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Design and Development of an Eco-Innovation Management Information System to Accelerate Firms' Digital Transformation Strategy

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ABSTRACT It is vital for firms to measure, and, report on, the impact of eco-innovation towards their environmental performance. Additive Manufacturing is an eco-innovation that contributes towards reducing the environmental impact of manufacturing. However, there is a lack of practical tools for management to monitor and report on firms' eco-innovation implementation and performance. This paper presents a prototype Eco-innovation Management Information System (EiMIS), developed to enable a firm's management to systematically manage and report on eco-innovation performance. Using a top-down approach, the EiMIS is developed through utilizing the C# and SQL programming languages for the Graphical User Interface (GUI), Database Management System (DBMS) and other technologies to collect, store (into a relational database) and manage eco-innovation performance data. A 4-tier architecture enables the EiMIS to: store, view and retrieve or generate eco-innovation performance reports; and generally, manage firms' eco-innovation performance data. This developed prototype could, help introduce information system platforms that: assist firms to collect data that can model their additive manufacturing; ease firms' eco-innovation performance reporting; improve environmental data management capabilities; and complement firms' digital transformation strategy.

INDEX TERMS Big data analytics, digital engineering, eco-innovation, environmental management information system, environmental management system, software development.

I. INTRODUCTION

Eco-innovation encompasses any innovation that, upon implementation, aims to minimize negative impacts to the natural environment whilst, maximizing economic gains from the onset [1]. As a result of eco-innovation's ability to simultaneously reduce harm to the natural environment whilst generating positive economic returns, eco-innovation has been credited with providing firms an avenue to engage in value creation activities in an environmentally and economically sustainable manner [2], [3]. Specifically, eco-innovation enables firms to lower the greenhouse gas (GHG) emissions their value creation efforts generate (e.g., lowering the Carbon Dioxide (CO_2) footprint of their value creation activities), in an economically cost effective and efficient manner [4]. This then, enables firms to buttress the notion of sustainable development viz the firms' value creation [5].

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However, to enable firms and their stakeholders the ability to monitor and/or gauge the impact eco-innovation has towards their value creation efforts, it is imperative for firms to report on the impact of their eco-innovation implementation in a transparent and proactive manner [6]. Additive manufacturing (AM) is a prominent eco-innovation implementation, which aids firms to create value in an economically and environmentally sustainable manner i.e., by reducing the negative environmental impacts and economic costs of manufacturing [7]. Increasing availability of data and information concerning the value creation impact of eco-innovations like AM would facilitate standard reference points for industries and firms to base comparisons on [8], vis-à-vis their environmental performance.

Environmental Management Systems (EMS) could provide a pathway for organizations to obtain information related to environmental performance, as they enable firms to develop environmental performance databases and utilize the information to communicate with both internal and external stakeholders [9]. In fact, since an EMS enables a firm to improve on its environmental performance accounting and auditing, the management of environmental information within the firm becomes an important aspect in the timely availability of such information to stakeholders [10]. Environmental performance information is also pivotal in lifecycle assessment (LCA) and material utilization maximization – key elements of metal AM [11]. In Malaysia, some of the reasons why firms would be interested in implementing an EMS include reducing pollution; improving the ability to comply with regulations and laws; increasing stakeholder's consciousness of environmental stewardship issues; enhancing environmental performance, company reputation and quality of environmental information [12].

Although it is not mandatory for firms in Malaysia to implement an EMS [13], firms in Malaysia are encouraged to implement EMS' due to their ability to assist firms in: measuring; managing; improving upon the environmental impact of their value creation activities [14], [15]; as well as, assisting management in decision making [16]. In addition, EMS implementations that comply with international standards certifications like ISO 14001 send a signal to the firm's stakeholders of its commitment to the natural environment [13]. However, implementation of EMS' by Malaysian firms remains low, with: the lack of implementation tools; high implementation costs; and lack of/unavailability of accessible data and information being cited reasons for the low implementation [17]. Specifically, information relating to a firm's environmental or eco-innovation activities or impact is also scant [18], thus, it remains quite obscure for stakeholders to gauge the impact of value creation efforts of the firm [19]–[21]. Therefore, it becomes imperative for firms to embrace an information system that can be used as a tool to capture this value creation data and information [22].

Environmental Management Information System (EMIS) – which consist of information technologies such as database and real-time data acquisitions systems – supports the overall EMS by providing firms the ability to efficiently measure, collect, and store environmental performance data in an integrated enterprise-wide architecture or stand-alone end-user architecture [23]. From this juncture, there are two overarching challenges that need addressing. Firstly, the development of accessible eco-innovation and environmental data and information systems for firms to utilize [24]–[26]. Secondly, for firms to transition from identifying and analyzing problems to designing effective system solutions (which remain relatively underexplored) [27]. This paper, therefore, aims to describe the design and development of such an environmental management information system i.e., the Eco-innovation Management Information System (EiMIS). This EiMIS, which can be classified as a novel subset of environmental management information system (illustrated by Fig. 1), aims to assist and enable firms to capture, store, and communicate eco-innovation performance information to stakeholders.

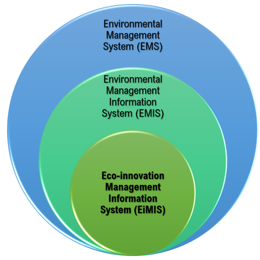

FIGURE 1. Illustration of the subsets of EMS.

As illustrated by Fig. 1 above, EMS is the foundation i.e., the main set. An EMIS, which is an information technology that assists firms to keep tabs on their environmental data, is built on the foundation of EMS. EiMIS, therefore, goes further – by merging the economic and environmental value creation aspects i.e., eco-innovation, into an information technology.

Given that eco-innovation performance information is essential to stakeholders [28], communicating such information to stakeholders digitally could provide an indicator for firms' commitment towards greater natural environment stewardship. Digitization through usage of information technologies offers firms numerous benefits such as innovations in value creation, as well as, novel avenues to communicate with stakeholders. Digital transformation strategy is based upon this premise, and its scope cuts across the entire firm, including the digitization of the firm's interaction with stakeholders [29]. As firms embrace greater natural environment responsibility through reporting the environmental impact of their value creation activities, the digitalization of functions within their value creation activities becomes essential vis-à-vis their digital transformation strategy [30]. Thus, the potential benefit of EiMIS includes creating an avenue for firms to digitalize eco-innovation performance data and information, as part of the firms' digital transformation strategy. In addition, metal AM utilization by firms enables them to leverage certain aspects of their unique value creation characteristics [31]. Thus, when EiMIS is a part of the firms' digital transformation strategy, new business models are potentially created by having information and insights into the value creation activities of the firm.

The rest of this paper is organized as follows: Section 2 presents an overview of environmental reporting and also on environmental management information systems. Section 3 presents the method utilized in designing the Eco-innovation management information system (EiMIS). Section 4 presents the results, whilst section 5 delves into discussing the findings. Lastly, section 6 concludes this paper.

II. LITERATURE REVIEW

A. OVERVIEW OF THE STATE OF ENVIRONMENTAL PERFORMANCE REPORTING

To foster greater transparency, as well as, better align stakeholder interests and communication to the respective stakeholders, the concept of integrated reporting (IR) is an emerging area that enables firms to communicate to stakeholders the value their business activities create over time. IR aims to communicate to firms' stakeholders the value created by the firms' activities to itself, as well as, to the other concerned stakeholders' groups [32]. IR goes beyond simply producing sustainability or financial reports/performance statements. Instead, it enables firms to give a greater account of the impact of its value creation activities [33]. IR potentially enables investors and other stakeholders' access to more value creation performance metrics for decision making. Hence, IR requires firms to include important information that helps these critical stakeholders make important decisions, based on, the overall value the firm is able to create for itself and for its stakeholders [34].

Some of the information that is critical in IR includes information related to the performance of the firm. With growing attention being paid towards the state of the natural environment, non-financial information such as, that relating to the environmental performance of a firm is also critical to communicate to stakeholders, especially as IR goes beyond simply providing a "sustainability statement" [35]. Whilst the need to implement IR is gaining traction worldwide, in Malaysia however, the transition towards implementing IR is low, with only a handful of companies engaging in IR [36]. This has been attributed to several reasons, chief amongst them the lack of practical tools and technologies to produce the integrated report and required data and information [37]. Specifically, data and information related to the firm's value creation efforts (e.g., eco-innovation) as well as environmental performance is scant, and, where such information is availed, it is descriptive in nature and not quantified [38]. As a result, environmental and economic performance data, operating in tandem, is usually omitted or lacking in those limited instances where reports are available, thus, contributing towards the low implementation of IR in Malaysia [39].

B. OVERVIEW OF ENVIRONMENTAL MANAGEMENT INFORMATION SYSTEMS

Early forays into EMIS design and development saw the proliferation of web-based reporting systems by the likes of Isenmann [40], Allam, *et al.* [41], and José-Andrés, *et al.* [42]. However, web-based information systems tend to produce numerous issues. For instance, they often require complex architecture of database management systems and indexes so they may be able to handle large volumes of information [43]. In addition, designs often hosted the web-based system on premise, which makes availability, throughput, and response time dependent on the host computing and networking resources available such as bandwidths, protocols, processing speed, physical and virtual memory, as well as storage capacity [44].

Other researchers such as Gong, *et al.* [45] and Kouziokas [46] then attempted to include location services and near real time capabilities in their architecture of an EMIS by incorporating geographic information system (GIS) and relational database management system (DBMS) into their EMIS design. Such an architecture enables multiple concurrent access to the database over internet or network protocols, as well as, mapping capabilities.

Whilst such an EMIS architecture is useful at macro level, for micro applications such as, firms' eco-innovation reporting purposes, it may drive up costs given the complex database management system requirements. Simpler low cost EMIS architectures built using the rapid application development approach can also be utilized without losing value generated from outputs [47]. Usage of a simpler, cloud-based architecture may help overcome some of the issues stated above, as well as, facilitating collection and processing of data [48]. However, Elkhatib, *et al.* [48]'s architecture was focusing on macro-based systems with little attention being paid towards firm wide usage. This viewpoint was also noted by Zhang [49] stating the need for EMIS to systematize firm level environmental reporting system to help in the access and distribution of environmental information to stakeholders.

In fact, micro or firm level utilization is one of the main aims of EMIS, as it could assist firms in managing implementation of environmental initiatives and crafting strategies for optimal usage of firm resources. As data relating to the environment is expected to increase in volume, there is a need to develop well organized and optimally sized data warehouses to cater for this expected increase in volume. Usage of cloud platforms for housing a database provides a window of opportunity for EMIS enterprise designs to be cost effective, flexible, and enable greater collaboration. Thus, the functionalities that constitute a decent EMIS include the ability to: collect and manage data; store data & transform it into knowledge; view the environmental impact data; as well as to make reports & audits [50].

Whilst EMIS is formidable in distributing environmental information within firms [51], its focus on environmental data has created an inherent lack of data pertaining to the economic aspect of a firm's value creation activities. It is this notion that makes EiMIS distinct from EMIS. EiMIS goes beyond EMIS by integrating economic (i.e., eco-sales, cost of eco-sales [52], eco-investments [53], quality certifications (QC) [54] and eco-patents [55]) and environmental (i.e., waste [54], recycling, and standards certifications [55]) data to measure a firm's value creation efforts. Fig. 2 below highlights this notion:

Hence, by combining both the economic and environmental dimensions, EiMIS aims to go beyond providing only environmental performance information to stakeholders, so that the stakeholders can visualize the simultaneous economic and environmental benefits of the firm's environmental stewardship. EiMIS can thus, help firms to generate reports that highlight both the environmental and economic impact of their value creation efforts.

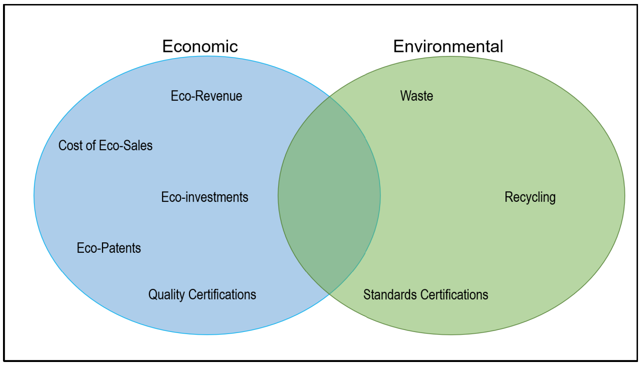

FIGURE 2. Economic dimensions ∪ environmental dimensions.

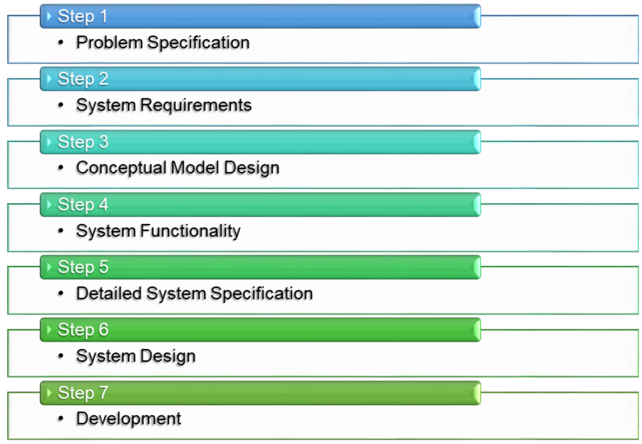

FIGURE 3. Illustration of the steps for developing EiMIS (as adapted from Artz [53]).

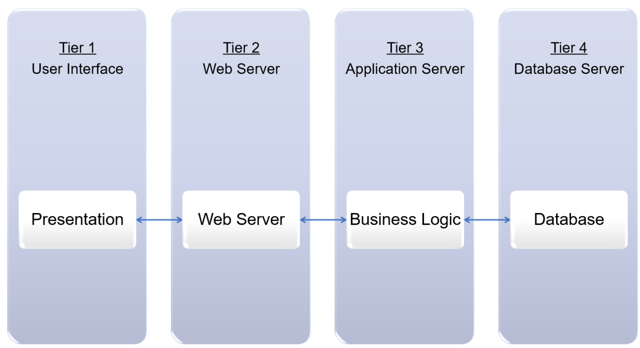

FIGURE 4. EiMIS' 4-tier architecture (as adapted from Kouziokas [46]).

III. ECO-INNOVATION MANAGEMENT INFORMATION SYSTEM (EiMIS)

A. DESIGN AND DEVELOPMENT OF EiMIS

Design and development of Information Systems can follow either of two broad pathways – i) the bottom-up approach or ii) the top-down approach. The bottom-up approach is whereby, the end user is the focal point. Thus, the greater focus is on functionality [56] as opposed to being problem oriented. However, in order to design a solution to enable eco-innovation data and information to be accessible to stakeholders, this paper follows the recommendations of Sudeikat, *et al.* [57] by employing a top-down approach to the design of the EiMIS. The top-down approach enables the development process to follow a stepwise refinement process, thereby, allowing the EiMIS to be broken down into a series of steps or hierarchy or subsystems centered on providing the solution [58]. Thus, this paper embraces and adapts the top-down steps recommend by Artz [59] in designing and developing the EiMIS namely: Problem Specification; System Requirements; Conceptual Model Development; System Functionality; Analysis; Design and Development. Fig. 3 Illustrates the steps followed in developing the system.

A top-down approach to developing the system architecture provides benefits such as the ability to be hinged on domain understanding and also allowing the developed system to be guided by a vision & framework particularly in implementation phases [60].

1) STEP 1: PROBLEM SPECIFICATION

For the first step, the problem to be addressed was articulated in section 1 of this paper. Specifically, the problem that is being addressed by EiMIS is the lack of eco-innovation data and information, due to a lack of reporting tools for eco-innovation. Thus, EiMIS aims to provide firms a decent reporting tool that facilitates the logging, storage and display of eco-innovation data and information. This includes data related to the economic aspect, as well as, environmental aspects of value creation i.e., eco-innovation. The user interface needs to be able to carry out these tasks in a user-friendly manner to be usable by the management teams of firms. These information, business, operational and user-interface objectives were a guide to the development of EiMIS and are a pivotal part of the development process.

2) STEP 2: SYSTEM REQUIREMENTS

In the second step, the architecture of EiMIS was established. Part of the parameters that help shape the architecture of EiMIS is the placing of operational constraints viz the application, development and user environments. The overall system architecture of EiMIS looks at the implementation technologies to be utilized in selecting the application and development platforms i.e., the supported platform for the application and the tools to be utilized in developing the software. Since EiMIS is to be used in a firm setting, a graphical user interface (GUI) is required, to allow the user to interface with EiMIS. Also, a database is required and EiMIS is to run on an enterprise platform. Thus, the system's architecture is to consist of 4 tiers i.e., the Presentation Tier, Web Server Tier, the Business Logic Tier and the Database Tier. Fig. 4 illustrates the proposed EiMIS architecture.

A 4-tier system architecture is common for database applications and is facilitated by evolution of various facets of information technology such as server computing power

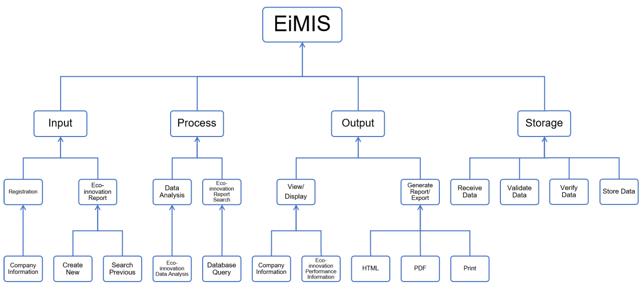

FIGURE 5. **Conceptual model of EiMIS.**

(physical and virtualized), telecommunications infrastructure (e.g., fifth generation of mobile internet standards – ''5G''), distributed computing, and service-based cloud computing to name a few [61]. Developments in these facets of information technology have resulted in an increased uptake of 4-tier system architecture, so as to: increase the quality of service; and, lower capital and operating costs through reducing investments in physical infrastructure such as servers [62]. Cloud computing based business models such as Infrastructure-as-a-service (IaaS) and Platform-as-a-service (PaaS) also contribute in making a 4-tier architecture viable for developed applications [63]. Programming languages provide the tools to develop the EiMIS architecture. The GUI in the presentation layer of EiMIS is developed using C# 8.0, as it is an object-oriented programming language that is optimized for applications that interface with a database, and also, allows the developer to use objects in order to create applications with a GUI [64]. Meanwhile, the database in the database layer of EiMIS is developed using Structured Query Language (SQL), due to the fact that the programming language C# 8.0 is optimized to work with SQL syntax in an integrated manner via the Language-Integrated Query (LINQ) capability of C# 8.0 [64].

3) STEP 3: CONCEPTUAL MODEL DEVELOPMENT

In the third step, the storyboard of EiMIS began to form. Rough sketches of how EiMIS is to flow also were established here, as well as conceiving how the sub branches of EiMIS based on metaphors like ''eco-innovation report'' are to link up. This was done so as to showcase what EiMIS might look like before the actual application is built, as illustrated by Fig. 5.

Thus, to accomplish the task of generating eco-innovation performance reports, the EiMIS consists of sub-systems that are responsible for input, process, output and storage of eco-innovation data. These are further delineated into the various sub-systems in a step-wise manner, so as to facilitate the functioning of the EiMIS.

Some of the sub-systems include Eco-innovation report creation; Analysis of data; and also viewing generated reports.

4) STEP 4: SYSTEM FUNCTIONALITY

In this fourth step, the plausibility of the EiMIS architecture requirements specified in step 2 was assessed i.e., if they can be testable and thus, incorporated into the actual functionality of EiMIS. Under this step, several assertions were made concerning the indexing and query capabilities of EiMIS, information provision, user interface characteristics as well as how the eco-innovation data and information is to be distributed and secured.

5) STEP 5: ANALYSIS

In this fifth step, the nature and characteristics of the required data and information was analyzed and mapped onto their possible representation in the EiMIS. The predominant data structure of EiMIS consists of structured data that is to be stored in tables within a database. The schema of the database supporting the EiMIS also took into consideration what's available/supported by current technologies. The database and application will be able to validate the data upon entry by the user i.e., if the data is in correct data type, and warn users if required data is missing or if invalid data type has been entered.

6) STEP 6: DESIGN

In this sixth step, the details concerning the EiMIS are then specified in details. Specifics regarding page color; font type, style or color; background type, style and color; images; and formatting were specified to reflect the nature of eco-innovation. To cater for a simple and easy to use interface, plain background colors of grey and white were utilized, with Arial font type (size 12 for text & 16 for headings) selected due to its ability to ease reading, eliciting greater control from users, and reducing likelihood of reading errors [65].

7) STEP 7: DEVELOPMENT

In this last step, the development work of EiMIS took place. The EiMIS development process included information gathering and loading, image construction, and document conversion. The writing of the EiMIS source code, and the creation of individual pages also took place in this step according to the detailed design. Microsoft Visual Studio Community 2019 was utilized as the Integrated Development Environment (IDE), because it available for free use within an academic setting [66].

B. VERIFICATION AND VALIDATION OF EiMIS

The verification steps followed in this paper included, inspection of source code and user interface designs, to ensure the specification requirements of the EiMIS were being achieved. This was done through the debug option in the IDE. An additional benefit of using Microsoft Visual Studio Community 2019 as the IDE is, it allows the developer to check for possible syntax, logic or run-time errors in the source code. Following the user interface design, and, source code writing and inspection, the EiMIS was then executed in debug mode.

If syntax errors exist, the IDE does not compile and execute. The debug option has the benefit of highlighting and flagging possible errors in the syntax, allowing the developers to correct them. Where syntax errors were highlighted by the IDE's error list, they were corrected, in an iterative process until the EiMIS compiled and executed successfully. Logical errors were also traced with iterative data entry, to ensure EiMIS functioned in the manner intended to. Normal, boundary, and erroneous data values were also used to ensure that possible run-time errors such as division by zero, were identified and corrected.

With regard to the initial validation of the EiMIS, periodic review meetings were undertaken by the developers to ensure that the goals of the EiMIS were comprehended, and the development of the EiMIS was aligned to the overall goals and objectives. Furthermore, brief interviews with potential users (i.e., managers and administrators) to demonstrate the functionality of the EiMIS was also undertaken, with their feedback being documented.

IV. RESULTS

A. EiMIS AND ECO-INNOVATION PERFORMANCE REPORTING

To process information, the proposed EiMIS provides an avenue for the firm's accountable managers to input the firm's eco-innovation data and subsequently store this data into a database. The EiMIS begins on the home page where users are presented with choices regarding their next course of action. First time users of EiMIS have the option to register their firm's details. Users wishing to register and utilize the EiMIS will be directed to the registration page. Users are prompted to enter the details of their respective firm, such as the firm's trading name, registration number, address and contact information. These details relating to the firm can be inserted by the respective user. This data helps in creating the profile for the firm and storing the information securely in the user database. Also required will be the user's chosen password so that users are able to securely sign-in or securely key-in data. Most of this required can utilize the text data type with character masking utilized for the password. Other options include creating eco-innovation report, viewing previous eco-innovation report, and viewing eco-innovation performance information.

To facilitate this entry of data that constitutes an eco-innovation report, the EiMIS GUI gives users a chance to select/consent to the terms and conditions of utilizing this software as private data may be required to be stored on a database. The GUI also consists of numeric boxes, text boxes, and trackbars to allow user to key-in the economic (eco-sales, cost of eco-sales, eco-investments, QCs and eco-patents) and environmental dimensions (waste, recycling, and standards certifications) of eco-innovation. The data for both eco-innovation dimensions is numerical in nature. Thus, eco-innovation report generation relies on decimal type data, as well as, datetime to store and trace the time of report generation.

The eco-innovation report page view allows the user to key-in the economic & environmental dimensions of eco-innovation. Should, prior to submitting the performance report, the user opt to cycle back to the main menu, they may click the "back" button and the view cycles back to main menu. Once the user completes the key-in of the eco-innovation data and is satisfied, the GUI features a "submit" button to allow the user to submit the data (See Fig. 6).

Once the user clicks the "submit" button they are prompted with a final confirmation window before final submission. Submitting this data equates to the eco-innovation performance report (See Fig. 7).

Once the eco-innovation data has been entered, the proposed EiMIS prototype aims to provide a firm's stakeholders access to this eco-innovation data and information viz the eco-innovation performance report. In order to execute this mandate, the EiMIS retrieves, disseminates and processes the eco-innovation data, subsequently compiling it into information by generating the eco-innovation performance report.

The retrieval of information is facilitated by indexing and search capabilities of EiMIS. The processing of eco-innovation data into information for stakeholders is accomplished by the analytical capability of EiMIS i.e., statistical data analysis. The dissemination of the eco-innovation performance information is also facilitated by the EiMIS GUI's presentable and easily accessible layout and functionality – which enables the eco-innovation report to be displayed in a presentable manner. Generated eco-innovation reports can be viewed or exported as HyperText Markup Language (HTML) or Portable Document Format (PDF) to an unstructured database.

B. EiMIS AND ENVIRONMENTAL DATA MANAGEMENT CAPABILITIES

To be able to boost the environmental data management capabilities of firms, the EiMIS features an architecture that allows it to be useful in an enterprise setting. As pointed out earlier in section 3, EiMIS' architecture consists of 4 tiers i.e., the Presentation Tier, Web Server Tier, the Business Logic Tier and the Database Tier. The Presentation tier is where the GUI is located and enables the users to interact with the system via the menus, and data entry forms. Second, the web server tier is responsible for handling the static content requests from clients to process onto the business logic. Microsoft Internet Information Services 7 (IIS7) is the recommended web server software due to its ability to support numerous languages including those supported in the ASP.Net framework in a secure manner [67]. This fact also buttresses the usage of .NET framework for the application server. The application layer houses the business logic, which is responsible for processing requests from the web server onto the database server. The database tier meanwhile, utilizes SQL Server for the database server in order to store and process the eco-innovation data.

This 4-tier architecture allows the users of EiMIS to store the environmental performance aspect of eco-innovation in a database i.e., the database tier. This data is stored in a structured relational database with the tables relationship being one-many. Utilizing SQL Server for the database of EiMIS enables firms to store the economic and environmental dimensions of their eco-innovation in a secured manner. Depending on configuration, this data can be made available for usage by other applications within the enterprise setting, ensuring consistency of environmental data within the firm setting. EiMIS thus, enables firms to develop reference and master data of eco-innovation, one of the pillars of data management capabilities. Master and reference data, (as exemplified by Fig. 8), can be then used by the firms for their business intelligence concerning performance.

In addition, a relational database like SQL Server allows firms the possibility of migrating to cloud-based database platforms like Microsoft Azure. Cloud-based database platforms would also offer firms a plethora of environmental data management capabilities such as reducing costs associated with on-premise database, further data exploration capabilities, data lakes, big data analytics, data-driven processes, and improved data security.

C. EiMIS AND DIGITAL TRANSFORMATION STRATEGY

One of the key pillars of digital transformation strategy is use of digital technologies i.e., a firm's ability to utilize and exploit information technologies such as software [29]. Digital transformation within firms is thus, driven primarily by information technology and also by, evolving stakeholder expectations, as well as, greater availability of data [30]. The eco-innovation performance reports from the EiMIS are generated by the eco-innovation data availed by the firms. By offering firms an ability to report on eco-innovation digitally and ensuring greater data availability, EiMIS assists in driving digital transformations of firms, in the face of a growing need to increase digital transformation coverage to environmental sustainability [30].

Thus, the proposed EiMIS prototype is able to offer firms an innovative method to communicate its value creation efforts from eco-innovation, through enabling firms to digitally generate eco-innovation performance reports (See Fig. 9).

The eco-innovation performance report will then enable the firm to communicate the eco-innovation performance information to stakeholders. Performance information that is provided by the eco-innovation report includes profit from eco-innovations, return on eco-investments (ROeI), total number of certifications, and total waste generated. The EiMIS GUI is also designed in such a way to enable the firm's accountable managers to view the performance information via the eco-innovation performance report.

Besides viewing, the managers may export the performance information in the report, so they may include it in their reporting media via several options such as print screen or copy/paste. Having access to the eco-innovation data and information will assist firms towards improving the ability to report on their eco-innovation and environmental impact as highlighted earlier in section 1.

The proposed EiMIS' ability to produce eco-innovation performance reports will also act as an enhancement to the firm's image, especially as firms are facing increasing stakeholder pressure to exhibit greater transparency concerning reporting of the environmental efforts they are making. Fig. 10 below illustrates the stakeholder groups that may benefit from the performance information contained in reports generated digitally from EiMIS:

As illustrated by Fig. 10 above, the proposed EiMIS is expected to benefit the three firm stakeholder groups and their respective elements, by providing vital performance information from both an economic and environmental perspective. The proposed EiMIS will hence, be beneficial to these stakeholders of the firm, by furnishing performance information via digital eco-innovation performance reports generated by the software that is easy to use, reliable and secure.

D. EiMIS AND POTENTIAL AM APPLICATION

AM offers firms several advantages, such as potential reduction in waste generation, as well as, the opportunity to gather more data and information across its digital spectrum. This is because, as parts are being fabricated through AM, important data and information such as geometry, processes, and materials (ferrous/non-ferrous/non-metallic and required consumables) is being gathered [68]. This data and information, sourced from designing and fabricating products through AM, can be a vital source of data for both the environmental and economic dimensions of eco-innovation.

Eco-innovation report creation requires through EiMIS requires users to input data related to: cost of sales (which factors in manufacturing costs for companies which manufacture their own products [69]); number of eco-products (for the economic dimension of eco-innovation); and waste generated (for the environmental dimension). Thus, data and information from the AM digital spectrum can ease the calculation of such figures and/or provide ready figures for the users of EiMIS to key-in this data, and, better understand their performance. This data and information from AM can help ensure accurate and transparent eco-innovation performance reporting, reducing likelihood of errors, and improving the quality of data available for analysis [70] for the performance reports generated by EiMIS.

V. DISCUSSION

A. THEORETICAL IMPLICATIONS

This paper contributes in design and development of environmental management information systems by designing and developing the EiMIS. This paper developed this tool in order to address the current gap in literature regarding the need for tools and measurement systems for eco-innovation performance measurement. This was achieved by using a top-down approach and following the suggested steps recommended by Artz [59]. By following this approach in developing the

EiMIS, this paper's findings make several contributions to academia.

Firstly, this paper began by delving into literature concerning currently developed EMIS, and unearthed the need for a EiMIS. Given that there are few practical tools developed to help measure eco-innovation, scholars of eco-innovation can take the queue from this EiMIS to further develop tools to gauge other areas of eco-innovation such as diffusion. The nature of eco-innovation is multi-disciplinary with numerous theories explaining eco-innovation and its diffusion. Scholars from disciplines like economics, marketing, sociology, as well as, agent-based modelling, all attempt to explain eco-innovation diffusion from their respective theoretical lenses e.g., evolutionary environmental economics, evolutionary economics and diffusion of innovations [71], to name a few [72]. Management scholars also weigh in on diffusion of eco-innovation. From a management perspective, adoption of EMS can possibly influence the diffusion of eco-innovations within firms [72]. As scholarly coverage towards EMS from a management perspective gains traction, management scholars can also look at the potential influence of EMS based information systems such as the EiMIS designed in this paper (which improves information availability of firms' eco-innovation performance) towards eco-innovation diffusion rates and diffusion paths. This in turn will help scholars to possibly conceive new or further refine existing theories of diffusion of eco-innovations.

Secondly, besides developing tools to understand eco-innovation diffusion, this paper's findings also may also provide scholars' an impetus to develop much needed environmental management information systems that help to address the lack of environmental performance data and information management systems. Compared to developed markets, emerging markets such as the South-East Asian region see fewer literature concerning development of tools for managing and storing data related to environmental performance and value creation emanates [73] yet, numerous environmental issues are prevalent in this region [74].

Lastly, this paper further buttresses the scholarly notion of utilization of a top-down theoretical approach in designing information systems by actualizing this theoretical approach in a practical manner. Actualizing this theoretical approach viz the 7 steps illustrated in this paper translated to a base EiMIS design that can form the skeleton for other methods to actualize top-down theoretical approaches of information system design. Thus, this current EiMIS design can serve as a foundation for scholars to develop more detailed EiMIS that can address further shortfalls in literature, by adding more functions to the current base design.

B. MANAGERIAL IMPLICATIONS

EiMIS implementation by firms has numerous potential benefits for industry. Firstly, this developed system can enable the management of firms, especially those in operational roles, the opportunity to gain an understanding on the influence eco-innovation has on the firm's operations and performance. This is achieved by the fact that EiMIS provides managers an avenue to perform quick analysis of eco-innovation data and thus, gauge its real impact – something that often times, managers may struggle to see or visualize. This can then spur them to conceive and/or possibly implement more eco-innovations, leading to greater diffusion of eco-innovation across the firm. Although managerial awareness of the potential benefits of eco-innovation is increasing, diffusion and financial benefits of eco-innovation in firms remains somewhat enigmatic for most managers [75]. Diffusion, in this context is concerned with the conditions and process with which innovations permeate into value creation systems. One of the key dimensions that determine diffusion of innovations generally, is communication with stakeholders. Communication also plays a role in determining availability of information, as well as, awareness of the relative advantage of the particular innovation [72]. Communication can help alleviate information availability between stakeholders, thereby improving the diffusion rate and diffusion path of the innovation. Thus, a tool like EiMIS can enables the managers of firms to gain a better understanding and visualize the impact of eco-innovation in their firm through, providing ready-made information such as, profitability and ROeI or by creating further performance metrics with this information (e.g., a profit: waste ratio or an eco-investment: waste ratio).

Secondly, since diffusion also factors in the embracement of eco-innovations over a period of time [76], managers can also benefit from the performance reports generated by EiMIS, as they track and potentially visualize the performance of eco-innovations over time. This understanding of eco-innovation performance, through the information provided by the eco-innovation performance reports of EiMIS (e.g., sales, costs, ROeI, profitability, etc.) can thus, help managers to understand diffusions more quantitatively – since eco-innovations are a recent development and some may need time to reach widespread adoption in numerous markets (e.g., photovoltaic (PV) energy storage systems for households [77]).

Thirdly, the EiMIS provides firms a platform to store, and document data and information concerning their eco-innovation performance. This database can then provide firms with an ability to retrieve stored eco-innovation performance data for analysis and insights. Since this data is mostly numerical and structured, it can be integrated into the Enterprise Resource Planning (ERP) software of firms for storage, further analysis and/or insights into the overall performance of the firm, especially as data is a precious resource in the current competitive landscape. Storing eco-innovation performance data and information can also provide the firm's management performance baselines (i.e., performance reference points) so as to ascertain their present performance and also, possibly enable prediction of future performance. Having more historical data and information at hand viz the EiMIS then subsequently enables the firm to conduct deeper analysis and identify past, current, and future trends – helping to possibly lower the risk associated with eco-innovations [78].

Fourthly, because EiMIS also helps firms' management to capture and document eco-innovation data and information, firms' management are thus, able to improve on their corporate environmental reporting. Because there are furnished with more data, firms would then be able to illustrate or highlight their environmental efforts and communicate them to stakeholders such as consumers, employees or host communities as opposed to greenwashing [79]. This would help improve the image of the firm in the viewpoints of consumers concerning their sincerity and dedication to sustainable development via eco-innovation. In fact, as firms target to commit towards meeting the Sustainable Development Goals (SDGs), EiMIS can help firms track and monitor their own performance and know how they are contributing towards realizing the SDGs.

Lastly, given that EiMIS consists of a 4-tier system architecture, the application does not necessarily need to be physically installed on the accessing device. As the presentation layer runs on the system device, the user potentially only needs a device to access the application i.e., a web browser (present on desktop or mobile device). Thus, this can enable the application to fall under the Software-as-a-Service (SaaS) which offers firms numerous benefits such as: firms improving their ability to innovate (i.e., product, process or service provision); lowering both types of costs (i.e., ownership costs of application development and also servicing costs associated with system maintenance); as well as; improved efficiency (i.e., the firm does not need to rely/develop software development capabilities itself) [80]. Therefore, having EiMIS as a SaaS means firms could also benefit by needing only the necessary computing or network infrastructure [81] – which is seeing an increase in intention and actual utilization in most firms [82], thus, potentially lowering potential capital costs associated with implementing EiMIS.

C. POLICY IMPLICATIONS

Policy makers may also benefit from EiMIS via several means. Firstly, the tool can potentially provide policy makers with an avenue to gauge and assess the performance or legitimate efforts firms are making towards improving their environmental performance and commitment to sustainable development. This is because, by having real data concerning eco-innovation, policy makers may thus, be able to identify firms' areas of strength, and possible weakness and therefore formulate remedial policies and tools e.g., tax incentives, etc. [83].

Furthermore, the EiMIS may provide policy makers with greater monitoring capability as they may also be part of the recipient of eco-innovation performance data and information. This can also help policy makers to know which firms are complying, reactive to policy or proactive to policy as far as (eco-innovation) environmental efforts are concerned [84].

In addition, identifying trends is also important to policy makers as the EiMIS can help alleviate the problem faced by numerous economies where policy makers lack the data and information to identify trends and thus, make policy recommendations. Trends and performance information concerning eco-innovation can thus, help the policy makers to perform their own analysis to identify national policies and frameworks [85].

Lastly, SDG number 12 aims to bring improvements regarding the production and consumptions patterns in the globe [86]. Hence, the embracement of EiMIS could potentially help policy makers by accelerating or fostering companies towards improving and increasing the amount of data and information available via eco-innovation reports. By increasing the amount of available and accessible environmental performance related data and information, a system like EiMIS can potentially assist in developing sustainability and integrated reports. This, can subsequently be vital in helping policy makers compile national data and information concerning national progress towards the SDGs.

D. LIMITATIONS AND FUTURE DIRECTIONS

The developed system offers several interesting avenues for future development. Firstly, given that the EiMIS aims to capture and store eco-innovation data and information, the initial system relies on manual data input by users. To overcome this limitation, future research may look at further developing EiMIS into automating some of the eco-innovation data input into the system parameters. For instance, eco-product data input into the EiMIS can be automated by having the eco-products equipped with newer generation Radio Frequency Identification (RFID) tags that can more closely and accurately monitor eco-products [87] and ping the relevant information to the EiMIS, instead of relying on manual input of such data. This type of automation will not only improve the data quality and integrity, but also lead to enhanced product lifecycle management.

In fact, future research can also look at how EiMIS can possibly be integrated into Product Lifecycle Management (PLM) systems [88] to enhance this firm level capability and improve on reporting capability. Also, given the expected transition towards Industry 4.0, future research can also look at how the data generated by the utilization of EiMIS by firms can enhance their big data analytics capabilities. Big data analytics capabilities can further bolster a firm's data science capabilities and help provide insights to the firm's top management, leading to reduced uncertainty of eco-innovations and improved decision making [89]. This equates to boosting the digital transformation of firms under Industry 4.0 viz accelerating firms' Industry 4.0 preparedness and capability development.

Future studies may also look at measuring or testing how this system may be received by potential users. This can be achieved using several models such as Technology Acceptance Model (TAM) or Technology-Organization-Environment T-O-E) or any other similar frameworks for example. In addition to these frameworks, it would also be interesting to observe if the utilization of EiMIS could possibly assist firms to attain or improve on their environmental reporting capability. Environmental reporting capability may

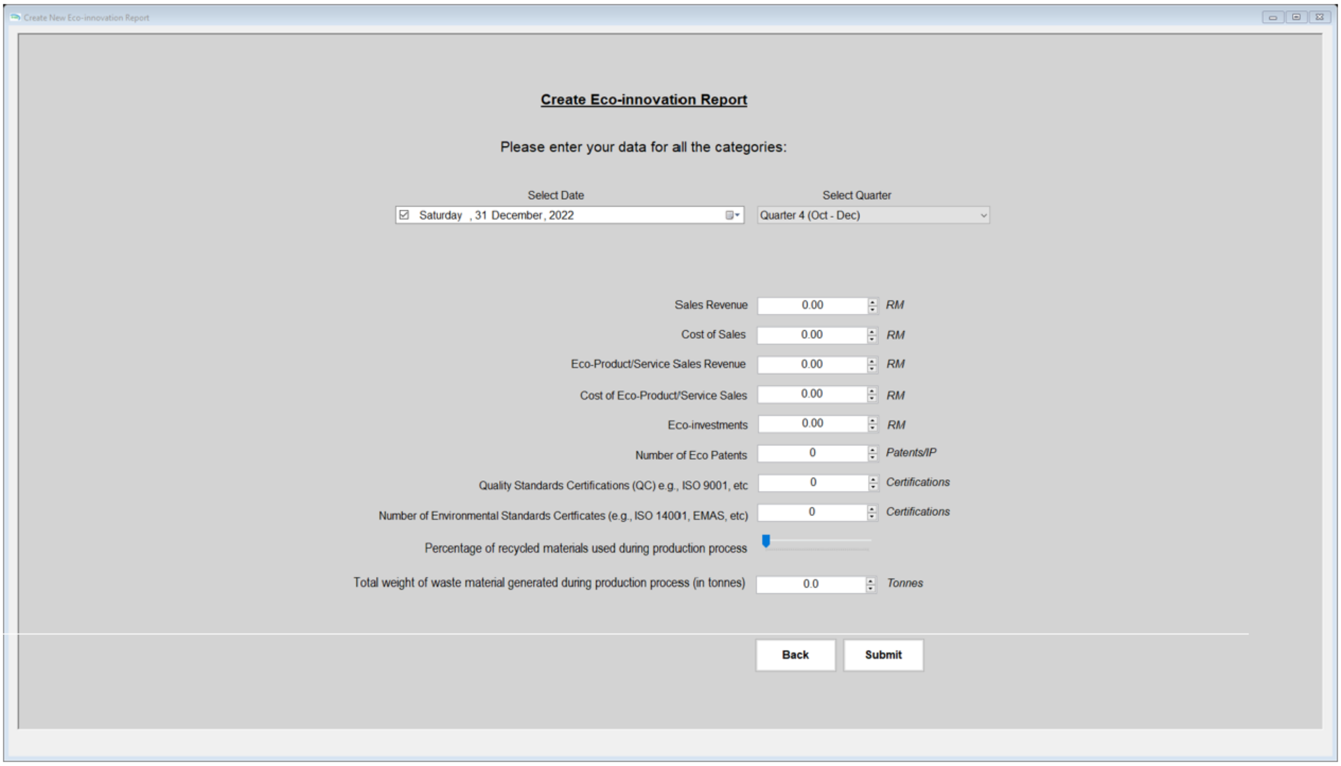

FIGURE 6. Eco-innovation performance report generation.

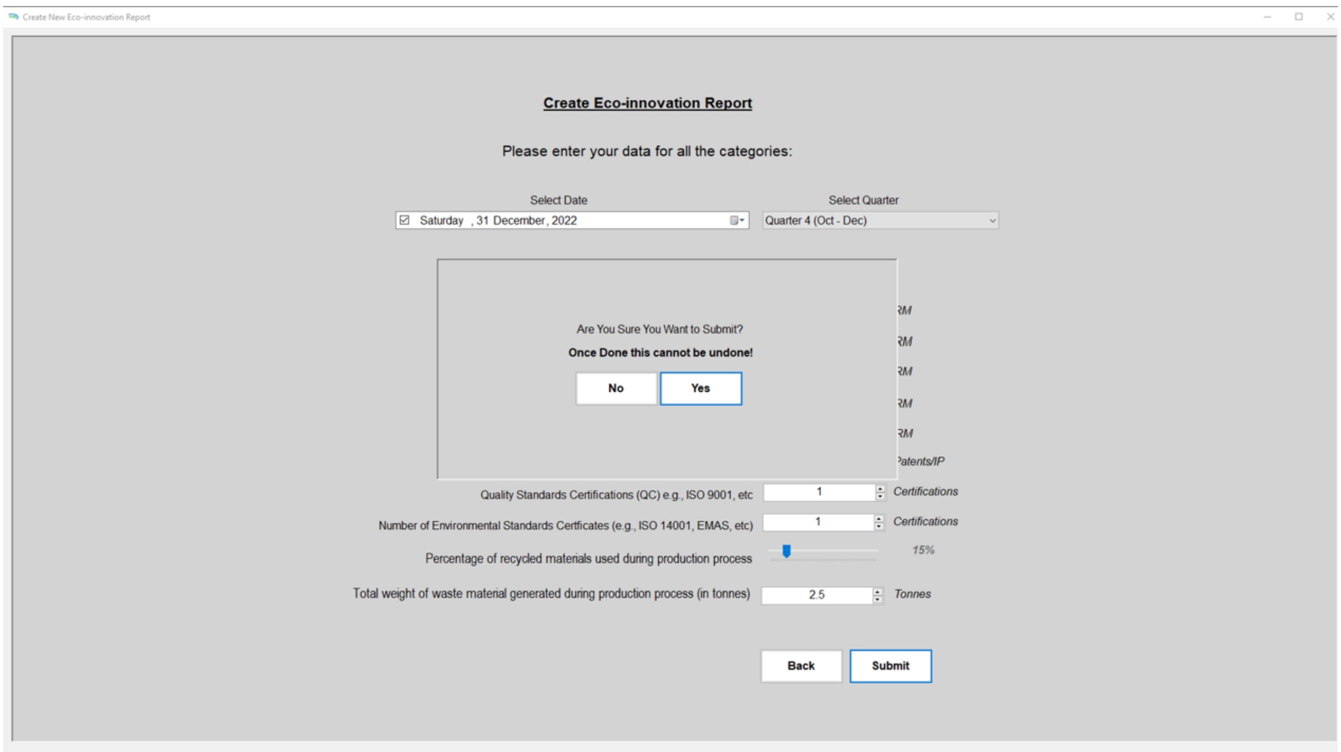

FIGURE 7. Submitting the eco-innovation performance report.

subsequently catalyze Malaysian firms expected uptake of integrated reporting (IR) as well as support firms' digital transformation strategies in Industry 4.0.

Lastly, EiMIS utilization by firms may also lead towards an increased interest/attention to environmental stewardship by firm's top management. Therefore, it may also be interesting

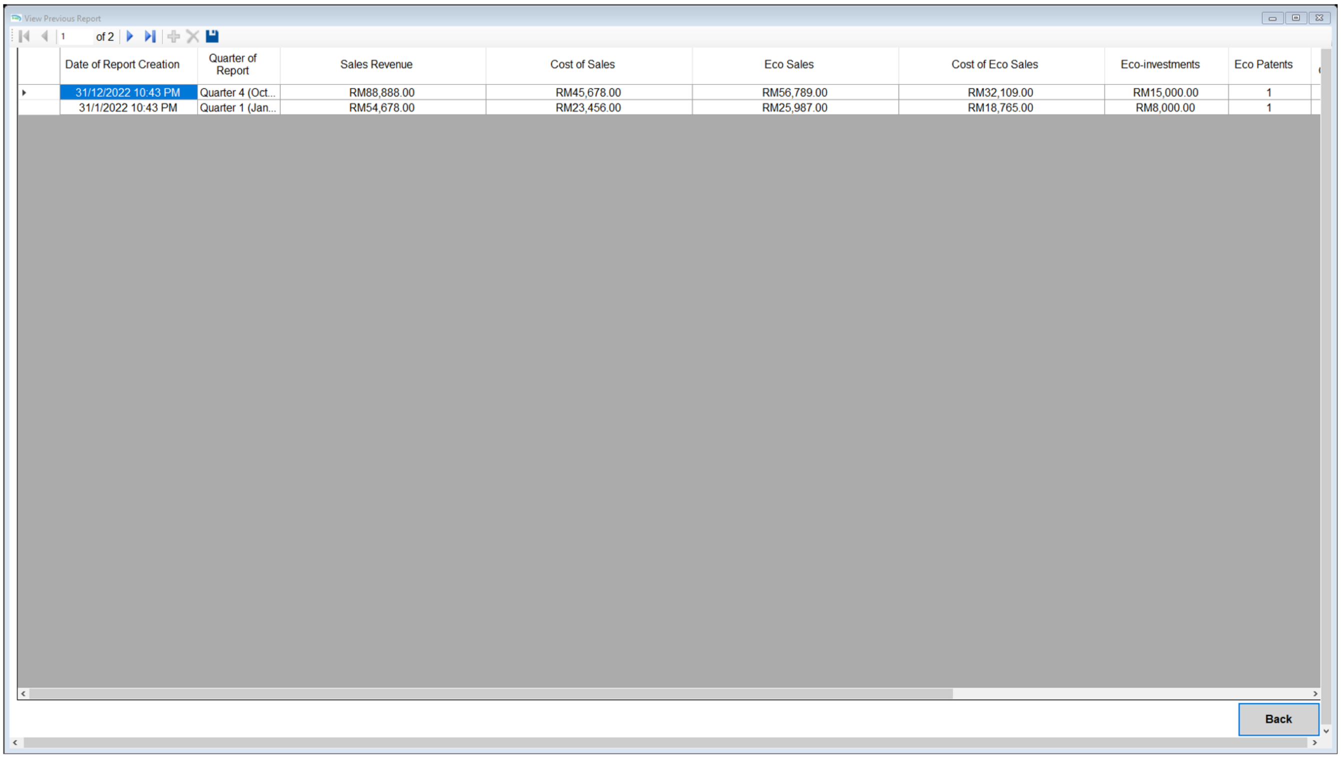

FIGURE 8. Eco-innovation stored master data example.

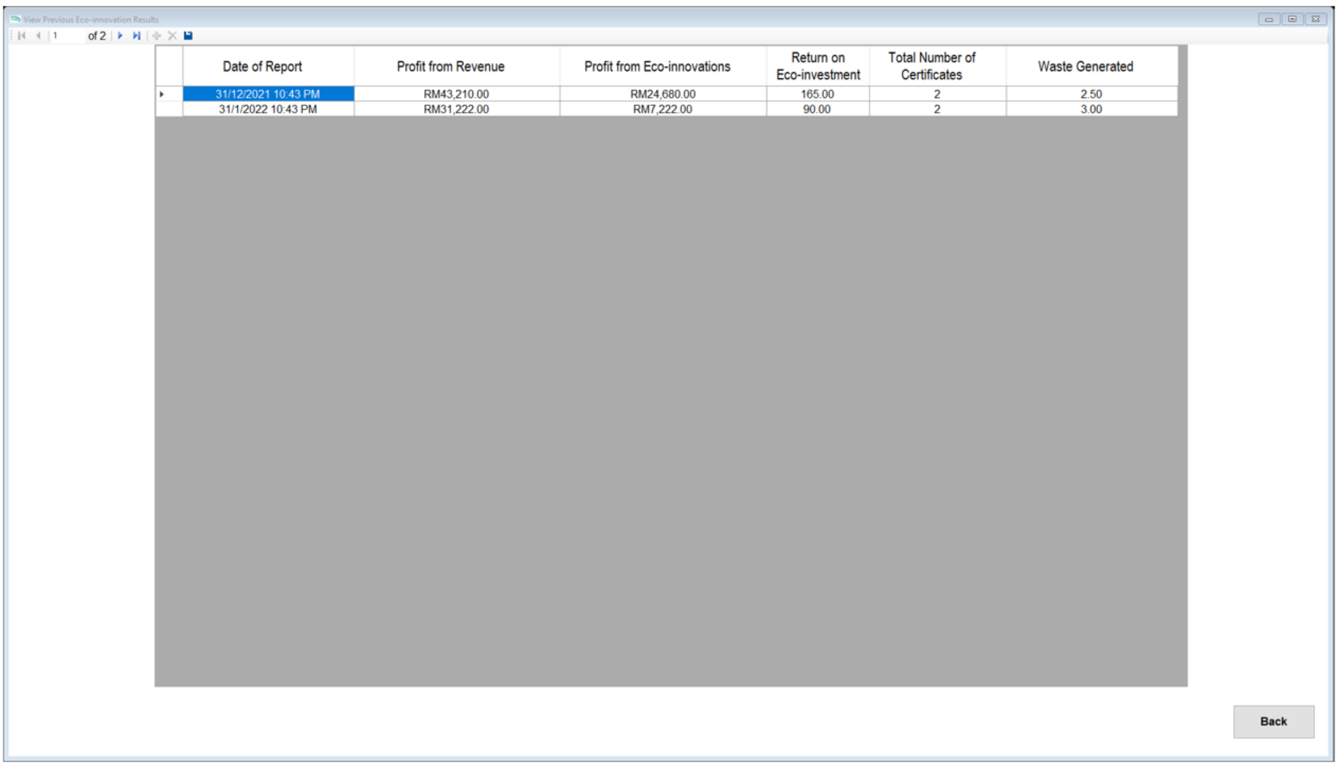

FIGURE 9. Example of eco-innovation performance report.

to observe if utilization of EiMIS may act as a catalyst for firms to develop natural environment capabilities so as to develop or preserve their competitive advantage [90]. This could be achieved through other study approaches such as conducting focus group, expert interviews or case study by beta testing EiMIS in an organizational context.

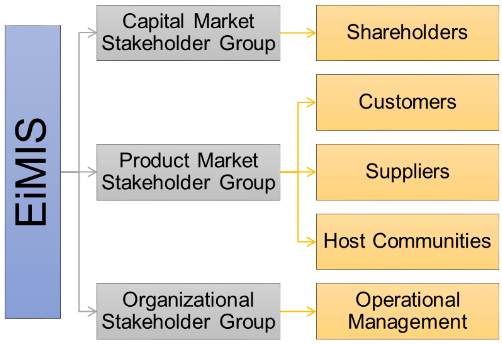

FIGURE 10. Stakeholder groups to benefit from the EiMIS.

VI. CONCLUSION

This paper sought to develop an environmental management information system – the Eco-innovation Management Information System (EiMIS) through a top-down approach. In order to do this, a 7-step method was followed that buttressed design and development of the EiMIS. Undertaking the 7-step method, in which the design and development process was broken down into a series of steps enabled the foundations of EiMIS to be established. The design and development process began by articulating the purpose and problem to be solved by the EiMIS. Thereafter, the requirements needed to bring EiMIS were crafted and included specifying the potential users of EiMIS i.e., the stakeholders of firms. Next, the proposed architecture of the system was drafted, which resulted in a 4-tier architecture to enable the users to access and use EiMIS, with tier 1 being the user interface layer and tier 4 being the database layer. Tier 2 and 3 hosted the web server and business layers respectively. To accomplish its objective, the EiMIS conceptual model was arrived viz a stepwise process with the module being broken down into sub-modules and subsequent sub sub-modules. The next key steps included determining the data needs (e.g., eco-product sales) needed by the system and also the relationships within the relational database. The design and development of EiMIS stages resulted in a presentation of a GUI that users could possibly easily use and easy navigation between pages. Thus, EiMIS, through enabling users to insert, save, view or export eco-innovation performance reports can possibly buttress the environmental strategy of firms who are able to utilize or further develop this system using the procedure demonstrated in this paper. Information from eco-innovation reports can also lead to development of interesting performance ratios that integrate economic and environmental dimensions like a profit: waste ratio or an eco-investment: waste ratio. Further development of EiMIS can also buttress the digital transformation strategies of firms, something that is essential given the expected shift towards Industry 4.0.

APPENDIX

See Figs. 6–9.

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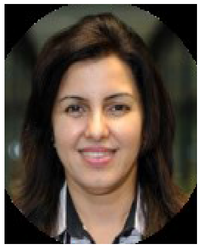

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