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Evaluating and managing the sustainability of investments in green and sustainable chemistry: An overview of sustainable finance approaches and tools

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Abstract

Green chemistry (GC) was developed to maximise resource efficiency and minimise hazards in chemical processes and products. Over time, the approach evolved into green and sustainable chemistry (GSC), which aims at promoting the development of an ecologically friendly society. GSC encourages society's reliance on sustainable materials and technologies/processes and supports the ambitious sustainability targets set by international organisations. It also steers public attention to the provision of sustainable solutions for producers, consumers and investors. Since GSC implementation requires significant financial investment, this paper describes a broad range of approaches and tools to assess the sustainability of potential investments and shows, although with a primary focus on environmental sustainability, how life cycle approaches could be used to define enhanced key performance indicators. Thus, the paper may serve as a useful reference for: (i) chemical companies interested in evaluating the sustainability performance of activities requiring financial investment, and (ii) investors interested in evaluating the sustainability of potential financial investments.

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Green and sustainable chemistry, Financial investment, Key performance indicators, Life cycle assessment, Sustainable finance.

Introduction

Chemistry is involved in the creation of all products used in daily life, and the production and consumption of these products drive societal challenges such as climate change and environmental pollution. Traditionally, the chemical industry has followed linear pathways of production for profit (i.e., processing limited, non-renewable resources and generating emissions and waste) [1]. However, in light of increased awareness of environmental and social concerns, there is growing acknowledgement of the need for a paradigm shift towards more circular and sustainable processes and products [2]. This shift will depend on a re-thinking of conventional processes and products to ensure the efficient use of natural resources in cycles of production, use, recovery and remanufacture [3].

In line with this, green chemistry (GC) was conceived in 1998 as an approach for designing chemical processes and products with maximal resource efficiency and minimal hazards. GC introduced 12 principles for reducing the negative impacts of chemical systems on human health and the environment, including the prevention of waste and pollution (principles 1 and 11), the adoption of inherently safer solutions (principles 3, 4, 5 and 12), the use of renewable feedstocks (principle 7), the integration of material and energy efficiency measures (principles 2, 6, 8, 9), and design for degradation (principle 10) [4]. In addition to providing protection rules for health and the environment, GC also made economic sense, by reducing waste removal, protective equipment, regulatory compliance, liability and manufacturing security costs [5], as well as other societal costs.

The concept of sustainable chemistry (SC) was later introduced to address the three pillars of sustainability (i.e., planet, people, profit) [6]. At times, GC and SC have been used synonymously, though this conflation is misleading and inaccurate [7,8]. Recently, the concept of 'green and sustainable chemistry' (GSC) was adopted [9,10] to emphasise that the integration of environmental and safety aspects in chemical systems is not sufficient to address societal challenges and promote a transition towards sustainability; rather, economic, social, political and technological factors must also be considered. GSC is of critical importance for post-COVID recovery, since more sustainable options and investments are needed in all countries [11].

The search for sustainable means of production and environmental conservation led to the development of the green finance (GF) and sustainable finance (SF) concepts [12,13]. While GF addresses financial stocks and flows in support of environmental protection and climate-related goals [14], SF more broadly covers environmental, social and governance (ESG) issues and risks [13]. Although SF is relatively mainstream – partly due to work done in the context of the EU taxonomy [15,16] – there remain two major barriers associated with green and sustainable investments: (i) a lower rate of return in the short term and (ii) a perceived higher financial risk [17]. However, many academic and business studies have reported that GC/GSC initiatives can be profitable in the medium to long term (e.g., see Refs. [18–20]). Indeed, there is a bidirectional relationship between companies and customers/investors, with companies' green attitudes that can influence the behaviour of their customers and investors, and vice versa [21].

Against this background, GSC requires sound approaches and tools to assess the sustainability of potential investments. Such approaches and tools are paramount for orienting both private and public investments towards companies that are truly involved in green and sustainable activities, and not those that are merely greenwashing.

The remainder of the paper is organized as follows: Section 2 outlines common approaches used to evaluate the non-financial performance of investment decisions, in support of GSC; Section 3 describes how a life cycle approach can be used to enhance the assessment of investment decisions (with the main focus of this paper being on environmental sustainability); and Section 4 provides concluding remarks and recommendations.

It is anticipated that this review may be useful for: (i) chemical companies interested in evaluating the sustainability performance of activities that require financial investment, and (ii) investors interested in evaluating the sustainability of potential financial investments.

Approaches and tools for evaluating the non-financial performance of investments

Financial investments may aim at modifying existing processes, products, services and activities, or creating new ones (e.g., retrofitting a chemical process, developing carbon capture usage and storage technology). In SF, investment decision-making processes involve the assessment, screening and management of non-financial consequences based on an analysis of ESG factors [14]. Several tools are available for this purpose, providing both: (i) sustainability information and key performance indicators (KPIs) to assess the sustainability of potential investments and (ii) criteria for sustainability screening.

Corporate social responsibility (CSR) reporting can provide useful sustainability-relevant information about the operation and investment decisions of specific companies (i.e., how ESG concerns are integrated into their corporate management and financial decision-making) [22], integrating environmental and social concerns [23]. Typically, this reporting includes information on carbon emissions, as well as data on employee safety, human rights and training support [24], presented through KPIs [25]. The KPI framework is particularly useful for monitoring the sustainability dimensions of corporate strategy [26], as it can be applied to a wide range of internal processes, as well as to components of the value chain (e.g., product quality, environmental protection) [27].

While CSR reporting can provide key insights into the sustainability performance of individual companies [28], such reporting does not follow a standardised approach, and thus there is a significant risk of greenwashing [29]. A combination of managerial actions, including adherence to standardised and certified procedures, could greatly improve the credibility of CSR reporting [30]. In this respect, specific guidelines are needed to ensure that climate change information is recorded in both financial and non-financial terms [31].

Several tools are available to support companies and investors on the sustainability journey. One of the most popular of these tools is the Global Reporting Initiative (GRI) standards, which characterise the sustainability of corporate activities through a set of KPIs addressing economic and ESG factors. This tool is frequently referenced in companies' CSR and sustainability claims [32].

In addition to GRI standards and similar tools [33–36], third party–verified ESG rating schemes and certifications have also been developed (e.g., CDP,[1] Sustainalytics,[2] Dow Jones Sustainability Indexes,[3] FTSE4Good,[4] Ecovadis,[5] Stoxx[6]), with the aim of measuring the extent to which companies are effectively addressing specific ESG issues (e.g., management of

[1] https://www.cdp.net/en.
[2] https://www.sustainalytics.com/.
[3] https://www.spglobal.com/spdji/en/indices/esg/dow-jones-sustainability-world-index/#overview.
[4] https://www.ftserussell.com/products/indices/ftse4good.
[5] https://ecovadis.com/.
[6] https://www.stoxx.com/index-details?symbol=sxwesgp.

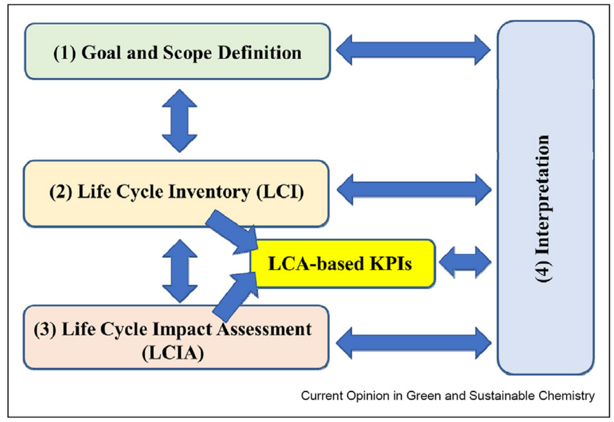
GHG emissions) and CSR principles. Furthermore, ESG ratings by independent companies (e.g., Arabesque S-Ray[7]) can measure the performance and sustainability of companies across the globe through a combination of big data analysis and assessment of ESG metrics.

The social dimension of SF is also addressed in social entrepreneurship and certification schemes. Social enterprises are organisations that use the profits from their activities to primarily achieve social objectives. Similarly, benefit corporations describe companies that balance purpose and profit [24] with the aim of long-term mission alignment and value creation [38]. B-Corporation (i.e., 'B-Corp') is one of the most comprehensive and popular sustainability certifications[8] used to mark ESG-aware companies [37].

The European Commission has invested significant effort in developing harmonised solutions in the area of SF, in order to reduce barriers to the integration of ESG factors in financial decisions [39]. First, the EU taxonomy was developed to set minimum criteria for environmental sustainability within economic activities [40], with the ultimate goal of facilitating investments in sustainable projects and improving non-financial disclosure [41]. The criteria address six objectives: (i) climate change mitigation, (ii) climate change adaptation, (iii) the sustainable use and protection of water and marine resources, (iv) transition to a circular economy, (v) pollution prevention and control and (vi) the protection and restoration of biodiversity and ecosystems. Furthermore, the taxonomy defines the following requirements for an economic activity to be considered environmentally sustainable: (i) it must contribute to the substantial improvement of at least one environmental objective, and (ii) it must do no significant harm (DNSH) to the other objectives. The taxonomy also provides social safeguard prescriptions. An extension of the EU taxonomy to more comprehensively cover social objectives (i.e., the so-called 'social taxonomy' [42]) and to identify activities that, for instance, significantly harm the environment (i.e., 'brown' activities) or fulfill the DNSH principle but do not provide a significant contribution to the six objectives [13,43], is currently under consideration.

Furthermore, in the EU, the Non-Financial Reporting Directive (NFRD) 2014/95/EU requires organisations with more than 500 employees to publish transparent ESG data. A Corporate Sustainability Reporting Directive (CSRD) was proposed in April 2021 to amend the NFRD by expanding its scope to all large companies, with reference to EU sustainability reporting standards [44]. The NFRD and CSRD are complemented by the Sustainable Finance Disclosure Regulation (EU) 2019/2088 (SFDR), which requires investment firms to disclose the environmental sustainability of all investments, the ESG risks of all investments, and the investment risks of ESG factors (double materiality).

Figure 1



Definition of KPIs based on LCA (adapted from Ref. [48]).

Assessing investment sustainability through a life cycle approach

As discussed in the previous section, the sustainability assessment of investments in pivotal sectors (e.g., GSC) must address ESG factors, which may also refer to the three pillars of sustainable development (i.e., environmental, social, and economic[9]). In this section, we describe how a life cycle approach [45,46] can be used to define KPIs (see Figure 1) assessing the environmental sustainability of potential investments, to be complemented by additional sustainability considerations. Although the focus is on environmental life cycle assessment (LCA) [45,46], the approach could be expanded to cover other pillars of sustainability in the so-called life cycle sustainability assessment (LCSA), which is the combination of LCA, social LCA (S-LCA) and the assessment of life cycle costs (LCC). However, differently from LCA, research effort is still ongoing to operationalise and mainstream LCSA for the integrated assessment of environmental, social, and economic impacts [47].

Definition of environmental KPIs based on LCA

KPIs are metrics that can be used to measure relevant characteristics of processes, products, and systems [27]. LCA can contribute a holistic perspective to the definition of environmental KPIs for SF [35,49], with potential extension to other dimensions of sustainability (see Section 3.2).

[7] https://www.arabesque.com/s-ray/.
[8] https://bcorporation.net/.
[9] Other two dimensions of sustainability (peace and partnership) have also been introduced more recently.

In GSC, a life cycle perspective can be applied to both chemical processes and products. The product life cycle begins with the extraction and supply of natural resources and their further processing and conversion into chemicals and other materials that comprise the products society uses to meet its needs; it ends with their decommission and disposal (the so-called end-of-life stage). Within the product life cycle, chemical processes are applied to convert input materials, using technologies and equipment that are planned, designed, developed, and constructed prior to their operation. In each life cycle stage, resources are consumed and pollutants are emitted (i.e., pressures), generating environmental impacts. LCA can be used to quantify environmental pressures and impacts, within particular system boundaries (i.e., with respect to the time horizon, processes/stages, and aspects considered) and the functional unit (i.e., the calculation basis of all indicators, such as 1 m^2 of mulched soil in a given time period).

Thus, LCA can be used to define KPIs that address both environmental pressures (i.e., via a life cycle inventory) and environmental impacts (i.e., via a life cycle impact assessment [LCIA]). In general, LCIA indicators can be differentiated into problem-oriented (midpoint) and damage-oriented (endpoint) indicators [50], targeting different areas of protection (Figure 2). Several LCIA methods have been developed (and are under development) to assess a broad range of environmental impacts [51–54]. In the EU, the Product Environmental Footprint (PEF) and the Organisational Environmental Footprint (OEF) are widely accepted methodological references [55,56] to measure the environmental performance of products (i.e., goods and services) and organisations under a life cycle perspective [57]. The most recent PEF recommendations suggest 20 midpoint indicators, addressing human health, ecosystem quality, and natural resources. However, a practical compromise must be sought, balancing comprehensive coverage (via an extensive set of indicators) with ease of quantification, interpretation, and communication of the results for relevant sectors and/or applications. This calls for the definition of specific category rules [58].

Consequently, the application of LCA to define environmental KPIs may be useful within the SF context and also fit within the six macro-objectives introduced in the EU taxonomy [15], as discussed in the following sections.

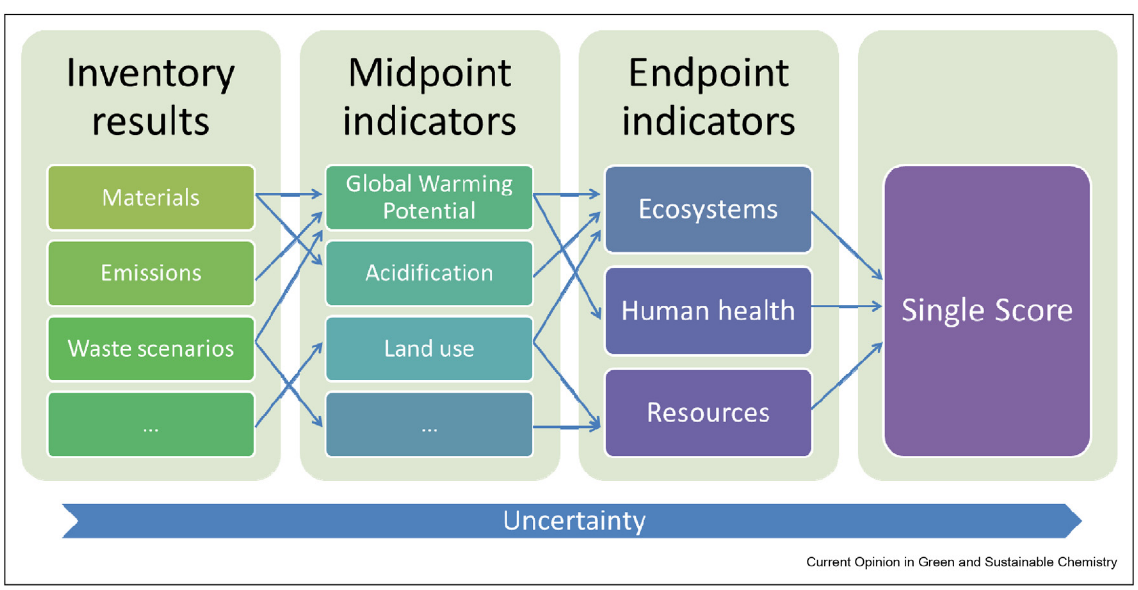
Climate change mitigation and adaptation (objectives 1 and 2)

The KPI that is conventionally used to monitor climate change mitigation is 'net emission of GHGs'. This is measured as kg CO_2eq., based on a global warming potential over 100 years [55]. Climate change adaptation requires more complex modelling, including an assessment of climate scenarios and their associated risks for ecological, social, and/or economic systems [60–63].

Sustainable use of water (objective 3)

Sustainable use of water refers to promoting management practices preserving the availability and quality of water resources and aquatic ecosystems, and reducing pressures on water bodies (e.g., wastewater discharges, contamination of water for human consumption, overconsumption of water).

Figure 2



Overview of midpoint and endpoint impact categories (adapted from Ref. [59]).

LCA indicators can be used for monitoring impacts associated with the use of water and impacts on water quality due to human activities. With specific reference to the consumption of water resources, the AWARE method can be used to quantify the 'water scarcity footprint' ($m^3_{eq.}$) and provide a measure of deprivation potential [55]. The water deprivation potential assumes the less water remains available in an area, the more likely another user will be deprived [55].

Transition to a circular economy (objective 4)

In a circular economy, wastes are recycled into resources, either through technological or natural ecosystem feedback mechanisms, so that the stock of resources is preserved [64]. The ultimate goal of the circular economy is an overall reduction in natural resource consumption and non-recyclable waste generation [65].

A variety of circular economy metrics exist [66], including absolute and relative indicators of different levels of complexity. ISO/TC 323 on the circular economy aims at harmonising various assessment methods. Among the most complex indicators, some measure the relative circularity of product systems and organisations [67,68]. Relatively simpler indicators are also proposed for financial applications [69], including:

- the overall use of resources and production of waste;
- the use of primary materials/recycled materials/bio-based materials; and
- the amount of recyclable/compostable material.

Table 1

EF indicators relating to pollution prevention and control.

Indicator	Unit	Method
Ozone depletion potential	kg CFC-$11_{eq.}$	WMO 2014 model
Human toxicity (cancer and non-cancer effects)	Comparative toxic unit for humans	USETOX model
Particulate matter impact on human health	Disease incidence	UNEP (2016a) model
Human exposure to ionising radiation	Equivalent exposure to U^{235}	Dreicer et al.
Photochemical ozone formation	kg $NMVOC_{eq.}$	LOTOS-EUROS model
Acidification	mol H + $_{eq.}$	Accumulated Exceedance model
Freshwater eutrophication	kg $P_{eq.}$	EUTREND model
Marine eutrophication	kg N_{eq}	EUTREND model
Terrestrial eutrophication	mol $N_{eq.}$	Accumulated Exceedance model
Ecotoxicity	Comparative toxic unit for ecosystems	USETOX model

Note: Further information on methods is available in the PEF [55].

Pollution prevention and control (objective 5)

Pollution prevention and control refers to a broad set of indicators and methods, as described in the PEF method [55] (Table 1). These are midpoint indicators addressing multiple targets (e.g., human health, quality of aquatic and terrestrial ecosystems), which can also be characterised at the endpoint level [50,70], as shown in Figure 2.

Protection and restoration of biodiversity and ecosystems (objective 6)

The protection and restoration of biodiversity and ecosystems are partly addressed by the EF indicators, and particularly affected by land use changes [71]. Land use that differs from the natural use (as would occur, e.g., in the destruction of the primary forest) can result in the dramatic loss of biodiversity and ecosystem services [72]. The recent Biodiversity Strategy of the European Commission is one of several frameworks that emphasises the critical need to protect land areas and primary forests [73].

Parameters that can reflect the protection and restoration of biodiversity and ecosystems include the area of land directly transformed (m^2) and/or used (m^2a) for certain functions (green areas excluded), including deforestation/afforestation. Indirect land use change is another important parameter for which there is still a degree of uncertainty [74].

Biodiversity equivalence factors for different land uses have also been developed [75]. However, methodological development is needed to ensure a satisfactory and systematic evaluation of biodiversity (i.e., loss/abundance) and ecosystem service impacts (see, e.g., Refs. [15,55,70,75]).

Complementary sustainability considerations

In sustainability assessment, it is desirable to verify whether the selected KPIs address all relevant (material) issues for the analysed system and/or if complementary sustainability considerations should be addressed, through quantitative or more qualitative approaches. In this sense, a key reference is set by the EU Taxonomy for sustainable activities, which is being expanded to cover also the social dimension of sustainability [42].

Notwithstanding, as presented for LCA, also economic and social aspects can be quantitatively assessed through life cycle approaches [76,77], or the allocation of ESG factors (KPIs) of organisations to processes and produces [78], although further methodological development is needed [47].

Furthermore, it should be noted that, although 'environmental relevance' is a distinctive element of ISO 14044 [46], even LCA may not be sufficiently mature to (quantitatively) address all relevant issues. For instance, it may be challenging to assess the case for food versus feed competition with respect to land use, as well as indirect land use changes, which are particularly relevant for bio-based products. It may also fall short of adequately assessing the environmental impacts associated with the plastic contamination of soils and oceans. However, it should be observed that methodological developments are contributing to addressing these needs [79].

Trade-offs and greenwashing

The use of a broader set of KPIs can provide more comprehensive descriptions of impacts. However, with this advantage comes greater complexity in the interpretation and communication of the results, especially with respect to trade-offs.

Trade-offs can be assessed through normalisation and weighting procedures [45,46] or scoring systems [80] that aggregate indicators. Such procedures may be particularly relevant for interpreting the sustainability profile of products in light of the EU taxonomy principle that environmentally sustainable activities must contribute to substantially improving at least one environmental objective (e.g., climate change mitigation) without significantly harming the others (e.g., pollution prevention and control). However, subjectivity and an acceptance of trade-offs must be implicitly acknowledged in such cases. In any case, for reasons of transparency, as well as to limit the margins of uncertainty and improve the reliability, comparability, and verifiability of the results [81], all assumptions and data used in the analysis should be third-party verified, documented, and reported [45,46,82].

Conclusions

Green and sustainable chemistry (GSC) is critically important for initiatives to shift consumers, producers, and investors towards circular and sustainable practices. However, the implementation of GSC principles requires significant financial investment, which could be disincentivised by a lower rate of return in the short term and perceived higher risk. Accordingly, public and private investors require sound approaches and tools to evaluate the sustainability of potential investments in support of GSC.

In this respect, the present work provides actors interested in GSC (e.g., companies, investors) with a useful overview of approaches and tools to inform sustainable finance decisions. It also shows how a life cycle approach can be used to determine enhanced key performance indicators (KPIs) to assess the environmental sustainability of investments from a more complete systemic perspective (via life cycle assessment, LCA), potentially extendable to other pillars of sustainability (via life cycle sustainability assessment, LCSA). The approach could be adapted to comply with future developments of the EU Taxonomy [42], or integrated with other relevant research and innovation activities relating to the safe and sustainable design of chemicals [83].

Nevertheless, despite its promises, the proposed approach comes with some challenges and potential limitations inherently related to optimising rigorousness and/or applicability of LCA (which become more critical for LCSA) with respect to, e.g., system boundaries definition and life cycle modelling [54], coverage of a manageable number of relevant indicators and dealing with trade-offs [58,83]. Bearing such aspects in mind, which call for further research, it is even more important to ensure critical interpretation and transparency over results, data sources, and assumptions. An associated research paper provides a test case for the approach by presenting its application to the assessment of bio-based and biodegradable plastics.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Papers of particular interest, published within the period of review, have been highlighted as:

* of special interest
** of outstanding interest

1. Zimmerman JB, Anastas PT, Erythropel HC, Leitner W:
** **Designing for a green chemistry future**. *Science* 2020, **367**: 397–400. https://doi.org/10.1126/science.aay3060.

This review aims at identifying the character, nature and production processes of synthetic chemicals for sustainability. By applying green chemistry principles, the authors offer alternative design strategies for tomorrow's chemical sector.

2. Morone P, Yilan G: **A paradigm shift in sustainability: from lines to circles**. *Acta Innov* 2020, **36**:17–32. https://doi.org/10.32933/ActaInnovations.36.1.

3. McDonough W, Braungart M, Anastas PT, Zimmerman JB: **Applying the principles of green engineering to cradle-to-cradle design**. *Environ Sci Technol* 2003, **37**:434A–441A. https://doi.org/10.1021/es0326322.

4. Maranghi S, Brondi C: *Life cycle assessment in the chemical product chain.* Springer; 2020.

5. Mulvihill MJ, Beach ES, Zimmerman JB, Anastas PT: **Green chemistry and green engineering: a framework for**

sustainable technology development. *Annu Rev Environ Resour* 2011, **36**:271–293. https://doi.org/10.1146/annurev-environ-032009-095500.

6. Hutzinger O: **The greening of chemistry-Is it sustainable?** *Environ Sci Pollut Res Int* 1999, **6**:123. https://doi.org/10.1007/BF02987605.

7. Blum C, *et al.*: **The concept of sustainable chemistry: key drivers for the transition towards sustainable development**. *Sustain. Chem. Pharm.* 2017, **5**:94–104. https://doi.org/10.1016/j.scp.2017.01.001.

8. Nimkar U: **Sustainable chemistry: a solution to the textile industry in a developing world**. *Curr. Opin. Green Sustain. Chem.* 2018, **9**:13–17. https://doi.org/10.1016/j.cogsc.2017.11.002.

9. Kümmerer K, Clark J: **Green and sustainable chemistry**. In *Sustainability science*. Edited by Heinrichs H, Martens P, Michelsen G, Wiek A, Eds, Dordrecht: Springer; 2016:43–59.

10. * Zuin VG, Eilks I, Elschami M, Kümmerer K: **Education in green chemistry and in sustainable chemistry: perspectives towards sustainability**. *Green Chem* 2021, **23**:1594–1608. https://doi.org/10.1039/D0GC03313H.

This study provides a useful summary of the similarities and differences between green chemistry and sustainable chemistry.

11. Macchiavello E, Siri M: **Sustainable finance and finch: can technology contribute to achieving environmental goals? A preliminary assessment of 'green finch'**. *EBI Working Paper Series* 2020, **71**. https://doi.org/10.2139/ssrn.3672989.

12. Dikau S, Volz U: **Central bank mandates, sustainability objectives and the promotion of green finance**. *Ecol Econ* 2021, **184**:107022. https://doi.org/10.1016/j.ecolecon.2021.107022.

13. European Parliamentary Briefing: ***Green and sustainable finance***. https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2021)679081. [Accessed 9 February 2022].

14. * Migliorelli M: **What do we mean by sustainable finance? Assessing existing frameworks and policy risks**. *Sustainability* 2021, **13**:975. https://doi.org/10.3390/su13020975.

This paper aims at enriching the debate over the definition of sustainable finance. It proposes a workable definition of sustainable finance and identifies the main policy and financial risks that stem from this definition.

15. European Commission: ***EU taxonomy for sustainable activities***. https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities_en#:~:text=What%20is%20the%20EU%20taxonomy%3F. [Accessed 18 February 2022].

16. European Commission: ***Platform on sustainable finance***. https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/overview-sustainable-finance/platform-sustainable-finance_en. [Accessed 18 February 2022].

17. Yoshino N, Taghizadeh-Hesary F: **Alternatives to private finance: role of fiscal policy reforms and energy taxation in development of renewable energy projects**. In *Financing for low-carbon energy transition*. Edited by Anbumozhi V, Kalirajan K, Kimura F, Eds, Singapore: Springer; 2018:1–13.

18. Gatto F, Daniotti S, Re I: **Driving green investments by measuring innovation impacts. Multi-criteria decision analysis for regional bioeconomy growth**. *Sustainability* 2021, **13**. https://doi.org/10.3390/su132111709.

19. Susa A, Facchi E: **Building the future of green chemistry**. In *Studies in surface science and catalysis*. Edited by Basile A, Centi G, De Falco M, Iaquaniello G, Eds, vol. 179. Elsevier; 2020:41–52.

20. Coish P, McGovern E, Zimmerman JB, Anastas PT: **The value-adding connections between the management of ecoinnovation and the principles of green chemistry and green engineering**. In *Green chemistry*. Edited by Török B, Dransfield T, Eds, Elsevier; 2018:981–998.

21. IBM Institute for Business Value: ***Meet the 2020 consumers driving change***. http://www.ibm.com/thought-leadership/institute-business-value/report/consumer-2020. [Accessed 15 March 2021].

22. Haski-Leventhal D: *Strategic corporate social responsibility: tools and theories for responsible management*. London: SAGE; 2018.

23. Czinkota M, Kaufmann HR, Basile G, Ferri MA: **For-Benefit company (fBComp): an innovative social-business model. The Italian case**. *J Bus Res* 2020, **119**:377–387. https://doi.org/10.1016/j.jbusres.2018.12.022.

24. Goloshchapova I, Poon S-H, Pritchard M, Reed P: **Corporate social responsibility reports: topic analysis and big data approach**. *Eur J Finance* 2019, **25**:1637–1654. https://doi.org/10.1080/1351847X.2019.1572637.

25. Parmenter D: *Key performance indicators: developing, implementing, and using winning KPIs*. John Wiley & Sons; 2019.

26. Hristov I, Chirico A: **The role of sustainability key performance indicators (KPIs) in implementing sustainable strategies**. *Sustainability* 2019, **11**:5742. https://doi.org/10.3390/su11205742.

27. Lindberg CF, Tan S, Yan J, Starfelt F: **Key performance indicators improve industrial performance**. *Energy Proc* 2015, **75**:1785–1790. https://doi.org/10.1016/j.egypro.2015.07.474.

28. Hsu BX, Chen YM, Chen LAL: **Corporate social responsibility and value added in the supply chain: model and mechanism**. *Technol Forecast Soc Change* 2022, **174**:121302. https://doi.org/10.1016/j.techfore.2021.121302.

29. * Garcia-Torea N, Fernandez-Feijoo B, De La Cuesta M: **CSR reporting communication: defective reporting models or misapplication?** *Corp Soc Responsib Environ Manag* 2020, **27**: 952–968. https://doi.org/10.1002/csr.1858.

This paper analyses the application of Global Reporting Initiative guidelines on CSR reporting. The study provides some criticism of CSR reporting practices and calls for current reporting practices to be redirected towards a more effective approach.

30. Becchetti L, Ciciretti R, Hasan I, Kobeissi N: **Corporate social responsibility and shareholder's value**. *J Bus Res* 2012, **65**: 1628–1635. https://doi.org/10.1016/j.jbusres.2011.10.022.

31. Curtó-Pagès F, Ortega-Rivera E, Castellón-Durán M, Jané-Llopis E: **Coming in from the cold: a longitudinal analysis of SDG reporting practices by Spanish listed companies since the approval of the 2030 agenda**. *Sustainability* 2021, **13**:1178. https://doi.org/10.3390/su13031178.

32. Global Reporting Initiative (GRI): ***What is GRI?***. https://www.globalreporting.org/how-to-use-the-gri-standards/gri-standards-english-language/. [Accessed 20 January 2021].

33. Sorovou D, Politou A, Kalligeris S, Topouzidou S: **D3-KPI manual Part I: general methodology**. *Inform Soc Technol Program* 2001. IST-2000−28760.

34. Graham I, *et al.*: **Performance measurement and KPIs for remanufacturing**. *J Remanufacturing* 2015, **5**:1–17. https://doi.org/10.1186/s13243-015-0019-2.

35. Feiz R, Ammenberg J, Baas L, Eklund M, Helgstrand A, Marshall R: **Improving the CO2 performance of cement, part I: utilizing life-cycle assessment and key performance indicators to assess development within the cement industry**. *J Clean Prod* 2015, **98**:272–281. https://doi.org/10.1016/j.jclepro.2014.01.083.

36. ** Lauesen LM: **Sustainable investment evaluation by means of life cycle assessment**. *Soc Responsib J* 2019, **15**:347–364. https://doi.org/10.1108/SRJ-03-2018-0054.

This paper evaluates LCA and environmental profit and loss for sustainability investors, while considering implementation in social responsibility standards.

37. Grimes MG, Gehman J, Cao K: **Positively deviant: identity work through B Corporation certification**. *J Bus Ventur* 2018, **33**:130–148. https://doi.org/10.1016/j.jbusvent.2017.12.001.

38. Riolfo G: **The new Italian benefit corporation**. *Eur Bus Organ Law Rev* 2020, **21**:279–317. https://doi.org/10.1007/s40804-019-00149-9.

39. Moody's Investor Service: ***Global: beyond passive, ESG investing is the next growth frontier for asset managers***.

https://www.moodys.com/login?ReturnUrl=http%3a%2f%2fwww.moodys.com%2fviewresearchdoc.aspx%3fdocid%3dPBC_1194847%26lang%3den%26cy%3dglobal. [Accessed 18 February 2022].

40. European Commission: ***Sustainable finance: TEG final report on the EU taxonomy***. https://knowledge4policy.ec.europa.eu/publication/sustainable-finance-teg-final-report-eu-taxonomy_en. [Accessed 18 February 2022].

41. European Securities and Markets Authority Press Release: ***ESMA proposes rules for taxonomy-alignment of non-financial undertakings and asset managers***. https://www.esma.europa.eu/press-news/esma-news/esma-proposes-rules-taxonomy-alignment-non-financial-undertakings-and-asset. [Accessed 18 February 2022].

42. European Commission: ***Call for feedback on the draft reports by the Platform on Sustainable Finance on a social taxonomy and on an extended taxonomy to support economic transition***. https://ec.europa.eu/info/publications/210712-sustainable-finance-platform-draft-reports_en. [Accessed 18 February 2022].

43. Esposito L, Mastromatteo G, Molocchi A: **Extending 'environment-risk weighted assets': EU taxonomy and banking supervision**. *J Sustain Financ Invest* 2021, **11**:214–232. https://doi.org/10.1080/20430795.2020.1724863.

44. European Commission: *Corporate sustainability reporting*. 2021. https://ec.europa.eu/info/business-economy-euro/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en. [Accessed 17 January 2022].

45. ISO 14040: *Environmental management – life cycle assessment – principles and framework*. 2006.

46. ISO 14044: *Environmental management – life cycle assessment – requirements and guidelines*. 2006.

47. Alvarenga RAF, *et al.*: *Best available approaches for LCSA, v3-final-clean_301121.pdf?msclkid=2422e7f5aac011ecb386d26e1670c972*. 2021. https://orienting.eu/wp-content/uploads/2022/01/D1.6-Best-available-approaches-for-LCSA-v3-final-clean_301121.pdf?msclkid=2422e7f5aac011ecb386d26e1670c972. [Accessed 24 March 2022].

48. Dorn C, *et al.*: **A Systematic LCA-enhanced KPI evaluation towards sustainable manufacturing in industrial decision-making processes. A case study in glass and ceramic frits production**. *Procedia Cirp* 2016, **48**:158–163. https://doi.org/10.1016/j.procir.2016.03.146.

49. Janjua SY, Sarker PK, Biswas WK: **Development of triple bottom line indicators for life cycle sustainability assessment of residential buildings**. *J Environ Manag* 2020, **264**:110476. https://doi.org/10.1016/j.jenvman.2020.110476.

50. Bare JC, Hofstetter P, Pennington DW, De Haes HAU: **Midpoints versus endpoints: the sacrifices and benefits**. *Int J Life Cycle Assess* 2000, **5**:319–326. https://doi.org/10.1007/BF02978665.

51. JRC: *Recommendations for life cycle impact assessment in the European Context - based on existing environmental impact assessment models and factors*. Luxembourg: Publication Office of the European Union; 2011. https://eplca.jrc.ec.europa.eu/uploads/ILCD-Recommendation-of-methods-for-LCIA-def.pdf. [Accessed 2 January 2021].

52. Life Cycle Initiative: *UNEP, global guidance for life cycle impact assessment indicators*, **1**; 2016. v–1, https://www.lifecycleinitiative.org/training-resources/global-guidance-lcia-indicators-v-1/. [Accessed 2 January 2021].

53. Life Cycle Initiative: *UNEP, global guidance on environmental life cycle impact assessment indicators – Volume 2*. 2016. https://www.lifecycleinitiative.org/training-resources/global-guidance-for-life-cycle-impact-assessment-indicators-volume-2/. [Accessed 2 January 2021].

54. Manfredi S, *et al.*: **Comparing the European Commission product environmental footprint method with other environmental accounting methods**. *Int J Life Cycle Assess* 2015, **20**: 389–404. https://doi.org/10.1007/s11367-014-0839-6.

55. Zampori L, Pant R: *Suggestions for updating the product environmental footprint (PEF) method, EUR 29682 EN*. Luxembourg: Publications Office of the European Union; 2019. https://doi.org/10.2760/265244. JRC115959.

56. European Commission: *Recommendation on the use of environmental footprint methods*. 2021. https://ec.europa.eu/environment/publications/recommendation-use-environmental-footprint-methods_en. [Accessed 18 February 2022].

57. Dyllick T, Rost Z: **Towards true product sustainability**. *J Clean Prod* 2017, **162**:346–360. https://doi.org/10.1016/j.jclepro.2017.05.189.

58. Cordella M, Hidalgo C: **Analysis of key environmental areas in the design and labelling of furniture products: application of a screening approach based on a literature review of LCA studies**. *Sustain Prod Consum* 2016, **8**:64–77. https://doi.org/10.1016/j.spc.2016.07.002.

59. Goedkoop M, Heijungs R, Huijbregts M, De Schryver A, Struijs J, Van Zelm R: **ReCiPe 2008. A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level**. *VROM* 2009, **1**:1–126.

60. Hinkel J, Schipper L, Wolf S: *A framework for climate change vulnerability assessments*. India: Dtsch. Gesellschaft für Int. Zusammenarbeit GmbH; 2014.

61. ISO 14080: *Greenhouse gas management and related activities – framework and principles for methodologies on climate actions*. 2018.

62. ISO 14090: *Adaptation to climate change – principles, requirements and guidelines*. 2019.

63. ISO 14091: *Adaptation to climate change – guidelines on vulnerability, impacts and risk assessment*. 2021.

64. * Peña C, Civit B, Gallego-Schmid A, Druckman A, Caldeira-Pires A, Weidema B, Mieras E, Wang F, Fava J, Milà i Canals L, Cordella M, Arbuckle P, Valdivia S, Fallaha S, Motta W: **Using life cycle assessment to achieve a circular economy**. *Int J Life Cycle Assess* 2021, **26**:215–220. https://doi.org/10.1007/s11367-020-01856-z.
This is a recent position paper of the Life Cycle Initiative (UNEP). The paper describes how LCA can support the achievement of a circular economy.

65. Cordella M, Alfieri F, Sanfelix J, Donatello S, Kaps R, Wolf O: **Improving material efficiency in the life cycle of products: a review of EU Ecolabel criteria**. *Int J Life Cycle Assess* 2020, **25**: 921–935. https://doi.org/10.1007/s11367-019-01608-8.

66. * Moraga G, *et al.*: **Circular economy indicators: what do they measure?** *Resour Conserv Recycl* 2019, **146**:452–461. https://doi.org/10.1016/j.resconrec.2019.03.045.
This paper provides a broad overview and classifies indicators for aspects of the circular economy.

67. Bachmann TM, *et al.*: ***Critical evaluation of material criticality and product-related circularity approaches***. https://orienting.eu/wp-content/uploads/2022/01/D1.4_Criticality_circularity_Final-1.pdf. [Accessed 18 February 2022].

68. Razza F, Briani C, Breton T, Marazza D: **Metrics for quantifying the circularity of bioplastics: the case of bio-based and biodegradable mulch films**. *Resour Conserv Recycl* 2020, **159**: 104753. https://doi.org/10.1016/j.resconrec.2020.104753.

69. * UNEP Finance Initiative: ***Financing Circularity: demystifying finance for circular economies***. https://www.unepfi.org/publications/general-publications/financing-circularity/#:~:text=UNEP%E2%80%99s%20report%20Financing%20Circularity%3A%20Demystifying%20Finance%20for%20the,their%20highest%20value%20long-term%20and%20to%20reduce%20waste. [Accessed 18 February 2022].
This report outlines how the financial sector can scale up financing to accelerate the shift to circular business models. It also explores strategies and actions that financial institutions can take to manage related risks and opportunities.

70. Huijbregts MAJ, *et al.*: **ReCiPe2016. A harmonized life cycle impact assessment method at midpoint and endpoint level**. In *Report I: characterization. RIVM report 2016–0104, natl. Inst. Hum. Heal. Environ. Bilthoven*; 2016.

71. Marques A, *et al.*: **Increasing impacts of land use on biodiversity and carbon sequestration driven by population and economic growth**. *Nat Ecol Evol* 2019, **3**:628–637. https://doi.org/10.1038/s41559-019-0824-3.

72. García-Vega D, Newbold T: **Assessing the effects of land use on biodiversity in the world's drylands and Mediterranean environments**. *Biodivers Conserv* 2020, **29**:393–408. https://doi.org/10.1007/s10531-019-01888-4.

73. European Commission: **Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions. EU biodiversity strategy for 2030: bringing nature back**. *COM* 2012:673. 2012, https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52012DC0673. [Accessed 18 February 2022].

74. Finkbeiner M: **Indirect land use change – help beyond the hype?** *Biomass Bioenergy* 2014, **62**:218–221. https://doi.org/10.1016/j.biombioe.2014.01.024.

75. * Crenna E, Marques A, La Notte A, Sala S: **Biodiversity assessment of value chains: state of the art and emerging challenges**. *Environ Sci Technol* 2020, **54**:9715–9728. https://doi.org/10.1021/acs.est.9b05153.
This critical review provides a comprehensive analysis of studies that have assessed the impact of value chains on biodiversity. The authors underline the need for improvement in the current LCA framework to support decision-making based on different sets of biodiversity indicators.

76. UNEP: *Guidelines for social life cycle assessment of products and organizations*. 2020.

77. UNEP/SETAC Life Cycle Initiative: *Towards a life cycle sustainability assessment making informed choices on products*. 2011.

78. Boffo R, Patalano R: *ESG investing: practices, progress and challenges, Technical report*. Paris: OECD; 2020. https://www.oecd.org/finance/ESG-Investing-Practices-Progress-Challenges.pdf. [Accessed 18 February 2022].

79. MarILCA: *Integrating potential environmental impacts of marine litter into LCA*. 2019. https://marilca.org/. [Accessed 22 February 2021].

80. Bracquené E, Peeters J, Alfieri F, Sanfélix J, Duflou J, Dewulf W, Cordella M: **Analysis of evaluation systems for product repairability: a case study for washing machines**. *J Clean Prod* 2021, **281**:125122. https://doi.org/10.1016/j.jclepro.2020.125122.

81. European Commission: ***Initiative on substantiating green claims***. https://ec.europa.eu/environment/eussd/smgp/initiative_on_green_claims.htm. [Accessed 14 January 2021].

82. ISO/TS 14071: *Environmental management — life cycle assessment — critical review processes and reviewer competencies: additional requirements and guidelines to ISO 14044: 2006*. 2014.

83. European Commission, Joint Research Centre, Caldeira C, Farcal R, Moretti C, *et al.*: *Safe and sustainable by design chemicals and materials: review of safety and sustainability dimensions, aspects, methods, indicators, and tools*. 2022. https://data.europa.eu/doi/10.2760/879069.