**A Simplified Environmental Assessment Methodology as an Alternative to Life Cycle Analysis**

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**Abstract**

Small and Medium Enterprises and research institutes engaged on eco-innovative research projects are often required to account for environmental benefits of new products, processes or services. This paper describes an environmental claims assessment methodology for calculating auditable environmental benefits for industry-led PhD projects across a wide variety of subjects. It addresses the challenges involved in conducting assessments of products that have yet to be commercialized by taking into account the quality and confidence of the data and enabling non-experts to engage with the process to a well informed level. The method draws on the most pertinent and accessible information to develop a reliable overview of the reportable outputs whilst minimizing the resource and expertise required. The process is flexible enough to cater for projects from a range of sectors, with different expertise levels, but in-depth enough to be considered an acceptable quantification of environmental outputs by rigid external reporting requirements.

1. INTRODUCTION

Small-Medium Enterprises (SMEs) account for over 99.9% of businesses in Europe, and 99.7% of all companies in the United States, with estimates from 45% to 60% of all CO2 emissions produced from their business activity (Vickers et al., 2009). At the same time, their activity also accounts for a significant proportion of new or improved products, processes and services developed with the primary intention of delivering traceable environmental outcomes (Hansen and Grosse-Dunker, 2013). Despite their significance in being able to deliver a ‘low carbon’ economy, SMEs represent a large but often under-researched constituent of the business community, with much existing research on environmental impact focusing on larger firms (Revell and Rutherfoord, 2003). Acknowledging this, Higher Education Institutions (HEIs) and funding bodies that drive research are increasingly recognising the role that small and medium-sized businesses play in delivering eco-innovation, and are actively supporting industry-focused programmes to reflect this (BIS, 2014). Additionally the IPCC report on the impact of global warming (IPCC, 2018) reinforces the need for all avenues of greenhouse gas reduction to be employed, including technological innovation, driven by policy instruments. This is supported to some extent in the UK through the Clean Growth Strategy (BEIS, 2017), defining clean growth as achieving economic growth while cutting carbon emissions.

This recognition coincides with the rise of sustainability as a central theme within the calls of many major funding bodies. For example, under current guidelines, expenditure by European-funded projects must be eligible in terms of the Operational Programme (LUC, 2014), the relevant European Commission Regulations and the National Eligibility Rules, with environmental sustainability being a cross-cutting theme for all the English European Regional Development Fund (ERDF) programmes (CLG, 2009). Similarly, for schemes in the UK and Europe, funding instruments such as Innovate UK, Horizon 2020 (H2020) and INTERREG either operate funding calls for specific sustainable themes or place a substantial emphasis on the environmental impacts of research projects. For example, over £500M of England’s 2014-2020 ERDF funding period is allocated toward projects supporting a shift toward a low carbon economy (DCLG, 2014). All projects receiving this fund must monitor and report estimated greenhouse gas reductions, with a total target reduction in CO2 equivalent greenhouse gases of over 1.2M tonnes over the 6-year funding period. Beneficiaries of the funding include SMEs, universities, and the public sector with individual projects ranging from around £500k to £5M. Employing full ISO or alternative standards in all of these projects would be impractical, yet there is no agreed methodology to quantify or estimate reductions.

Reflecting the proliferation of sustainability as a central theme in funding opportunities, the reporting of environmental impact data both as a project output and a funding requirement has become similarly common. Additionally, environmental benefits achieved as a result of university research can be employed to demonstrate the impact of research in the wider community (HEFCE, 2015), which is becoming more influential in the allocation of research funding generally. Yet, despite the increasing importance placed on quantifiable and demonstrable outputs, it is often overlooked that university projects face substantial capacity issues, both in terms of resource and providing in-depth analysis within tightly defined and closely monitored timescales. Such a capacity gap mirrors the experiences of small and medium enterprises where findings have suggested a similar lack of confidence with in-house capabilities and a reluctance to engage with new techniques (Fulton and Hon, 2010).

Small and medium sized enterprises’ hesitancy to engage with the processes of identifying environmental impacts comes despite the fact that contracts are more frequently being awarded to businesses working to environmental standards (Walker and Brammer, 2009; Walker and Jones, 2012). The authors’ own experience has identified that only one of 70 companies engaged in eco-innovative PhD projects in the North West of England has an environmental standard, in this case ISO 14001 environmental management system and PAS 2050 carbon foot-printing (BSI, 2011); the latter being funded through an European development programme. None of the 500 companies engaged with the authors’ industry-led eco-innovation research projects has paid for a formal life-cycle analysis (LCA) or life-cycle inventory. This is despite evidence that smaller comapnies can achieve a greater market share through engaging in environmental practices (Menguc and Ozanne 2005). A survey conducted by Testa et al. (2016) demonstrates that quantifiable environmental claims are employed by SMEs particularly to endorse ‘green’ marketing activities as they positively impact on company brand and influence customers’ intention to purchase a product (Molina-Murillo and Smith 2009).

The economic incentives for SMEs engaging with environmental standards are therefore three-fold: (i) supply chain pressures, (ii) increased funding opportunities, and (iii) marketing and brand perception. Making environmental claims without sufficient evidence, or if the offering is ambiguous, confusing or short on evidence can even be detrimental to a company, and dismissed as greenwash (Bickart and Ruth, 2013). This may ultimately be off-putting to consumers (Bustillo, 2009), thus further demonstrating the need for an easily implementable systematic approach for accounting environmental claims. In light of this, and in an attempt to standardize approaches, a number of guidance documents have been created such as: the European Commission’s (EC) set of principles for communicating the environmental performance of products (European Commission, 2013). In the UK Defra has published guidance for making accurate environmental claims (Defra, 2016), and the EC has likewise published compliance criteria and guiding principles (EC 2012, 2016; Multi- Stakeholder Dialogue on Environmental Claims 2016; Ministe`re de L’Ecologie du

Développement Durable des Transports et du Logment, 2012) for environmental claims all of which require the inclusion of factual, referenced and current data. ISO standards have also developed to encompass environmental claims through general principles of environmental labeling and declarations (ISO 14020:2001) and comparisons between products (ISO 14025:2010) that, in contrast to the Defra and EC guidelines, both rely on the company undertaking a formal ISO 14044 LCA.

Building upon the previously identified gap in the literature which fails to cater for small and medium enterprises and universities undertaking eco-innovative research projects, this paper seeks to explore how that gap might be closed through the use of an environmental assessment process that address existing shortfalls, most notably by drastically simplifying the work that has to be undertaken whilst still producing credible and auditable outputs. The process is based on an LCA-like standardized systems approach and follows aspects of LCA principles in that boundaries are set, functional units defined, upstream and downstream effects are considered, and outputs are quantified. LCA streamlining techniques are employed to reduce the complexity of the assessment, such as focusing on specific environmental impacts, limiting or eliminating upstream and downstream stages, and applying threshold criteria (Todd and Curran, 1999).

Importantly, this methodology is not intended to be a substitution for a full LCA or simplified LCA, but a repeatable and structured process to determine the change in environmental metrics through development and deployment of a new or improved product, process or service. By focusing on the *change* in circumstances many variables considered for a full LCA need not be included. This is justified through the companies’ and funders interest in the benefits of investing in the new or improved product as compared with the status quo. Also, it is often difficult or impossible to directly measure the impact; this methodology allows outputs to be estimated through logical assumptions. It has been employed by the authors on 70 industry-led collaborative PhD projects and is subsequently being applied by additional universities for similar industrial eco-innovation projects at the request of the funder on a further 50 PhDs and 35 1-year Masters by research projects.

2. CASE STUDY

The methodology described in this paper has been developed and tested on the Centre for Global Eco-Innovation and the Low Carbon Eco-Innovatory. Both of which are university programmes part-funded by the European Regional Development Fund, undertaking collaborative industry-led research in the development of new products, processes and services that are energy- and resource-saving. At the time of writing over five hundred companies have been assisted, including seventy PhD projects that commenced between October 2012 and July 2017. All applications for assistance must clearly demonstrate the potential for significant environmental benefits that, as a requirement of the funding body, need to be reported across four areas, namely:

1. Reduction in CO2 emissions
2. Re-use in material or material reduction
3. Reduction in material sent to landfill
4. Water saved

The objectives of the companies, universities, and the funded research programmes, are therefore closely interlinked, with all parties motivated to reduce negative environmental impacts of products through clean growth.

As the fundamental driver for the research programmes is the development of eco-innovative products, processes and services they are not bound by sector nor subject, but by commercial needs. Consequently, assisted projects cover a diverse range of sectors relating to a variety of topics. Reflecting the diversity of these projects, the range of academic departments engaged with the programmes is similarly diverse. This array of projects, sectors and faculties, therefore, not only demonstrates the need for a cross-cutting methodology for calculating environmental outputs but simultaneously provides an ideal platform for developing and testing a universal process to assess eco-innovative research projects’ environmental claims for use with both university research projects and commercial R&D outputs.

3. AN ENVIRONMENTAL ASSESSMENT

This section describes the implementation of a methodology designed according to the considerations above, and examines the application of those simplified processes in a practical setting by applying it to the industry-led PhD projects. The aim of such an exercise is to determine whether the recommendations represent a meaningful processes relating to environmental claims, and the extent to which they can address the capacity issues of both industry and academic researchers in accounting for the environmental outputs of their work. Section 4 of this report contains some examples of the approach detailed below, demonstrating how the methodology’s rationale has been developed and applied.

From the outset, and acknowledging the complexities of such an array of research projects spanning numerous industrial sectors, the basic expectation was that the each researcher would take on a significant responsibility for developing the assessment of their project. This would both be more practical and represent a value-added output as part of the project. Acknowledging the researchers lack of familiarity with the underlying principles of life-cycle analysis, life-cycle thinking and environmental accounting, they would each have access to a facilitator who had some relevant experience, but was not necessarily a certified or professional environmental assessor.

To guide the researchers through the process, a pro forma was designed that could also be used as a tool for auditing purposes which also allowed for data across a number of projects to be quickly collated. In this instance, the pro forma was developed to reflect the funders output monitoring criteria, taking into account the principles discussed thus far via decision points to determine:

1. Subject; the main contributing factors: CO2, water, material, landfill.
2. Scale; identifying baseline quantities to set minimum thresholds below which the benefits are considered negligible.
3. Scope; boundary setting through identifying elements that can reasonably be attributed to the project outputs and can be quantified or directly measured.

The pro-forma was developed across two distinct stages. The first, outlined in Figure 1, details the processes for subject selection and boundary setting; the second, shown in Figure 2, quantifies the outputs. In the case of the Centre for Global Eco-Innovation, all projects received funding based on their ability to contribute to a minimum of one of the output monitoring criteria listed in section 2. All Low Carbon Eco-Innovatory projects were funded based on their ability to contribute toward CO2 reductions, as required by England’s Operational Programme Priority Axis 4 (Ministry of Housing, Communities & Local Government,, 2019)

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Figure 1 – Initial Boundary and Threshold Setting Process for Identification of Contributing Activities

* 1. *Boundary Setting*

The application of the methodology begins by looking at what can be measured, estimated, judged and interlinked. This starts with an initial boundary-setting exercise that helps to identify and justify the inclusion of the appropriate activities and outputs. In this case, for example, not all projects will report reductions in waste to landfill or water savings.

Additional considerations include feedback and rebound effects (Sandén and Karlström, 2007; Font Vivanco et al., 2016), such as what happens to material that will no longer be used as the result of a modified process, or improvements in efficiency driving costs down resulting in consumers spending more with the liberated income, thereby increasing overall energy consumption. These are, however, generally considered outside the scope of the assessment unless a direct link to rebound or feedback effects can be demonstrated and verifiable data can be recorded.

The boundary setting is also informed by a self-identification of the project’s minimum threshold values for each reportable output. In most cases an eco-innovation is developed with a clear understanding of the major environmental benefits. Thus, by identifying the main contributing activities and potential reportable outputs, minimum thresholds could be set on a case-by-case basis. Some projects may need to report a number of outputs through various sub-criteria, while others may have only one major contributing mechanism or activity to quantify. For example, section 4.4 describes a PhD project that has many potential different mechanisms to reduce CO2 emissions through optimizing shipping, more efficient dredging, and reducing construction of large-scale coastal defences; all of which require distinct approaches to calculating the environmental benefits, and each account for thousands of tonnes of CO2 reductions. Another, on the other hand, had water consumption as the single major contributing factor, saving over 600 tonnes of water per day at a local airport. Other minor energy consumption parameters such as 7.2 KWh per day used by water quality monitors were insignificant in comparison and need not be included. This aims to focus effort on high quality reporting and reduce time spent on reporting potentially insignificant sub-criteria i.e. the methodology does not require the practitioner to record *every* potential environmental saving or *every* activity related to their project, only those making a significant contribution.

Upstream and downstream components are also considered. Most, if not all, of these effects will be outside the control and scope of their project, however, may be reported if significant and quantifiable. For the above example, developing a process to dramatically reduce water usage, is required to investigate upstream effects of reduced water consumption but not necessarily required to fully assess the potential for recycling its materials at end of life unless the design offers significant advantages over existing products and is an integral part of the overall product development. This again helps to omit calculations that may be beyond the capacity of the researcher that can lead to additional unaccountable, erroneous or questionable environmental impacts to be recorded. Justifications are required for impacts omitted from the calculation to ensure that there are no unreasonable exclusions.

Building on the discussions of the capacity issues of small and medium sized businesses, the researchers were also encouraged to focus on first generation impacts, i.e. those which would be caused directly or reduced by their projects. In doing so, this minimised opportunities for them to become sidetracked through attempting to procure and analyse extraneous data such as consequential, uncontrollable external effects, i.e. what may happen in the future as a result of the product development. Guidance notes were also provided at this point, detailing additional advice such as sources of information on carbon emissions, carbon calculations, embedded carbon, changing various data from imperial to the international system of units, calculating energy use from kWh and basic guidelines for scenario building (Börjeson et al., 2006).

* 1. *Standardising the approach*

The next stage is to conduct the substantive part of the assessment within one (or more) of the reportable outputs. An outline of this process is set out in Figure 2.

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Figure 2 – Example Outline of the Decision Making and Data Collection Process for Calculating CO2e

At this point, the format of the outputs was standardised, with data originally reported in two sections:

(i) Section 1 focused on project lifetime; defined as activity that would occur within the lifetime of the PhD project. This was only intended to form a small part of the assessment exercise; to introduce the researchers to the basic principles.

(ii) Section 2 focused on the longer-term outputs of the research, forming the major focus of the assessment and providing a significant indication of what the projects will achieve. There is not an expectation to answer *every* question but rather to self-select the most relevant to the individual project.

It was quickly discovered that Section 1 was causing confusion; with many of the researchers concentrating on reporting daily travel and power consumption which would be insignificant when compared to the outputs recorded through the development of the new product. An example of this is given in 4.1 below in which the potential environmental benefits of the project far outweighed the daily travel and power savings that were judiciously and comprehensively calculated by the researcher. The assessments therefore concentrated solely on Section 2, the long-term outputs.

Within a particular subject (i.e. reportable output), the first stage is to identify the nature of the measurement. Metrics for material (tonnes) diverted from landfill, water and raw material saved, are relatively simple to calculate, with CO2 reductions being more involved.

*3.3 Calculating Reductions in Greenhouse Gas Emissions*

Using CO2 emissions as an illustrative example, as shown in Figure 2, the potential source/nature of all emissions are considered, such as transport, manufacturing or chemical processes, and treatment of waste. This is primarily calculated through energy use in each of the processes before and after the innovation, which is later converted to carbon equivalent (CO2e).

Any variables that have readily available carbon conversion factors need not be considered at this stage and can be added to the calculations while converting all variables to CO2e, in equation (5). Materials, for example, are generally not considered at this point as there are a number of databases listing a wide range of materials such as the UK government greenhouse gas conversion factors (BEIS, 2018). Other variables such as transportation that might also be included in standards can be added later in the process rather than being included from the outset in equations (1) and (2). For example, transportation of many construction products such as concrete and aggregates is standardised into kgCO2e/km thereby simplifying the calculations in many situations. This can considerably reduce the resource and expertise required. The following equations are used as the basis of the CO2 calculation:

***e****a* = ***t****a* + ***p****a* + ***c****a* + ***w****a*+ ***u****a* (1)

***e****b* = ***t****b* + ***p****b* + ***c****b* + ***w****b*+ ***u****b* (2)

where ***e*** is the total lifetime energy of the product (kWh) excluding any variables that have standard conversion factors, consisting of: ***t*** energy use due to transportation and logistics, ***p*** energy consumed in manufacturing processes, ***c*** energy use in chemical processes, ***w*** energy used in the treatment of waste, and ***u*** the energy used in situ by the product. In (1) above, subscript *a* denotes the original value, prior to the new or improved product or process, and in (2) *b* denotes the status as a result of the research.

Importantly, if the value of the variable is insignificant or there will be a negligible variation from the original to the new product it may be ignored as it is not necessary to calculate the total CO2e of the product, rather the change in CO2e due to the outputs of the research project.

Each energy source may also be broken down to constituent parts, for example a manufacturing plant may use a mix of energy with different CO2e conversion factors. For example:

***p****a* = ***p****ar* + ***p****af* + ***p****ag* (3)

where ***p****ar* +is the energy from renewable sources, ***p****af*  is the energy from fossil fuels and ***p****ag* is the energy from natural gas. A similar breakdown may often be relevant for transportation or energy use. Section 4.2 describes a project whereby an examination of an energy mix enabled a safari park to dramatically reduce its carbon footprint by purchasing electricity from only renewable sources.

At this point each assessment will derive an individual expression. Assuming an example in which there will be no change in transportation or waste disposal, no chemical processes but a 3-part energy mix used in production, there will be 3 variables for production energy as in (3) above, plus the estimated energy consumed by the product in situ, giving:

***e****a* = (***p****ar* + ***p****af* + ***p****ag*) + ***u****a* (4)

Equation (4) demonstrates a significant shift from a holistic LCA, where all contributing factors would be required.

At this stage the CO2e is calculated and any variable that was excluded from (1) and (2) due to the availability of conversion factors, such as materials and transport, are entered into the calculation.

***C****a=*(***p****ar \*****f****1* ***+ p****af \*****f****2 +* ***p****ag\*****f****3*)+ ***u****a\*****f****4* + ***t****a\*****f****5**+* ***m****a\*****f****6…* **+ *x****a****f****n*(5)

Where ***C****a* is the GHG (CO2e) equivalent of the original product that is subject to change (i.e. ignoring any parameter that will remain constant), ***f****1..n* are the associated conversion factors to CO2e, ***t*** is the transportation mileage (km), ***m*** is the amount of material used (kg), and ***x***denotes additional variables which have standard conversion factors that were not included in equations (1) and (2). Similarly for the new product:

***C****b=*(***p****br \*****f****1* ***+ p****bf \*****f****2 +* ***p****bg\*****f****3*)+ ***u****b\*****f****4* + ***t****a\*****f****5**+* ***m****a\*****f****6…* **+ *x****b****f****n*(6)

For many calculations, this is comparatively straightforward, especially when utilizing data from, for example, existing production facilities that will not change significantly to process an upgraded product. If the production facilities do not change and transportation remains the same for the new product then the ***p*** and ***t*** terms in equation (6) may not be different for the new product; thus only the material and its in-situ energy use may be relevant.

In all cases the before and after calculations are then completed:

***ΔC*** = ***C****a* - ***C****b* (7)

where Δ***C*** is the total change in CO2e due to the new product or process.

For completely new products it will not be possible to calculate a baseline ***C****a* value, but it may be possible to compare against existing products. If there are no comparable products the value will be derived from the in-use benefit of the new product versus the CO2e attributed to its production and distribution. For example, one PhD is developing a novel anti-biofouling coating that can be applied to ships hulls to reduce the drag coefficient has no comparable product, however, the production and installation will require additional materials, processes and distribution when compared to the status quo. The benefits will solely be realized through more efficient use of ships fuel. In this case the CO2 reductions will be calculated by:

***e****a* = ***t****a* + ***p****a* + ***c****a* + ***w****a*+ ***u****a* (8)

where:***t****a* , ***p****a*, ***c****a*, and ***w****a = 0*

i.e. only the energy from fuel use (***u****a*) is taken into account, as there is no current comparable product applied to ships hulls to reduce drag, thus no energy involved in any transportation (***t****a*), production (***p****a*), chemicals (***c****a*), or waste (***w****a*). For the new product:

***e****b* = ***t****b* + ***p****b* + ***c****b* + ***w****b*+ ***u****b* (9)

where: ***t****b* , ***p****b* , ***c****b* and ***w****b* will be energy used in the manufacturing, logistic and such, related to the new coating; however, ***u****b* should considerably offset this through being significantly less than ***u****a* i.e.:

***u****a>* ***t****b* + ***p****b* + ***c****b* + ***w****b*+ ***u****b* (10)

and,

***e****a >****e****b* (11)

For new services there may also be no comparison, in this case the default will be the difference compared to doing nothing or maintaining the status quo.

*3.4 Auditable Records for Project Management*

When presenting results, all calculations and rationale are recorded in order to demonstrate robust logic and to identify any flaws. As an extension to this, it allows data to be presented within a set of upper and lower boundaries. This is particularly appropriate if product or service outputs are based on market penetration, or predicted levels of usage. Although this is in contrast to the European Commission’s guidance on environmental claims that recommends achievements rather than aspirations are reported (Multi-stakeholder Dialogue on Environmental Claims, 2016), in the case of research projects the aspirations of the product are an important factor for understanding the potential impact of the innovation. Such projections are useful internally within the company, to guide the innovation process and strategic decision making (Saunders et al. 2013) and for potential funding applications.

The final stages involve attributing a self-identified set of values to the data. The first is an indication of the confidence of the data. By indicating a data confidence level, each environmental assessment can suggest the likelihood that the calculations will be realised, taking into account the quality of data available. Combining this with the perceived quality of the data allows for reasonable representations of expected environmental impacts to be estimated, enabling the project monitoring team to model potential scenarios and progress toward funders targets. For the above example of developing anti-biofouling films, the likelihood of the sufficient quantities of the product being manufactured and in service on a fleet of ships by the completion of the PhD is low, however, the potential reduction in CO2 emissions if applied to a small number of vessels could equate to millions of tonnes per annum. It is therefore important not only to record the actual output of the PhD project but also the projected potential, the quality of the data and the likelihood of the projection. Section 4.3 describes an assessment in which a highly detailed scientific analysis of the materials and processes was conducted, but market penetration projections were not as confident and therefore an important inclusion in the reporting of the data.

**4. Example Applications of the Methodology**

To illustrate how the protocols can work for a variety of different projects, the following section focuses on four projects to demonstrate how these protocols were deployed and the challenges posed by a range of projects each attempting to report quantifiable outputs via disparate mechanisms.

*4.1 Example One – Service/Greenhouse Gas Emissions*

This project explores ways to improve the 3:1 success/rejection ratio of the planning process for wind turbines in the UK, creating mapping software to combine regulatory and environmental conditions. The environmental benefits of this will be two-fold: (i) by analyzing how and why previous applications have been successful or otherwise, the company can tailor their activity in response, and (ii) this has the potential to lead to an increase in the number of wind turbines by minimizing work on unsuccessful applications (Baban and Parry, 2001).  In the original draft, however, the researcher only considered the improvements in efficiency savings created by the technology due to a reduced number of site visits, as the information would be available remotely in the software. The researcher reported detailed CO2e calculations for bus, rail and car journeys and estimated the baseline of energy use in the project (i.e. the amount of CO2e created by one employee in a given period of time) using comprehensive emissions data.  During the follow-up meeting with the facilitator the additional benefits attributed to the project by increasing the uptake of wind technology were recognized by guiding the researcher through the boundary setting process. The assessment was therefore broken down into two main stages to reflect (i) the short-term reductions in energy use due to implementation of the improved planning application process and, (ii) the longer-term environmental outputs delivered by increased success in wind turbine applications.  Considered alongside one another, the assessment demonstrated that a single successful turbine application will offset over 100 years annual CO2e of an employee’s activity.  This is a clear example of how a full-blown LCA exercise could overcomplicate issues, encouraging the researcher to calculate insignificant impacts such as the day-to-day transport savings and all other minor office based impacts which are dwarfed by the main contributing factor.

*4.2 Example Two – Following the GHG Protocol*

This project aims to reduce the carbon footprint of a safari park to zero (Finnegan et al., 2018). Unlike most other PhDs in the programmes, this project is concerned with the carbon footprint of the entire business, and is not focusing on one product or issue in particular. Using a corporate level approach and applying the Greenhouse Gas Protocol (WRI, 2014) energy usage data for every aspect of the park was collated and converted into CO2e. This approach broadly follows the same principles as the methodology described in this paper, with scope and boundaries set at the outset and all relevant data examined. In this case, however, no variable was considered insignificant as the company wanted to have a complete account of the carbon footprint. Unfortunately, some data was not possible to accurately measure, such as diesel use in the fleet of vehicles. As with the general principles of the methodology described herein, the difference between precise and estimated diesel data was considered insignificant compared to the total annual energy use. Other items such as the CO2e of food consumed in the food courts or waste management were not accounted for as they may have been double counted through suppliers and third parties. This resulted in the same data being recorded via the GHG protocol and the environmental assessment methodology described herein. Tracking the change in output due to suggestions from the PhD project the following 12 months showed a reduction in CO2e from 489 tonnes to 400 tonnes, through investing in new energy monitoring technology, refurbishing all water systems, and changing the energy mix from suppliers to use a higher percentage of electricity from renewable sources.

*4.3 Example Three - Product/Material Savings*

In this example the project is refining the technology used in domestic washer-dryers, specifically attempting to reduce the amount of material used to coat the heater elements through the use of new heating elements and materials using porous metals for thermal management (Baloyo, 2017).  In this case the researcher is a chemist working with powder-based metal alloys, exploring material optimization whilst still delivering maximum heating efficiency. The project has wide-ranging environmental impacts, with significant reductions in both CO2 emissions and raw material use.  It was estimated that a saving of 90% could be made on the material used by replacing traditional coiled wire heating elements with flat panel installations sprayed with a novel alloy powder with vastly improved thermal properties.  Up-scaling this to reflect the company’s expected market penetration of approximately 20% of 1 million units per annum in the UK shows that the innovation can be expected to save 9 tonnes of raw material per annum.  This assessment highlights the value of utilizing confidence assessments within the data analysis.  The material savings are delivered with a high degree of confidence, backed up by detailed scientific calculations.  Energy consumption calculations generated from complex production process maps estimated that production of each coiled wire heating element requires 2.28kWh input compared to flat panel heating elements only requiring 0.5kWh. Based on the respective operating temperatures of the two products (to generate the same end use drying effect) the new flat panel heating elements were estimated to be 20-40% more energy efficient. From this, 90,000 tonnes of potential emissions savings were calculated through the use of more efficient domestic appliances, albeit with a lower confidence. This reflected uncertainty in the quality of longer-term data such as market penetration, efficiency savings and consumer habits. In this case a number of sub-criteria were used to calculate the overall benefits: (i) improving the manufacturing process, (ii) utilization of novel materials, and (iii) investigating potential applications, all contributing towards describing potential environmental benefits, albeit with various confidence levels for different applications.

*4.4 Example Four – Coastal Defenses and Shipping*

This project is developing a novel radar system for sustainable port operations and coastal management by integrating navigation and traffic management capabilities with remote depth and hydrodynamics measurement (Bell, 2016; Bird 2017). In this case the environmental benefits will vary greatly between different port authorities and will very much depend on uptake of the technology, as every port that adopts the radar system will substantially increase the reportable environmental outputs. The key impacts are:

1. Predicting sediment migration will enable better targeting of fuel intensive dredging operations. Using existing data for dredger fuel consumption, the estimated fuel use for dredging operations was equated to over 6,600 tonnes of CO2 for the prototype site on the River Mersey. It is estimated that this can be reduced by at least 5% per annum, i.e. a saving of over 300 tonnes of CO2 per year for a single installation. The company has contracts with over 20 ports globally, each requiring a range services. Thus substantial additional long-term CO2 savings are probable, but not yet quantifiable.
2. Reduced requirements for regular ship-based morphology surveys will reduce fuel use further, although no data were available at the time to report the duration or miles completed by ships during the surveys.
3. Shipping routes can be optimized in real time to reduce the amount of time ships move against the current. As fuel use is a function of ships’ speed, which will be dependent on the velocity of the current, this has the potential to reduce fuel use further.
4. A reduction in volume of dredged sediment dumped in designated spoil zones. In the River Mersey, where the prototype system is situated, 148,127 tonnes of sediment was removed in 2010 (Bailey, 2010). Reducing this by only 5% would result in a significant reduction in the amount of sediment being dumped (over 7,000 tonnes).

Reporting actual data for (i), (ii) and (iii) above is not currently practical as part of the environmental assessment process due to the amount of parameters required to conduct complex fuel use calculations for particular types of vessels conducting various operations in each location. In addition each port will have unique bathymetry, currents, traffic and dredging requirements. Data will only be available to demonstrate the environmental benefits once the prototype system has been in situ for enough time to compare dredging operations before and after installation. This example highlights the challenges in: (i) obtaining useful data after identifying the major sources of environmental benefits, (ii) how conducting a formal LCA can become resource intensive when reporting additional benefits, and (iii) how the impacts of additional sites and new clients can dramatically change the outputs.

Following increased use and development of the technology the company was able to determine that a 1km length of planned sea defense would not require a large precast section concrete structure as used on a beach with similar topology along the same coastline. By using only a rock armour the structure would save over 10,000 tonnes of CO2e associated with manufacturing and transporting thousands of 14 tonne reinforced precast concrete modules. In this case there is an overall increase in CO2e emissions, due to the construction of a new rock armour structure, however the project has led to an estimated 90% reduction from the original concept.

**5. Results and Analysis**

Of the initial 50 PhD projects 90% were able to follow the methodology to record environmental outputs, with only 5 examples unable to attribute environmental impacts to the product or service. Eight were unable to complete due to either commercial sensitivities, late starters replacing researchers that were no longer on the programme, and attrition. As discussed earlier, the likelihood of each of the environmental outputs was an integral part of the process. The weighting that each assessment attributed to the calculations allowed for these outputs to be grouped into two broad categories: (i) conservative, with a ‘high likelihood’, i.e. with an estimated 75-100% chance of being achieved; and (ii) reasonable, with a ‘good likelihood’ of happening, but relying on external factors, i.e. an estimated 50-75% possibility.

**Table 1 – CGE Projected Outputs (High Likelihood)**

\*Bold denotes when the target will be met

During the lifetime of the first funded programme, the Centre for Global Eco-Innovation, and based on calculations delivered to a conservative standard, the projects registered environmental outputs related to the funders target outputs (see table 1). Combined, the assessments identified a ‘high likelihood’ of over 60,000 tonnes of CO2, 731,000 tonnes of water, and over 13,000 tonnes of material diverted from landfill by the end of the initial monitoring period. This demonstrated that, although significant, the outputs would only be on track to meet CO2 emissions and water saved target on completion of the PhD projects.

**Table 2 – CGE Projected Outputs (Reasonable Likelihood)**

\*Bold denotes when the target will be met.

The addition of calculations that were considered to be of a credible nature, however, significantly improved progress against the environmental targets with water, material savings and CO2 emissions on track to be met by 2017 (see table 2), the environmental impact target deadline.

There were also a number of outputs that were difficult to quantify as a reportable output but no less worthy of inclusion, owing to being delivered across longer timescales or displaying outputs that were not directly related to the 4 monitoring criteria, for example, an increase in biodiversity on building sites for new homes due to environmental technology or the ability to monitor important ecosystems such as wetlands and saltmarshes via marine radar.

50% of current PhD projects have been able to report potential or actual CO2e savings within 18-24 months of the project start date. Due to the breadth of projects supported there is a wide range reductions from an estimated 10,028 tonnes due to a reduction in the scale of a coastal defense structure, as described in section 4.2, to just 3 tonnes per annum from a company developing and installing aquaponics in local hospitals, school and businesses, which is expected to improve with increased market penetration.

In addition to the PhD projects the process has also been applied to smaller scale projects; from 1 month internships, 3-6 month dissertations, short post-doctoral projects typically spanning 1 week to 2 months, plus 1-year masters projects. Over 300 such projects have resulted in over 100 assessments being conducted for projects where potential CO2e reductions were noted. It should be noted that not all projects will deliver an outcome, some may advise businesses on potential solutions or strategies and others may determine a product is not viable, or requires further research.

**5.1 Reflections on the Environmental Assessment Efficacy**

The completed assessments can be described in four main categories:

1. projects that were able to identify quantifiable outputs albeit, some prior to full commercialization,
2. those relying on experimental data before results could be confidently reported and environmental outputs attributed to the research,
3. projects unable to definitively attribute environmental outputs to the development of the product or service, and
4. difficulties in reporting outputs as yet due to commercial sensitivities.

*5.1.1 Successfully Reported Results*

Approximately 50% successfully identified and reported confident and auditable outputs in one or more of the reportable output criteria without additional meetings with the facilitator. The remaining 50% fell within categories (ii), (iii) and (iv) above. This figure at first appears to be relatively low, but should be considered in the context of eco-innovation development, i.e. prior to development of the innovation it can be difficult to definitively attribute or quantify an environmental output. The assessments were initially instigated in order to monitor and understand the scale of the overarching programme’s environmental outputs, thereby enabling the management team to plan around any potential shortfalls. The completed assessments gave much greater insight into the mechanisms for environmental benefits of the new products than the original applications completed by the companies and academic supervisors prior to funding being allocated to the projects. This suggests that the methodology enabled the researchers to engage with the process to develop arguments, through robust and traceable assessments and assertions in order to quantify auditable outputs and refute potential accusations of ‘greenwash’. Following submission, the researchers answered a questionnaire relating to their experiences, the results of which demonstrated that very few considered themselves to be experienced in producing environmental assessments which also suggests that building capacity is not required if a facilitator is available guide practitioners through the process.

*5.1.2 Reliance on Experimental Results*

Twenty-two projects were able to identify the mechanism for reducing negative environmental impacts but were not able to quantify the outputs, due to a reliance on experimental data that had yet to be obtained. This is due to the timing of the assessments exercise within the PhD projects. In order to monitor expected environmental benefits from existing projects and plan accordingly, the management team instigated the assessments half-way through the 3-year projects.

In 10% of cases, and despite guidance to the contrary, some assessments initially focused heavily on section 1 of the assessment, i.e. activity that would occur within the lifetime of the PhD project, in an attempt to compensate for lack of experimental data. Conversely, others went significantly beyond the scope of a reasonable project boundary, focusing heavily on the consequential longer-term applications of their projects. Whilst in many ways, this is encouraging and suggests a clear engagement with the process, this also represented a challenge for the researchers’ time management in delivering their research within tight timeframes, especially given that the processes were designed to optimize their time.

*5.1.3 Difficulty identifying attributable outputs*

Five projects were not able to directly attribute environmental benefits as a direct output of the project. This was not due to the methodology creating unnecessary obstacles but rather the researchers could not definitively justify any additional environmental benefits as a result of the product development. For example, although a mobile app designed to create a more involving and interactive experience for ramblers may be considered environmental as it promotes walking rather than driving through countryside, it is difficult to definitively attribute additional take-up of walking rather than any other form of transportation to the app itself. Here, it was considered that unaccountable environmental rebound effects were likely but could not be assessed; more users of the app may indicate less car journeys through the countryside, however, more hikers may drive to the countryside because the app enhances their walking experience, thereby actually increasing energy consumption. Another example where results could not yet be attributed was a construction supply chain project designed to integrate life cycle inventory data collection. Prior to the system being deployed, and its uptake within the construction industry, it was not possible to quantify the outputs. Here the potential of the process is described, but reporting any hard data would be misleading.

*5.1.4 Commercial Sensitivities*

Although much of the literature surrounding small and medium enterprises and LCA focuses on a lack of capacity that drives their engagement with the field (Põder, 2006), commercial sensitivities are also an influencing factor. In one instance, the assessment had reported a reduction in the material wasted from 40% of raw material per usage to almost nil but, pointing towards a production line that responded to customer demand on a case-by-case basis, the company was uncomfortable with releasing a figure for total material used in any given time period, making it difficult to obtain a functional unit from which to extrapolate.

*5.1.5 Large Ranges of Potential Outcomes*

A sub-group of project was identified, spread evenly between categories (i) and (ii) (as described in 5.1.1 and 5.1.2 above), where the scale of the environmental benefits very much depended on the number of clients employing the products or service. These were within companies with a limited number of customers, such as the marine radar system, where huge variations in environmental impacts were possible with increased take-up of the technology, as opposed to systems that were expected to sell to large existing customer bases with minor fluctuations in sales. In these cases the assessment was conducted judiciously, but there was a large range within which the expected outcomes could fall. Here the confidence indices played an important role in describing the most likely outcomes.

6. DISCUSSION

The methodology directly addresses the challenges involved in conducting an environmental assessment of products, processes and services which are under development and yet to be commercialized. It has shown that the quality or confidence in the data is dependent on the type of research being undertaken and the products readiness for commercialization. Given the wide-ranging nature of such an undertaking, however, it should be expected that a number of issues could arise that would need to be refined if others were to repeat the exercise. Indeed, whilst this exercise provided a platform to calculate the environmental impacts of a number of projects across a variety of fields, there were several issues that require addressing, as outlined below.

*6.1 Improving Capacity by Increasing Understanding and Developing Expertise*

The processes provided a platform for a more in-depth consideration than might have been provided had the researchers been left to complete the exercise alone. Moreover, this allowed non-experts to engage with environmental assessment and deliver auditable and credible outputs which maintained the spirit and principles of ISO standards without the associated embedded costs (both time and monetary).

*6.2 Inclusion of various data*

The boundary-setting exercise at the outset of the methodology allows for the utilization of data from a number of sources provided there is a robust rationale for their inclusion, such as: quantitative data, founded estimates, and value judgments and assertions based on known or assumed connections and consequences. This allows the assessment to draw on the most pertinent and accessible information to develop a reliable overview of the reportable outputs whilst minimizing the resource and expertise required to conduct the analysis.

*6.3 A Facilitator*

As indicated earlier, the PhD students most likely to deliver the most effective assessments were those who took the opportunity to review with a facilitator. This was intended to overcome the capacity issues of both company employees and university researchers and was a demonstrable success, with 79% of researchers feeling that the presence of a facilitator was helpful. This underpins the usefulness of the facilitator’s role but also demonstrates that the success of the assessments was related to access to expertise and guidance, even if minimal contact (i.e. 2-3 hours) was required. Given that only 15% of the PhD students felt that they would have been able to undertake their assessment using secondary guidance alone, it suggests that a facilitator needs to be in place, or a future exercise without a facilitator would have to improve the depth of the guidance to compensate for this. This would have to mitigate the need for the initial contact time, and be robust enough to eliminate the need for drop-in sessions.

*6.4 Towards a Revised Environmental Assessment*

Building upon the work done so far, and reflecting the strengths and weaknesses outlined above, the next step is to develop the methodology further, both for the use of smaller industrial engagement projects (i.e. Masters and undergraduate dissertation projects, internships and commercial assistance) and for future use by similar schemes in universities or small and medium-sized businesses. The foundation of any refined environmental assessment should be that it is concise, clear and unambiguous. Although the original processes had this criteria as a keystone throughout their development, it is clear that more can be done to make sure that they are easier to follow, for instance by deepening the guidance notes that are provided, including things such as step-by-step guidance to minimize the need for a facilitator. In doing so, the revised assessment should continue to eschew the complexities that have previously limited smaller businesses’ engagement with environmental standards. In order to continue to differentiate between a more concise methodology and those of the ISO suite, the focus must remain on the benefits such an approach can bring compared to existing guidance. Thus far, the wide range of projects has covered sufficient ground to demonstrate the revised process’ value to a spectrum of projects. The revised assessment process should strive to remain sufficiently robust, continuing to acknowledge the different inherent capacities, and requirements of individual researchers, projects and companies.

Whilst the environmental assessment is concerned with the direct outcomes due to a particular research project, the methodology could be expanded to better understand the broader outcomes such as environmental rebound effects (Font Vivanco et al, 2016). Although it may not be possible to collect data during the research phase of a project, potential feedback mechanisms could be highlighted for future interrogation once the product is commercially available and economic and environmental effects may be clearly demonstrated.

7. CONCLUSIONS

The design and implementation of an environmental has targeted what Selech et al. (2014) identified as an accessibility gap in allowing small and medium-sized business owners to engage with environmental auditing. The processes have created a methodology designed to be less prescriptive than ISO standards, whilst still affording a thoroughness that allows assumptions and assertions to build on hard data and adhering closely to environmental declaration guidance, with the exception of estimating forecast data of pre-market innovations. In doing so, the environmental assessment is more appropriate to the needs of non-expert research and development projects.

By placing a strong emphasis the identification of appropriate data sources at the beginning of the exercise, the assessment processes allow for focused calculations to be produced, whilst also revealing previously unconsidered environmental benefits.

Novel additions to the methodology were: (i) focusing on the *change* in circumstances rather than taking a holistic perspective in (ii) a self-assessment of the likeliness of the targets being realized was a novel addition that allowed for the management team to understand current potential outputs and plan accordingly, (iii) the utilization of a variety of data, such as value judgments, founded estimates and assertions, (iv) exclusion of data that would not be significantly different from the status quo, and (v) self-defined minimum thresholds to exclude analyzing and reporting data that would not significantly impact on the output data, created a streamlined approach. Combined, these allowed the methodology to quantify and describe the likely environmental impact of a product, process or service during its development via a robust and traceable argument that addresses potential concerns of ‘greenwash’, meets the auditing needs of funders, and demonstrates impact of university research outside academia.

The implementation of the methodology highlighted the importance of thorough guidance to assist non-experts, particularly if a facilitator is not available to conduct the initial engagement. Nonetheless, it demonstrated that non-experts can engage with environmental assessment principles in a cogent manner. Importantly, however, this engagement does not make them experts, but rather embodies only the appropriate skills for each researcher. Given the longer-term aim is to develop protocols that can be used independently, it is clear that this issue should be addressed further to ensure that any guidance included is sufficiently comprehensive to cater to all reasonable requirements.

The method has shown that it is not necessarily about creating/raising the capacity of non-experts in order to achieve this, but rather creating the conditions (via access to a facilitator, or detailed guidance) in which non-experts can swiftly engage with environmental assessment to a well informed and appropriate level, without needing to engage with costly measures which only distract from core business activities.

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