertise in each segment of the lithium ion battery value chain

Value chain segment	Some / basic knowledge	Intermediate/ working knowledge	Strong expert knowledge
Exploration, mining and concentration	o	o	o
Processing and refining (metals and chemicals)	o	o	o
Electrochemical production (anodes, cathodes, electrolytes)	o	o	o
Cell manufacturing	o	o	o
Integrated systems (packs, etc.)	o	o	o
Reuse / recycling	o	o	o

Q3: Weighting of criteria

What do you think are the most important factors that we should consider when building a research program for this mission? Please allocate 100 points across these categories to reflect this.

Criteria	Weighting
Alignment with Government priorities	
Ability to make large-scale market impact	
Alignment with industry needs	
Strength of CSIRO's science capabilities	
Timeframes to commercial impact	
Attracting industrial collaborators	
Australia's current competitive position	

Q4: Mission goal and pillars

You are encouraged to refer to the pre-read materials that were sent to you earlier. This is a high-level summary.

Mission: Critical Energy Metals. Goal: Establish a competitive lithium-ion battery industry in Australia by 2030. High-purity metals and chemicals are the missing link between Australia's minerals and a viable domestic lithium-ion battery industry. This mission will focus on closing that gap, while creating a viable industry of its own: economical, low-carbon footprint battery commodities that can be sold on the international market that can serve as the stepping stone to develop our own vertically integrated battery manufacturing industry.

Pillar 1: Direct routes to metals and chemicals. **In a Sentence:** Develop novel approaches to shorten the path from ores to battery-grade metals and chemicals to the least number of steps, reducing energy consumption, environmental footprint, and costs. **Description:** Development of new mineral exploration, mining, and processing technologies that minimise the number of steps to get from ore to refined battery metal precursors or cathode active materials. Such approaches should also reduce energy intensity, costs and the CO2 footprint and of final products. Nickel might be a centrepiece of this Pillar, because of use concentration in new battery chemistries, and the environmental impact of laterite nickel mining and processing likely to meet demand.

Pillar 2: Developing the natural graphite-to-anode industry. **In a sentence:** Make Australian flake graphite perform on par with synthetic versions, while retaining its environmental edge, thereby unlocking the value of natural graphite resources. **Description:** Developing more efficient routes to high-performance natural graphite is the key to unlocking Australia's graphite resources. Although natural flake graphite is more environmentally friendly it does not perform as well as synthetic graphite, limiting its use to around 50% of the anode formulation in lithium batteries. This pillar will focus on developing and scaling up processes/formulations that make natural graphite perform on par with synthetic versions retaining its environmental benefits.

Pillar 3: Revolutionising the economics of battery recycling. **In a sentence:** Make recycling of low-cobalt, large-format batteries economical. **Description**: Reduced cobalt use in batteries will erode recycling economics. Instead of recovering elemental metals, this pillar focuses on capturing high-value engineered materials (ultra-pure metals and engineered materials like electrolyte salts). These recyclates can be fed directly into battery component and cell manufacturing. It will focus on processing techniques (including hydrometallurgical and electrolytic, and others).

Pillar 4: Next generation batteries: **In a sentence:** Future-proof the emerging battery industry by working on breakthroughs that will catalyse in the next generation LIB technologies. **Description**: The pillar will focus on developing next generation battery components and systems including electrolytes, anodes and cathodes such as lithium-sulphur, metal-air, advanced electrolytes, and battery management systems.

I have read and understand the proposed goal and research pillars: Yes / No

Q5. Alignment with Government priorities

Question: How much might Australian Government spend on addressing each pillar in the next 3 years?

Pillar	Less than $1m	Between $1m-$10m	Between $10m-$50m
Pillar 1: Direct routes to metals and chemicals	o	o	o
Pillar 2: Developing the natural graphite-to-anode industry.	o	o	o
Pillar 3: Revolutionising the economics of battery recycling.	o	o	o
Pillar 4: Next generation batteries	o	o	o

Q6. Ability to make large-scale market impact

Question: How much of a positive impact might innovations from this pillar make?

Pillar	Low impact on global market dynamics and structure	Medium impact on global market dynamics and structure	High impact to global market dynamics and structure
Pillar 1: Direct routes to metals and chemicals	o	o	o
Pillar 2: Developing the natural graphite-to-anode industry.	o	o	o
Pillar 3: Revolutionising the economics of battery recycling.	o	o	o
Pillar 4: Next generation batteries	o	o	o

Q7. Alignment with industry needs

Questions: How much might all of Australian industry be willing to spend on addressing this pillar in the next 3 years?

Pillar	**Less than $1m**	**Between $1m-$10m**	**Between $10m-$50m**
Pillar 1: Direct routes to metals and chemicals	o	o	o
Pillar 2: Developing the natural graphite-to-anode industry.	o	o	o
Pillar 3: Revolutionising the economics of battery recycling.	o	o	o
Pillar 4: Next generation batteries	o	o	o

Q8. Strength of CSIRO's science capabilities

Question: How strong are CSIRO's capabilities in terms of people, IP, facilities, know-how and scalability?

Pillar	**CSIRO has negligible capabilities**	**CSIRO has some capabilities**	**CSIRO's capabilities are world leading**
Pillar 1: Direct routes to metals and chemicals	o	o	o
Pillar 2: Developing the natural graphite-to-anode industry.	o	o	o
Pillar 3: Revolutionising the economics of battery recycling.	o	o	o
Pillar 4: Next generation batteries	o	o	o

Q9. Timeframes to commercial impact

Question: With proper funding, how soon might you expect commercialisation (market introduction) of key technologies within each pillar?

Pillar	**Between 5-10 years from now**	**Between 3-5 years from now**	**Between 1-3 years**
Pillar 1: Direct routes to metals and chemicals	o	o	o
Pillar 2: Developing the natural graphite-to-anode industry.	o	o	o
Pillar 3: Revolutionising the economics of battery recycling.	o	o	o
Pillar 4: Next generation batteries	o	o	o

Q10. Attracting industrial collaborators

Question: What is the likelihood of attracting industry partner(s) with right reputation that can provide a clear path to market to make 'at scale' impact?

Pillar	Low likelihood	Medium likelihood	High likelihood
Pillar 1: Direct routes to metals and chemicals	o	o	o
Pillar 2: Developing the natural graphite-to-anode industry.	o	o	o
Pillar 3: Revolutionising the economics of battery recycling.	o	o	o
Pillar 4: Next generation batteries	o	o	o

Q11. Australia's current competitive position

Question: Are Australia's industry and research sectors in a strong position to compete in this space?

Pillar	Australia is behind International rivals	Australia is on par with international competitors	Australia is ahead of international rivals
Pillar 1: Direct routes to metals and chemicals	o	o	o
Pillar 2: Developing the natural graphite-to-anode industry.	o	o	o
Pillar 3: Revolutionising the economics of battery recycling.	o	o	o
Pillar 4: Next generation batteries	o	o	o

Q12. Additional thoughts

Question: Do you have any specific thoughts on the scope of the mission as proposed, including opportunities to collaborate?

Thank you!