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Realignment of Product Stewardship towards Chemical Regulations, the Circular Economy and Corporate Social Responsibility – a Delphi Study

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ABSTRACT

Chemical regulations exist to limit and control the amount of hazardous chemical substances being used by industry. Increasing awareness of diminishing natural resources, increasing pollution, and reducing the amounts of harmful waste, has led towards increasing societal and regulatory pressure on industry to change from the traditional closed-loop manufacturing towards the adoption of sustainable materials and open-loop manufacturing systems as part of the Circular Economy. Corporate Social Responsibility (CSR) extends the relationship between industry and society. Product Stewardship (PS) provides a platform for organizations to assess impacts to manufacturing systems ensuring adequate measures are in place to understand, control or limit any impact(s) from manufacturing and using products. The research question answered in this paper relates to understanding the impacts on PS. This paper has been written based on a literature review and Delphi study. The outcomes from this paper will attempt to outline a framework for PS to align with Chemical Regulations, the Circular Economy and CSR.

Keywords: *chemical regulations, product stewardship, circular economy, corporate social responsibility, environmental management, leadership, sustainability*

1. INTRODUCTION

A product can be described as a physical item such as a chemical substance, mixture, material, semi-component, component, product which are either manufactured for sale on their own or collated with other products to produce assemblies or higher-level finished products (Takhar & Liyange, 2019). Supply chains can be defined as a collection of actors working together to enable: (1) availability of raw materials (2) conversion of raw materials into chemical substances, chemical mixtures, materials, semi-components, components, into finished products; (3) distribution of the finished products to end consumers (Skinner, 1978; Porter, 1980; Johnson & Scholes, 1988; Beamon, 1998; Min and Zhou, 2002; Wagner & Sweeney, 2010; Takhar & Liyanage, 2018).

The traditional linear economic maintained the need to: (1) mass produce products at the lowest possible costs; (2) the key to being successful was seen as pricing products cheaper than competitors in the marketplace; (3) little regard was paid to storing and recycling waste production materials; (4) products were designed with defined lifespans; (5) limited end of life product recycling was being undertaken, and; (6) product functionality and safety formed the basis of internal products reviews. The Brundtland report (WCED, 1987) highlighted issues with mass production resulting in increased pollution and a rapid depletion of natural resources, outlining four key areas: (1) sustainable development; (2) environmental protection; (3) economic growth, and; (4) social equity, which evolved into modern day sustainability, which gave rise to increased recycling and defining the need to reduce dependency on critical natural resources. Product Stewardship (PS) is evolved during the 1990s as industry started as examining the health, safety, environmental and social impacts of a product across its life span (Bennett, *et al*, 2018).

Extending on from the Brundtland report, the UN Sustainable Development Goals (UN, 2021) established an globally agreed set of 17 goals, implemented as a mixture of 169 mandatory or optional control measures by signatory nations towards the aim of future sustainable growth. Corporate Social Responsibility (CSR) a concept that first arose in the late 1960's (Friedman, 1970), where there was a belief that industry should act more in responsible ways towards society and the environment, not purely to generate economic gain for its stakeholders, became a catalyst to motivate industry to adopt broader sustainability strategies.

The Circular Economy from circa 2010, extended sustainability, by introducing the concept of open-loop systems, where products lifespans are extended significantly via the use of repairs, repurposing and recycling to generate new secondary raw materials to significantly reduce the amounts of waste ending up in landfill or incinerated to generate electricity (Zeng, *et al,* 2017; Ellen MacArthur Foundation, 2020; Pattnaik & Pattnaik, 2019).

Increasing industrial innovation has seen the rapid growth of new chemicals and product development, whilst globalisation has augmented the traditional supply chains locally, nationally and globally to enable products to be purchased 24/7 from around the world (Gale, 1960; Porter, 1980; Chong and Hendry, 1986; Dias and Ierapetritou, 2017; Huddiniah and Mahendrawathi, 2019; Pattnaik & Pattnaik, 2019). Chemical regulations exist to limit the use of hazardous substances within society in order to protect humans and the environment. Chemical regulations place a reporting burden on industry by mandating the provision of additional information when placing products onto a marketplace. Depleting natural resources and societal awareness of environmental and social impacts of industry has led to global and international treaties such as the Basel Convention (UNTC, 1989), the Montreal Protocol (UNEP, 2020), and the UN SDGs (UN, 2021).

The objective of this paper is to review current literature relating to both chemical regulations, sustainability, the circular economy, CSR and PS, utilizing a systematic literature review and the outcomes from a Delphi study to present a framework to enable the realignment of PS strategies to the needs of chemical regulations, sustainability, circular economy, and CSR. The research within this paper is organized to address these objectives:

1. What are the current PS methodologies in use within industry?
2. What are the current sustainability, circular economy and CSR methodologies in use within industry?
3. Do current state PS align with chemical regulations, sustainability, circular economy and CSR objectives?
4. How can PS align with chemical regulations, sustainability, circular economy and CSR objectives?

2. RESEARCH METHODOLOGY

2.1 Literature Review Search Terms

The search terms used were ‘chemical regulations’, ‘sustainability’, ‘circular economy’, ‘corporate social responsibility’, and ‘product stewardship’ appearing within the title of an article. The search engines used were: (1) Google Scholar; (2) Scopus; (3) ScienceDirect, and; (4) PubMed.

2.2 Delphi Study

A Delphi study was created to apply empirical research to develop a consensus from a panel of experts to derive a framework to enable realignment PS activities towards the needs of chemical regulations, sustainability, the circular economy and CSR (Williams & Webb, 1994; Phillips, 2000; Okoli & Pawlowski, 2004). Three rounds of Delphi surveys were conducted between March 2019 and July 2019. The questionnaires were presented as online surveys, in which participants were invited to complete within an allocated time frame of at least 3 weeks duration between each round. Individual participant responses were kept anonymously from other participants, to ensure the results did not influence other participants. Participants were chosen from: (1) authors of research papers identified in the literature review; (2) researchers who regularly published articles; (3) academic lecturers of related topics; (4) other participants who expressed a willingness to participate in the research topic based on a LinkedIN post requesting participation in the study (Takhar, 2019). Participant types (1), (2), (3) and (4) follow a defined process on how experts may be included within a Delphi study (Okoli & Pawlowski, 2004; Emmel 2013). Topic areas to be addressed in different rounds of the Delphi study are presented in **Figure [1]**. The Delphi study was designed to illicit both closed (directed) and open (illicit feedback) type question responses from participants, to enable both review and brainstorming of the conceptual framework being presented (Okoli & Pawlowski, 2004; Emmel 2013). Each round of the Delphi study built upon the responses of the earlier rounds (Ruschkowski, *et al*, 2013; Emmel 2013). Delphi study, round 1, conducted between March and April 2019, focused on eliciting participant awareness of PS, chemical regulations, sustainability, circular economy, and CSR topic areas. The questions posed direct awareness of the topic areas and / or specific individual elements which could fall under multiple topic areas.

Delphi study, round 2, conducted between May and June 2019, expanded on Round 1, by presenting participants with questions that: (1) aimed to establish consensus in any topic areas, where consensus was not previously established during round 1, and (2) respondent understanding of a product lifecycle, and (3) respondent feedback on potential questions which may be utilized in a potential framework.

Delphi study, round 3, the final round of questions, conducted between July 2019 and August 2019, presented participants with questions that (1) aimed to establish consensus in topic areas, where consensus was not previously established, and (2) present a potential framework, with closed questions used to confirm participant consensus.

This paper is organized as follows section 2 outlines the research methodology, section 3 then presents the literature review, section 4 shows the outcomes from a Delphi study. Discussion is shown in section 5, Conclusions are shown in section 6.

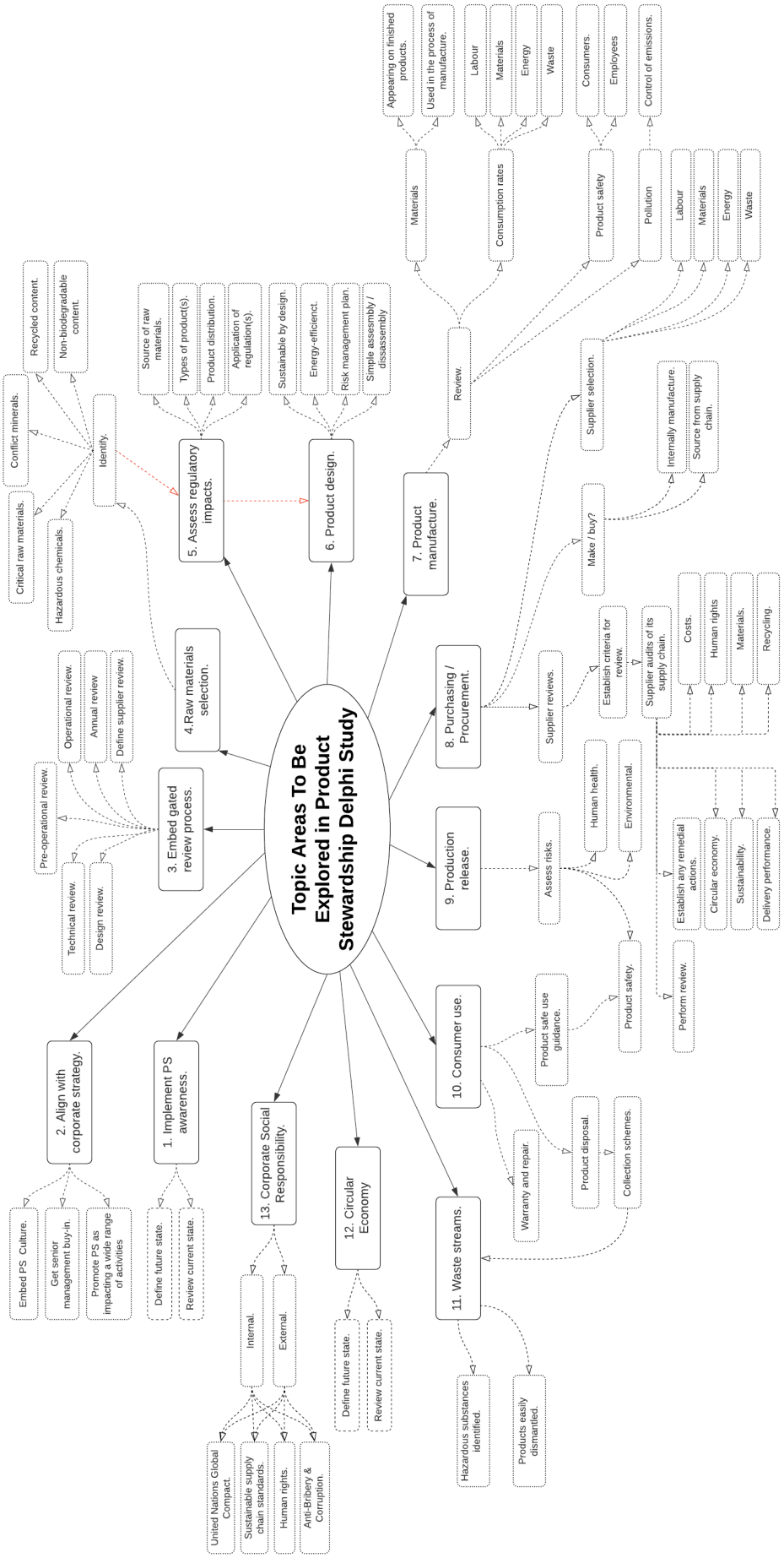


Figure 1. Topic areas explored within Delphi study.

3. LITERATURE REVIEW

3.1 Chemical Regulations

A chemical substance is the lowest level ingredient which can be used on its own or combined with other chemical substances to produce mixtures or materials. The standard periodic table displays the 118 known elements (PubChem, 2021). However chemical substances generated from these elements, exceed over hundred chemical substances in existence. Data from the main chemical database, the Chemical Abstract Service (CAS), shows the speed of innovation in terms of new chemical substances being developed: (1) the CAS registry system was first established in 1965; (2) the modern day CAS database was launched during the 1980s; (3) by 1990, 10 Million chemical substances were defined; (4) by 2009, 50 Million chemical substances were defined; (5) by 2015, 105 Million chemical substances were defined; (6) by the end of 2020, 169 Million chemical substances were defined (CAS, 2020). Chemical regulations aim to control and limit the use of hazardous chemicals, by establishing a regulatory framework to: (1) manage the manufacture of chemical; (2) identifying the use of chemicals; (3) application of adequate labelling to enable safe use and disposal. Chemical regulations define: (1) standards manufacturers need to comply with; (2) monitoring of chemical substances; (3) controlling and / or restrict the use of more hazardous substances; (4) the activities of regulatory bodies to enforce the industry control measures (Botos, *et al*, 2018). Processing this information is a very manually intensive process for industry requiring support from across all functional areas within a business, a lot of time is required in order to transmit, receipt and verify data. The level of resources needed with increase depending on product complexity, supply chain size and locations. Chemical regulations implement data reporting requirements which aid data collection from industry to identify gaps related to: (1) known uses of a substance, or; (2) whether a substance is safe or not; (3) identification of risk assessment measures; (4) research and development; (5) enabling the use of safer alternative substances (Koch & Ashford, 2006; Wilson & Scharzman, 2009; Tickner, *et al*, 2015; Krimsky, 2017; Botos, *et al*, 2018). Not understanding usage of substances has the potential to cause supply chain disruption, in the event of additional controls or restrictions via chemical regulations being placed against chemical substances (Takhar & Liyanage, 2017; Takhar & Liyanage, 2018). **Table [1]** presents a high-level view of the common EU chemical regulations, that require the reporting of any hazardous substances in products.

Table 1. Summary of EU chemical regulations (prevent / record the use of hazardous chemicals)

Regulation / directive name	Scope	Source
EU regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), (EC) No 1907/2006.	Established ECHA and processes to review and assess hazardous chemicals. Chemicals listed in the ECHA Candidate list must be identified in material declarations to downstream users, where applicable additional notifications where a given chemical substance appears on the more controlled substance lists.	EU, 2006a.
EU Directive on Waste Batteries and Accumulators, 2006/66/EC.	Limits the amount of Mercury, Cadmium and Lead content in batteries.	EU, 2006b.
EU Regulation on Classification, Labelling and Packaging of substances and mixtures (CLP), (EC) No 1272/2008.	EU implementation of UN GHS, which defines a standardized labelling system for chemical substances and mixtures, that enables users to identify any associated risks of using a chemical substance.	EU, 2008; UN GHS, 2019.
EU Directive on Restriction of Hazardous Substances in Electrical and Electronic Equipment. (RoHS), 2011/65/EU.	Banned substances which cannot be used win electrical or electronic products unless an exemption is granted for continued uses. Has spawned several RoHS type regulations globally.	EU, 2011.
EU Directive on Waste Electronic and Electrical Equipment, 2012/19/EU.	Implemented EPR for electrical goods, where product manufacturers pay a fee to enable safe collection and recovery of electrical and electronic products.	EU, 2012.
EU Waste Framework Directive, (EU) 2018/851.	Implemented the requirement to report data additional data from EU REACH supply chain material declarations into ECHA SCIP database, from 5th January 2021.	EU, 2018a.
EU Directive on Packaging and Packaging Waste, (EU) 2018/852.	Defines the process of handling and managing chemicals of concerned identified in products.	EU, 2018b.

3.2 Sustainability and The Circular Economy

The traditional linear economic model focuses on raw materials being consumed with other raw materials to produce products. These products are then used by end consumers, who dispose of them as waste products with little recycling taking place. This results in a scenario where natural resources become scarcer and scarcer due to increasing demand for new products. The Brundtland report (WCED, 1987) focused on stating the current needs of society could be achieved without diminishing resources and capabilities for future generations. The key areas from the Brundtland report have formed the basis for sustainability frameworks (economic, social, environmental). Key aims of sustainability include: (1) designing products which do not rely on scarce natural resources; (2) producing products which last longer and do not require replacement or repair; (3) products are made using materials which can be recycled

easily (WCED, 1987; Carter & Rogers, 2008; Tate, *et al*, 2012; Kanchanapibul, et al, 2014; EC, 2015; Kolotzek, *et al*, 2018). The circular economy model extends on sustainability by proposing the use of open-loop manufacturing systems, where the fundamental aim is to maintain the use of products via the R-imperatives: (1) reduce the amounts of consumer demand and use of scarce materials by a manufacturer, (2) resell / reuse of products, which are used by one consumer then sold and reused by another consumer; (3) repair small ad-hoc changes applied to products for continued use; (4) refurbish products where products are overhauled, (5) remanufacture products where new parts may be added to a product; (6) repurpose products for new uses; (7) recycle materials from a product to extract secondary raw materials (Tate, *et al*, 2012; EC, 2015; Zeng, *et al*, 2017; Reike, *et al*, 2018; Ellen MacArthur Foundation, 2020). Moving towards the circular economy requires a long-term shift in societal behavior in the adoption of products which are either recycled or contained recycled materials.

3.3 Corporate Social Responsibility (CSR)

CSR research dates to the 1950's, when the concept of a socially responsible business was first discussed in research circles. In 1970, Milton Friedman coined the phrase *"social responsibility of business"* (Friedman, 1970), primarily focusing on bringing about social improvements via charitable donations. CSR is built on the belief that industry should act in responsible ways towards society and the environment, not purely to generate economic gain for its stakeholders. CSR research has evolved considerably since the 1990's due to: (1) climate change and global warming issues; (2) media coverage highlighting organizations acting irresponsibly, for example negative natural resource consumption, waste pollution, worker conditions; (3) increasing consumer pressure for changes from industry. CSR has now become a multidisciplinary methodology which can be applied across all functional areas of a business to bring about a change in corporate culture, to enable organizations to act in a more responsible manner (Carroll, 1999; Porter & Kramer, 2002; Porter & Kramer, 2006; Kirat, 2015; Lim & Greenwood, 2017; Zhou, et al, 2018).

3.4 Product Stewardship (PS)

PS examines a product in terms of reviewing all aspects of a new product(s) lifecycle in terms of health, safety, environmental and social impacts (Bennett, *et al*, 2018). Actions undertaken using PS methodologies include: (1) an assessment of materials used within a product; (2) product(s) which minimize the use of hazardous chemicals; (3) product(s) which can be safely manufactured by employees; (5) products which can be produced without causing any environmental issues; (6) products which can be safely used by consumers; (7) products which can be easily and safely be repaired; (8) utilizing recycling schemes which enable product(s) to be collected at their end of life stage; (9) recycling of materials contained within products, for potential reuse as secondary raw materials, and; (10) safely disposing of products where no recycling can be undertaken.

3.5 Environmental, Social and Corporate Governance (ESG)

Initially developed as a set of tools developed by the financial sector to review potential investments (Wikipedia, 2021), based on zero-carbon, sustainability, diversity, human rights, consumer protection, animal welfare and environmental protection. ESG methodologies are being implemented widely by the European Commission (EC) as a means of bringing directed change towards achieve 2030 goals for zero waste, toxic free, sustainable targets, through the implementation of an extensive series of directives and regulations between 2020-24, as shown in **Table [2].**

Table 2. Summary of emerging EU policies and direction towards developing ESG methodologies

Regulation / directive name / Consultation	Scope	Source
EU Framework for the setting of ecodesign requirements Directive 2009/125 EC	Established initial ecodesign requirements.	EC, 2009.
EU Green Deal COM/2019/640	EU overarching strategy towards achieving climate change zero carbon objectives through direct / indirect regulation, policy, and investments.	EC, 2019.
Trade Policy Review *Consultation*	Revision of EU Trade Policy that includes sustainability and other CSR related topics. Core aim to foster trade relations in relation to the EU Green Deal.	EC, 2020a.
EU Sustainable Europe Investment Plan COM/2020/21	Sustainable investment plan to support EU Green Deal investment projects until 2030. Originally launched with a €1 Trillion budget, later expanded due to coronavirus impacts with a further €1.8 trillion. Funding from this plan aids member state governments and industry for sustainability related projects.	EC, 2020b.

Table 2. Summary of emerging EU policies and direction towards developing ESG methodologies (con't)

Regulation / directive name / Consultation	Scope	Source
EU Chemicals Strategy for Sustainability Towards a Toxic-Free Environment COM/2020/667	EU overarching strategy to pursue a non-toxic chemicals environment, through direct / indirect regulation, policy, and investment. Strategy will define sustainable chemicals criteria, expansion to scope of existing chemical regulations and new reporting requirements and scrutiny of any industry to justify any sustainability claims.	EC, 2020c.
EU General Product Safety Directive *Consultation*	Updated product safety requirements including updates for internet connected devices, enhanced market surveillance and process for product recalls to be defined.	EC, 2020d.
EU Critical Raw Materials List 2020	List of critical raw materials for EU industry, this list is then referenced in the EU Ecodesign Directive and EU Green Public Purchasing (GPP) criteria for EU public authorities to follow.	EC, 2020e.
EU environmental sustainability claims *Consultation*	New regulation updating Environmental Footprint methods for products to prevent industry from 'green washing' making products appear environmentally friendly, when in fact they are not.	EC, 2020f.
EU Environmental Law – better access to justice *Consultation*	Updated regulations proposal to enable NGOs to become extended stakeholders in non-legally EU acts, to act as independent guardians to ensure protection of environment.	EC, 2020g.
EU Circular Economy Action Plan (CEAP) *Action Plan*	New (8th) Environmental Action Programme detailed plan of high-level environmental actions for EU between 2021-2027.	EC, 2020h.
EU Environmental performance of products and businesses – substantiating claims *Consultation*	New regulation defining new detailed requirements: (i) 'sustainable by design' reporting requirements for new chemicals, mixtures, materials, and products placed onto the EU marketplace; (ii) new EU ESG requirements to ensure sustainable claims by industry are being monitored and achieved; (iii) penalties for non-provision of data under EU non-financial framework directive reporting.	EC, 2020i.
EU Non-financial reporting by large companies (updated rules) *Consultation*	Application of ESG type data models into a reporting structure which will be required to reported in annual operational performance reporting, where the new EU Environmental performance of products and businesses – substantiating claims regulation will drive requirements and formats.	EC, 2020j.
Sustainable products initiative *Consultation*	Revision EU Ecodesign Directive to establish additional data collection and reporting, covering (i) harmonized standards; (ii) additional reporting to ensure industry can identify sustainability data; (iii) standardizing product types to reduce environmental footprint for example standardizing USB-C cables; (iv) implementing consumer 'right to repair' where consumer product design will need to follow a modular design to enable consumers to self-repair consumer products to maintain use; (v) establish digital passport concept, where multiple data points can be viewed for a given product, for example identification of any hazardous chemicals, sustainable chemicals, critical raw material content, product safety, etc.	EC, 2021a.
EU Green Public Procurement (GPP) criteria	Specific product type, green requirements that public authorities need to follow when tendering for products and services.	EC, 2021b.
EU Sustainable Corporate Governance *Consultation*	Proposed series of updates to the EU regulatory framework on company law and governance. Includes identification of value chains and establishing new sustainability requirements that can be audited and reviewed by EU regulators.	EC, 2021c.

3.6 Literature Review Summary

Industry exists to generate some form of economic return for its stakeholders, by selling products and services at higher value than the cost of inputs. Products are created by the manufacturing sector utilizing raw materials consisting of chemical substances, mixtures, materials, component, products, etc. Increasing manufacturing output gave rise to the rapid depletion of scarce natural resources, with the resultant rise in industrial emissions leading to concerns relating to hazards to human health and increased global warming, increased awareness of these concerns led the development: (1) development of global protocols and convention, (2) national and regional chemical regulations; (3) increased monitoring organisational activities**. Figure [2]** depicts the high-level correlation between innovation and industrial output leading to increased industrial emissions, which in turn has led to increasing direct and indirect control measures to offset adverse impacts.

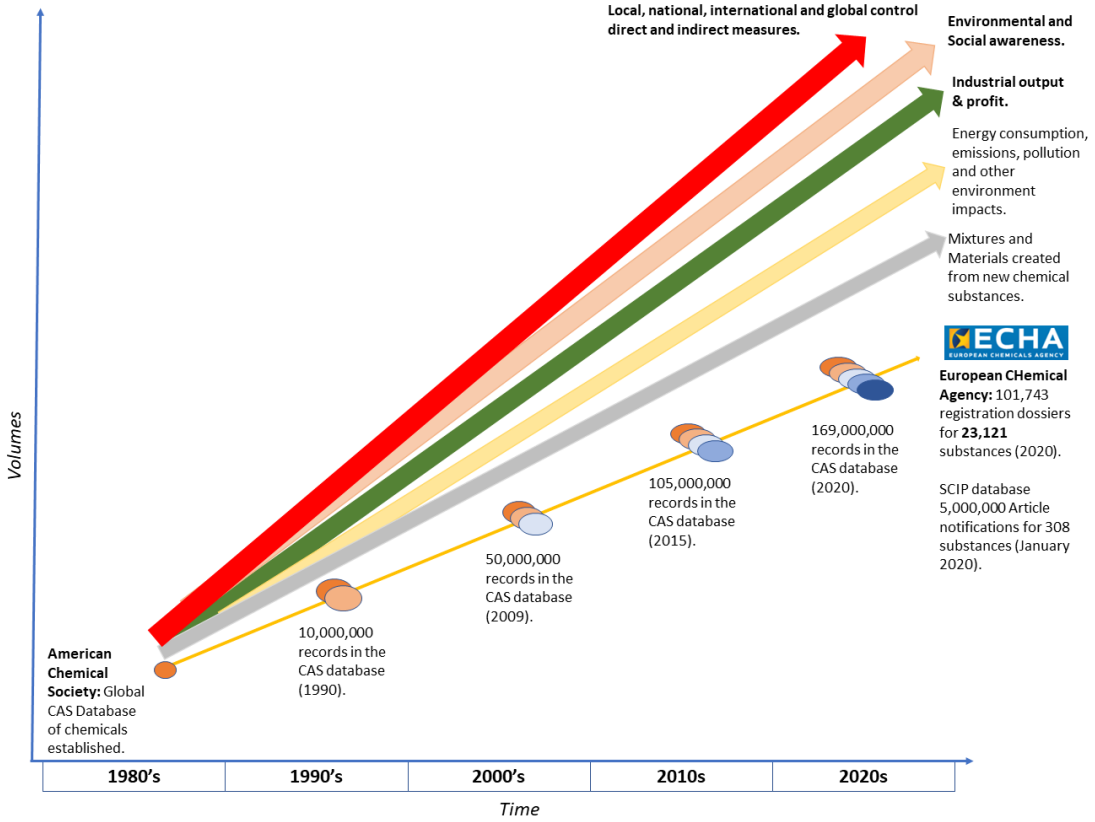


Figure 2. Innovation, growth, impacts, control measures.

The application of direct and indirect measures has resulted in the need for industry to shift focus away from the traditional economies of scale model (Smith & Skinner, 1982) manufacturing at the lowest cost price and selling at a higher price to maximize profits, towards enhanced awareness of the role of the organization across its own value chain and extended across wider analysis of societal and environmental impacts by reviewing as increasingly wider set of criteria for example reporting data on carbon footprint, human rights, hazardous chemicals, conflict mineral, critical raw materials, recycled material content (Pine & Gilmore, 1998; Tukker, 2015; Pattnaik & Pattnaik, 2019). **Figure [3]** shows the evolution of increasing requirements and resultant expansion in reporting has led to the from PS, CSR and ESG.

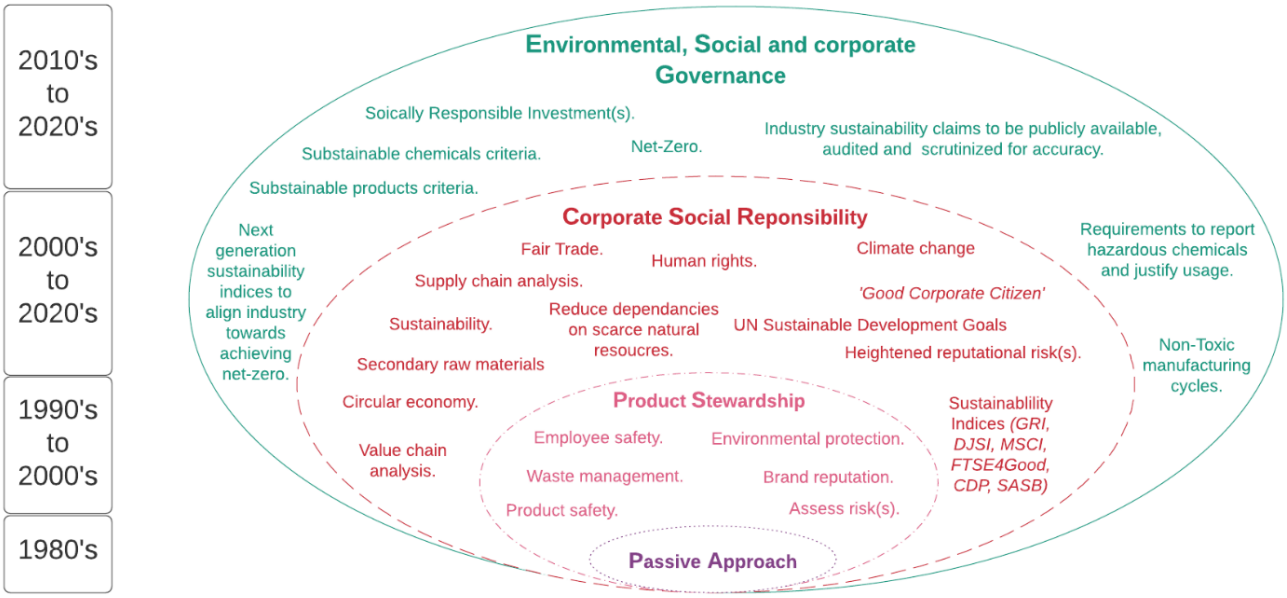
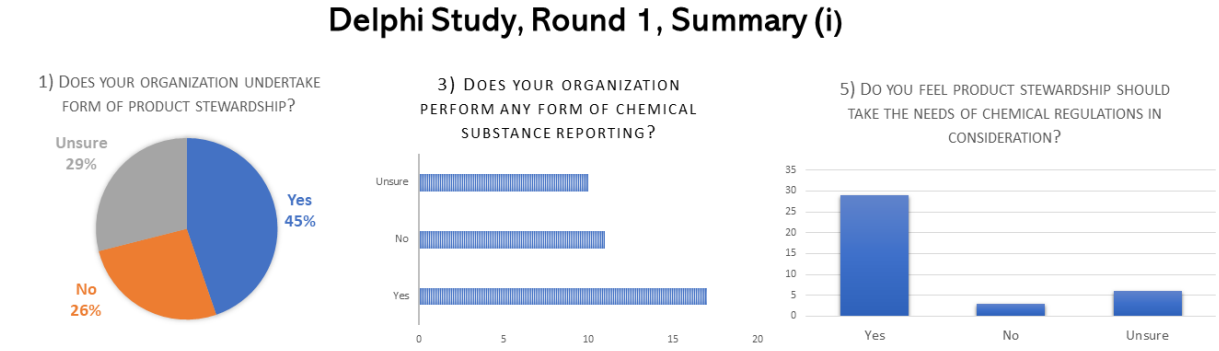


Figure 3. Evolution from PS, CSR, towards ESG.

4. DELPHI STUDY FINDINGS

4.1 Round 1

83 participants were invited to participate, 38 (45.79%) fully complete and 4 (4.82%) incomplete responses were received. **Figures [4]**, **[5]** and **[6]** present the summary data from the round 1 of the Delphi study. **Figure [4]** shows that the respondents had a basic understanding of products stewardship and the role of chemical regulations.



2) PS Elements Respondents Identified With	%
Senior management buy-in for PS.	55.3%
PS commitment communicate to all employees.	44.7%
Use of sustainable practices (design / manufacture).	44.7%
Supply chain data sharing understands the risks and hazards across a supply chain .	42.1%
PS commitment communicated to supply chain.	42.1%
PS has a clear governance procedure.	36.8%
Health and safety risk assessments undertaken	36.8%
Shared responsibility concept, every actor within the lifecycle of a product takes responsibility at different lifecycle stages.	36.8%

4) Chemical Regulation Elements Respondents Identified With	%
Requesting chemical substance reporting information from the supply chain.	42.1%
Assessing Material Safety Data Sheets (MSDS) or Safety Data Sheets (SDS) when substances and mixtures arrive on site.	39.5%
Chemical regulation formatted statements (REACH, RoHS, Prop 65, WEEE).	39.5
Assessing Material Safety Data Sheets (MSDS) or Safety Data Sheets (SDS) when substances and mixtures are purchased [34.2%].	34.2%

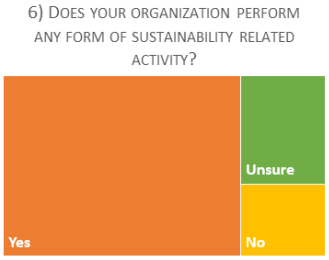
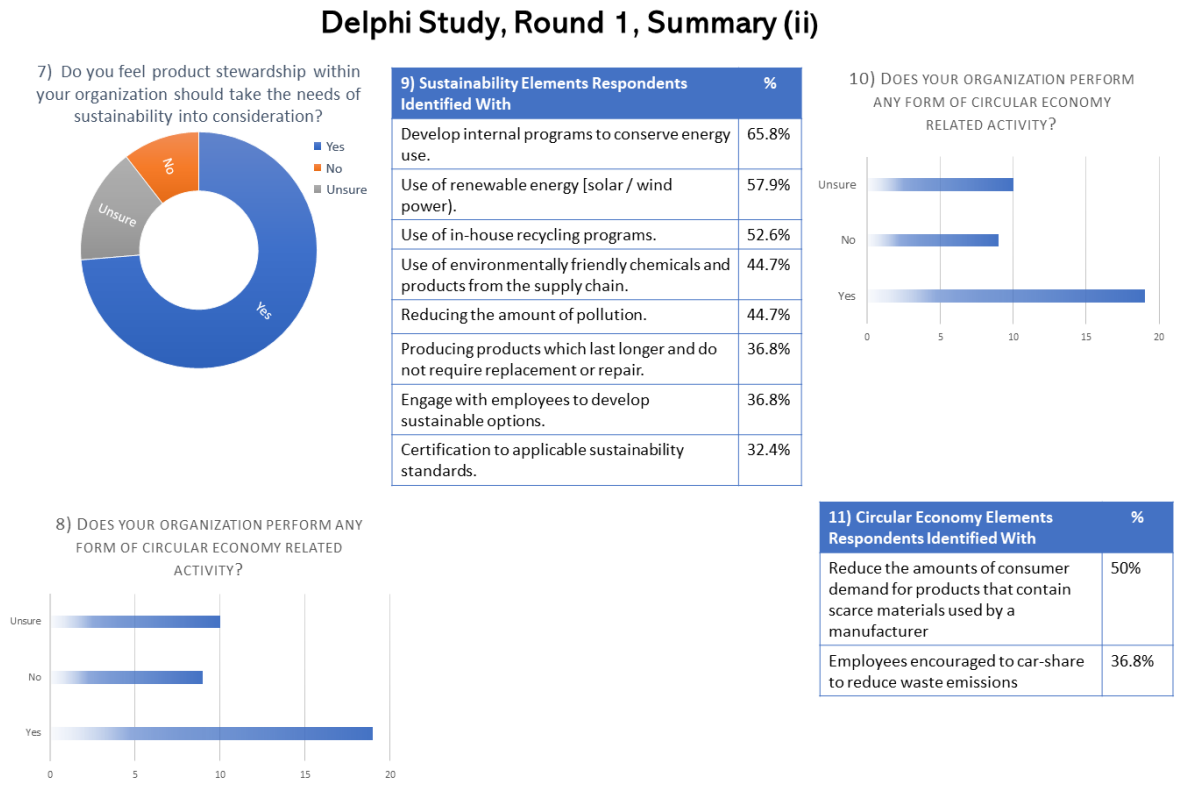


Figure 4. Delphi study, round 1, summary of results (i).

Figure [5] showed that the respondents had a understanding of sustainability and the circular economy, however responses to (Q9) where respondents were asked to identify sustainability elements, from a list 15 potential answers, the strongest consensus was formed against elements relating to: (1) energy use; (2) renewable energy, and (4) recycling. In (Q10), respondents were asked to identify circular economy elements, from a list of 10 possible answers, the strongest consensus formed against elements relating to: (1) reduce the amounts of consumer demand for products that contain scarce materials used by a manufacturer, and (2) employees encouraged to car share to reduce waste emissions.

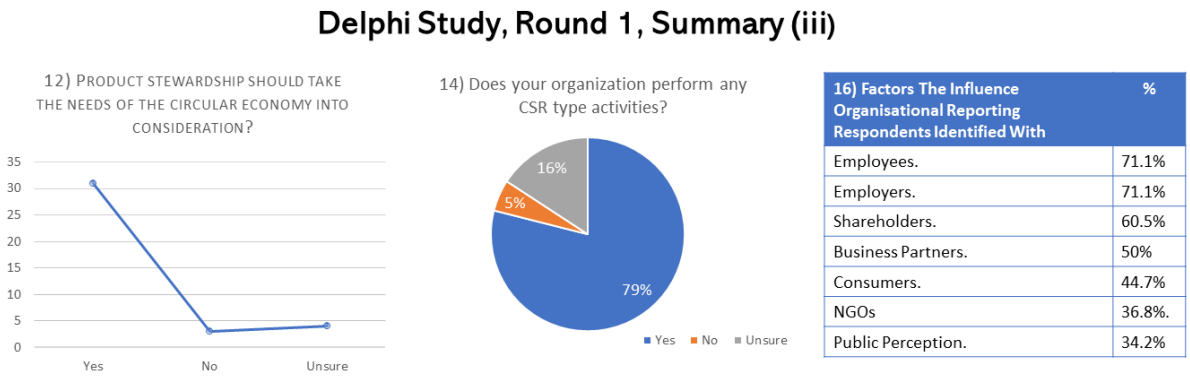


9) Sustainability Elements Respondents Identified With	%
Develop internal programs to conserve energy use.	65.8%
Use of renewable energy [solar / wind power).	57.9%
Use of in-house recycling programs.	52.6%
Use of environmentally friendly chemicals and products from the supply chain.	44.7%
Reducing the amount of pollution.	44.7%
Producing products which last longer and do not require replacement or repair.	36.8%
Engage with employees to develop sustainable options.	36.8%
Certification to applicable sustainability standards.	32.4%

11) Circular Economy Elements Respondents Identified With	%
Reduce the amounts of consumer demand for products that contain scarce materials used by a manufacturer	50%
Employees encouraged to car-share to reduce waste emissions	36.8%

Figure 5. Delphi study, round 1, summary of results (ii).

Figure [6] showed a general awareness of the circular economy and CSR, interestingly in (Q16), NGOs and public perception were not as widely agreed as the other possible answers in terms of elements that influenced organisational reporting.



16) Factors The Influence Organisational Reporting Respondents Identified With	%
Employees.	71.1%
Employers.	71.1%
Shareholders.	60.5%
Business Partners.	50%
Consumers.	44.7%
NGOs	36.8%.
Public Perception.	34.2%

13) Does your organization have a policy in which it makes a commitment to respecting (i) environmental regulations; (ii) labour rights; (iii) human rights; (iv) preventing anti-corruption?	%
Yes.	78.95%
No	57.9%
Unsure	15.79%

15) External Standards Respondents Identified With	%
ISO 9001:2015 - Quality Management System	63.2%
ISO 14001 – Environmental Management System	44.7%

Figure 6: Delphi Study, Round 1, Summary of Results (iii)

4.2 Round 2

All 38 respondents from the round 1 were invited to participate in round 2. 29 (78.95%) completed responses were received in round 2. **Table [3]** shows the product lifecycle elements where consensus was achieved. **Table [4]** shows the potential questions to be used within a PS framework where consensus was achieved.

Table 3. Delphi Study round 2, product lifecycle elements where consensus was achieved.

Element	%
Design - Products should be designed from the outset to be: (i) environmentally friendly; (ii) use materials which are not scarce and do not endanger the environment; (iii) capable of being easily dismantled at their end of life.	89.7%
Manufacture - The product manufacturing process should: (i) avoid the use of hazardous substances; (ii) limit excessive use of energy; (iii) avoid dangerous emissions; (iv) produce products which are safe and environmentally friendly.	89.7%
Use - Products should: (i) be safe to use; (ii) be energy efficient.	79.3%
Disposal - Products should be disposed via appropriate collection points to enable: (i) refurbishment and reuse; (ii) repurposing into other products; (iii) recycling of materials contained within products to generate secondary raw materials which can then be used to make new products.	79.3%
Waste - The only materials which end up in waste streams such as landfill, should be those which cannot be reused, repurposed or recycled.	75.9%
Repair - Products should be easily repairable to prolong continued useful life.	72.4%
Additional respondent feedback comments: • *Some products may not be appropriately dismantled. Consider, for example, down-the-drain soaps and detergents. Not all products are appropriately repaired or disposed of through reuse, repurposing, or recycling. Again, consider down-the-drain products or food products.* • *All materials used in a product should be either reusable or biodegradable.*	

Table 4. Delphi Study round 3, questions that may be included within a PS framework where consensus was achieved

Element	%
Are any renewable energy sources utilized?	72.41%
How much waste is generated as part of the manufacturing cycle?	68.97%
Are any product collection schemes used when a product reaches the end of its useful life? - if there are any collection schemes, how are they implemented and managed?	62.07%
What are the materials required to manufacture a product?	58.62%
How much energy is needed to manufacture a product? – this may be aggregated across all products.	58.62%
How is the waste generated as part of the manufacturing cycle handled?	58.62%
Are any previously used products recycled? - how are materials prioritized for recycling activities?	58.62%
Have you taken any steps to integrate your supply chain towards sustainability and the circular economy?	58.62%
Do you perform any supply chain monitoring activities with regards to compliance with (i) chemical regulations; (ii) sustainability, (iii) the circular economy, and; (iv) corporate social reporting?	58.62%
What are the materials contained within a product?	55.17%
Have you identified the economic, social and environmental impacts of your products?	51.72%
How do you measure the economic, social and environmental impacts of your products?	48.28%

4.3 Round 3

All 29 respondents from the round 2 study were invited to participate, 18 (62.07%) responses were received back of which 15 (51.75%) were fully completed responses. Tables [5], [6], [7], [8], [9], [10], [11], [12] and [13] depicts the respondent consensus statements in regards to different elements that should be included within a PS framework.

Table 5. Delphi Study round 3, PS elements where consensus was achieved.

Element	%
PS impacts a wide range of business activities.	93.3%
Senior management buy-in for PS.	93.3%
PS examines the environmental, health and safety impacts of a product across its entire lifespan.	86.7%

Additional respondent feedback comments:

- *Too often industries take a narrow view of PS. For example, companies making chemicals are very good at stewarding the chemicals from factory loading dock, through the factory to the transportation network to the next factory gate. However true stewardship needs to go further. True stewardship would look at consumer product use of chemicals, packaging, and energy to use the product (in the cases of laundry liquid and shampoo, for example)*
- *By product one needs to include its packaging, logistics support and any take back of material involved. A question arises as to whether stewardship standards or certification are required. In my view they are mandatory, and fines allotted if not followed. as prescribed.*

Table 6. Delphi Study round 3, Product design elements, where consensus was achieved.

Element	%
Review any product design changes as they occur.	93.3%
Review when a product is first designed.	86.7%
Review product use of materials which are either reusable or biodegradable.	73.3%
Review substances, mixtures and materials to ensure they are not hazardous.	73.3%
Review product materials to ensure they are not scarce.	66.7%
Not all products can be designed using materials which are not scarce; easily dismantled; non-hazardous; reusable; biodegradable; or energy efficient. There will always be some products which display these types of properties.	66.7%
Review products to ensure they can be easily disassembled for repair and recycling activities.	60%

Table 7. Delphi Study round 3, procurement elements where consensus was achieved.

Element	%
Review purchasing criteria for products labelled as being environmentally friendly.	80%
Review internal energy consumption rates.	80%
Review decisions to either manufacture products internally or outsource from a supply chain.	73.3%
Review internally generated waste rates.	73.3%
Additional respondent feedback comments: • *Ownership by a PS group is not necessarily appropriate and depends on the company organization;* • *One should also consider whether the product could be rented or leased instead of sold. In that way the waste / reuse / up-cycled final product can be controlled*	

Table 8. Delphi Study, round 3, supply chain management elements where consensus was achieved.

Element	%
For new suppliers, any supplier assessments should be reviewed.	86.7%
Review supplier data on how much waste is created to manufacture a product.	86.7%
Review the substances, mixtures and materials used by suppliers. Suppliers may be encouraged to use safer alternative substances.	80%
Suppliers shall be encouraged to utilize recycled materials.	80%
Suppliers should demonstrate a commitment to sustainable supply chains (certification against ISO 14001 / ISO 9001 / ISO 20400 / other).	80%
Review environmental performance criterion set for suppliers.	73.7%
Review environmental audits conducted on suppliers.	73.7%
Suppliers may be encouraged to perform recycling activities.	73.7%
For existing suppliers, review any supplier assessments.	60%
Suppliers should provide a policy commitment to the "Universal Declaration of Human Rights".	53.5%

Table 9. Delphi Study, round 3, product manufacture elements where consensus was achieved.

Element	%
Review existing manufacturing processes.	80%
Review any changes to manufacturing processes.	73.3%
Review materials used within manufacturing processes.	73.3%
Review the amounts of pollution / emissions generated as a result of manufacture can be identified by pollution / emission type against each product type manufactured.	73.3%
Review substances, mixtures and materials contained within finished products manufactured internally.	66.7%
Review energy sources.	66.7%
Review the amounts of energy consumed to manufacture products can be identified by energy type against each product type.	66.7%
Prioritization shall be given to the use of recycled materials where possible.	60%
Review the amounts of waste being generated.	60%

Table 10. Delphi Study, round 3, production release of products elements where consensus was achieved.

Element	%
Review any product risks to the environment are identified as part of the design and manufacture cycles.	86.7%
Review any product risks to human health are identified as part of the design and manufacture cycles.	80%
Ensure products have appropriate safe use guidance.	80%
Ensure product safety labels are created and reviewed.	73.3%
Ensure product safety testing is conducted and reviewed.	66.7%

Table 11. Delphi Study, round 3, consumer use elements where consensus was achieved.

Element	%
Review procedures should be defined in relation to proper use of products.	73.3%
Review instructions for consumers on in relation to product disposal.	73.3%
Review procedures should be defined in relation to improper use of products.	66.7%
Review procedures in relation to handling product defects.	60%
Additional respondent feedback comments:	
• *A question arises as to who would be qualified to repair the product. This also needs to be institutionalized*. (In the context of products being repaired and maintained by a product OEM).	

Table 12. Delphi Study, round 3, social impact elements where consensus was achieved.

Element	%
Review internal procedures should be defined in relation to human rights.	66.7%
Review internal employee working conditions.	66.7%
Reviews any social improvement projects to aid local communities.	60%
Review internal employee policies in relation to gender, race and disability equality.	60%
Review internal employee working hours.	53.3%
Additional respondent feedback comments:	
• *The organization that owns the means of production shall also have a clear review process to ensure that value reverts to the local group as opposed to exclusively shareholders.*	

Table 13. Delphi Study, round 3, circular economy elements where consensus was achieved.

Element	%
Review third party schemes are used to manage the collection, recycling and disposal of EOL products.	80%
Where feasible, review data from waste stream operators. With the data feeding back into product design cycles to enable future reductions.	80%
Review procedures define the collection of End-of-Life (EOL) products from collection points or directly from consumers.	73.3%
Review waste collected during product manufacturing processes and reprocessed.	73.3%
Products shall be simple to repair where possible to prolong active life. Review repair statistics.	66.7%
Review third party providers who refurbish products, to ensure refurbished products meet quality and safety criteria to protect brand reputation.	66.7%
Review third party providers re-purpose products.	66.7%
Review where products have been processed into secondary raw materials.	66.7%

4.4 Delphi Study Summary

Responses to the Delphi study, round 1, showed a mixed understanding of PS, chemical regulations, sustainability and the circular economy. The highest rated responses from the Delphi study, round 1, were used as the basis for the questions in Delphi study, round 2 survey. Round 2 survey responses showed a stronger alignment of framework questions which could potentially be applied to a PS framework. Round 3 survey responses showed the need for PS align with the needs of: (1) product lifecycle stages; (2) consumer use; (3) societal impacts, and (4) circular economy.

5. DISCUSSION

5.1 Literature Review Findings

The literature review highlighted a correlation between: (a) industry existing to generate increasing returns for its shareholders, and; (b) increasing mass production and outsourcing of manufacturing resulting in increasing industrial emissions leading to pollution and climate change issues, and; (c) ever increasing demands of industrial innovation, leading to a dramatic rise in the rate of at which new chemicals, mixtures, materials are being generated, and; (d) the potential of increasing social inequality for workers being exploited in regions where worker rights are not protected, and; (e) Increasing media coverage of environmental and social impacts of industry, resulting in increased pressures from consumers and the civil society (NGO's) for reform, which in turn is resulting in regulatory authorities introducing direct and indirect measures into the marketplace. As new control measures such as recycling, environmental and human safety, were being introduced, industry had to think beyond traditional product management methodologies.

5.2 Delphi Study Findings

A high-level summary of the Delphi study findings is shown in **Figure [7]**, where the centre depicts core PS, CSR and ESG concepts, with the elements, where consensus was reached by respondents from the Delphi study shown on either side of the core PS, CSR and ESG concepts.

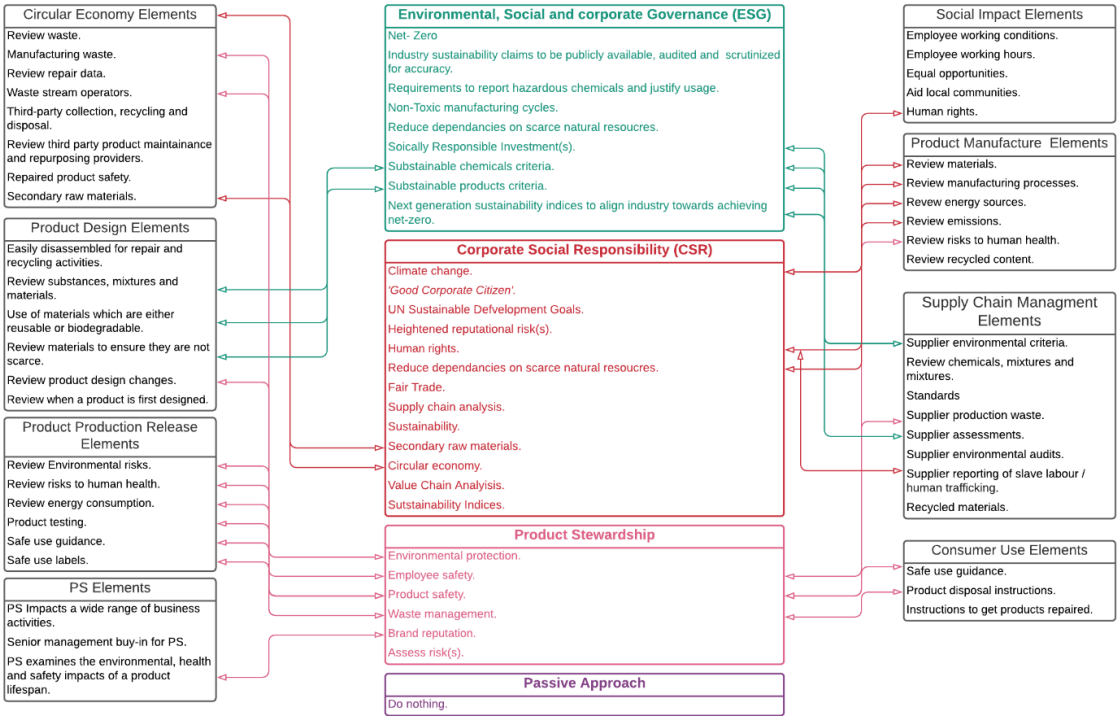


Figure 7. Application of Delphi Study elements into PS, CSR and ESG.

5.3 PS Conceptual Framework

Industry can longer maintain the passive approach of *'do nothing'*. The progression towards sustainable development, zero-toxic and zero-waste (low carbon) and the circular economy has seen the need for organizations to examine their end to end operations, beyond internal product manufacture, to considering a much wider set of potential societal and environmental impacts as conceptualized under CSR and ESG reporting model, as shown in **Figure [3]**. Organizations need to examine internal and external stakeholders, **Figure [8]** presents stakeholder analysis based on a typical Aerospace and Defence (AD) type organization, derived from the Author's PhD research, which can be augmented and applied to other industry type organizations.

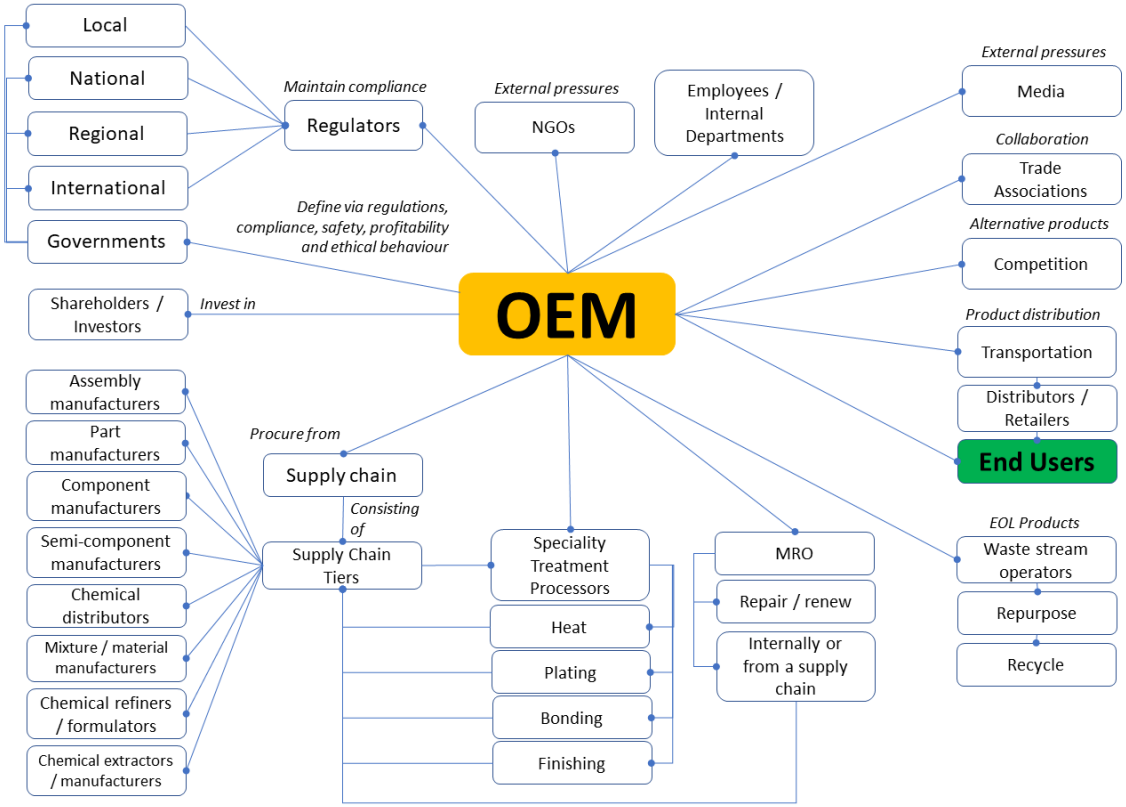


Figure 8: Identification of stakeholders (*AD example*).

Following stakeholder identification, an action plan should be developed as shown in **Table [14]** which outlines the tasks that need to be conducted to establish initial review gates.

Table 14. Action plan to embed PS

Concept / Feature	Meaning
Identify internal actors.	Engage with all internal stakeholders such as design, purchasing, manufacture, quality, sales, etc. All stakeholders within a business need to be engaged. PS will then be able to allow effective reviews.
Agree actors.	Clearly identify who will be part of the PS panel. Actors need to be committed to attend, PS panel review meetings, and support the PS process.
Establish initial objectives.	Review production stewardship, regulatory, sustainability, circular economy, and CSR literature. Brainstorm and set high-level initial goals.
Embed and engage to create a PS culture.	Embed PS panels in as many business decisions making processes as possible. This will require the actors supporting the PS process to engage with all related functions explaining the new PS culture being adopted.
Define more detailed objectives.	Develop a more thorough set of objectives. This will include setting clear targets: (1) on the use of regulated chemicals; (2) developing products which are more sustainable (materials and resources) and can feed into the sustainability, circular economy; (3) defining a set of CSR objectives. The objectives should result in clear targets.
Gap analysis and roadmap.	Analyze the current state organization. Identify gaps which exist today, which prevent the objectives from being completed. Develop a roadmap of activities.
Identify external stakeholders.	Identify key external stakeholders to your organization who will be impacted by changes required by the action plan. Engage with stakeholders to provide insights of the proposed changes. Understand impacts of changes on external stakeholders. Review initial feedback, adjust the action plan as required.
Identify and establish gated reviews.	Have a gated review process for key business processing stages. Establish key milestones for different functional areas within an organization to engage with the PS panel for a review.
Enforce gated reviews.	Ensure all relevant business decisions are reviewed by the PS panel.
Continuous improvements.	Regularly monitor the changes reviewed by the PS panel. Adjust decisions and actions to align with chemical regulations, sustainability, circular economy, and CSR targets.

Utilizing the data elements that achieved consensus in the Delphi study as shown in **Figure [7],** the conceptual PS framework is shown in **Figure [9].** Additionally the questions shown in **Table [4]** may be utilized as reference set of questions to aid the development of PS systems.

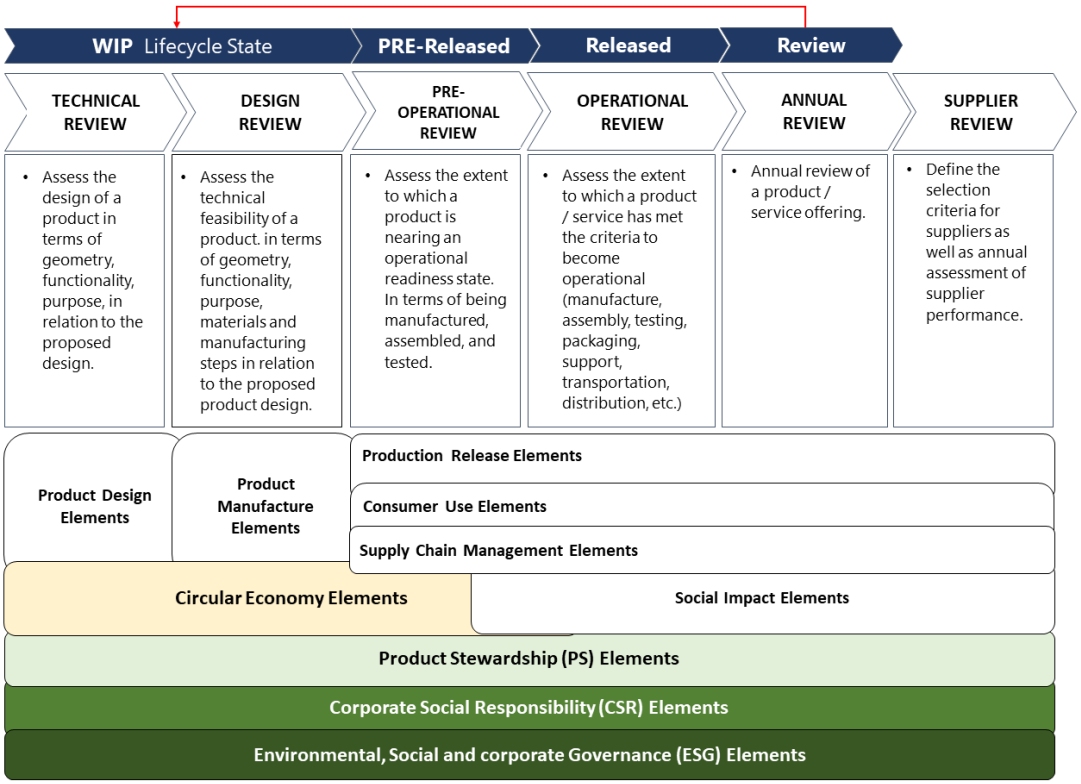


Figure 9. Internal review gates and Delphi study elements.

PS systems themselves can then either evolve (1) into CSR and ESG type systems, or (2) expand existing PS systems to include CSR and ESG methodologies.

6. CONCLUSIONS

The purpose of this paper was to extend previous research (Takhar & Liyanage, 2019) via an updated literature. and Delphi study examining respondent views in relation towards the realignment of PS towards the needs of chemical regulations, sustainability, the circular economy, and CSR. **Table [15]** depicts how the research paper has accomplished its's original research objectives:

Table 15. Review of research objectives

Research question / objective	Achieved via
1.What are the current PS methodologies in use within industry?	• PS section in literature review. • Delphi study, round 1, **Figure [4].**
2. What current state sustainability, circular economy and CSR methodologies are in use within industry?	• Sustainability and circular economy sections in literature review. • CSR section in literature review. • ESG section in literature review. • Delphi study, round 1, **Figure [5]** and **Figure [6].**
3. Does current state PS, align with chemical regulations, sustainability, circular economy, and CSR objectives?	• Chemical regulations section in literature review. • Delphi study, round 1, **Figure [4]**, **Figure [5]** and **Figure [6]**.
4. How can PS align with chemical regulations, sustainability, circular economy, and CSR objectives?	• Delphi study, round 2. • Delphi study, round 3. • Delphi study findings. • PS conceptual framework.

The contributions to theory outcomes of this research are that the PS conceptual framework will enable organizations to: (1) understand the needs of chemical regulations, sustainability, circular economy, and CSR; (2) identify and engage with appropriate internal and external stakeholders; (3) Develop an action plan to embed a PS culture and establish gated reviews.

Implementing PS with gated reviews enables an organization to review, observe and pursue new opportunities in a coherent manner. PS should act as an independent ombudsman within an organization managing the alignment of existing systems and processes to the needs of chemical regulations, sustainability, the circular economy, and CSR.

Limitation of the research are: (1) the topic areas (chemical regulations, sustainability, circular economy, and CSR) were quite diverse. They may have been best served as individual research papers and surveys against each topic; (2) the duration of the surveys could have been extended to 2-3 months between the launch and close of a survey to enable more respondents; (3) specific industry sectors could potentially have been targeted for the Delphi study in terms of industry sectors which are known to perform a topic area well versus those sectors which are known to not perform a topic area well.

Future development of this research includes: (1) Delphi studies to be conducted against specific topic areas: (a) chemical regulations; (b) sustainability; (c) circular economy; (d) CSR, and (e) ESG; (2) specific industry sectors identified in terms of sectors identified as performing limited PS activities; (3) longer duration between each round of a Delphi study; (4) engaging with organizations that have implemented PS within their organizations that aligns to the topic areas. This could be undertaken to compare the PS conceptual framework versus a real-world use case.

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