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Design of Decision Support System for Sustainable Energy Storage

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1. Introduction

Energy Storage Systems, a paramount feature for the implementation of Renewable energy sources(Baumann, et,al., 2019), have been recognised to further achieve a reduction in Co2 emissions and environmental impacts(Dell and Rand,2001). With the increasing intermittent Renewable Energy sources across UK and the World, energy storage technologies that poses greater potential for the utilisation of fluctuating energy from renewables have become more crucial(Lee and Gushee,2008).In the UK, storage is expected to help reduce the overall cost of the electricity grid by between £ 2 billion and £ 7 billion by 2030 by helping to incorporate lower-cost renewable energies and to expand the usage of other network assets
(Thomas,2019).

As discussed above, ESS for implementation of large-scale varying renewable energy sources, has a key role to play in advancing the adoption of these renewables to capture and store the resources until they are required due to the highly erratic and intermittent nature of these RENs (Satkin, et,al., 2014). However, procurement of such an ESS is often a task that involves complex and competing interests, trade-offs and alternatives that decision makers/stakeholders need to consider(Vo,et,al.,2017). Given the multiple available alternatives i.e. mechanical, thermochemical, thermal, chemical and electrical energy storage, it is often a challenging task to determine the right-fit for the solution.

According to Hadjipaschalis, et,al. 2009,various ESS have various characteristics for evaluating performance based on the triple bottom-line of

sustainability i.e. Economic, Environmental and Social(Christopher,2018). Looking at the capital costs for pumped-hydro energy storage as compared to Hydrogen energy storage, they have a high difference; also, their impacts on the environment are different. Additionally, their impacts and acceptability in the society vary from safety, cleaner way etc. perspectives(Winskel& Kattirtzi,2020). Hence decision-making on the selection of technology is of a crucial importance for the decision makers to select the best alternative that affects the business positively.

Vo et,al., 2017 studied the MCDM model for the selection on an ESS and suggested employed cost, position flexibility, discharge time and efficiency are a few key indicators of performance. Baumann et,al., 2019 suggest storage time and exemplaric power rating as key indicators for selection of an ESS. Analytical Hierarchy Process(AHP) is used to develop an alternative evaluation methodology to analyse the electrical energy storage systems with reference to costs and other performance parameters. This study can be further referred to by decision-makers, procurement professional and various other stakeholders in making an informed decision for the selection of an Energy Storage System. There is however a research gap. There is no certain method available to determine the weights of criteria that represent the priority order/preference of the decision-maker. To overcome this, AHP is often used in selection of alternatives to aid the decision makers in making an informed decision. A 9-point based scale is used that consists of numeric crisp numbers and their reciprocals for the stakeholders to create a comparison matrix.

2. Case Study

The sponsor Company, Network Rail wants to explore the sustainability of Energy Storage Systems to integrate them with Renewable Energy Storage systems. Primarily scoped to a replacement of Diesel Generators that support ancillary services with Energy Storage Systems in Operating depots, this article depicts the work of determining the sustainability of ESS. This article discusses the development of frameworks and implementation of the same to cater the business needs.

3. Methodology

This section is divided in two parts.

1. The criteria for sustainability assessment of Energy Storage have been presented in 3.1.
2. AHP based framework for the selection of alternatives is presented in subsequent sections.

3.1 Criteria for Sustainability assessment

The most-widely used definition of sustainability can be derived from the Brundtland commission of The United Nations,1987. This definition as suggested states that "Sustainability is about meeting the needs of the present without undermining the future generations' capacity to meet their own"(Christopher,2016). Thereafter embracing the parallel triple bottom-line, the 3 Arenas that govern sustainability are : Economic, Environmental and Social. For such an alternatives selection technological integration also play a key-role, was inferred from interviews with Sponsor Company's Project Engineers. Further academic literature(Ren,2017) was reviewed combined with Company's Social Performance and Energy and Carbon Policy documents to determine 9 Characteristics of Sustainability assessment in 4 categories ; Economic, Environmental, Social and Technology, for the Project namely- Capital Cost(EC1),Whole-life cost(EC2), Operating Cost(EC3) in Economic, Carbon Density(EN1), Integrated Environmental Impact(EN2) in Environmental, Social Impact and Acceptability(S1) in Social, Energy Efficiency(T1), Energy Density(T2), Technological Readiness Level(T3) in technological domain.

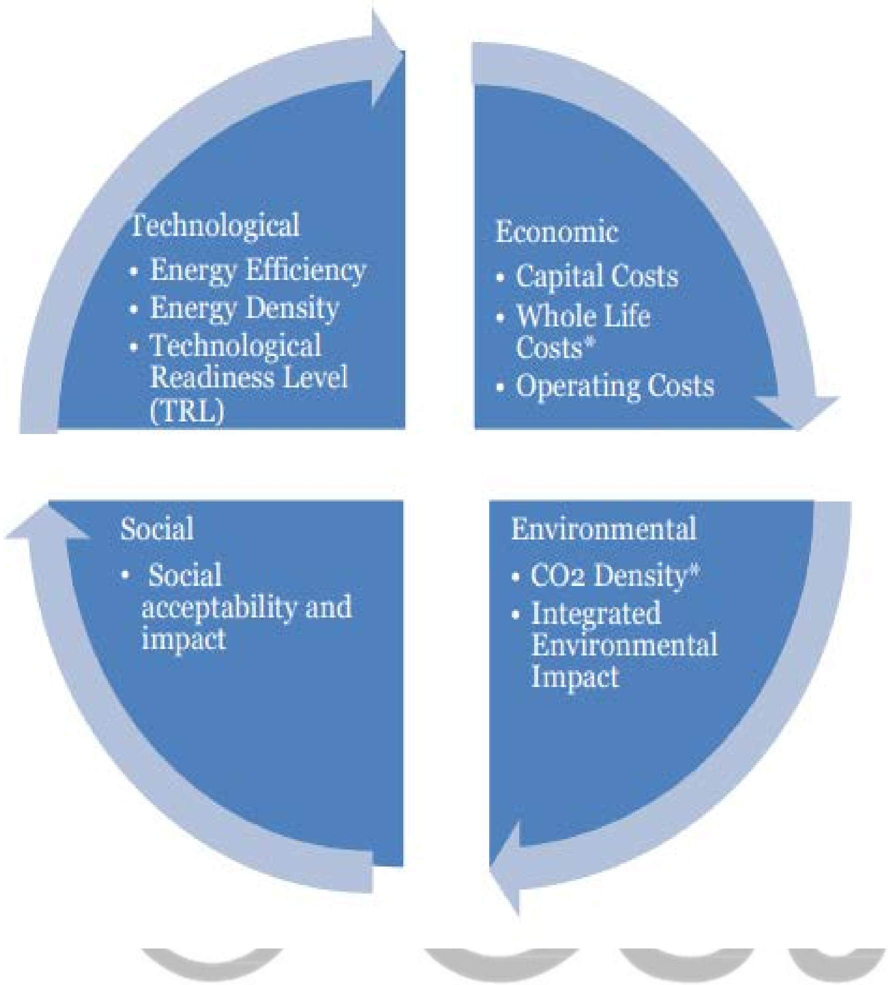

Figure 1 – Sustainability Assessment Framework

3.2 The AHP based Framework for Alternatives selection

A framework was adapted in-line with Ren,2018's work . The Framework was a 2-staged process, the first being determining the weights of the 9 characteristics using AHP and the second stage being generating a priority sequence for the alternatives. With consultation from subject matter experts from within Network Rail, 4 alternative technologies were selected for running a pilot of the framework.

4. Results

The 4 Technologies namely - Compressed Air Energy Storage, Flywheels Energy Storage, Battery Energy Storage, Hydrogen Energy Storage. The ESS technologies have been specified as follows-

Compressed Air Energy Storage(CAES) : Compressed Air Energy Storage has been developed on the conventional gas turbine technology that stores energy in underground storage caverns. Turbines are traditionally used to transform the stored compressed air into kinetic energy using diabatic, adiabatic or isothermal methods(Breeze,2018). **Flywheel Energy Storage** : Flywheels are a spinning mechanical mechanism that are used to store the rotational motion(Dell and Rand,2001).Flywheels can respond to the grid signals immediately thus providing better adoption to frequency control changes and provision of better electric efficiency(Nguyen,2020). **Battery Energy storage :** Batteries are devices that consist of one or many electrochemical cells that transform stored chemical energy into electrical energy(Energy storage website,2020). **Hydrogen Energy Storage** : Electricity can be converted to hydrogen by electrolysis. Further this hydrogen can be re-electrified. Hydrogen is used to generate fuel cell electricity(Hemmati, et,al.,2020). The Nine characteristics in 4 categories(Economic, environmental, Technological and Social) were employed to assess the sustainability of these ESS namely, Capital Cost(EC1), Whole-life Cost(EC2), Operating Cost(EC3) I Economic domain, CO2 density(EN1), Integrated Environmental impact (EN2) in Environmental domain, Energy efficiency(T1), Energy Density(T2), TRL(T3) in Technological domain, Social Acceptability and impact(S1) in Social domain. AHP was first implemented to obtain the weights of the four categories and later on the priority sequence for the 4 Alternatives.

Several Executives from the Company were involved in determining the weights of these characteristics from Program Managers, Senior Project Engineers to Finance Business Partners and Environment Managers.

Step 1 : Pair-wise comparison Matrices were obtained through e-mails and interviews from the identified stakeholders for the 4 domains.Responses were obtained from the respective stakeholders.

The responses were further normalised and the final weights were obtained.

ECONOMIIC	
EC1	0.24
EC2	0.66
EC3	0.1

Figure 2 – Weights for Economic Aspects

ENVIRONMENTAL AND SOCIAL	
EN1	0.62
EN2	0.29
S1	0.09

Figure 3- Weights for Environmental and Social Aspect

TECHNOLOGY	
T1	0.62
T2	0.31
T3	0.07

Figure 4 – Weights for Technological Aspect

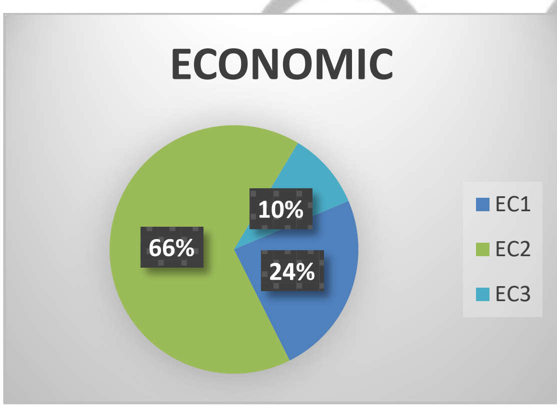

Figure 5 – Segmentation for Weights in Economic domain

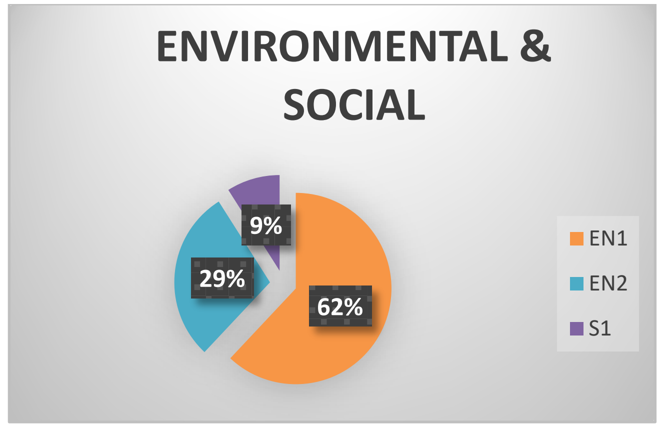

Figure 6 – Segmentation for Weights in Environmental and Social domain

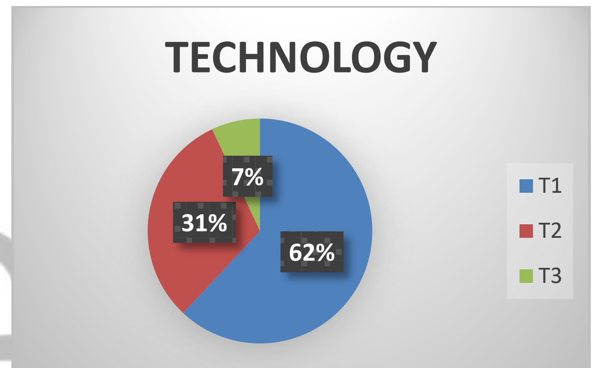

Figure 7 – Segmentation for Weights in Technological domain

Step 2 : Through a focus group workshop, 4 alternatives were compared and AHP was implemented to obtain a priority sequence. However, it was observed that there are a few uncertainties with Hydrogen Energy Storage and hence a few pair-wise comparisons were left for further research. Furthermore, Responses were noted and the following score cards were developed.

Fly Wheel			
Criteria	Weight	Score	Total Score
EC1	0.24	0.59	0.1416
EC2	0.66	0.54	0.3564
EC3	0.1	0.22	0.022
EN1	0.62		
EN2	0.29		
S1	0.09	0.28	0.0252
T1	0.62	0.59	0.3658
T2	0.31		
T3	0.07	0.59	0.0413
TOTAL			0.9523

Figure 8 – Scorecard for Flywheels

Compressed Air			
Criteria	Weight	Score	Total Score
EC1	0.24	0.12	0.0288
EC2	0.66	0.04	0.0264
EC3	0.1	0.62	0.062
EN1	0.62		
EN2	0.29		
S1	0.09	0.08	0.0072
T1	0.62	0.05	0.031
T2	0.31		
T3	0.07	0.04	0.0028
TOTAL			0.1582

Figure 9 – Scorecard for Compressed Air Energy Storage

Batteries			
Criteria	Weight	Score	Total Score
EC1	0.24	0.25	0.06
EC2	0.66	0.29	0.1914
EC3	0.1	0.11	0.011
EN1	0.62		
EN2	0.29		
S1	0.09	0.57	0.0513
T1	0.62	0.28	0.1736
T2	0.31		
T3	0.07	0.26	0.0182
TOTAL			0.5055

Figure 10 – Scorecard for Battery Energy Storage

Hydrogen and Fuel Cells			
Criteria	Weight	Score	Total Score
EC1	0.24	0.04	0.0096
EC2	0.66	0.14	0.0924
EC3	0.1	0.05	0.005
EN1	0.62		
EN2	0.29		
S1	0.09	0.06	0.0054
T1	0.62	0.07	0.0434
T2	0.31		
T3	0.07	0.11	0.0077
TOTAL			0.1635

Figure 11 – Scorecard for Hydrogen and Fuel Cells

Hence the obtained scorecards show the preference to fly-wheels and Batteries as opposed to the other 2 technologies with Flywheels being highly preferred over batteries. However, due to space constraints on flywheels and other intrinsic values that batteries bring to the value proposition, a hybrid solution of batteries and Flywheels is recommended.

5. Discussion

The results of implementing the AHP framework to obtain scorecards for the ESS are as discussed above. Furthermore, mind maps were created to visualise strengths, weakness, Opportunities and threats for flywheel technology and Battery storage, as these two emerged as the 2 best suited technologies. These are discussed as below.

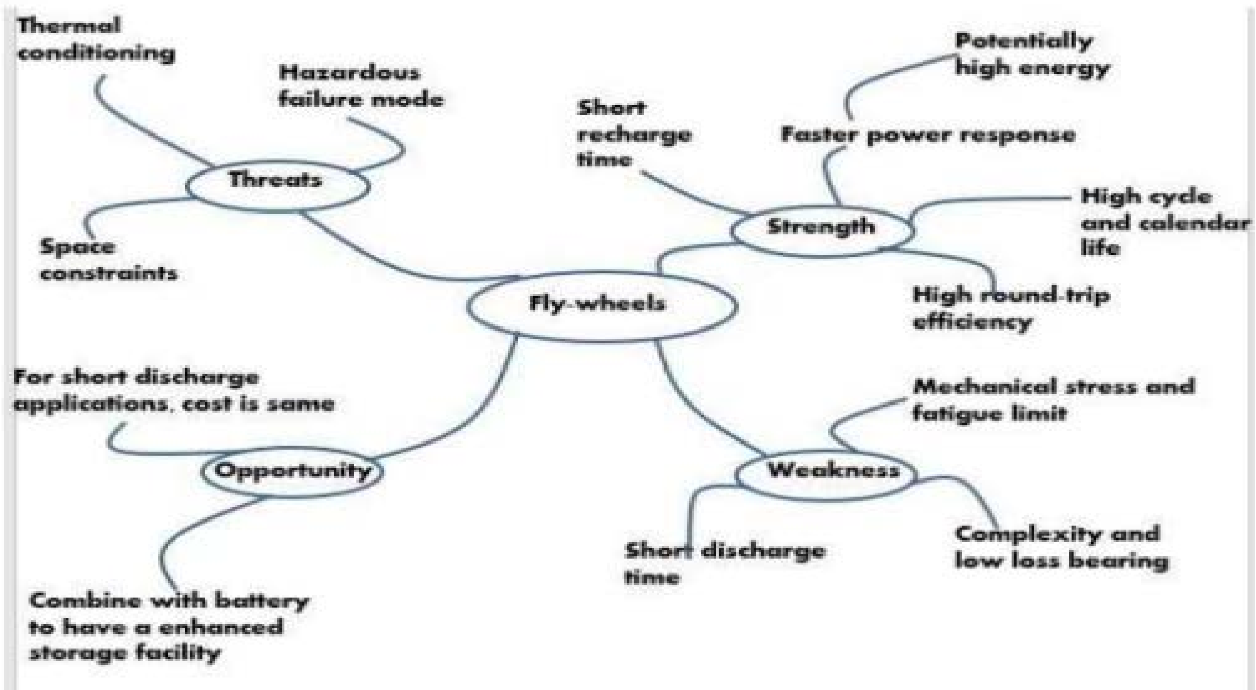

Figure 12 – Mind maps for Fly wheel technology

The shortcomings mentioned above, space constraints being the most dominant ones, are the underlying reason behind the recommendation for a hybrid system to be adapted.

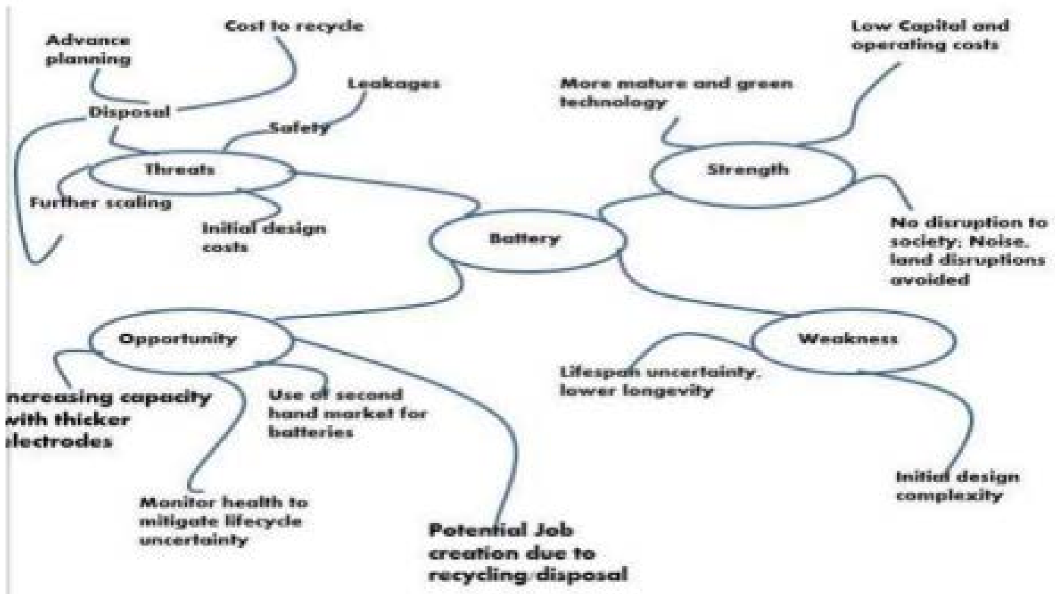

Figure 13 – Mind maps for Battery Energy Storage

The battery storage, advancing with a high speed of innovation has become a popular mode of Energy Storage in the past decade and has been showing an exponential growth potential with the rise in electric vehicles to facilitate the demand(Ning, et,al.,2019). Thus, the sustainability assessment has been done with the AHP based methodology for the selection of a Sustainable Energy Storage System. It is interesting to note that with progress in technological aspects, these assessments would need further calibration to adapt to the innovation and any policy changes by the regulating bodies for Environment.

6.Conclusion

The objective of this study was to develop an AHP based Multi criterion decision making model for the sustainability assessment of the Energy storage Systems. The AHP based model allows the decision maker to evaluate the trade-offs and quantify the relevance of the alternatives with the help of the scorecards that were developed. 4 alternatives namely, Compressed air energy storage, Battery Energy Storage, Hydrogen and fuel cells and fly wheels were evaluated based on 9 metrices of sustainability and a priority/preference order was generated. According to the stakeholders and subject matter experts, Flywheels and Battery Energy Storage are the most preferred ones.

However, due to various shortcomings in the implementation of a purely Flywheels based system, a hybrid structure of batteries and flywheels is proposed with an opportunity for the company to advance in the area of second hand use of batteries in order to improve the circularity of the supply Chain. The research although has a fair mix of internal stakeholders and Subject matter experts but is limited to the internal customers of the company/executives. Future work would be required to involve relevant third parties in this decision making to have a perspective on the social and environmental impacts. The research is primary explorative study to move forward with a definitive path with an evidence-based value proposition. The future work also extends to assess the other constraints on the ground level and explore the second-hand battery markets to make the procurement of the ESS a sustainable business decision.

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