Towards a renewable energy decision making model

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Abstract

This paper presents the Renewable Energy Decision Making Model, and applies it to a case study of a Hydrogen Bus Fleet. The model intends to aid users who are planning small scale renewable energy projects during the decision making phase in order to identify if the entire lifecycle of the project is sustainable economically, environmentally and socially. This Renewable Energy Decision Making Model incorporates the Triple Bottom Line approach utilizing a combination of three different analyses: After Tax Analysis, Streamlined Life Cycle Analysis, and Stakeholder Analysis. The results of the model are beneficial to decision makers in that they will show the level of sustainability by indicating negative or positive impacts of a proposed renewable project. Further, it allows for alterations to the design, during the planning phase to improve the sustainability of the project.

Keywords: sustainable; sustainability; renewable energy analysis; sustainability analysis; triple bottom line; renewable energy; decision making; decision making model; engineering economics; after tax analysis; streamlined life cycle assessment; life cycle analysis; stakeholder analysis.

1. Introduction

The move into the twenty-first century has coincided with a global cultural revolution that has placed emphasis on a sustainable world1. Sustainability is the ability to utilize natural resources while maintaining their availability and quality for future generations2; however, the concept of sustainability diverges for different perspectives3,4. It is also defined by the International Institute of Environment and Development as “A development...
path that can be maintained indefinitely because it is socially desirable, economically viable, and ecologically sustainable.” Currently, eighty-six percent of the world’s resources are being consumed by just twenty percent of the world’s population. The existing supply of fossil fuels is not sufficient to meet the current demand; in order to satisfy this trend the world would need five times the natural resources it has. As developing countries progress, and the population increases, the demand is only likely to increase; because of this shortfall the international community is concerned with long-term economic, environmental and social stability. Advances in the field of sustainability research will allow us to protect the natural environment on which we rely so heavily in many aspects of life.

A chief component of the sustainability industry is renewable energy. Renewable energy comes from sources that cannot be exhausted or sources that have the power of regrowth. Renewable energy can be harnessed from multiple sources, however most sources are intermittent meaning that when they are not available, they do not provide energy. Renewable sources such as solar, wind, tidal and geothermal are the most popularly researched and implemented forms today. There are many benefits of renewable energy the most important benefit being a significant reduction in emissions when compared with the fossil energy sources. There are also some disadvantages that must be explored during the decision making phase of determining whether to implement renewable energy projects. These disadvantages are in the form of economic, environmental or social impacts; therefore, a complete decision analysis must incorporate these three factors.

Traditionally, a focus on the potential profit margin was the only project feasibility analysis conducted. However, to assess sustainability, this focus must be re-evaluated. John Elkington’s creation of the Triple Bottom Line concept emphasizes the importance of the environmental and social effects of a project as well as its economic feasibility. Due to the varied potential impacts of renewable projects, sustainability assessment requires an interdisciplinary approach. Combining aspects of environmental engineering, systems engineering and engineering management, this research produced a model (accessible to a broad spectrum of stakeholders) to assess the Triple Bottom Line for renewable projects.

Due to their structure, decision making and approval processes, macroeconomic projects require a different approach than microeconomic projects. Typically, macroeconomic projects are impacted by policies and take place on the government and federal level with applicable regulations, whereas microeconomic projects are much smaller scale and are not equally affected by policies. On the federal level, the National Environmental Protection Act (NEPA) was developed and signed into law in 1970 requiring all federal agencies to conduct environmental impact assessments on all proposed projects and identify alternative actions when there are significant impacts. In industry, the Global Reporting Initiative (GRI) is an authority that develops sustainability reporting techniques for corporations, financial institutions and civil society. The GRI challenges businesses to consider and assess their triple bottom line in order to prioritize sustainability across a corporation or society.

Assessment frameworks have been researched and documented in the literature for projects on the microeconomic level. Modularity approaches are presented, whereby first the economic factors are assessed, then the environmental impacts assessed, and finally social impacts are identified. Often, these models identify the impacts during the operation and maintenance phase.

Sustainability models for the government, industry and corporate level have been well documented and successfully applied, such as NEPA and GRI. The sustainability models for the project level are varied and each researcher presents a different approach to assessing sustainability. The distinguishing feature of the Renewable Energy Decision Making Model is that it applies the three foci of sustainability using lifecycle analyses. Therefore, applying this model during the planning and decision making phase provides the ability to identify negative impacts across the entire lifecycle of the project and allows for consideration and comparison of alternatives.

The model incorporates the Triple Bottom Line concept utilizing the following: After Tax Analysis, Streamlined Life Cycle Analysis, and Stakeholder Analysis. Research must be conducted for each project in order to obtain significant findings. This model is not meant to be exhaustive, however, it is meant to assess and identify values for the useful high-level metrics that indicate the likelihood of successful implementation. In order to accomplish sustainability, assessments which encompass economic, environmental and social impacts must be practiced; yet most companies do not conduct sustainability assessment because it is considered too complex and costly. This paper discusses each of these three analyses and presents them via application to a case study using a model that is efficient and cost effective.
2. Triple Bottom Line Concept

2.1. Economic: after tax analysis

An after tax analysis (ATA) is an appropriate way to evaluate the economics of implementing green technology. "ATA is necessary because the government is a ‘partner’ in every capital decision. Depreciation rates, tax rates, investment tax credits, and capital gains taxes greatly influence the attractiveness of capital expenditures. In addition, ATA is used to determine the impact of borrowing on the project’s profitability." Bastian and Trainor generated a case study demonstrating ATA at the United States Military Academy in order to identify the risks and practicability of installing a wind farm on campus. In Alaska, Wang et al. also used ATA to conclude the viability of implementing a wind power generation system. The finding in both papers was that applying ATA is a useful tool that identifies how these specific wind farm installations would be favourable, due to the usage of a renewable energy source and a decrease of the cost of energy throughout the project lifespan.

The ATA incorporates figures of merit discussed in engineering economic analysis. The time value of money is considered in every step. The modified accelerated cost recovery system of accelerated depreciation factor is considered since depreciation plays a major role in capital investments on technology. The debt/equity ratio, cash flow, net present value (NPV), breakeven point internal rate of return and minimum acceptable rate of return are all useful figures of merit that predict project acceptability.

This technique defines the life cycle cost for the entire operation, from financing the project (i.e. loan rate) to capital investments made in equipment and land and the project revenue. This approach requires research to determine the parallel costs and revenue rates, however, the results from conducting the after tax analysis using the life cycle costs allows for a solid final decision based on actual figures and predefined economic criteria. Upon completion of the after tax analysis, a sensitivity analysis will determine how variation in the defined factors will affect the internal rate of return.

2.2 Environmental: streamlined life cycle assessment

There are myriad approaches to life cycle analysis. Life cycle analysis is conducted to: perform a comparative analysis of products or processes; determine impacts to stakeholders or potentially affected groups; identify potential improvements; serve as an aid for designing products or processes; and to identify the environmental costs associated. In order to do a complete life cycle analysis, all aspects from inception to project retirement and all interactions must be calculated; this has proven to be costly and time consuming. The first step is to conduct an inventory analysis and determine the inputs and outputs of the product or system, the next step is to conduct an impact assessment of the relative inputs and outputs, the final step is the improvement stage where mediation strategies or better designs are recommended.

As stated, a full scale Life Cycle Assessment is often costly and time consuming to complete, therefore, a streamlined life cycle assessment (SLCA) is the preferred industry approach. Graedel and Allenby devised The Environmentally Responsible Product Assessment Matrix to serve as a streamlined life cycle analysis. The environmentally responsible process matrix is an SLCA method that analyses each phase of a process with regard to five environmental concerns. The five life stages displayed in the rows of the matrix are: Resource Extraction, Product Manufacture, Product Delivery, Product Use, and Refurbishment, Recycling and Disposal. The five environmental concerns displayed in the columns of the matrix are: Material Choice, Energy Use, Solid Residues, Liquid Residues, and Gaseous Residues.

Each cell in the matrix is scored using a scale from zero to four, with zero meaning the process has a very high environmental impact and four meaning the process has no impact. When scoring a cell, the impacts are compared to typical amounts based on current processes or methods; this will be further explained in the following case study.

2.3 Social: stakeholder analysis

Historically, shareholder satisfaction would guarantee a company’s continued economic performance and therefore, economic and subsequent technological feasibility were the analyses used in the decision process for
Choosing projects. Presently, a company’s economic performance is dependent on a different type of stakeholder, the consumer. Business accountability is tantamount and society has a right to know what occurs in their backyard\textsuperscript{18}. News availability and social media have created a consumer revolution, whereby consumers have more information about the products they purchase and the companies that make those products. Sustainability has gained popularity, and morally conscious consumers are choosing the more sustainable over the more economical products or projects.

Environmental and sociologic assessments provide a company the opportunity to show their stakeholders how they are progressively attaining sustainability. Stakeholder input is a necessity to achieve economic success; however, variance in opinions can make it difficult to see the bigger picture. In a world with increasing numbers of stakeholders, reconciling stakeholder values for sustainable projects is bound to be a daunting task.

Systems Engineering methods recognize the importance of stakeholder analysis\textsuperscript{19}. The social assessment category of this Renewable Energy Decision Making Model mirrors systems engineering stakeholder analysis. Stakeholder involvement can drive a project to fruition or stifle progress, and a balance must be achieved so that all stakeholders receive maximum benefits. The most appropriate method to obtain feedback is a multi-stakeholder approach involving public officials, businesses, and individual citizens, as well as users of the system to identify issues and create solutions\textsuperscript{20}.

The standard method for stakeholder reconciliation is to prioritize requirements based on their relevance to the project. For example, the owners and users (employees, consumers, contractors, subcontractors, and consultants) are the most influential and their requirements are of prime importance along with those of any regulating agencies. The owner, user, and regulating agency requirements are typically related to the technological and economic performance of a project. The most difficult aspects to measure are those in relation to the social performance of a project, which come from the stakeholders that are affected by the project.

Surveys, interviews, focus groups, and public hearings are the most common methods for obtaining stakeholder requirements and values. Requirements and values gathering must occur during the planning or scoping stage of the project, as this is when the stakeholders can influence decision making. Incorporating stakeholders early will increase their acceptance and sense of ownership of the project. Once all requirements are defined, they are mapped out to identify any overlaps and consistencies\textsuperscript{20}. All remaining requirements are carefully considered, those that are appropriate and feasible must be incorporated and those that are unachievable must be disregarded.

3 Hydrogen bus case study

3.1 Background

The focus on sustainability has generated an interest in clean-burning fuels. The combustion of fossil fuels releases significant amounts of carbon dioxide into the atmosphere; the large quantity of carbon in the atmosphere has been argued as the main contributor to climate change and the resultant weather extremes currently being experienced on planet Earth, consequently global warming has become a concern\textsuperscript{21}. Research has been conducted to identify cleaner fuels. Hydrogen is the most abundant element on Earth, however only under rare conditions does it occur naturally. In its natural state (H\textsubscript{2}), hydrogen is combined with another element, the most common of which is oxygen in the form of water (H\textsubscript{2}O). Once it is separated from the other element, for example, oxygen, it can be used by converting it to electricity or burned as a fuel.

The idea of using hydrogen buses in urban public transit arose from the necessity of combatting and essentially reducing the number of particulates that are emitted into the atmosphere by the diesel buses used currently. Beginning in 2002, hydrogen powered buses have been implemented and demonstrated in the transit fleets of 20 cities worldwide\textsuperscript{22}. Because of these demonstrations and associated capital investments, research has continued to be conducted and has improved hydrogen fuel cell technology. This case study applies a Renewable Energy Decision Making Model to a fleet of 250 hydrogen buses.

3.2 Applying after tax analysis

Bonilla and Merino discussed the cost of implementation of a fleet of 250 hydrogen buses using project life cycle costing\textsuperscript{12}. A sensitivity analysis identified the most sensitive variables; in this case they were: Bus Cost, Carbon Credit\textsuperscript{23}, Loan Rate, and Ticket Price. The ATA identified a negative NPV, which indicates that this project is not viable due to the large capital investment cost. After conducting several iterations of the base case by varying the
most sensitive factors, the following three options make the project acceptable: minimization of the capital cost; maximization of carbon credits; or using financial leverage by increasing the loan amount to 80% of the total cost.

It was decided that the internal rate of return (IRR) method would be used as criteria for acceptability of this project, a base-case scenario was identified where the IRR was as close to 14% as possible, which was the indicated minimum attractive rate of return (MARR). Assumptions were derived from the journal article, *Economics of a Hydrogen Bus Transportation System: Case Study using an After Tax Analysis (ATA) Model*, written by Oscar Bonilla and Donald N. Merino and from research conducted to ascertain realistic costs for a hydrogen bus fleet and statistical distributions for the four most sensitive variables identified in the sensitivity analysis.

Identifying the base case scenario for the Hydrogen Bus Fleet required determining assumptions based on the information provided in the case study, as well as, researched information, and realistically modifying the assumptions to reach the goal of 14% IRR. During the determination of the base case, it became clear that some assumptions, or variables, had much more influence on the IRR than others. In Figure 1, the lifecycle years 13 through 18 are shown, the project life was assumed to be 18 years. In row 20, the IRR is shown to be 18.8%.

Although the IRR reflects an acceptable base case, the negative NPV would make this project unacceptable. The intent of this case study was to identify how varying the four variables that had the most influence on the IRR would make this project acceptable or profitable. Crystal Ball discrete event simulation software was used to conduct simulations of each variable to reach the MARR of 14%. Once that was completed, a simulation of all four variables was conducted.

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Figure 1: Hydrogen Bus Fleet, After Tax Analysis (life cycle years 13-18 shown)

The Crystal Ball simulation was run for 100,000 trials using all variables (bus cost, ticket price, loan interest rate, and carbon credit) as is shown in Figure 2. The simulation for this project showed a mean IRR of 10.7% and a median of 9.8%, there is a 20% chance of achieving an IRR greater than 12%. Based on the probability distribution, the most likely IRR is approximately 9%. Since the simulated IRR of 9% is lower than the MARR of 14%, this project would be unacceptable. The owners would have to find financial leverage to support this type of project. The financial leverage that would make this project acceptable would be the loan amount. With a higher loan amount, greater than 80% of the total investment, the project becomes acceptable because the risk is translated from the owner to a financing company.
The above sensitivity chart in Figure 3 shows how the variables affect the IRR. Bus cost has the greatest negative effect on IRR, -54.5% sensitivity, signifying that as the cost of the buses increases, the IRR is negatively impacted significantly. The carbon credit variable has the greatest positive effect on IRR, with a sensitivity of 33.3% indicating that an increase in the value of carbon credits will lead to a very positive affect on the IRR. Ticket price also has a positive effect on sensitivity with 11.9% sensitivity. The interest rate for the loan is the least sensitive variable, at -0.2%. Because the results show that the lower the loan interest rate the higher the IRR, further working on the loan interest rate would not be a profitable benefit. Therefore, the recommendation would be to increase the loan amount in order to compensate for the negative effects of the loan interest rate uncertainty in the IRR.

Since bus cost and carbon credits have the greatest effect on the project IRR, owners should focus on the value of these two variables. If one can obtain Hydrogen buses at a low cost, around $1.4 million each, and can sell carbon credits at rates greater than $9 per metric tonne of carbon, the project would be acceptable and profitable. However, if it is not possible to meet these two criteria, the project would be unacceptable due to the high cost of capital investment.

3.3 Applying streamlined life cycle assessment

The environmentally responsible process matrix SLCA was utilized to identify the environmental impact of the fleet of 250 hydrogen buses. The SLCA, as shown in Figure 4, was completed by analysing each phase of the entire process; the five lifecycle stages were: 1) Hydrogen Development, 2) Manufacture of Buses and infrastructure, 3) Delivery of Buses, 4) Operation and Maintenance, 5) Fleet Retirement. Scores compared implementation of a
Hydrogen Bus Fleet versus a typical Diesel Bus Fleet and research was conducted to determine the impacts. It is difficult to find reliable data for this type of project due to a lack of publicly available sources, for example specific values for bus components, hydrogen fuel cell components used on hydrogen buses, and the fuelling infrastructure required for a fleet of this size, however, assumptions and generalizations were made to identify an outcome.

### The Environmentally Responsible Process Matrix

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<table>
<thead>
<tr>
<th>Total Environmental Concern Value</th>
<th>6 6 12 12 11</th>
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**Legend:**

- 4 = No environmental impact
- 3 = Minimal environmental impact (i.e. less than the expected average)
- 2 = Moderate environmental impact (i.e. about the average)
- 1 = Substantial environmental impact (i.e. more than the expected average)
- 0 = Very high environmental impact

Figure 4: Streamlined Life Cycle Assessment (SLCA)

The first row identifies the Hydrogen Gas Development and Fuelling Infrastructure lifecycle stage of this project. The most efficient process for delivery of Hydrogen fuel is to produce the Hydrogen fuel on site, as compared to trucking the gas, which would negatively impact the energy and emissions ratings. Since new fuelling stations must be built and infrastructure for the manufacturing of Hydrogen gas must be installed, the materials and energy usage have a greater impact than that of diesel fuel, leading to a score of one for each category. The most energy and cost efficient commercialized technology currently available to manufacture Hydrogen gas is steam reforming, utilizing fossil fuels as an input for the production. The utilization of fossil fuels creates gaseous by-products, namely carbon dioxide, which led to a score of two for this category because of the similarity to diesel fuel. The solid and liquid residues arise during the construction of the hydrogen fuelling station; therefore, the values for these two categories are two since the impact will be the same as that of diesel fuelling station construction.

The second lifecycle stage shown in the second row is Manufacture of Buses and Garage Infrastructure. The difference between diesel buses and hydrogen buses is the removal of the diesel fuel tank and engine and addition of the Hydrogen fuel cell system which “include(s) the fuel cells, hydrogen storage system, electric traction motor, power management system, auxiliaries, and a modified space frame to support the roof-mounted components” 29. Garage infrastructure will be similar to that of diesel bus storage.

Delivery of Buses is the third lifecycle stage analysed, and shown in the third row of the matrix. Diesel bus curb weight is 28,500 lbs30, Hydrogen bus curb weight is 34,800 lbs31. Since diesel buses have been in use since around the 1970s, there are numerous manufacturers throughout the United States, also, used buses can be purchased at a fraction of the cost (albeit with higher maintenance costs). There are few hydrogen bus manufacturers in the US
and throughout the world. Based on these facts, delivery for hydrogen buses will be more expensive than for diesel buses\(^2\), therefore this entire lifecycle stage scored a one in all categories, excluding liquid and solid residues because they are not present in this stage.

The Operation and Maintenance lifecycle stage, shown in the fourth row, is the stage during which the hydrogen buses are in use. Hydrogen buses have a shorter vehicle range and longer refuelling time; however, hydrogen buses are nearly two times more fuel efficient than diesel buses requiring less hydrogen fuel than diesel fuel for the same trip\(^3\). Regarding energy use, the previously mentioned two points balance out and allow for a score of two. Due to the longer refuelling time, more Hydrogen pumps would be required leading to a score of one for materials choice. There are no solid or gaseous residues that adversely impact the environment, and the liquid residue is water, these three categories each scored a four.

The fifth row depicts the Fleet Retirement life cycle stage. The materials used for the chassis in Hydrogen buses are generally similar to the material used for diesel buses; therefore the structure of the bus will be the same and pose the same type of impact to the environment. The hydrogen fuel cell, however, is what causes the low scores in energy use, solid, liquid and gaseous residues. The platinum catalyst in the fuel cell must be recycled; this will require high-energy consumption\(^2\). Unless the bus can be retrofitted and reused, the fleet retirement life cycle stage is the most damaging to the environment.

The SLCA matrix uses colour coding to give the viewer a perspective on how environmentally friendly the product or process being analysed actually is. More green and yellow boxes indicate a more environmentally friendly value, whereas more red and orange boxes indicate a less environmentally friendly value. From the SLCA matrix shown in Figure 4, the columns and rows with the lowest values, or most red boxes represent the environmental concern that is mostly affected or the most damaging lifecycle stage. From the matrix, one can see that the life cycle stage with the most negative environmental rating is phase five, fleet retirement. It is energy intensive due to the requirement of recycling the fuel cells. The most environmentally friendly life cycle stage is during operation and maintenance. Materials choice and energy use are the worst rated categories for environmental concerns, however, investment in research and development will improve the scores for these categories.

### Applying Stakeholder Analysis

The importance of stakeholder involvement cannot be understated\(^2\). Lack of stakeholder involvement during the design process has been a downfall for companies\(^3\) and stakeholder involvement must occur at all levels, from the owners of the system to the users and those participating in the supply chain. With proper stakeholder management, stakeholder requirements are gathered during the beginning phase of a project, this allows for major issues to be identified and discussed during the planning and decision phase. Value is created when stakeholder requirements are satisfied relative to their importance and need\(^2\). Designing the system with stakeholder requirements in mind will lead to a smoother transition period and greater acceptance of the system.

During the years of 2002 to 2007 several cities in the United States, Europe, China, Japan and Australia held demonstrations of Hydrogen buses that used technologies such as Hydrogen-fuelled internal combustion engines or Hydrogen fuel cells. A major goal of the pilot projects was to raise awareness of hydrogen buses and educate the public. The pilot projects\(^2\) were also proof of concept for determining the feasibility of implementing hydrogen bus fleets.

To understand stakeholder input and gauge user acceptability of hydrogen powered buses, The Federal Transit Administration of the U.S. Department of Transportation utilized an in-depth targeted interview method. The survey results were compiled from users across the 20 cities that implemented the buses. The stakeholders that were part of the assessment included the bus riders, the bus drivers, and city government officials who took part in the demonstrations\(^3\).

The results of the survey showed that over 85% of respondents had positive opinions of the hydrogen bus demonstration projects. On average, 55% of those surveyed supported the project due to environmental concerns. Support of a large-scale implementation of Hydrogen bus fleets was demonstrated by 78% of the respondents. In regards to the commute provided by the Hydrogen bus, 73% found the fuel cell bus quieter than diesel and 58% found the bus to be smoother than conventional diesel. Drivers noted the smooth rides and were less tired after their shifts due to the quieter motors of the hydrogen buses.

The demonstrations identified areas for improvement for future hydrogen bus fleet rollouts. They also revealed a need for future research in hydrogen bus fuel cell technology specifically the fuel cell durability, cost and
energy storage, as well as the other bus components that are auxiliary to the fuel cell, more hydrogen fuelling stations and associated infrastructure reliability, and quicker hydrogen filling times. Proof that stakeholders support the idea of hydrogen buses was obtained via the stakeholder surveys, and investment in hydrogen technology and its associated research is necessary to ensure the profitability of commuter hydrogen bus fleets and improvement in the environmental feasibility aspect.

4 Conclusions

This Renewable Energy Decision Making Model is resourceful since it assesses only the fundamental high-level metrics required for decision-making. The easy-to-interpret charts display analysis results in an easy to understand format that can be efficiently shared with all stakeholders.

The presented Renewable Energy Decision Making Model allows engineers that are implementing a renewable project to efficiently assess its Triple Bottom Line viability. Selecting high-level, user-friendly analyses as well as combining them into a single model is in alignment with Lean Systems Engineering principles. The inclusion in this model of easily understood charts reduces time spent interpreting results by decision makers and brings into focus the key elements of the project. The aim of the creation of this model is to encourage the practice of conducting sustainability assessments using a model that can be completed through research and contact with experts in a cost effective and time efficient manner.

Managers should be interested in applying sustainability principles during the decision making phase. In the long term, it is in businesses’ best interest to assess sustainability. Companies that focus on sustainability see a boost in their bottom lines in the long-term. The boost comes from an enhanced public image and acceptability of exports in more stringent but lucrative markets, as well as, savings due to increased efficiency35. Environmentally responsible companies that complete reporting on sustainability have greater acceptance in the global supply chain. Companies that have done the most reporting and have been the strongest advocates for sustainability reporting include those operating in some of the most environmentally damaging industries like automotive, oil, gas and chemicals, specifically in Europe, Japan, Australia and North America36.

Corporate environmental reporting is the most effective way for a company to show they are in touch with and responding to the consideration of stakeholders. Business leaders in Europe, North America and Japan believe required environmental disclosure will continue and become stricter by increasing scope and the effect on all industries36.

SustainAbility carried out a survey administered by Deloitte and Touche Tohmatsu International on international companies that create sustainability reports. An interesting finding was that the main target audience for sustainability reports is the employees because they are most concerned with the way their employer operates37. Another survey finding showed that the majority of the respondents believe that companies that place a strong emphasis on environmental, social, and ethical performance will outperform those who do not. Corporate social responsibility performance will become an essential element of further investment decision making38.

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References