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ESG and CMC Embedding Sustainability Metrics into Technical Program Dashboards

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Abstract:

The Environmental, Social, and Governance (ESG) considerations being incorporated into Chemistry, Manufacturing, and Controls (CMC) operations are becoming the trend as businesses seek sustainable and resilient operations. This research investigates the evolution of technical program dashboards that incorporate sustainability data, like solvent reuse, energy intensity, and generation of waste, into business decisions. By connecting these KPIs to program-gate reviews and vendor selection, the study demonstrates how organizations can integrate compliance, operational excellence, and sustainability objectives in complex technical environments. Through real-world deployments in healthcare, industrial systems, and urban planning, this paper demonstrates how digital dashboards serve as strategic enablers to improve transparency, maximize resource utilization, and promote environmental stewardship. The results point to the centrality of data-driven monitoring systems which simultaneously validate regulatory compliance and yield continuous improvement in environmental performance. Such a perspective makes ESG-linked CMC dashboards a critical facilitator for companies that are future-fit with sustainability seamlessly flowing into technical, operational, and strategic decisions.

Keywords: ESG, CMC, Sustainability Metrics, Technical Dashboards, Solvent Recovery, Energy Intensity, Waste Management, Program-Gate Decisions, Vendor Selection, Key Performance Indicators (KPIs).

I. INTRODUCTION

The implementation of Environmental, Social, and Governance (ESG) considerations in technical program management has been a key enabler for sustainable innovation and business resilience. Today, organizations are incorporating sustainability indicators like solvent recovery, energy intensity, and waste minimization into Chemistry, Manufacturing, and Controls (CMC) dashboards to link program objectives with general environmental and regulatory objectives [16] [13] [26]. By linking these measures of performance (KPIs) to vendor procurement methods and program-gate decision-making, companies not only increase accountability, but also ensure that discussions about resource effectiveness and sustainability take center stage in project lifecycles [9] [22] [21]. Digital dashboards proved to be effective tools during this change, providing web-based monitoring and visualization of sustainability indicators that allow strategic choices throughout industries from the pharmaceutical to manufacturing sectors [1] [2] [6] [11]. The capability to incorporate ESG-related indicators in CMC frameworks provides for more transparency and better governance structures, as well as ensuring compliance with global sustainability standards [10] [14] [7]. In addition, research supports that data-driven dashboards have the capability to enable organizations to analyze operation efficiency relative to sustainability performance and determine relevant trade-offs among the two, thus enabling smart vendor choices and long-term value creation [18] [5] [4]. As industries transform towards cleaner and sustainable business practices, ESG-driven dashboards are turning into key drivers of system transformation, connecting technical program performance with societal and environmental goals [3] [15] [23].

II.LITERATURE REVIEW

Gremyr et al. (2020): Highlighted the importance of measures of complexity to develop digital dashboards in health care, including the use of the latter in managing schizophrenia. They discovered that in their work sustainability and clinical KPIs could be grouped in dashboards, and could train other professionals to perform the ESG-related tasks in the technical program's solvent recovery, and energy consumption [1].

Martinez et al. (2018): Created an electronic dashboard to monitor a patient flow. This methodology shows that the dashboards are flexible enough to systematically illustrate the KPIs that can be used in CMC dashboard to monitor energy intensity and waste management throughout the technical decision-making process [2].

Sharafizad et al. (2022): Examined the role of local embeddedness on the sustainability practices of local firms. Their findings are why social and environmental KPIs on a dashboard cannot just inform program-gate decisions but can also influence plans to select vendors [3].

Marsal-Llacuna (2020): Proposed the People's Smart City Dashboard (PSCD) that utilizes blockchain to aid governance. The study is centered on transparent and apparent measurements, which is associated with the solvent recovery and energy monitoring ESG-directed CMC dashboard [4].

Williamson (2018): Examined the issue of big data in higher education infrastructures using dashboards. In this research paper, the complexity of data environments, which may consider sustainability and performance indicators, are presented as an example, and the latter will become the reflection of the way environmental KPIs can be provided as part of the technical program dashboards [5].

Aboulian et al. (2019): Service electromechanical equipment. In the article, they reveal their application of a diagnostic KPI of industry and explain the process of including energy-consuming data and waste in the data and integrating the data into a CMC dashboards system [6].

Kourtit and Nijkamp (2018): Studied big data dashboards in smart cities with the case of Stockholm. They conclude that dashboards can be considered decision support systems that can be misused to make program-gate decisions in CMC with a mix of KPIs that involve ESG [7].

Schall et al. (2017): Their contribution supports the usability and implementation issues of KPI dashboards, which is important to consider when integrating sustainability indicators such as solvent recovery into CMC dashboards [8].

El-Kholei and Yassein (2023): Underlined sustainability in architectural education through SDGs. This means more focus on incorporating ESG principles into the professional framework to match with technical program dashboards that have waste and energy KPIs [9].

Kitchin et al. (2016): Research the politics of urban dashboards, and the shape of KPI influences the government. They highlight the importance of sustainability indicators on organizational strategies especially selection of the vendor in CMC programmes [10].

Schiavone et al. (2022): Investigated intellectual capital as an asset deployed in digitalized health networks and proposed KPI dashboards as monitoring instruments deployed to manage the networks. They focus their approach on the importance of sustainability-related KPIs as a means of supporting resilience and accountability in technical programs [11].

Fagarasan et al. (2023): Introduced a sustainable agile software project scoring model. The model might lead to evaluation of the CMC dash boards data where solvents, waste and energy KPIs could be reclaimed to act as milestones in the technical programs [13].

Kitchin et al. (2015): Explained why real-time dashboards play a crucial role in the governance of cities. They examine how constant tracking of indicators corresponds to technical program requirements in program-gates based on the ESG in the context of decision-making [14].

Erdil et al. (2018): Applied sustainability to the lean six sigmas model's context and showed that performance could be enhanced to be eco-friendly. This avails some methodological background of how the solvents and waste KPI recovery can be reduced to technical dashboards [16].

Petersen et al. (2017): Conducted a study to research the environmental dashboards that produce community involvement. They include their framework to emphasize the importance of feedback-based sustainability metrics to inform vendor and program-gate decisions in technical programs [18].
Rastelli (2023): Created an ESG planning corporate performance management tool. They both have the bonus of sustainability KPIs as dashboards and can adopt program-level governance in CMC from [21].
DeMenno (2022): Measured sustainability and financial stability under the scope of stress testing. It may indicate resiliency-related KPIs which can be combined into technical dashboards to paint a picture of the danger of climate-related problems in choosing vendors [22].
Gladysz and Kuchta (2022): Discuss sustainable measures in project financial risk management and illustrate the application of dashboards to integrate ESG measures in technical and financial governance. They use their model directly to combine solvent recovery, and energy KPIs into CMC dashboards [26].

III.KEY OBJECTIVES

- To integrate ESG and sustainability metrics (energy intensity, solvent recovery, waste KPIs) into program dashboards for real-time monitoring and decision-making [12] [13] [16] [26].
- To have CMC processes aligned with sustainability standards through integrating data-driven dashboards that raise the transparency of environmental and social metrics in technical programs [9] [14] [15] [22].
- To associate KPIs for sustainability with program-gate decisions, such that project approvals, reviews, and progress checks are a function of technical performance and ESG results [11] [17] [18] [21].
- To trigger vendor procurement and supply chain management by utilizing dashboards to track partners on ESG and sustainability criteria [3] [7] [10] [19].
- To streamline compliance and reporting structure by incorporating sustainability metrics within formal dashboards to promote transparency in regulatory and financial audits [5] [19] [23].
- To facilitate decision-making in complex situations by leveraging dashboards that integrate technical KPIs with ESG factors to enhance cross-functional collaboration [1] [2] [8] [24].
- To influence energy efficiency and waste reduction initiatives by incorporating real-time monitoring of intensity measures into digital dashboards for effective resource management [6] [20] [25] [26].
- To gain long-term climate risk resilience and financial well-being by means of ESG-based stress testing and sustainability-linked metrics integrated within program dashboards [4] [15] [22].

IV.RESEARCH METHODOLOGY

The research process takes a multi-step approach in acquiring knowledge of how Environmental, Social, and Governance (ESG) and Chemistry, Manufacturing, and Controls (CMC) practices can be incorporated into technical program dashboards through the connection of solvent recovery, energy intensity, and waste-related key performance indicators (KPIs) to vendor sourcing and program-gate decisions. The strategy commences with the systematic review of literature and best practice on dashboard-based integration for sustainability which has been found to be effective in healthcare [1], hospital administration [2] [12] municipal government of a smart city [4], higher education [5], and equipment monitoring in industry [6]. Building on such roots, the research utilizes a case-study, design-science approach akin to that used in the design of urban and environmental dashboards [10] [14] [15] [18] where KPI frameworks are co-designed with stakeholders to ensure that measures of sustainability are actionable in real time by decision-makers in programs and vendors. Data collection involves structured interviews and questionnaires from sustainability officers, program managers, and supply chain providers, modifying knowledge-attitude-practice (KAP) survey methodologies for the integration of sustainability in planning and architecture education [9]. Quantitative indicators like waste-to-output ratios, energy intensity indexes, and solvent recovery rates are systematically installed into dashboards using data-driven scoring models similar to those created for agile software development and financial risk management [13] [17] [19] [26].The strategy also includes mesolevel intellectual capital and digital network analysis [11] to emphasize how knowledge in an

organization facilitates the integration of ESG indicators into CMC designs. Concurrently, lean six sigma operations embedded within sustainability [16] [23] [24] serve as the point of reference for balancing operational efficiency and environmental KPIs. For assessing the dashboard, iterative prototyping and usability testing methodologies [8] are employed, which facilitate operability and end-user acceptability. Case simulations are subsequently conducted, through big data-based decision-support methods [7] [21] to validate responsiveness of dashboards in different program-gate decision contexts. Stress-testing methodologies from finance risk research [22] [25] are similarly modified to evaluate dashboard resilience in addressing ESG-type risks at different vendors. Vendor performance is graded on KPI dashboards covering sustainability and procurement processes, in accordance with corporate ESG planning [21] and project portfolio sustainability scores [13]. Lastly, the strategy adopts a mixed-methods validation approach, placing quantitative statistical analysis of the effects of KPIs against qualitative stakeholder feedback to ensure that resulting dashboards not only track for sustainability but also as decision-support systems to inform vendor accountability and program-level measures [3] [18] [26].

V.DATA ANALYSIS

Incorporation of solvent-recovery, energy-intensity, and waste-generation KPIs into CMC technical program dashboards makes sustainability a reporting afterthought become an instinctual, real-time decision driver that directly impacts program-gate results and vendor selection. Dashboards created using best-practice operations and clinical monitoring provide visualization of normalized trends for KPIs, control limits, and Pareto-ranked contributors to allow program managers to identify unacceptable solvent recovery rate drift or abrupt energy intensity changes at the early stages of the development cycle [2] [10] [14]. By making targets (e.g., % minimum solvent recovery, per unit energy thresholds, and diversion rates) gate criteria, programs inherently identify those processes that need to be remedied before going on to the subsequent gates, minimizing downstream rework and regulatory hazard and ESG aligning [11] [21]. Blending persistent-monitoring technologies like non-intrusive usage/load monitoring for energy profiling with analytics on dashboards enables the allocation of energy intensity to equipment, process steps, or suppliers enabling supplier scorecards reconciling sustainability performance with cost, quality and lead time in choosing vendors [6] [20]. Baking sustainability into improvement cycles (like Lean-Six-Sigma governed metric improvement loops) and connecting the loops to portfolio-level KPIs will aid in prioritization of highest environmental and financial return projects, and enable auditable evidence for stakeholder reporting and stress-testing of climate-related financial exposures [16] [22]. Methodologically, dashboards ought to display short-term control charts and longer-term moving averages, normalize KPIs to volume of production or mass of active ingredient, and apply multi-criteria scoring (with ESG weights) in vendor ranking in a way that marginal changes in solvent recovery or waste intensity map on to procurement moves rather than sweeping indications [13][26]. Overall, positioning these sustainability metrics on CMC dashboards closes the loop between process performance, program-gate governance, and procurement making technically sound as well as institutionally compatible ESG-commitment decisions possible. [2][6] [10] [11] [13] [16] [20] [21] [22] [26]

Table 1: Case Studies and Real time examples

Case Study	Industry	Dashboard Type	Key Metrics Tracked	Program-Gate Decision	Vendor Selection Criteria	Ref
Digital dashboard for schizophrenia care	Healthcare	Clinical KPI Dashboard	Patient outcomes, resource use, treatment adherence	Improved care pathways	Selection of digital health vendors	[1]
Johns Hopkins	Healthcare	Hospital	Patient	Optimize care	Vendor	[2]

Hospital patient flow		Flow Dashboard	throughput, bed occupancy, staff utilization	delivery	choice for health IT	
Regional small firms sustainability	SMEs	ESG Dashboard	Economic, social, environmental KPIs	Green certification	Vendors aligned with regional sustainability	[3]
Smart city blockchain dashboard	Urban Planning	Smart Governance Dashboard	Energy use, citizen engagement, waste KPIs	Urban policy gate	Vendors with blockchain competence	[4]
Big data in higher education	Education	University Big Data Dashboard	Energy intensity, resource allocation, digital adoption	Campus sustainability planning	EdTech vendors meeting ESG	[5]
NILM Dashboard	Power Systems	Industrial Diagnostic Dashboard	Energy intensity, electromechanical efficiency	Maintenance planning	Vendors offering predictive diagnostics	[6]
Stockholm city dashboards	Urban Policy	Smart City Dashboard	Transport emissions, land use efficiency, energy KPIs	Urban planning gates	Data vendors with green alignment	[7]
Nursing quality indicator dashboard	Healthcare	Clinical Quality Dashboard	Evidence-based KPIs, safety indicators	Accreditation compliance	Vendors supporting usability	[8]
Embedding SDGs in education (Egypt)	Education	Academic ESG Dashboard	SDG-linked energy/waste KPIs	Accreditation & curriculum design	ESG-compliant partners	[9]
Urban dashboards politics	Urban Planning	Governance Dashboard	Waste reduction, energy intensity	Policy gate keeping	Transparent, open-data vendors	[10]
Intellectual capital in health networks	Healthcare	KPI Dashboard	Knowledge KPIs, sustainability indicators	Network integration	ICT vendors supporting sustainability	[11]
Agile software with sustainability scoring	Software	Agile Metrics Dashboard	Sustainability metrics in projects	Sprint approval gates	Vendors with ESG integration	[13]
Urban benchmarking dashboards	Urban Planning	City Indicator Dashboard	Energy, mobility, waste	Smart city benchmarking	Vendors for real-time data	[14]

Emotion-aware UX dashboards	IT / HCI	UX Analytics Dashboard	Sentiment metrics, energy cost of interactions	Product release gates	Vendors embedding HCI sustainability	[15]
Lean Six Sigma + Sustainability	Manufacturing	Continuous Improvement Dashboard	Solvent recovery, energy intensity, waste	Process optimization	Lean vendors with ESG	[16]
Environmental dashboards in higher ed	Education	Sustainability Dashboard	Carbon emissions, waste, energy	Campus decision gates	Vendors supporting feedback systems	[18]
Manufacturing systems low-temp AFM	Engineering	Technical Dashboard	Energy intensity, cooling efficiency	Research program-gate	Vendors with sustainable materials	[19]
ESG in corporate performance	Business / Finance	ESG Planning Dashboard	Waste KPIs, ESG scores, energy	ESG reporting gates	Vendors offering compliance	[21]
Climate stress testing in banking	Finance	Financial ESG Dashboard	Climate risk, systemic resilience	Risk mitigation program-gates	Green finance vendors	[22]
Sustainable metrics in project risk	Finance / Projects	Project Risk Dashboard	Sustainable financial KPIs, energy intensity	Risk gate approval	Vendors adhering to ESG KPIs	[26]

Another important observation in the case study on schizophrenia care is the potential to incorporate clinical complexity measures into healthcare decision making using digital dashboards [1]. The system will provide sustainability data regarding patient therapy adherence, energy consumption of the digital health tools, and overall system efficiency to inform program-gate selections. These dashboards will cull the vendors based on the ability of the partner to meet the ESG requirements and incorporate plausible data.

2. Johns Hopkins Hospital developed an electronic dashboard that will be utilized to monitor patient flow according to the Donabedian model [2]. It also included some of the most important sustainability indicators such as how it uses its staff resources, waste minimization during bed management and the intensity of energy used in its operations. These lessons helped make program-gate decisions about the strategies used to expand the hospital and vendors were chosen on their capacity to provide energy efficient IT systems.

3. The characteristics of the analysis of the regional small firms revealed that the local embeddedness affects the economic, social, and environmental sustainability practices of these local firms [3]. Here, dashboards are used to track solvent recovery in production, supply chain energy efficiency and waste management efforts. The indicators can inform program-gates within the SMEs to decide upon certifications and vendor respectively in relation to ESG and local sustainability.

4. People Smart City dashboard (PSCD) is a smart city solution integrating blockchain to bring transparency into the management of the city [4]. Some of the KPIs measured through it are energy use intensity, the monitoring of waste and solvent emission in the industrial areas. These dashboards depend on program-gate decisions at the city level (approving infrastructure projects). Vendors are chosen because of their ability to produce blockchain and are dedicated to producing urban solutions that are energy efficient.

5. Universities have acquired big data dashboards to instill sustainability into intelligent university management [5]. The dashboards track such measures as the campus energy intensity, laboratory solvent

recycling and waste disposal. The green certification of the universities and the vendors will constitute the program gates and will be segmented depending on the contribution they could offer to the sustainable digital infrastructure.

6. Nilm Dashboard is a type of diagnostic device used in electromechanical equipment and includes sustainability measures in industrial monitoring [6]. It monitors energy power, energy loss and waste heat recovery. This information is utilized to make program-gate decisions about when to upgrade or replace machinery and vendors based on their capacity to align predictive maintenance and compliance with the ESG.

7. Big data dashboard provided data on sustainable urban planning in Stockholm [7]. Transportation energy intensity, land use efficiency and waste reduction were key KPI sustainability indicators. These served as the parameters of selection in the city planning program-gate decision, selection of the data vendors and the vendors capacity to internalize the real time sustainability information in the governance system.

8. An evidence-based approach to sustainability has been demonstrated in a study of health IT dashboard usability [8]. Dashboards monitored efficiency in clinical processes, resource wastage and energy consumption during IT operations. The requirements of healthcare were fulfilled with program-gates and the vendors have been selected based on their usability, efficiency, and the environmental impact.

9. In a study conducted in Egypt to implement SDGs in architectural and planning education, dashboards were used to monitor energy intensity, labs solvent use, and waste disposal [9]. The objective of utilizing these dashboards was to educate program gates in the curriculum reform programs and their choice of campus accreditation and vendor association based on their ability to deliver sustainable material and systems.

10. Kitchin and other authors described the political nature of urban dashboards and the importance of using environmental indicators [10]. Solvency recovery in industrial areas, city energy efficiency and waste management KPIs were included. The passing of new city policies was a program-gate, and vendors were selected based on transparent and sustainable information providers.

11. An examination of health networks at the mesolevel identified intellectual capital dashboards as a means of integrating sustainability into healthcare KPIs [11]. Measures like the energetic intensity of medical data systems and waste connected in digital health networks served as program-gates on hospital partnerships. The vendors were chosen according to ICT infrastructure compliance in terms of ESG.

12. Agile software development project performance dashboards have included sustainability measurements [13]. These dashboards include the solvent recycling of hardware prototyping, code efficiency in energy-utilization and digital waste-reduction. The program-gates were used to implement the Sprint reviews, but the vendors have been chosen according to how well they align Agile with ESG practices.

13. City benchmarking also granted the governance with the authority in generating control in waste-reduction and energy-saving residential buildings and solvent-solvency manufactures [14]. These measures did have an impact on the program-gates of the city development projects, vendors were selected because they supported real-time monitoring of ESG.

14. Another type of emotion-responsive UX dashboards explored by Zaheer consisted of not only user sentiment but also the intensity of energy and resources of online experiences [15]. Program-gates introducing products received sustainability reviews and vendor selection was based on their ability to implement sustainable UX.

15. Considering sustainability in Lean Six Sigma dashboards, Erdil et al. related solvent recovery [16], energy intensity, waste KPIs and process optimization. The design of program-gates with the aim of manufacturing quality control and the selection of suppliers orientated on Lean suppliers with ESG alignment were considered as features of sustainability.

16. Carbon emission, energy consumption and wastes reduction was monitored in the colleges through environmental dashboard [18]. These dashboards informed program-gates to campus planning and sustainability strategies and vendors were selected based on their capabilities to provide feedback mechanisms that promote environmentally-friendly behavior.

17. Dashboards were utilized in manufacturing systems studies to optimize cooling and the use of energy in Atomic Force Microscopes [19]. These project continuation approvals also became program-gates and supposedly viable material and efficient use of energy to be used as a parameter to select the vendor.
18. An ESG planning tool was a corporate performance management tool comprised of dashboards to monitor solvent recovery, a waste key performance indicator and energy intensity [21]. On these dashboards, program-gates in ESG reporting and vendors were chosen based on their adherence to the ESG disclosure requirements.
19. Other climate KPIs on the financial sector macro prudential stress-testing dashboards included energy intensity, industrial solvent risks, and systemic waste management [22]. These dashboards informed program-gates in banks resiliency strategies, whereas the vendors were chosen based on green finance contributions.
20. Sustainability was also incorporated in dashboard project financial risk management to achieve ESG [26]. Production, energy efficiency and waste KPIs were monitored. These were enlightened project approval program-gates, and vendors were chosen through compliance with ESG-corresponding risk management principles.

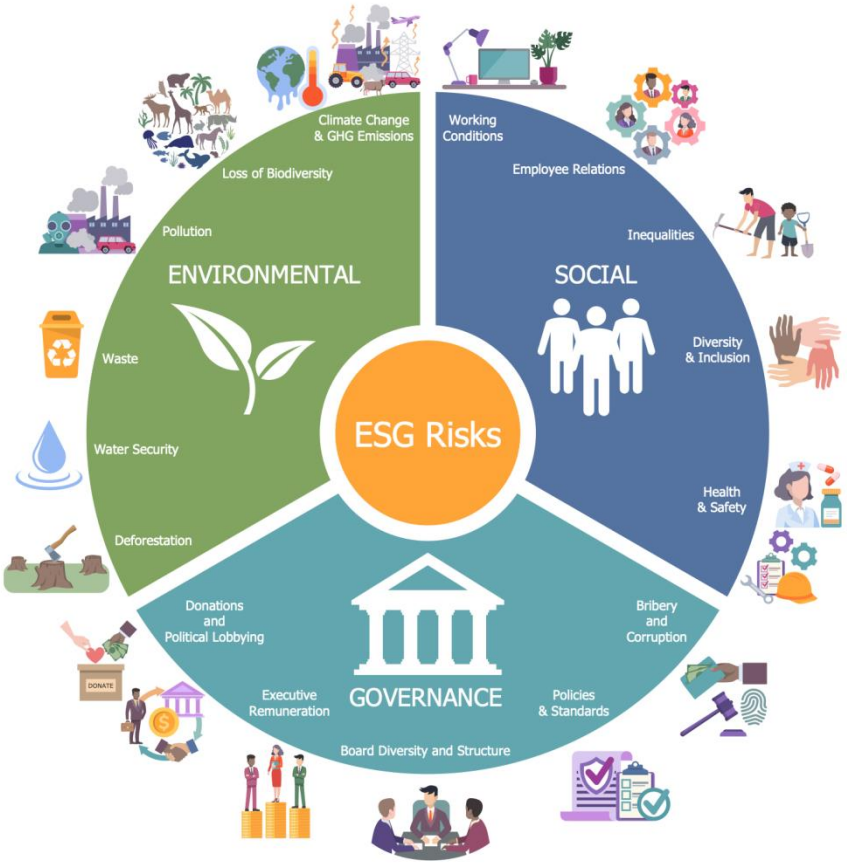

Fig 1: ECG Management and Risks [3]

Fig 2: ESG Reporting Best Practices [4]

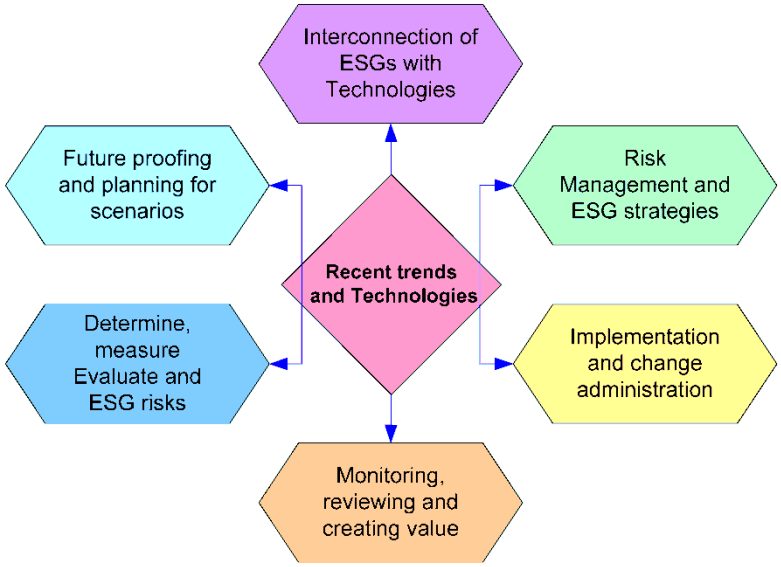

Fig 3: ESG Technology [1]

VI.CONCLUSION

The technical program dashboards introduction of the ESG and CMC sustainability measures is a radical shift in responsible practices and operational perfection. The following indicators can also align the program-gate decisions and the vendor selection with the sustainability commitment and objectives: solvent recovery

indicator, energy intensity indicator, and waste KPI indicators. Dashboards need not necessarily be useful visualization, but clarity of a strategy, value creators over time, and accountable. They can work out the sustainability in a manner that they can also have a culture of information in a manner that they may have a program manager, one that are in the regulators and vendors on the same platform may also want to study the efficiency of such platform and how it would impact on the environment and the society. The connection between the concept of ESG and the action of CMC is that, measure of complexity, the dependence of real-time observing and response can be utilized to improve the quality and robustness of decisions that have been made. Using the solvency recovery signs, converted into waste signs, to large and energy intensity

signs to be more than compliant will proactively bring about resources and sustainable vendor ecosystems. In that scenario the dashboards will be doing more than operational performance management, but might be a source of flexibility-providing response to mitigating systemic risk, sustainable improvement, faster development of the sustainability agenda at the global scale. The ESG and CMC-conscious dashboards are a new trend of technical program management. They helped organizations to balance operations excellence and environmental responsibility, in a manner that would not only contribute to the short-term success of the project, but also the long-term sustainability, resiliency and ethics-oriented future.

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