A framework for environmental risk management

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ABSTRACT

Aero engine designs can have a life time of over 45 years, which is long enough for the understanding of environmental problems to change significantly. This places the aero engine designer in a position of uncertainty, as unforeseen environmental problems could affect the viability of a design. 'Risk' is used to describe future uncertainties that can lead to undesirable consequences. This paper presents a framework for environmental risk management that allows the designer to answer the question: what is the risk to a design from its environmental impacts over the life cycle? The framework provides a process for turning complex environmental business hazards into a form that can be used to develop mitigating actions within the design process. The paper demonstrates the framework through two examples and discusses findings, leading to conclusions on what is required to implement the framework into a business.

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NOMENCLATURE

Business risk	multiplying the likelihood of a hazard by its potential impact on business objectives
Environmental Business hazard	stakeholder response to environmental impacts with the potential to cause harm to business objectives
Environmental business risk	subset of business risks from environmental business hazards
HHI	Herfindahl-Hirschmann Index
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
Life cycle	Consecutive and interlinked stages of a product system, from raw material extraction, or generation from natural resources, to final disposal[1]
NGO	Non-Governmental Organisation
Risk management	Activities to control and manage risk in an organisation[2]
REACH	Registration Evaluation Authorisation and restriction of CHemicals
SVHC	Substance of Very High Concern
WGI	World Governance Indicator

1.0 INTRODUCTION

A constantly evolving awareness of environmental concerns presents a particular problem for designers of aero engines that can have a life time of over 45 years[3]. In the latter part of the 20th century awareness of environmental concerns such as ozone depletion, acid rain and global warming increased to the extent that legislation and social pressures affected businesses, through for example the Montreal protocol on ozone depleting substances[3]. To address these issues typical questions for the environmental designer include: what are the environmental impacts over the product life cycle? Which need to be addressed, why and how?[4] Answers to these questions are unlikely to be the same now as they will be in 40 years, which leaves the aero engine designer in a position of uncertainty, not knowing whether or not the viability of a design will be affected by an unforeseen environmental problem.

'Risk' lacks universal definition, however it is always used to describe future uncertainties and usually where they can lead to undesirable consequences[5], typically assessed as a two-dimensional calculation of likelihood (related to the uncertainties) and impact (to consequences)[6]. Therefore the question for the aero engine designer becomes: what are the risks to a design from its environmental impacts over the life cycle? This paper presents a framework for environmental risk management that produces answers to this question, identifying future environmental business hazards and translating them to be compatible within standard design processes. Although developed for the Rolls-Royce design system, the framework is applicable throughout the aerospace industry and others that produce long life products.

The risk based approach has several benefits. Significantly it does not create a new set of processes for addressing environmental problems in design, instead integrating them into existing design risk management processes in a format that the business can understand. It solves the problem of deciding which environmental impacts need to be addressed, as logically those that pose the

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highest risk will be prioritised. Using risk also provides traction in addressing environmental impacts over the product life cycle, where the 'in use phase' traditionally dominates[3].

This paper provides: (1) a precise definition of what is meant by risk in this context, the specific questions the framework has been designed to answer and why, (2) a description of the framework, and (3) two examples to describe the practical application of the framework. The two examples show that the framework for environmental risk management works, however, whilst the framework process is sound, it does highlight several difficult problems. The paper draws on experiences from working through these problems to conclude with recommendations for implementing the framework into a business.

2.0 PROBLEM DEFINITION

Business risk is a well established concept (details can be found in the relevant British standards[2,7]). It is concerned with identifying hazards that have the potential to impact on business objectives. Risk is defined here as the product of the likelihood of a hazard occurring with the impact it would have on the business if it did[6].

There are many sources of harm that can impact on business objectives. This paper is concerned with one type in particular. Termed 'environmental business risks', they have been defined from the observation that if a business has an impact on the environment, this in turn can create circumstances that will lead to an impact on business objectives. As observed by Matten[8] and Sharratt and Choong[9], these circumstances are manifested not directly from the environment itself, but through a stakeholder† response to an environmental impact. Stakeholder responses could come from, for example, regulators (national and international), shareholders, employees, customers, local communities and Non-Governmental Organisations (NGOs)[8,9]. Consistent with the definition of environmental business risks, an 'environmental business hazard' is defined here as a stakeholder response to environmental impacts with the potential to impact on business objectives.

Environmental business risks, as defined, are particularly nebulous and difficult to manage. The stakeholder responses can come from a complex mixture of actual, potential or perceived environmental impacts and be influenced by dynamic political factors and societal values. They are not obvious and it is not surprising that businesses tend to overlook them (see e.g. Elkington and Trisoglio, 1996[10]).

The ideal way to mitigate environmental risks is to manage them when a product is being designed, consistent with the pro-active logic behind all environmental design[11]. The most successful approaches to environmental design apply a methodology relevant to the decision making context[12,13], which involves using environmental analysis tools to meet the demand for environmental information[14]. Risk is consistent with the design decision context at Rolls-Royce. The framework for environmental risk management provides a methodology for integrating environmental risks into existing design risk management processes.

2.1 Two perspectives

There are two sides to the problem of managing environmental business risks, as shown in Fig. 1. The design perspective approaches the problem through understanding the environmental impacts of a product, which are the sources of the risk. The question is: how can these environmental impacts lead to an environmental business risk? For example if a design incorporates a substance that is hazardous to the environment, what is the likelihood that the use of this substance will be restricted by regulation leading to an impact on business objectives?

†Here stakeholders are broadly defined as anyone who can affect or is affected by the activities of an organisation[9].

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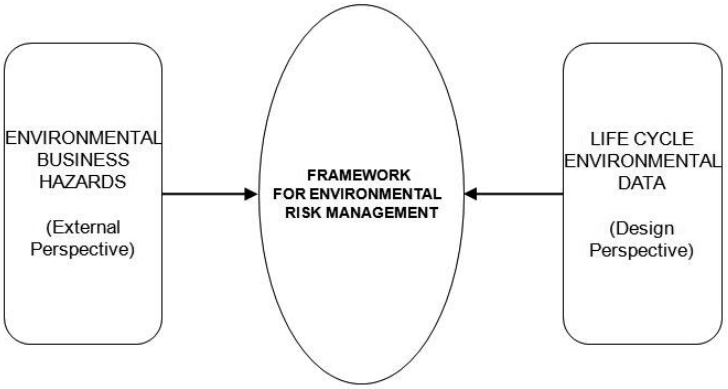


Figure 1. Design and external perspectives on environmental business risk.

The external perspective approaches the problem through attempting to identify environmental business hazards more broadly. The question is: what existing and future positions on environmental issues might occur that would impact on the expected product portfolio? For example, is future regulation likely to restrict the use of environmentally hazardous materials used in our products?

The framework captures the interplay between product environmental impacts and environmental business hazards, feeding connections between the two into standard risk management processes.

From both the design and external perspectives the framework needs to incorporate a means of understanding the environmental impacts of a product. Considering the whole product life cycle, defined as consecutive and interlinked stages of a product system from raw material extraction to final disposal[1] (Fig. 2), is important. Even though significant environmental impacts across the life cycle will not be directly related to an organisation, events from indirect environmental impacts can have an effect on objectives[16]. Life Cycle Assessment (LCA) provides a comprehensive way of collating and understanding the environmental impacts of a product, although it is usually simplified as an environmental design tool due to its complexity[17].

The incorporation of a simplified product based environmental assessment is represented in Fig. 1 as life cycle environmental data. The challenge is to link this data to environmental hazards and vice versa. The remainder of the framework that makes this link has been built upon the standard steps within risk management[2], addressing the following questions:

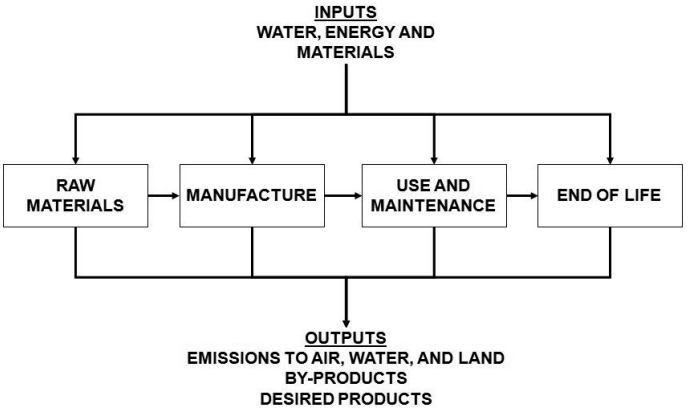


Figure 2. Simplified product life cycle[3,15].

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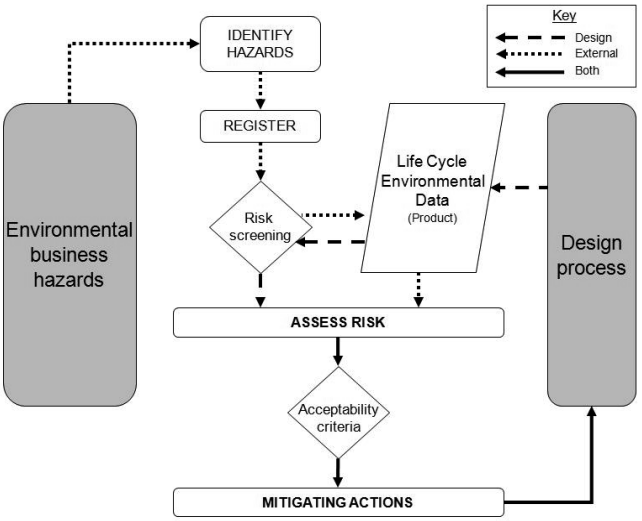


Figure 3. Framework for environmental risk mannagement.

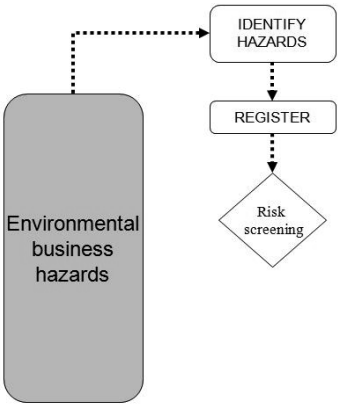


Figure 4. Identifying hazards.

- How are environmental business hazards identified?
- How are likelihood and impact assessed to measure the environmental business risk?
- How are the risks evaluated to understand whether or not mitigating actions are required within the design process?

Businesses already consider risk within design processes. The framework provides a means of using existing risk management methods to address environmental business risks in the same way.

3.0 FRAMEWORK

The framework for environmental risk management is presented in Fig. 3, connecting product life cycle environmental data from the right hand side of the figure with environmental business hazards on the left. To describe the framework it is separated into three parts:

1. Identifying environmental business hazards.
2. Connecting hazards and products, from both the external and design perspectives.
3. Assessing risk and defining mitigating actions.

3.1 Identifying environmental business hazards

For ease of explanation, the process for identifying hazards is highlighted from the rest of the framework in Fig. 4. It consists of two steps:

1. identifying environmental business hazards
2. risk screening.

There are numerous environmental business hazards, occurring over the product life cycle. As mentioned before they are not necessarily obvious. Identifying them is a complex task, requiring judgements from people with sufficient knowledge of environmental problems and how these are

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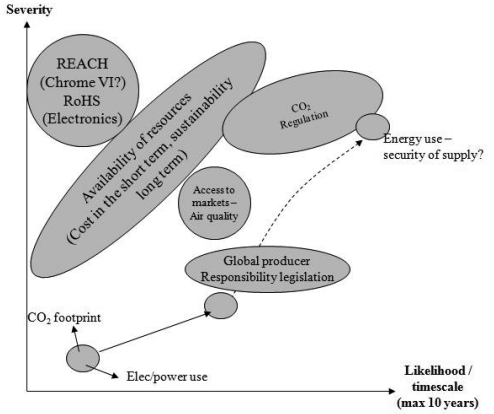


Figure 5. Example risk screening chart.

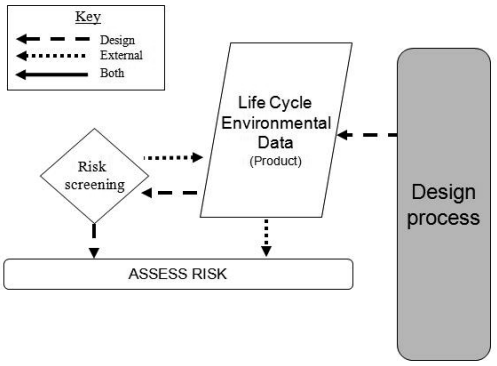


Figure 6. Connecting hazards and products.

relevant to a business' products. The subjective nature of identifying hazards is prevalent within many contexts of risk management. In this case, hazards were identified through the use of focus groups to capture the judgements of environmental specialists within Rolls-Royce. Other social research methods could have been used, such as interviews or more informal workshops. Focus groups were chosen to facilitate discussion.

There are likely to be a number of environmental hazards identified; risk screening is required to prioritise those that require a quantitative risk assessment. These prioritised hazards have an identifiable impact on the business that is of sufficient concern to warrant a quantitative assessment. To screen hazards judgements are required from people with knowledge of the hazard (for example, whether it relates to specific emissions, substances or materials) but also of the business, its objectives, its products and how the hazard can impact upon these. Judgements are also required to assess whether or not the hazards are of sufficient concern, which is dependant on the veracity of the hazard and how it is perceived by the business.

In effect, risk screening is a risk assessment, although it relies upon judgements of impact and likelihood rather than a quantified assessment. Since the framework was developed primarily for use within Rolls-Royce, focus groups of key personnel within the business were used to screen hazards, capturing judgements of likelihood (or the estimated timescale over which the hazard might occur) and significance using a simple chart as shown in Fig. 5. Hazards towards the top of the chart were prioritised for quantitative risk assessment.

3.2 Connecting hazards and products

The next part of the framework connects hazards with products, highlighted for ease of explanation in Fig. 6. A business' objectives are set around the provision of products. By connecting a hazard to a product it can be understood how the hazard affects the ability of the business to provide that product. The impact this would have on business objectives if it did can then be quantified.

By definition, hazards come from environmental impacts, whether or not they are directly or indirectly related to the organisation, across the product life cycle. Life cycle environmental data provides an assessment of the environmental impacts of a product. What is required is to connect the two together. How the connection is made depends on whether or not it is done from the design or external perspective.

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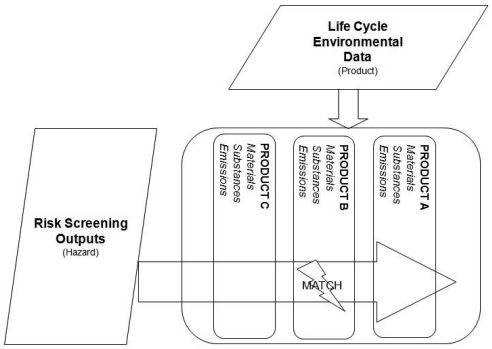


Figure 7. Connecting hazards and products from the external perspective.

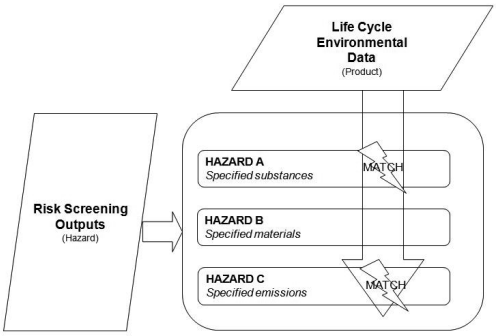


Figure 8. Connecting a product with hazards from the design perspective.

Making the connection from the external perspective is shown in Fig. 7. Hazards are connected to products by matching the known emission, substance or material that is the source of the hazard with product life cycle environmental data. A quantified risk assessment can then be completed.

The design perspective works the other way around, as shown in Fig. 8. A set of product life cycle environment data, containing emissions, substances and materials, is matched with hazards that have come out of the risk screening process. A quantified risk assessment can be completed when a connection is made between an aspect of the product life cycle environmental data and one related to a hazard.

3.3 Assessing risk and mitigating actions

The final steps of the framework are highlighted in Fig. 9, providing a process for quantifying the risk from prioritised hazards and evaluating it to define mitigating actions. Risk is quantified by assessing the likelihood that an environmental hazard will occur and multiplying it by the business impact it would have if it did. Information on significant risks can then be fed back to the design processes and appropriate modifications applied. Assessing risk is the same irrespective of whether the starting point is the external or design perspective.

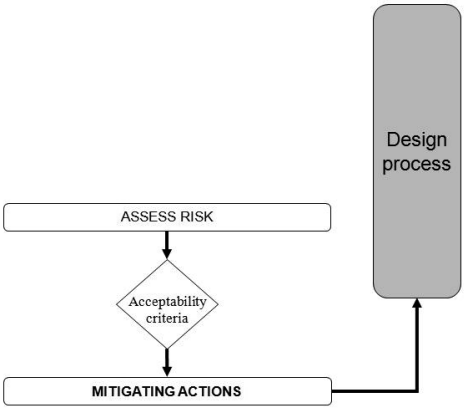


Figure 9. Assessing risk and mitigating actions.

Environmental business risks should be managed like any other risks within an organisation's standard risk management systems, which provide:

- The objectives of the business, required to determine the impact of the risk.
- A common methodology for combining the likelihood and impact to quantify risk.
- Risk criteria for evaluating the significance of the risk and whether mitigating actions are required.
- Risk management processes enabling the integration of environmental business risks into existing design and management systems.

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Likelihood (L)						
	Very high > 50%	5	10	15	20	25
	High 25% < L ≤ 50%	4	8	12	16	20
	Medium 5% < L ≤ 25%	3	6	9	12	15
	Low 1% < L ≤ 5%	2	4	6	8	10
	Very low ≤ 1%	1	2	3	4	5
		Very low ≤ £1m	Low 1m < £ ≤ 5m	Medium 5m < £ ≤ 15m	High 15m < £ ≤ 25m	Very high > £25m
		Impact (£s)				

Figure 10. Sample impact likelihood matrix.

3.3.1 Risk assessment

The standard technique for risk assessments used within Rolls-Royce is 'if...then' statements. Qualifying and multiplying the likelihood of the 'if' and the impact of the 'then' provides structure to the risk assessment. For example:

If emission X is regulated to certain levels…Then the cost of the process will double to keep emission X within limits;

If the cost of the process doubles…Then this will increase the unit cost of parts that are manufactured using the process;`

If the cost of the part increases…Then product margins will be reduced decreasing profits.

In this example, the risk can be quantified by assessing the likelihood of emission X being regulated and calculating the potential decrease in profit if it was.

Assessing risk requires a common methodology to measure likelihood, impact and multiply them together, so risks from different sources can be compared and prioritised[5]. The Rolls-Royce system applies a risk matrix similar to the one shown in Fig. 10.

In this matrix, likelihood can either be represented on a percentage scale or based on judgements varying from very low to very high. Impact is measured in £s. The scale of impact varies depending on the level of the business at which the risk assessment is being performed. A very high impact at a project level will be viewed as lower when assessed at the level of the whole business. Each measure of likelihood and impact is given a score of between one and five, which are then multiplied together to quantify the risk.

As the example demonstrates, the likelihood of an environmental risk will depend on the hazard. In the example given above this would be the likelihood that an emission with a known environmental impact will be subject to regulation. It may be that an assessment of the likelihood is dependent on expert judgements, for example from an environmental manager with knowledge of emissions regulations. It may also be the case that a more deterministic approach can be used. Either way the assessment of likelihood needs to be done in a meaningful way, represented on the scale applied within the risk matrix.

The business impact is related to the business' objectives, which are based on the provision of products, related services and the profit that this provides. For example the profit for providing aero engines to airlines, calculated by subtracting the cost of providing the engine from revenue.

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An environmental business risk is likely to impact on the ability of the business to provide these products by either:

1. Affecting the ability of the business to manufacture a product, for example through restrictions on the availability of substances or materials.
2. Affecting product cost.

The impact will be a function of how the hazard affects the product. In the example above the impact on profits may be quite small, as the hazard only increases the cost of one process used to manufacture a product. However the risk will be large if it places a restriction on the ability of the business to make a product, for example if the use of certain substances is banned. All revenue related to the provision of that product is potentially affected. The impact is also likely to be large if it affects more than one product.

3.3.2 Mitigating actions and residual risks

The final step in the process evaluates the risk to determine if mitigating actions are required. Risks are evaluated against risk criteria, which outline thresholds for the acceptability of risks, above which mitigating actions will be required. Risk criteria will typically be defined within an organisation's risk management system.

At Rolls-Royce the acceptability of risks is defined at the various levels of the organisation at which risks are assessed, from across the whole group down to an individual project, as an initial input to the risk management process. Whilst the level at which risks become unacceptable is not prescribed, typically the following levels of risk require mitigating actions:

- any risk with a very high potential impact;
- high impact and a likelihood of medium (>5%) or higher; or
- medium impact and very high likelihood (>50%).

This is displayed by the shaded area towards the right hand side of the risk matrix in Fig. 10.

If a risk is beyond acceptability criteria, the process examines how they could be mitigated. Possible actions include:

- Replacing the source of the environmental risk, for example a harmful substance or scarce material.
- Developing alternatives if they are not available.
- Re-design components or processes to remove the source of the environmental risk.

The process also provides a means of identifying and assessing residual risks associated with mitigating actions, for example the costs of developing alternatives, achieving regulatory compliance or re-designing a component. There may also be residual risks associated with increases in product cost, should a re-designed part be more expensive, or if the component life is reduced affecting maintenance costs.

4.0 EXAMPLES

The following sections use two environmental hazards to describe how the framework for environmental risk management works in practice, from the design and external perspective. These hazards were prioritised as an output of the risk screening example shown in Fig. 5.

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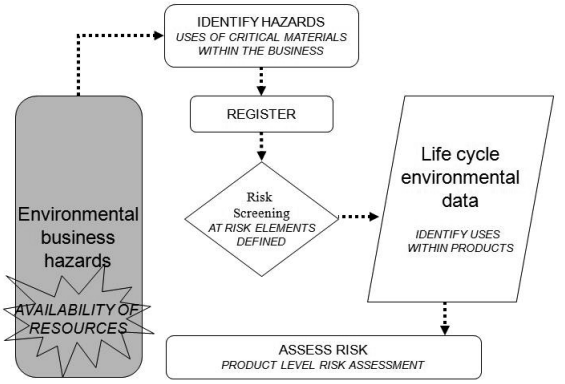


Figure 11. Availability of resources from the external perspective.

1. ***External***: Availability of resources, using the example of platinum (Pt), which is used in coatings for turbine blades.
2. ***Design***: Registration, Evaluation, Authorisation and restriction of Chemicals (REACH), a European regulation related to the use of chemicals, using the example Trichloroethylene.

4.1 External perspective: Availability of resources

Availability of resources refers to the phenomenon of constraints being placed on the accessibility of material commodities as a result of geological, environmental, social and economic factors. An example case is the Cobalt crisis in the 1970s[15]. It is not solely an environmental problem, however accounting for the depletion of resources is incorporated within Life Cycle Impact Assessment (LCIA)[‡] and it falls within the definition of an environmental business risk. Whilst the availability of resources is not a new problem, the increasing dependency of modern industry on scarce elements has recently raised awareness of the risks. The complexity of the issues makes it impossible to predict with certainty when or if a material supply restriction might occur and what the effect might be on availability or price. However, businesses are beginning to develop ways of assessing the risks in order to implement any necessary mitigating actions[19].

From the external perspective of the framework for environmental risk management, it is necessary to identify materials that have a likelihood of supply restrictions and determine where these are used within products through life cycle environmental data. Analysing historical price volatility or making qualitative judgements of the importance of a material to the business can be used to identify materials that are important to the business and are likely to become unavailable.

Connecting the use of an element, for example platinum, to a product facilitates an assessment of the business risk (Fig. 11).

4.1.1 Risk assessment

The risks related to the availability of resources are a function of the:

1. likelihood of a material's supply restriction
2. potential impact on the business should a restriction occur.

Several recent papers and reports have been published on the topic of 'materials scarcity', which have sought to assess the likelihood of materials supply restrictions, for example, European

[‡]Abiotic (non-living) resources are addressed in terms of their availability in the present and future[18].

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Commission[20], DEFRA[21], Duclos *et al*[19], Morley and Eatherley[22] and Alonso *et al*[15]. Each study approaches the topic slightly differently, although they all apply an assessment method using static metrics. The metrics are developed to represent the underlying mechanisms that can place a restriction on the availability of materials. Materials are then assessed using the metrics to determine the likelihood that they will be restricted in the future. Alonso[23] highlights limitations of the static metric approach, which fails to 'capture the dynamics of the materials systems they attempt to represent' (p61). Modelling the dynamics of materials systems provides a more accurate assessment, although this has only recently become the subject of active research.

Developing a likelihood assessment method is beyond the scope of this paper, so the method developed for the European Commission[20] has been applied. The EC method has been selected as it presents the most transparent methodology, with publicly available data so the assessment can be repeated. The EC report assessed 'supply risk' (the likelihood of a supply restriction) using the following metrics:

- Herfindahl-Hirshmann Index (HHI): a measure of supply diversity used to highlight monopolies that could increase the likelihood of a supply restriction. The HHI is calculated by summing the squares of the supply percentages (S_{ic}) of producing countries (c) for a given material (i), which produces a score of between 0 and 10,000:

$$HHI_c = \sum_c S_{ic}^2 \quad \ldots (1)$$

- World Governance Indicators (WGI): a measure of political stability calculated by the World Bank, on a scale of –2·5 to 2·5, which was linearly adjusted to 0 to 10 (10 representing the highest possible risk). Political stability highlights materials that come from unstable producing regions, increasing the likelihood of a material supply restriction. Scaled WGI scores were multiplied by the supply percentages of producing countries to produce a modified HHI, with a possible score of 0 to 100,000, scaled to 0 to 10:

$$HHI_{WGI} = \sum_c S_{ic}^2 WGI_c \quad \ldots (2)$$

- Recycling rate (ρ), percentage of supply met from old scrap, based on the assumption that an increased reliance on recycled sources reduces the likelihood of a restriction, presented as a decimal, based on EU data.
- Substitutability (σ): how easily the use of a material can be substituted in all applications within the economy, based on the assumption that restrictions in the supply of a material will only have an economic impact if it cannot be substituted. The following decimals were used, with the assessment performed by material using expert judgement.

Table 1
Substitutability indices[20]

Score	Substitutability potential
0	Easily and completely substitutable at no additional cost
0·3	Substitutable at low cost
0·7	Substitutable at high cost and/or loss of performance
1	Not substitutable

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Supply Risk (SR) is calculated for a material (i), by multiplying the HHIWGI scores by the recycling rate (ρ_i) and substitutability index (σ_i) as shown below, with a theoretical maximum score of 10, minimum 0:

$$SR_i = \sigma_i(1 - \rho_i)\, HHI_{WGI} \quad \ldots (3)$$

Results for elements with the five highest SR scores are presented in Table 2.

Table 2
Top five results for Supply Risk (SR)[20]

Material	SR
Rare Earth Elements (REEs)	4·9
Platinum Group Metals (PGMs)	3·6
Niobium	2·8
Germanium	2·7
Antimony	2·6

In reality it is very unlikely that a material will score 10 in the SR assessment, as this would mean a material is 100% sourced from a country with a WGI score of 10 (the Democratic Republic of Congo had the highest score of 8·6[20]), which is not substitutable or recycled in anyway.

Reflecting the actual results shown in Table 2, with a highest score of 4·9 for rare earth elements, the SR scores have been calibrated to the likelihood scale applied within the Rolls-Royce risk matrix (Fig. 10), giving the assessment method shown in Table 3. This scale was used to assess the likelihood of a materials supply restriction in this case.

Table 3
Likelihood assessment

Score	Likelihood (L)	SR score
5	Very high $> 50\%$	$SR \geq 4$
4	High $25\% < L \leq 50\%$	$3 \leq SR < 4$
3	Medium $5\% < L \leq 25\%$	$2 \leq SR \leq 3$
2	Low $1\% < L \leq 5\%$	$1 \leq SR < 2$
1	Very low $\leq 1\%$	$SR < 1$

The impact of a supply restriction on a business is a function of where a material is used, what business objectives are related to where it is used, and how the likelihood of a supply restriction will have an impact on these objectives. To assess impact two approaches can be taken:

1. Calculate the business impact based on the revenue effect should a material become unavailable, i.e. all revenue attached to a product reliant on a material is at risk.
2. Estimate levels of effect, on material availability or price, related to the likelihood of a material supply restriction. The impact on business objectives can then be calculated using this level of effect.

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In reality the likelihood of material supply restriction will be reflected in prices, so the second calculation method is preferred.

A level of effect was estimated by analysing the historical price volatility (*PV*) of materials, dividing the maximum market price by the minimum over a ten year period:

$$PV_i = Max.price \Big/ Min.price_{10\,years} \quad \ldots (4)$$

The impact on the business was calculated by multiplying the current price of a material by its price volatility and calculating how the increase in cost will affect business revenue.

4.1.2 Example: Platinum

Platinum (Pt) has been identified as a potentially critical element, being expensive, geologically scarce and having few sources of supply. Dispersive uses, for example as a catalyst, also make it difficult to recycle, increasing dependence on primary production[20]. The SR score for platinum from Table 2 is 3·6, which means it has a high likelihood of a supply restriction using Table 3. The price volatility of platinum over a ten year period is 5[††]. To calculate the potential impact on business revenues the price will be assumed to increase by this amount.

Platinum is used within aero engines as a coating for turbine blades. The potential impact on business revenues from the scarcity of platinum can be calculated by estimating the increase in the cost of turbine blades if the price of the coating was to increase by a factor of 5. Table 4 presents a simple hypothetical unit cost breakdown for a turbine blade and the effect of an increase in the price of the coating.

Table 4
Hypothetical unit cost breakdown for a turbine blade with and without potential cost increase

Cost element	Existing cost of Pt	New cost of Pt
Materials	£150	£150
Mould manufacture	£25	£25
Casting process	£75	£75
Machining	£100	£100
Finishing ops	£25	£25
Coating	£100	£500
Finishing ops	£25	£25
Total	£500	£900

To estimate the impact on the business it is necessary to determine the effect the cost increase in turbine blades will have on contract revenues. Table 5 presents an aggregated impact on revenues, multiplying the unit cost increase using hypothetical figures of the number of blades in an engine and how many engines make up a commercial contract. It is assumed that there are no service related costs. To estimate the total impact on the business the impact would have to be aggregated across all engines that use a turbine blade with a platinum coating.

Table 5
Aggregating unit cost impact on contract revenues

Increase in coated blade unit cost	£400
Coated turbine blades in an engine	120
Contracted engines	200
Total impact on contract revenues	£9,600,000

[††]Rolls-Royce data based on market prices.

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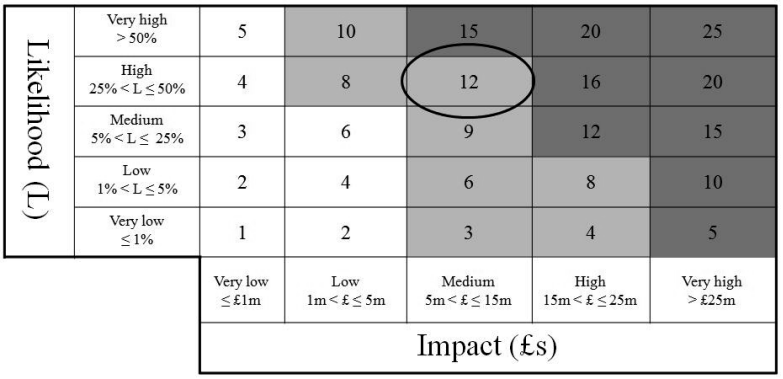


Figure 12. Hypothetical risk assessment for platinum.

Figure 12 presents an example risk assessment result, combining the likelihood assessment with the hypothetical impact figures. Such a large increase in cost aggregates to a significant impact on business revenues, reflected within the score on the impact scale, producing a medium risk when multiplied with the high likelihood. Being on the border of the unacceptable region, a risk of this magnitude will require some mitigating actions.

4.1.3 Availability of resources mitigating actions and residual risks

There are several mitigating actions that can be taken to reduce the risks associated with the use of platinum:

1. Use a different coating material, or design the blade so a coating is not required.
2. Develop alternative coatings or materials if none are available.
3. Ensure end of life materials recovery to retain platinum within a closed-loop supply chain. (Increasing reliance on recycled sources decreases the likelihood of a supply restriction[20]).
4. Use financial instruments to mitigate price risks in the short term.

It is likely that one of more of these options will be pursued to mitigate the risks from the use of platinum. In the short term it would be sensible to manage price volatility financially, for example through agreeing futures contracts. Recycling rates can be improved by developing a closed loop supply chain for material recovery, although design changes may be required to use the coating in a manner that maximises end of life recovery. The most sustainable option might be to remove the reliance on platinum either by re-designing components or developing alternatives. Although this would have to be balanced against the performance benefits of using platinum and the time and money taken to make any changes, including the costs of recertification.

Each of the mitigating actions will carry residual risks. For example, there may be quality concerns over using recycled materials in new components. Re-designing components to encourage end of life recovery or to reduce/remove reliance on platinum will carry costs and may have other detrimental effects on the design. Developing alternatives has residual risks in the costs incurred, together with any other unintended consequences of making design changes.

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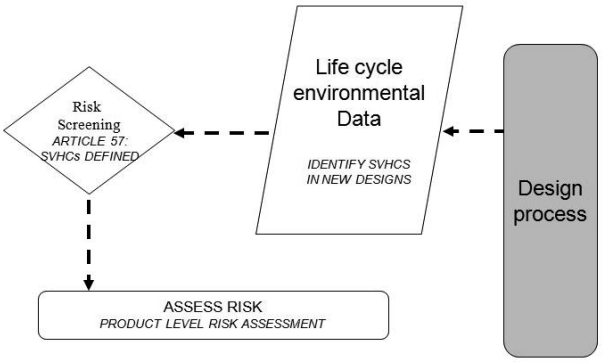


Figure 13. REACH design perspective.

4.1.4 Benefits

There are several benefits to managing availability of resources risks in this way:

- Rolls-Royce is aware of the supply risks associated with some of the materials it uses. However, at the moment there is no structured methodology for assessing the risks of a materials supply restriction. The framework for environmental risk management provides a structured process for doing this, allowing the risk to be properly quantified.
- By fully understanding the risks, it is possible for the business to implement an appropriate response through mitigating actions.
- By using the risk management system, risks are integrated into standard business decision making, relevant to the parts of the business that own the risk (the designers of the product), so that something can be done proactively if needed.
- The risk based approach provides a business case for recycling materials and developing end of life plans for components.

4.2 Design perspective: REACH

REACH is a European regulation that aims to improve the protection of human health and the environment from the risks[†††] posed by chemicals[24]. The authorisation requirement under REACH seeks to control the risks from particularly harmful substances, categorised as Substances of Very High Concern (SVHCs), through a process of progressive replacement. In time, using a SVHC or placing it on the market will only be allowed if the regulator grants an authorisation (substances requiring authorisation are placed on Annex XIV of the regulation), which is dependant on certain criteria. Any business using SVHCs will be affected, as at some point in the future continued use cannot be guaranteed. It would be prudent for a business to identify its usage of SVHCs and consider what the consequences are if a substance is no longer available.

From the design perspective it is required to identify whether or not any existing or new designs are reliant on the use of SVHCs within a product's life cycle. Life cycle environmental data can be cross-referenced with known SVHCs to begin the risk assessment (Fig. 13). The product level risk assessment is dependant on combining the likelihood of a substance becoming unavailable with the impact this would have on business revenues. Mitigating actions can then be defined within the design process.

[†††]Distinct from business risk, REACH identifies chemicals as the source of undesirable consequences, which impact on human health and the environment.

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4.2.1 REACH risk assessment

The risk from REACH authorisation is a function of:

1. the likelihood of a substance becoming unavailable due to REACH
2. the impact on business objectives should a substance become unavailable.

The likelihood of a substance becoming unavailable due to REACH is reliant on the regulatory process, specific details of which can be found in the legal text of REACH[25]. The criteria for identifying SVHCs and transitioning them towards authorisation are not entirely clear, as no substances have been all the way through the process. Table 6 presents an assessment of likelihood, developed through knowledge of the legal text using a scale from 1 to 5.

Table 6
Likelihood of a substance becoming unavailable due to REACH

Score	Likelihood (L)	REACH requirement
5	Very high > 50%	Authorisation required
4	High 25% < $L \leq$ 50%	Substance transferred to Annex XIV, sunset date for authorisation set
3	Medium 5% < L ≤ 25%	Substance on candidate list for transition to Annex XIV
2	Low 1% < L ≤ 5%	Known SVHC properties, similar substances on candidate list
1	Very low ≤ 1%	Known or suspected SVHC properties

In contrast to the previous example, calculating the impact if a substance becomes unavailable due to REACH is straightforward: if a substance is used in the product itself, or in a process to manufacture a product, if the substance is unavailable, the product cannot be made. All revenue

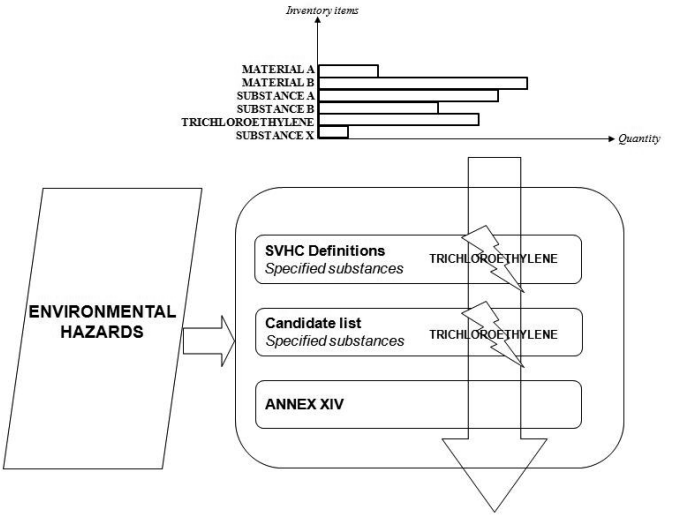


Figure 14. Connecting a product with Trichloroethylene.

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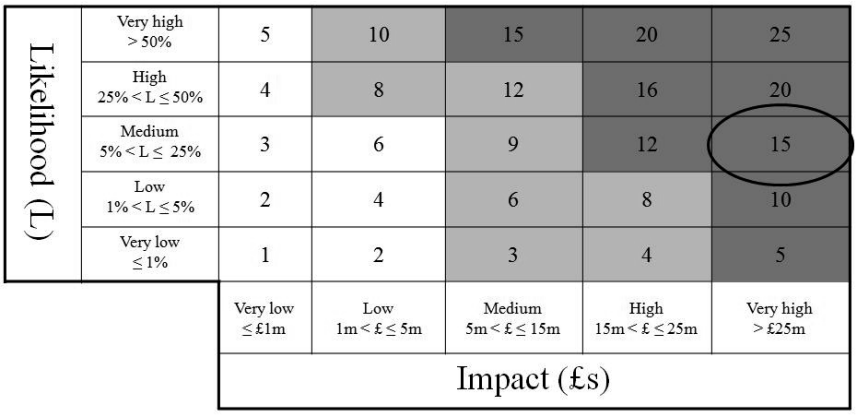


Figure 15. Risk assessment for Trichloroethylene acid used in corrosion resistant coatings.

attached to the provision of that product will be at risk. The risk assessment can be completed by using the risk matrix (Fig. 10) to combine assessments of the likelihood of a substance becoming unavailable with the impact this will have on business revenue.

4.2.2 Example: Trichloroethylene

Trichloroethylene is used in manufacturing processes for degreasing. It is considered to be a carcinogen, meeting one of the SVHC criteria under REACH. Trichloroethylene is currently on the candidate list of substances for transition onto Annex XIV (substance requiring authorisation)[24], which means that the likelihood of it becoming unavailable due to REACH can be given a likelihood score of 3 using Table 6.

To identify if a product uses Trichloroethylene in its life cycle, environmental life cycle data can be cross-referenced with REACH hazard filters as shown in Fig. 14.

If an engine is designed with a process that uses a Trichloroethylene, then if Trichloroethylene becomes unavailable due to REACH the engine cannot be manufactured. The impact on the business will be significant, as any potential revenues related to the supply of the engine will be at risk, producing a very high (>£25m) score on the impact scale.

The likelihood and impact assessment are multiplied and the risk assessment presented in Fig. 15. In this case the risk is in the unacceptable region and mitigating actions will be required.

4.2.3 REACH Mitigating actions and residual risks

To mitigate the REACH risks associated with Trichloroethylene its use will have to be replaced. Options include:

- use another degreaser
- redesign the process chain so degreasing is not required.

Whatever solution is used, there will be residual risks related to the costs of changing the process. Each re-design option will also carry other residual risks. For example, alternative degreasers may be more expensive increasing process costs.

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4.2.4 Benefits

The benefits of managing the risks from REACH in this way are:

- As with the availability of resources case, Rolls-Royce is aware that REACH presents significant business risks. The framework provides a structured process for quantifying them in a way that is consistent with standard risk management processes. Fully understanding the risk allows for measured mitigating actions to be taken.
- One of the main obstacles for understanding the risks related to REACH is making the connection between the use of hazardous substances and products, especially when the substance is used in a process, rather than in the product itself. The need for a product connection highlights the importance of life cycle environmental data within the framework.
- Quantifying and communicating the risks posed by REACH provides traction in removing the use of hazardous substances. In the past, top down policy approaches have been used to communicate substances that cannot be used. Using risk tells engineering teams why substances cannot be used for business reasons and allows them to control risk and its mitigation.
- The framework ensures the designs are checked for substances (either in the product or process) that are likely to be banned at some point in the future. Actions to remove the use of the substance can be taken proactively, making the design more robust.

5.0 DISCUSSION

The two examples have shown how the framework for environmental risk management provides a suitable process for managing environmental business risks, turning complex problems into something that the business can comprehend and use to develop mitigating actions within the design process. While the processes outlined in the framework are sound, they do present difficult questions:

- How are environmental business hazards identified?
- How is the likelihood of an environmental business risk assessed?
- What is required to integrate environmental business risks into existing business decision making processes?
- What life cycle environmental data is required?

This paper has shown that the framework works. From the experience of applying the framework, several recommendations can be made on how these questions need to be addressed if the framework were to be implemented, at Rolls-Royce or elsewhere.

As mentioned there will be many environmental business hazards, originating from various stakeholder responses, related to environmental impacts across the product life cycle. In this case focus groups were used to identify hazards, although the groups highlighted difficulties in both how hazards are identified and how a business prioritises hazards for quantified risk assessment. Identifying hazards requires expert knowledge of environmental problems and how a wide-ranging set of problems can be reduced to a manageable list. Prioritising hazards requires consensus within a business on the relative importance of the issues identified, which will contain subjectivities both within and between organisations.

From experience, the processes of identifying hazards and prioritising them need to be clearly separated. If the process were repeated hazard identification would be done in a more structured

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way, with the use of keywords, for example 'regulation', to prompt judgements from environmental specialists, relevant to each life cycle phase. Eventually, applying a full Life Cycle Impact Assessment (LCIA) to life cycle environmental data could be used as a more deterministic input to hazard identification. Using LCIA would highlight areas of environmental impact within the product system, which may give rise to an environmental business hazard in the future.

Whether or not the hazards matter is a business decision. In this case focus groups were used again, although involving senior managers with input from environmental specialists. In practice, existing risk management systems need to be extended to capture environmental business hazards, involving the relevant business stakeholders who have the responsibility to make the required judgements.

It was proposed that assessing the likelihood of environmental business risks is case specific, which was demonstrated by the two very different approaches used in the examples. In practice, assessing the likelihood of an environmental business risk was very difficult. Likelihood is usually assessed by using statistics to analyse historical data, which in this case does not exist. As a result any assessment will always contain significant uncertainties.

The uncertainty of assessing likelihood raises questions about how environmental business risks will be perceived. Whilst the perception of all risks is subjective, the level of uncertainty in this instance does present a particular problem. More robust assessment methods can be developed, although this will take time. A balance is required between making sure the risk is believable, whilst not creating an analytical burden.

More specific to Rolls-Royce, the experience of completing the examples showed how the framework requires new forms of co-ordination between different parts of the business. Design data was required from engineering, cost data from business groups and contract data from commercial groups, all woven together with the help of risk managers. The framework highlights where processes and responsibilities are required to coordinate different parts of the risk assessment, to ensure effective environmental business risk management.

Another problem to address is defining the requirement for environmental data within the framework, and how this can be supplied with the appropriate environmental assessment tools. The examples have demonstrated that product based life cycle environmental assessment is needed. A simplified form of LCA is the obvious solution. As with setting the goal and scope within LCA, there is still the problem of deciding which environmental impacts are of interest and what data needs to be collected to measure them. Deciding what data to collect can present a circular argument: knowing the hazards defines the data requirement, although to a certain extent data is needed to understand the environmental impacts that lead to the hazards. Rolls-Royce has defined its data requirements through using identified hazards together with data taken from environmental management systems. Over time the data collected will expand as more hazards and requirements are identified.

The data collected for this study was collected as a pilot project. To put the framework into practice a database of manufacturing process and materials production models is being developed, which hold environmental data by process or material. Life cycle environmental data is produced by linking together the materials and process database models for those processes and materials used to make a product. Rolls-Royce has been collaboratively developing a design tool for producing the assessment, which will eventually be integrated into computer aided design systems to remove extra work.

Getting information from supply chains is a common problem when performing product based environmental assessments. Most of the environmental business hazards and environmental management issues affecting Rolls-Royce will affect other businesses in the industry.

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Communicating the associated risks will make the case for data collection. However, common data collection methods are still required so that everyone collects the same data in the same way. Rolls-Royce is leading an initiative through cross-industry environmental working groups to develop common data collection methods that can be passed down the supply chain.

6.0 CONCLUSIONS

This paper has presented a framework to answer the question: what is the risk to my design from its environmental impacts over the product life cycle? The paper has drawn the following conclusions:

- Environmental business risks are defined as a subset of business risks related to environmental business hazards, which are defined as a stakeholder response to environmental impacts with the potential to cause harm to business objectives.
- A product based life cycle focus is important for managing environmental business risks, connecting external environmental hazards with the source of the risk – product design.
- Two perspectives are defined within the framework for environmental risk management – the external perspective, which captures external events and reflects these within the organisation, and the design perspective, which begins with a set of product based environmental data, cross referencing it with identified hazards.
- The framework provides a means of integrating environmental risks into standard risk management (and by default design) processes – it should not create a new layer of risk management.
- The problem of identifying environmental business hazards needs to be clearly defined in two separate parts, identifying the hazards, and deciding whether or not they matter.
- Assessing the likelihood of environmental risks is complicated, as no historical data exists. A balance is required between developing an assessment method that produces believable results whilst not producing an analytical burden.
- Organisational processes will be required to implement the framework for environmental management, facilitating the required cross-functional working relationships.
- Deciding what data to collect for the framework can create a circular argument. Rolls-Royce used the hazard identification results and data from environmental management as initial requirements for data collection.
- Collecting data from the supply chain would be helped by developing industry standards for environmental data collection.
- The framework requires a tool for creating the required life cycle environmental data in design.

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