Cleaner Environmental Systems 11 (2023) 100145

Contents lists available at ScienceDirect

Cleaner Environmental Systems

journal homepage: www.journals.elsevier.com/cleaner-environmental-systems

Twin Transition cosmetic roadmapping tool for supporting cosmetics manufacturing

Daniele Perossa *, Federica Acerbi, Roberto Rocca, Luca Fumagalli, Marco Taisch

Polytechnic of Milan, Department of Management Engineering, Piazza L. Da Vinci, 32, 20133, Milan, Italy

ARTICLE INFO

Keywords:
Twin Transition
Cosmetic industry
Industry 4.0
Roadmapping tool
Environmental sustainability
Assessment tool

ABSTRACT

The Twin Transition is gaining increasing relevance in the manufacturing sector as it strives to implement and exploit digital technologies to improve the Environmental Sustainability of companies. This topic holds particular relevance in the Cosmetic Industry. However, cosmetics companies, especially Small and Medium Enterprises, encounter challenges in effectively implementing digital technologies. This results in a substantial gap between the theoretical potential of the Twin Transition and the practical implementations. To fill the gap, a key role might be played by assessment and roadmapping tools that provide companies with the help and support they need. In this contribution a novel assessment and roadmapping tool is proposed. The employed methodology combines a systematic literature review with Action research approach. The proposed tool is called the Twin Transition Cosmetic Roadmapping Tool. It supports enterprises in the assessment of their current level of Twin Transition based on which a roadmap for improvement is framed. It is the first Twin Transition roadmapping tool specific for cosmetics industry. Furthermore, it encompasses all the mechanisms by which Twin Transition can be achieved throughout the entire product life cycle. The paper concludes with an application of the tool in an industrial case study, presenting and discussing the results.

1. Introduction

The substantial impact of the manufacturing sector on Environmental Sustainability (ES) is well-documented (Worrell et al., 2009). Notably, the interest among manufacturing companies in embracing sustainability is escalating (Acerbi and Taisch, 2020; Rosa et al., 2018; World Economic Forum, 2019). This interest is particularly pronounced in the Cosmetic Industry (CI), where consumers are highly sensitive to product ES (Acerbi et al., 2023; Bom et al., 2019; Rocca et al., 2022). Indeed, the literature reports evidence of a green consumerism trend (Rocca et al., 2022).

An example is the rise of the organic and natural products submarket, which was valued US$ 24,2 billion worth in 2022, with projections soaring to US$52.2 billion by 2030 (Researchandmarkets.com, 2023). Additionally, the global biodegradable cosmetic packaging sector is expected to increase, with estimates surpassing US$10 billion by 2029 (Data Bridge Market Research, 2022). Concerning ingredients, natural alternatives are progressively substituting chemical-based ingredients. A noteworthy instance is the substitution of the commonly used anti-aging ingredient, Retinol, with the natural-based Bakuchiol, with an anticipated Compound Annual Growth (CAGR) growth of 6,5% between 2021 and 2028 (Data Intelo, 2022). Furthermore, the global essential oil market, valued at US$ 9,02 billion worth in 2020, is expected to demonstrate a CAGR of 9,57% between 2021 and 2028 (PXR, 2022).

Digitalisation and Industry 4.0 (I4.0) are pivotal levers implementable by manufacturing companies to enhance their Environmental Sustainability Performance (ESP), (Mohamed et al., 2019; Uçar et al., 2020). In this context, the term Twin Transition (TT) is gaining significant traction. The TT defines the synergetic occurrence of Digital Transition (DT) and Green Transition (GT) (Montresor and Vezzani, 2022; Ortega-Gras et al., 2021). Nonetheless, Small and Medium Enterprises (SMEs) meet hurdles in approaching the TT (Horváth and Szabó, 2019; Stentoft et al., 2019).

An effort to assist companies in this direction is represented by tools, models and roadmaps developed to support either the GT (e.g. (Rocca et al., 2021),) or the DT (e.g. (Schumacher et al., 2019):). However, the synergy of the two is scarcely considered. For instance, Dikhanbayeva et al. (2020) conducted an analysis of twelve maturity models related to I4.0 and observed that they seldom tackle sustainability implications of I4.0 implementations. Additionally, there is an absence of guidance for enterprises seeking to understand how to use specific technologies to

* Corresponding author.
E-mail addresses: daniele.perossa@polimi.it (D. Perossa), federica.acerbi@polimi.it (F. Acerbi), roberto.rocca@polimi.it (R. Rocca), luca1.fumagalli@polimi.it (L. Fumagalli), marco.taisch@polimi.it (M. Taisch).

https://doi.org/10.1016/j.cesys.2023.100145
Received 9 May 2023; Received in revised form 25 September 2023; Accepted 28 September 2023
Available online 6 October 2023

List of abbreviations

CAGR	Compound Annual Growth
CE	Circular Economy
CI	Cosmetic Industry
DT	Digital Transition
ES	Environmental Sustainability
ESP	Environmental Sustainability Performance
GT	Green Transition
I4.0	Industry 4.0
PLPs	Product Life cycle Phases
SBMAs	Sustainable Business Model Archetypes
SDGs	Sustainability Development Goals
SLR	Systematic Literature Review
SMEs	Small and Medium Enterprises
TT	Twin Transition
TTCRT	Twin Transition Cosmetic Roadmapping Tool

accomplish GT. Thus, to address this gap, the research objective and purpose of this contribution is the development of a tool to support cosmetic SMEs in their path towards the TT. To address this objective, the research question is explored: "*How cosmetics SMEs can be* supported *in their path towards the TT?*".

The remainder of the paper is structured as follows. In section 2 the employed research methodology is presented. In section 3 the results of the literature review that puts the basis for the tool conceptualization are shown. In section 4 the development of the tool is described. In section 5 the tool application is presented. In section 6 and 7 respectively discussion and conclusions are drawn.

2. Research methodology

In order to address the research question, a dual research methodology comprising a systematic literature review (SLR) (Xiao and Watson, 2019) and Action Research is employed. Action Research is a well-established research approach of the Design Science, which is a research methodology widely used in operations management field (Holmström et al., 2009), and it finds application also in this study. Design Science methodology addresses a specific problem by developing an artifact, the utility of which is subsequently evaluated through industrial applications (Peffers et al., 2007). In this work, the problem under scrutiny is related to the technical difficulties met by cosmetics SMEs while performing the TT. the resulting artifact, in this case, is the tool to be developed to support them. The tool is then evaluated through an industrial application. Action Research-inspired approach adopted here is an adaptation of the GuRu methodology, as implemented by (Sassanelli et al., 2019). Although conceived for the integrated design of product and service features in Product-Service Systems, GuRu was adapted in this work to develop a managerial tool supporting industry practitioners, because of its iterative approach inclusion of practitioners. It is worth noting that, in Design Science, it is customary to apply expertise and insight from one knowledge domain to another (Holmström et al., 2009).

At the same time, the SLR is utilised to identify the inherent strengths and weaknesses of existing tools, models, and frameworks. Subsequently, after a preliminary analysis of the extant literature, a first version of a new tool is conceived. At this point, Action Research is employed to refine and improve the tool itself, incorporating trials within cosmetic manufacturing companies. The idea revolves around applying this tool to an industrial case, in collaboration with industry practitioners. Throughout the application process, feedback and improvement suggestions by the practitioners are collected and integrated. In this manner, the tool is honed and refined with the overarching goal of augmenting its effectiveness when applied to CI companies (i.e., making it more useful for practitioners). The procedural steps employed bear a semblance to the GuRu methodology, albeit tailored to the different objective of creating a decision-making support tool. Like in the GuRu methodology by (Sassanelli et al., 2019), in this research contribution is presented a cyclic improvement of the tool engendered by the interactions with industry practitioners. Notably, the methodological steps can be outlined as follows:

1. Application of the initial version of the tool to a selected industrial case, executed in collaboration with industry practitioners.
2. Gathering and compilation of feedback and critiques from the practitioners involved in the selected industrial case.
3. Implementation of the first cycle of refinements based on the feedback gathered in step 2.
4. Reiteration of the tool application to the same industrial case, again in collaboration with industry practitioners.
5. If additional critiques or suggestions for improvement arise, a subsequent cycle of refinements is enacted, followed by a repetition of step 4. Otherwise, the development process concludes.

In the specific context of this work, it required only the first cycle of refinements to achieve a version of the tool that was deemed satisfactory by the practitioners involved in the activity. Action Research has already been successfully employed in diverse instances of Roadmapping Tool development within the realm of digital technologies (Battistella et al., 2015; Bloem da Silveira Junior et al., 2018; Czachorowski and Haskins, 2022).

The decision to merge SLR and Action Research methodologies was made with the objective of incorporating two complementary perspectives in the process of development of the tool: on the one hand, it encompasses an assessment of the current State of the Art of managerial tools supporting companies in the TT developed by academics. On the other hand, it entails the consideration of the viewpoint and practical

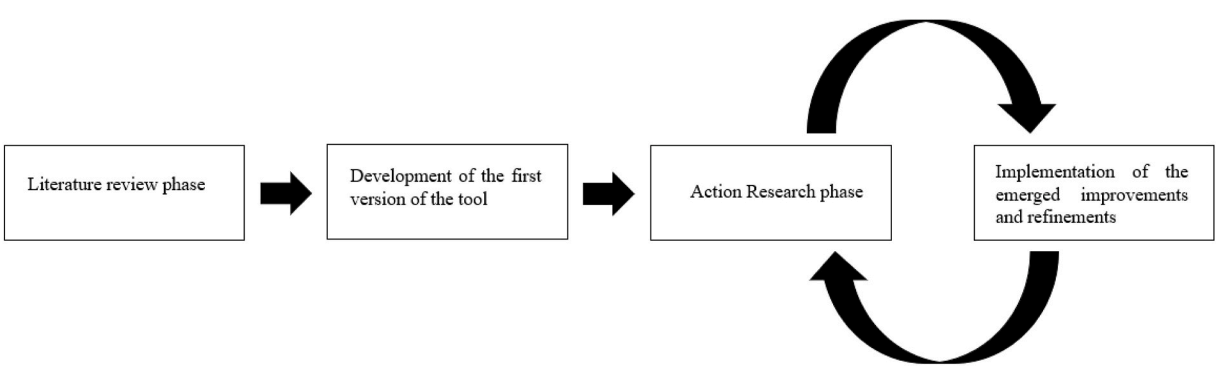

Fig. 1. Representation of the adopted research methodology.

requirements articulated by industry practitioners who will ultimately utilize the tool. The adopted methodology is summurised in Fig. 1

It was decided to include documents referred to any industry belonging to the manufacturing sector. This choice was motivated by the relatively limited number of contributions available within this specific research domain. The belonging of the tool to the manufacturing industry, along with its consideration of GT and DT served as pivotal factors in shaping the research string. The frameworks and tools encountered in the literature referring to the generic manufacturing sector, indeed, present features that are universally applicable across manufacturing industries.

The research was conducted on Scopus database. The used search string is the following:

TITLE-ABS-KEY ("twin transition" OR (("green transition" OR "sustainability" OR "environment" OR "environmental" OR "green" OR "circular" OR "sustainable" OR "energy efficiency" OR "circularity") AND ("digital transition" OR "industry 4.0″ OR "digitalisation" OR "digitalisation" OR "digitization" OR "digitization" OR "digital technologies")) AND ("manufacturing" OR "production") AND ("assessment tool*" OR "strategic tool*" OR "strategic framework" OR "maturity model" OR "transition framework" OR "transition model" OR "strategy framework" OR "strategy model" OR "structured methodology" OR "transition methodology" OR "transition strategy" OR "assessment instrument" OR "strategic instrument" OR "transition instrument" OR "transition method" OR "structured method" OR "strategic method" OR "strategic guidelines" OR "transition guidelines" OR "strategy guidelines" OR "implementation guidelines" OR "implementation strategy" OR "implementation tool" OR "support tool" OR "support guidelines" OR "supporting tool" OR "supporting guidelines" OR "supporting strategy" OR "Roadmap" OR "Roadmapping"))

Initially, a total of 268 papers were obtained. Subsequently, 28 papers were discarded from the analysis as their authors were labelled as unknown or the content was not written in English. Each remaining paper was deeply analysed. It was verified the consideration of ES, digitalisation, as well as their synergies and interactions, and if a manufacturing context was considered. After the scrutiny, 62 documents were identified as respecting these criteria. Among this subset, 21 proposed a tool, a roadmap, a model, or a framework and were therefore considered for the analysis detailed below in Fig. 2.

The included documents were analysed, with a primary focus on the following dimensions: (i) the range of digital technologies considered, (ii) the aspects related to ESP that were taken into account (e.g., CE, energy efficiency), (iii) the extent and level of detail in which the proposed instruments support companies in evaluating specific technologies for implementation, (iv) The applicability of these tools across the entire product life cycle and (v) the applicability of these tools to the CI.

The identification of the dimensions was guided by the need to understand the effectiveness of the support offered by the analysed tools to industry practitioners, considering their comprehensiveness and level of detail. Indeed, tools encompassing a broader spectrum of digital technologies and ESP aspects inherently provide more complete support to companies. Similarly, tools addressing a larger portion of the product life cycle offer a more comprehensive support. Furthermore, tools providing a more detailed guidance to practitioners in evaluating technologies for implementation are expected to be of greater utility. Lastly, the evaluation of usefulness of these tools to CI practitioners by considering tools applicability to CI was performed.

In addition, eleven more papers falling outside the scope of the review were exploited to support the tool development. These documents pertained to I4.0, Cosmetic Product Lifecycle Phases (PLPs), and ES and its implementation models. They were identified through a Snowball Effect approach, involving references from the reviewed papers and the prior knowledge of the authors.

3. Literature review results

In this section the results of the conducted SRL are presented. The findings are organized into five distinct sections, each addressing one of the different analysis dimensions detailed in the methodology section: (i) technologies considered, (ii) ESP aspects considered, (iii) extension and detail of the support to the enterprises, (iv) applicability across the entire product life cycle and (v) applicability to the CI. A summary of the analysis is subsequently presented in Table 1.

3.1. First analysis dimension: technologies considered

In this dimension of analysis, it was observed that several models encompassed a wide range of technologies, without a specific focus on any particular typology. For instance, some works proposed I4.0 Maturity Models that considered how digital technologies may enable or support ESP aspects (Stawiarska et al., 2021; Zoubek et al., 2021). In other studies, frameworks were presented that connected different typologies of digital technologies to ESP (Böttcher et al., 2023; Ghobakhloo et al., 2021; Prakash and Ambedkar, 2023; Sahu et al., 2022; Sun et al., 2022). Additionally, a subset of papers introduced roadmaps that considered diverse types of digital technologies, considering their positive effects on ESP (Ching et al., 2022; Lopes de Sousa Jabbour et al., 2018; Münnich et al., 2022).

Conversely, some documents focused only on some specific technologies. In certain instances, they were data driven technologies (Kenett et al., 2018; Leong et al., 2020; Kristoffersen et al., 2020). In other cases, the focus was on Additive Manufacturing (Hettiarachchi et al., 2022; Nascimento et al., 2022). In a singular instance, only technologies applicable during product design phase were considered (Miranda et al., 2019). Finally, one paper focused on the factors leading to the TT rather than delving into specific technologies (Kumar et al., 2022).

3.2. Second analysis dimension: Environmental Sustainability Performance aspects considered

Few works were found focusing exclusively on CE aspects (Lopes de Sousa Jabbour et al., 2018; Panayiotou et al., 2019; Sahu et al., 2022; Kristoffersen et al., 2020; Sun et al., 2022; Prakash and Ambedkar, 2023; Nascimento et al., 2022). In the remaining cases, the ES aspects under consideration were not confined to a specific area of ESP. Nevertheless, in some instances, there was a lack of specificity, with ESP being addressed in a generic manner (Bhatia and Diaz-Elsayed, 2023; Ferrera et al., 2017; Kaya et al., 2023). Furthermore, two of these studies introduced a fuzzy TOPSIS approach to build a framework to support SMEs in the DT (Bhatia and Diaz-Elsayed, 2023; Kaya et al., 2023). Initially ESP aspects were considered in a generic fashion, but notably, they were not featured in the application cases presented in these two papers. In the remaining analysed works, multiple dimensions of ESP were encompassed.

3.3. Third analysis dimension: extension and detail of the support to the enterprises

The majority of the analysed works did not present a punctual support for enterprises. For instance, (Kenett et al., 2018) did not provide concrete guidelines for technologies implementation within companies. In (Flumerfelt and Wenson, 2019) Technical and technological guidance for the companies is neglected as the work focuses on the implementation of a lean leadership learning system. In (Hettiarachchi et al., 2022) the analysis is stated to be aiming at orienting the future work of scholars, rather than supporting enterprises. In (Stawiarska et al., 2021) an I4.0 Maturity Model is proposed for assessment purposes only, without offering indications for future improvements benefitting the companies. The methodology proposed in (Leong et al., 2020) does not

Table 1
Synthesis of the analysed papers.

Paper	Generic description	Considered Industry	Points of strength	Points of weakness	Typology of model proposed
Kenett et al. (2018)	Usage of Advanced Data Analytics in Sustainable Manufacturing	Generic	Structured classification of the applications	Exclusive focus on Data Analytics and lack of implementation guidelines	Practical Framework
Hettiarachchi et al. (2022)	Support of Additive Manufacturing to CE	Generic	In depth analysis of both technical and managerial aspects	Framework conceived to be used by scholars and not by companies	Theoretical framework
Stawiarska et al. (2021)	I4.0 maturity model	Automotive Industry	Great relevance given to the exploitation of I4.0 to improve ESP	It does not provide a concrete support to companies and exclusively focused on automotive industry	Maturity model
Leong et al. (2020)	Green strategy implementation using I4.0 data driven applications	Processing sector	Sophisticated analysis and validation of the proposed methodology	Does not support technologies selection and utilization	Roadmap
Ghobakhloo et al. (2021)	Framework to develop sustainable innovation under I4.0	Generic	Same perspective of the TT adopted in the proposed work	No consideration of technical aspects	Practical framework
Lopes de Sousa Jabbour et al. (2018)	Roadmap to implement I4.0 and CE	Generic	Elaborated and well-structured roadmap	Exclusive focus on CE, not considering any other ESP aspect	Roadmap
Panayiotou et al. (2019)	Identification and analysis of the main barriers to application of I4.0 and CE	Gas Industry	Classification and analysis of relevant barriers.	No roadmap proposal	Theoretical Framework
Ching et al. (2022)	Roadmap to implement Sustainability through I4.0	Generic	Identification of the functions that I4.0 can perform for Sustainability and of the possible levels of impact	The roadmap is theoretical.	Roadmap
Zoubek et al. (2021)	Maturity model to implement I4.0 in support of ES	Generic	Complete and validated model	The model is unable to directly support further improvements	Maturity model
Sahu et al. (2022)	Framework supporting I4.0 and CE implementation	Generic	Classification of critical components and technologies	Framework supporting sheer research	Theoretical framework
Miranda et al. (2019)	Framework to develop smart and sustainable products	Generic	Provision of a concrete and useful support to companies	It focuses exclusively on product development	Practical framework
Kristoffersen et al. (2020)	Framework for the usage of Data Analytics tools to support CE practices	Generic	Provision of a concrete and useful support to companies	It considers only CE	Practical framework
Ferrera et al. (2017)	Framework to use I4.0 to improve industrial efficiency.	Generic	Flexible framework	Generic framework, not specific for the GT nor the TT	Practical framework
Kumar et al. (2022)	Identification and analysis of factors influencing I 4.0 implementation to reach sustainability	Generic	An extensive identification of drivers leading companies towards the TT.	It does not provide a concrete support to companies	Theoretical framework
Sun et al. (2022)	Framework connecting the industry 4.0 enabling technologies to reverse logistics processes and to the sustainability indicators	Generic	Well-structured framework.	It focuses exclusively on the logistics aspects of only End of Life phase. Furthermore, it does not work as an assessment tool	Practical Framework
Prakash and Ambedkar (2023)	Framework connecting different I4.0 technologies to different aspects of Circular Business Models.	Generic	Methodologically solid construction of the framework that even if theoretical may present interesting practical implications for companies	It does not work as an assessment model. Furthermore, it considers exclusively CE	Theoretical framework
(Munnich et al., 2022)	Extension of an existing Industry 4.0 maturity model to include sustainability-related aspects.	Generic	It is a comprehensive model, considering various ESP aspects. It also provides a workflow scheme to perform the roadmapping analysis	It fails in providing a punctual technical support to companies	Roadmap
Böttcher et al. (2023)	Framework supporting implementation of digital solutions for enabling different typologies of sustainable business models	Generic	Comprehensive consideration of possible business models	It does not work as an assessment tool. Furthermore, the adopted perspective is strategic, considering only business model design	Theoretical framework
Nascimento et al. (2022)	Roadmap for the evolution of the circular value stream mapping based on 3D printing	Generic	Clear and simple definition of key points and milestones needed to evolve toward CE by exploiting Additive Manufacturing	Focused exclusively on Additive Manufacturing technology and CE among possible ESP dimensions	Roadmap

support companies in technologies selection and utilization. The framework proposed by (Ghobakhloo et al., 2021) did not address specific technologies or technical interventions that enterprises should undertake to enhance the identified sustainable innovation functions. (Panayiotou et al., 2019) the analysis is confined to the mapping of barriers towards I4.0 and CE. The roadmap proposed by (Ching et al., 2022) remains theoretical, devoid of considerations regarding the specific I4.0 technologies to be used. In (Zoubek et al., 2021) a structured support for companies in improving their ESP is missing. The framework proposed by (Sahu et al., 2022) is stated to primarily aim to help in the research endeavour. In (Kumar et al., 2022) the analysis is focused on the drivers towards the TT. The works by (Sun et al., 2022; Munnich et al., 2022) present a practical framework and a roadmap, respectively, but neither provides a precise technical support for enterprises. The frameworks proposed by (Prakash and Ambedkar, 2023; Böttcher et al., 2023) are theoretical in nature and not conceived for corporate or product-level assessment or roadmapping.

Only few works present a precise technical support (Kristoffersen et al., 2020; Lopes de Sousa Jabbour et al., 2018; Miranda et al., 2019; Nascimento et al., 2022). However, as previously mentioned, some of these focus only on CE (Kristoffersen et al., 2020; Lopes de Sousa Jabbour et al., 2018), while others consider only select categories of digital technologies (Miranda et al., 2019; Nascimento et al., 2022).

3.4. *Fourth analysis dimension: applicability to the entire product life cycle*

In the conducted review, only a limited number of works were found concentrated exclusively on specific phases of the product life cycle. For instance, some studies exclusively delved into product development (Miranda et al., 2019), while others cantered the attention on logistics aspects during the end of life phase (Sun et al., 2022). As for the remaining works, a specific focus on limited life cycle phases was not discernible. Moreover, none of these works proposed a systematic approach to ensure comprehensive coverage of all product life cycle phases.

However, two notable exceptions were found (Lopes de Sousa Jabbour et al., 2018; Zoubek et al., 2021). In these works, although product life cycle phases are not explicitly addressed, actions were categorized based on their impact on different segments of the supply chain or value chain they impact on is performed. In one of these works the main approaches to CE are defined and crossed with supply chain phases they can impact on (Lopes de Sousa Jabbour et al., 2018). In the other work, four distinct areas along the value chain are identified, each one presenting three specific action typologies for the implementation of digital technologies aimed at improving ESP (Zoubek et al., 2021).

3.5. Fifth analysis dimension: applicability to the cosmetics industry

It was not uncovered in the literature review a model or a roadmap specifically designed for the CI. Furthermore, it was noted that the majority of the proposed exhibit a generic nature, lacking a focus on any specific industrial sector. While this generality allows a potential applicability to CI, it may not yield the same level of effectiveness as a sector-specific tool. Notably, there are three exceptions: (i) a maturity model for the automotive industry (Stawiarska et al., 2021), (ii) a roadmap developed within the context of the processing sector (Leong et al., 2020) and (iii) a framework specific for the gas industry (Panayiotou et al., 2019).

In summary, it was not identified a model or a roadmap encompassing all the following features simultaneously: (i) a comprehensive coverage of digital technologies for consideration, (ii) a wide array of actions for ESP improvement, (iii) a mechanism for providing practitioners with precise technical support, (iv) explicit consideration of potential actions and implementations across all the phases of the product life cycle, and (v) being specifically tailored for the CI characteristics and needs.

A comprehensive summary of all the investigated tools is provided in Table 1. It is worth noting that three of the included papers are not featured in Table 1, as they did not present notable strengths or distinctive features.

4. Twin transition cosmetic roadmapping tool development

A literature gap related to the lack of roadmaps supporting cosmetics manufacturing companies in achieving the TT is highlighted in this section. A proposal of a tool to fill this gap is presented.

4.1. Literature gap identification and tool conceptualization

As previously discussed at the end of the literature review results section, it was not identified a tool presenting the following features simultaneously: (i) consideration of a wide array of potential digital technologies for implementation; (ii) presentation of an extensive range of ESP improvement actions for implementation; (iii) provision of a mechanism to support in a precise and technical manner companies in performing the TT; (iv) explicit consideration of all product life cycle phases impactable by the TT; (v) tailored specifically for CI enterprises. Indeed, it has already been elucidated in the literature review results how some of the analysed works satisfied only part of these points. Therefore, this work, proposes a decision-making support tool aimed at fulfilling the aforementioned points. The proposed tool also integrates the concepts of assessment of the current situation and developing a roadmap. Indeed, the assessment of the current situation provides the foundational basis for the roadmap development.

4.2. Tool development

The proposed tool is structured into three main sections: (i) the know-why section to identify the objectives, targets, opportunities, threats, and motivations of the company, (ii) the know-what section to evaluate the ESP current situation of the company and identify its strengths and weaknesses, and (iii) the know-how section, to assess the digital resources available to the company for improving its current situation, as well as identifying areas of potential improvement.

Based on the considerations listed at the end of the literature review results section regarding the identified models and roadmaps, and the resulting literature gap, the proposed tool was required to be compliant with three objectives:

a) Comprehensive coverage of all sustainability aspects related to cosmetic products, explicitly considering all phases of their life cycle.
b) Ability to provide precise technical support in identifying a path to accomplish the TT consistently with company targets.
c) User-friendly and easily understandable, since it is aiming at supporting moreover SMEs, that are the backbone of the European CI according to (Rossi and Hoffman, 2007; Cosmetics Europe, 2022).

The structure of the tool, divided into the know-why, the know-what and the know-how, draws inspiration from the SWOT analysis (Helms and Nixon, 2010). Indeed, in SWOT analysis, the assessment of the current situation implies the identification of directions of improvement. By identifying its strengths, weaknesses, opportunities and threats, a company can determine how to take action. Afterwards, decisions are made regarding which weaknesses and threats to target and what strengths and opportunities to exploit. Building on this concept, it was considered internal and external opportunities and threats that a company is facing under the ES perspective. In the conducted SLR, their relevance had indeed emerged (Hettiarachchi et al., 2022; Sahu et al., 2022). These aspects are addressed in the know-why section of the tool. Furthermore, in any assessment process, it is crucial to identify strengths and weaknesses of a company. This also emerged from the SRL (Ching et al., 2022; Kristoffersen et al., 2020). These aspects are addressed in the know-what section.

The SLR underscored the significant role of digital technologies improve ESP (Ching et al., 2022; Lopes de Sousa Jabbour et al., 2018; Zoubek et al., 2021). Thus, the know-how section was introduced.

The tool is named of Twin Transition Cosmetic Roadmapping Tool (TTCRT). In Fig. 3 its structure is depicted.

The TTCRT is designed to assess and enhance the ESP of a single product along its life cycle. Thus, to evaluate the ESP of several products, the TTCRT must be applied to each product separately. The application of the tool can be divided into two main phases:

1. Assessment Phase: during this phase, the evaluation of the current company situation takes place. It involves the compilation of all the three sections of the, namely the know-why, the know-what and the know-how.
2. Roadmapping phase: the results of the Assessment Phase serve as a foundation for the Roadmapping Phase. Focusing on the weaknesses identified in the know-what section, in this phase it can be decided what aspects to improve, with guidance from the insights provided in the know-why section. Subsequently, through an analysis of the information provided in the know-how section, the identification of technological resources that can be adopted or further developed becomes possible.

4.3. Twin transition cosmetics roadmapping tool structure

In this section the TTCRT structure is presented. As highlighted

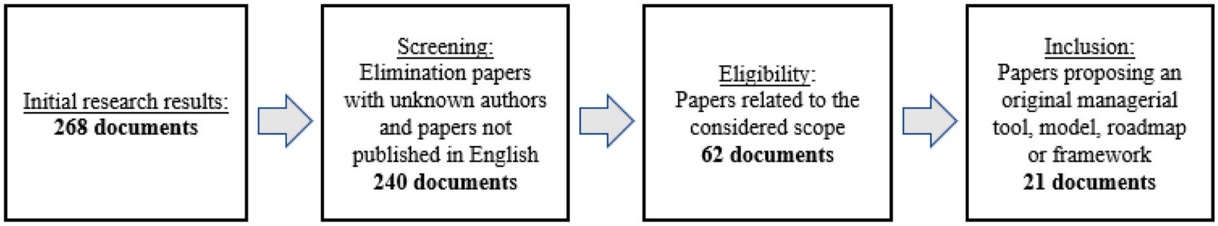

Fig. 2. Performed literature review.

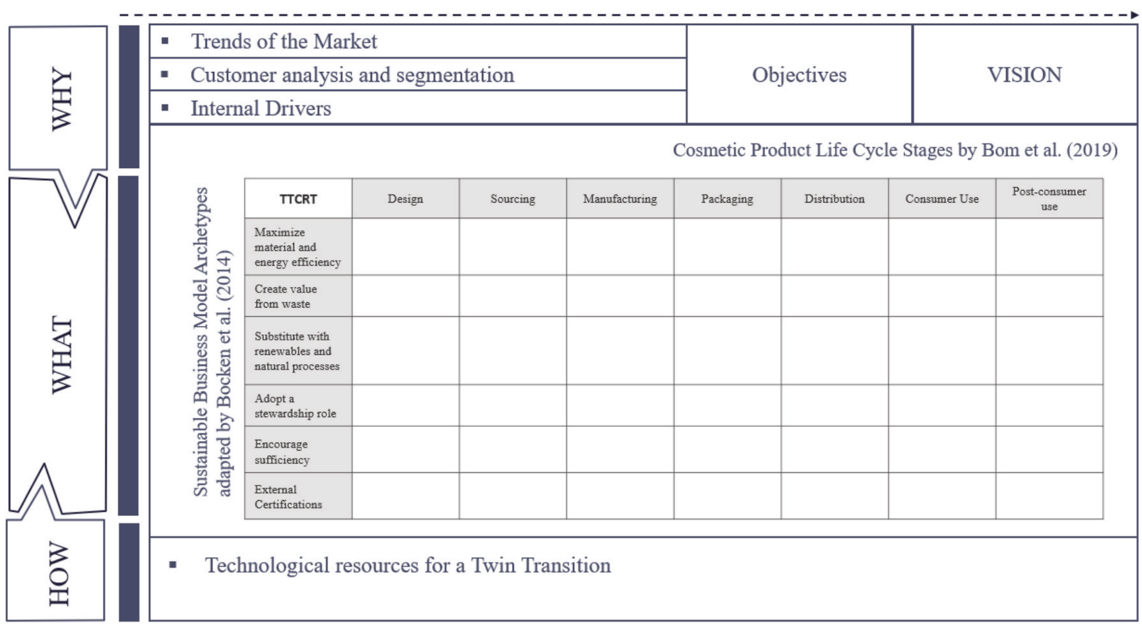

Fig. 3. Twin Transition Cosmetic Roadmapping Tool structure.

through this paragraph, some features of the tool were implemented during Action Research phase, which is described in the section dedicated to the tool application.

4.3.1. *The know-why section*

To identify and define company drivers and targets, a questionnaire intended for key company persons was developed. Before administrating the questionnaire, the selection of the product to which the TTCRT will be applied is necessary.

The questionnaire starts by defining the enterprise sustainability vision and by identifying which of the 17 Agenda 2030 Sustainability Development Goals (SDGs) (United Nations, 2020) align with this vision. Then a brief description of company mission and strategic objectives is required, with a particular emphasis on the aspects related to ES. Following this, the questionnaire proceeds to identify external drivers, to be selected from the following list in accordance with the SDGs: (i) increasing demand of scarce resources, (ii) fighting pollution and climate change, (iii) anticipating laws and regulations related to ES, (iv) anticipating market trends, (v) establishing a sustainable brand image, (vi) growing relevance of environment consumer and corporate purchasing decisions, (vii) responding to a specific request by a stakeholder, (viii) other. Considering the chosen product for the TTCRT application, respondents are then asked to identify the sustainability aspects most important to the targeted customer's segment. This is inspired by opportunities identified in previous research (Li et al., 2015), and options include: (i) using more sustainable raw materials for the product, (ii) using more sustainable raw materials for packaging, (iii) ES of the sourcing phase, (iv) ES of the production phase, (v) ES of the logistics phase, (vi) recyclability, biodegradability or re-usability of the product, (vii) recyclability, biodegradability or re-usability of the package, (viii) decreasing environmental impact during the use phase and (ix) ES of the product disposal.

It is worth noting that equal importance is placed on the product and its packaging, given the critical role of packaging in the CI (Cinelli et al., 2019).

Finally, interviewees are asked to identify internal drivers of the company towards ES. These are categorized into two groups: drivers that serve as motivation for the company towards ES and drivers that facilitate or enable ES improvements.

The sub-division was implemented after Action Research phase. The possible answers for the motivational drivers are as follows: (i) presence of company activities or processes with a high environmental impact, (ii) attainment of a certification (specifying what kind of certification), (iii) improvement of personnel motivation, (iv) introduction of a new product line, (v) operational costs reduction, (vi) improved attractiveness to investors, (vii) development of a market offering, and (viii) other.

A specific answer related to the attainment of ES certifications was prepared during Action Research phase, as certifications play a key role in CI (Bozza et al., 2022). As for internal drivers that serve as a lever for ES improvements, the possible answers include: (i) existence of company environmental policy, (ii) willingness to introduce technologies to optimise company ESP, (iii) willingness to hire qualified human resources to optimise company ESP, and (iv) other.

The aim of all the questions includes also making opportunities, threats, drivers and targets clear and explicit to the company itself.

4.3.2. *The know-what section*

To delineate the scope of intervention, both the stages of the PLPs requiring improvement and the exploitable approaches for delivering sustainability need to be identified. The know-what section employs a matrix structure, with PLPs represented on the horizontal axis and modalities for enhancing ESP on the vertical axis.

Regarding the horizontal axis, the PLPs of a typical cosmetic product identified by (Bom et al., 2019) were adopted. These include: (i) product and packaging design, (ii) sourcing, encompassing raw materials extraction and transportation, (iii) manufacturing, (iv) packaging, which includes both package manufacturing and the insertion of the product in it, (v) distribution, (vi) consumer use, and (vii) post-consumer use.

Establishing the boundaries of the company in terms of PLPs is necessary before pinpointing areas for improvement. This ensures the exclusion of areas beyond the sphere of influence of the company.

The identification of the potential modalities to improve ESP is based on the Sustainable Business Model Archetypes (SBMAs) presented by (Bocken et al., 2014), where eight different SBMAs are proposed: (i) maximising material and energy efficiency, (ii) creating value from waste, by reusing, recycling, or remanufacturing, (iii) substituting with renewable and natural processes, (iv) delivering functionality rather than ownership to reduce resource consumption, (v) adopting a stewardship role to promote ES among stakeholders, (vi) encouraging sufficiency by reducing demand-side consumption, (vii) repurposing the business, changing its ultimate target to achieving social and environmental benefits and (viii) developing scale-up sustainability solutions.

The last two points were excluded from consideration. Indeed, point 7 involves a radical change of the business model, which falls outside the scope of this work. Point 8 pertains to the development level of sustainability solutions inside a company, which is exactly what this tool aims to assess. During Action Research phase, the exclusion of also point 4 was decided. Indeed, in the CI it is impossible to deliver the functionality of a product without physically selling it.

To the 5 SBMAs a further row was added during Action Research phase, related to the ES certifications held by the company. Indeed, ES certifications play a crucial role in the CI (Bozza et al., 2022).

To construct the matrix by compiling criteria, five levels of implementation were defined, inspired by some previous works (Baumgartner and Ebner, 2010; Machado et al., 2017; Schaltegger et al., 2012). Adapting from these sources, the list of five levels for the TTCRT was developed. They assess the application strategy adopted by the company for each considered SBMA in the considered PLPs. A refinement of the levels definitions was implemented during Action Research phase. They are portrayed in Table 2.

Table 2
Definition of the levels of application strategy for a SBMA in the considered PLP.

STRATEGY	DEFINITION	LEVEL
Not applicable	It is outside study boundaries, or it is not possible to apply the considered SBMA to this PLP.	X
No strategy	Actions are not taken or are exclusively driven by the need to be compliant with laws and regulations. No targets are defined.	0
Defensive strategy	Actions are focusing on risk and cost reduction. Mainly the economic dimension is considered. Environmental targets are not defined.	1
Accommodative strategy	Actions are taken considering an ESP improvement approach and are mainly market driven. A Life Cycle Thinking approach is partially considered. Targets are clear but conservative and processes are partially monitored.	2
Proactive strategy	Actions are taken considering an ESP improvement approach. The company continuously seeks to integrate the sustainability vision by anticipating market requests embedding a Life Cycle Thinking approach. Targets are ambitious and processes are continuously monitored.	3

4.3.3. The know-how section

In the development of the know-how section, the first step involved identifying the digital technologies to be considered. For what concerns the Smart Manufacturing digital technologies, the list proposed by (Mabkhot et al., 2021) was adopted. It encompassed all the technologies impacting the SDGs. The only modification made in this work is the exclusion of Cloud Computing technology, as it is regarded as an enabler of the other technologies.

Two additional categories of technologies were taken into account, basing on (Wagire et al., 2021): (i) value chain and processes technologies and (ii) product and service-oriented technologies. The specific technologies within each category remained consistent with those outlined in (Wagire et al., 2021), with one notable change. The digitalisation of production equipment was taken away from value chain and process as it was already considered in this work within the Smart manufacturing technologies section. Each technology is crossed with a different PLP, as illustrated in Table 3.

Regarding the criteria for assigning grades, the I4.0 maturity model proposed by (Santos and Martinho, 2020) was adapted. These adaptations were made to align with the specific focus of this work on the TT. Subsequently, they were further refined during the Action Research phase. The grade assignment criteria are as follows:

- Level X: the technology is not applicable in the considered PLP.
- Level 0: No implementation of that technology in that PLP or its implementation does not consider ESP.
- Level 1: Pilot actions are in place to implement that technology in that PLP or, alternatively, the technology is well implemented in that PLP but with no ES objectives. Nonetheless, there are associated collateral ES benefits resulting from the considered improvement mechanism.
- Level 2: Implementation of the technology in that PLP is initiated and ES benefits are observable. Alternatively, the technology is well implemented in that PLP for other primary purposes, but conscious secondary aspects related ESP improvements are enjoyed and measured.
- Level 3: Advanced and mature implementation of the technology in that PLP mainly for ES purposes, resulting in clear ESP benefits.

5. Twin transition cosmetics roadmapping tool application and refinement

Action Research phase of the TTCRT development was conducted in an Italian cosmetics SME specialized in the creation, development, and manufacture of make-up products. During this phase, the refinements to the TTCRT previously discussed were implemented. As outlined in the methodology section, it required only one cycle of refinements to attain a satisfactory version of the tool. The results presented in this section stem from the application of this refined version of the tool. For the application of the TTCRT, a specific type of mascara was selected. The choice was made in consultation with the company, as the selected mascara ranks among their most produced and sold products. Thus, applying the tool to this particular product is valuable for the company.

5.1. The know-why phase

This section was tested by administering a survey to 13 people occupying managerial positions within the company to identify the main drivers and objectives.

- Objectives. The company was unable to provide specific quantitative targets. However, it exhibited a heightened focus on the following SDGs: (i) utilization of clean and renewable energy; (ii) preservation of life on earth and underwater.
- External drivers. The primary external motivations that emerged are: (i) responding to climate change; (ii) satisfying the growing

Table 3
know-how technologies matrix.

		Design	Sourcing	Manufacturing	Packaging	Distribution	Consumer use	Post-consumer use
Smart Manufacturing Technologies	IIoT							
	Big Data & Analytics							
	Simulation							
	Augmented Reality and Virtual Reality							
	Additive Manufacturing							
	Horizontal & Vertical System Integration							
	Autonomous Robots and Cobots							
	Identifiers like Bar code, QR code or RFID and RTLS							
Value chain and process	Digitalisation of vertical value chain							
	Real-time monitoring and control technologies							
	End-to-End IT-enabled planning and steering process							
	Digitalisation of horizontal value chain							
Product and service-oriented technologies	Blockchain technology							
	Smart Product							
	Additive manufacturing for prototyping							
	Mobile devices and Wearables							

significance of environmental considerations among customers. Other external drivers, though somewhat less significant than the former two, still hold notable importance. These are: (i) anticipating market trends; (ii) anticipating regulations; (iii) responding to a stakeholder request.

- Consumers. The main sustainability aspects influencing consumer preferences are identified as: (i) the recyclability, biodegradability, or reusability of the product and (ii) of the package; (iii) usage of more sustainable raw materials. Other influential drivers, though somewhat less important compared to the former three but still relevant, encompass: (i) ES during the production phase; (ii) sustainable product disposal processes.
- Internal drivers. For what concerns motivational drivers, the following were identified as most relevant: (i) the attainment of ES certifications; (ii) the development of a higher value offering; (iii) the reduction of operational costs. Regarding lever drivers, the most relevant were identified as: (i) willingness to introduce technologies to optimise ESP; (ii) presence of a corporate sustainability strategy.

5.2. The know-what phase

The compilation of the know-what section was accomplished with the active involvement of the company board. Notably, Consumer-use and post-consumer-use phases were excluded from the analysis, as the company lacks visibility on these stages. Furthermore, the coverage of the packaging phase by the company is limited only to the filling process. Concerning “Adopt a stewardship role” SBMA, it became evident that the company is more influenced than it is influential, moreover by the pressure coming from the market. This is the reason behind the mark assigned for that SBMA in Table 4.

The average grade attained in the assessment is low. According to the managers, this can be attributed to the fact that the journey of the company towards ES is still in its early stages. For each row and each column, the average is computed on all the numbers appearing in the specific row or column. The “Xs” are excluded from the computation.

The stages in which the company exhibits relatively better performance are (i) Manufacturing and (ii) Design, both achieving an average grade of 1. Follow (iii) Packaging (0,67), (iv) Sourcing (0,5) and (v) Distribution (0,2). This outcome is partly consistent with the results from the know-why. Indeed, the selection of raw materials during the design phase was among the main drivers coming from customers. Conversely, ES in production was not as crucial but still hold relevance.

For what concerns the SBMAs, the most widely implemented ones are: (i) “Create value from waste” with an average grade of 1,2; (ii) “Maximize material and energy efficiency” with an average grade of 0,8; (iii) “Substitute with renewable and natural processes”, with 0,8 of average. It is worth noting that the first and the second SBMAs are strongly related to “reduction of operational costs”, which had emerged as a crucial driver. For what concerns the certifications, it emerged that the company has a solid focus on product design in terms of raw materials choice but is lacking in other PLPs.

5.3. The know-how phase

The table related to the assessment of the technological resources within the company was compiled. The same PLPs that were addressed in the matrix of the know-what section were also considered in this context. Results are shown in Table 5.

The company has implemented very few digital technologies to support of GT. This can be attributed to two primary factors: (i) the company is at the initial stage of embarking on its journey towards GT; (ii) Until now, the company has primarily focused on other aspects of

Table 4
Analysed company know-what matrix.

	Design	Sourcing	Manufacturing	Packaging	Distribution
Maximize material and energy efficiency	0	1	2	1	0
Create value from waste	0	1	2	2	1
Substitute with renewables and natural processes	2	0	1	1	0
Adopt a stewardship role	0	0	0	0	0
Encourage sufficiency	2	0	X	0	X
Environmental Sustainability certifications	2	1	0	0	0

Table 5
Analysed company know-how matrix.

		Design	Sourcing	Manufacturing	Packaging	Distribution
Smart Manufacturing Technologies	IIoT	0	0	0	0	0
	Big Data & Analytics	0	0	0	0	0
	Simulation	0	0	1	0	0
	Augmented Reality and Virtual Reality	0	0	0	0	0
	Additive Manufacturing	X	X	0	0	X
	Horizontal & Vertical System Integration	0	2	1	1	0
	Autonomous Robots and Cobots	X	X	X	0	X
	Identifiers like Bar code, QR code or RFID and RTLS	X	0	0	0	0
Value chain and process	Digitalisation of vertical value chain	0	0	0	0	0
	Real-time monitoring and control technologies	0	0	0	0	0
	End-to-End IT-enabled planning and steering process	0	1	1	1	0
	Digitalisation of horizontal value chain	0	0	0	0	0
Product and service-oriented technologies	Blockchain technology	0	0	0	0	0
	Smart Product	0	0	0	0	0
	Additive manufacturing for prototyping	0	X	X	X	X
	Mobile devices and Wearables	X	0	0	0	0

ESP and has yet to substantially address the TT.

5.4. Roadmapping phase

The roadmap developed for the analysed company primarily focused on evaluating the potential deployment of digital technologies to improve the current situation. This was necessitated by the aforementioned absence of the previous TT interventions.

One of the prominent external drivers identified is the willingness to reduce environmental pollution. The limited TT interventions that have been initiated, as assessed in the know-how phase, mainly concentrate on the manufacturing phase. The company was advised to advance its ongoing pilot simulation initiatives, with the objective of transitioning from a pilot project state to an initiated implementation state (level 2). Additionally, it was recommended to commence pilot projects involving IoT and Big Data Analytics tools in the production phase. This move would foster a synergy between data input and simulation-based interventions. The SBMA that warranted focus within these interventions was identified as “Maximize material and energy efficiency”, with the aim of elevating its grade within Manufacturing PLP from 2 to 3. This is consistent with the emerged internal driver “reducing operational costs”. Finally, the same approach was recommended for the packaging phase.

Regarding the drivers coming from consumer preferences, the know-why section underscored the significance of recyclability, biodegradability and reusability of the product and its packaging. These features are mainly determined during the design phase. From the know-what matrix, it was evident that the company already achieved a commendable level for the SBMA “Substitute with renewables and natural processes” within the design phase. Nonetheless, nothing emerged for the strategy “Create value from waste”. For the product under consideration, the packaging emerged as the most relevant component, due to the substantial presence of plastics. It was therefore suggested to concentrate efforts on evaluating interventions related to the design phase. An example of a possible intervention entails launching pilot simulation projects geared towards the development of new packaging solutions, with the aim of enhancing recyclability. This proposed improvement is also aligned with the identified driver “development of a higher value offer”.

6. Discussions and limitations

In this work, it has been addressed the need for support in TT by CI and the pivotal role that assessment and roadmapping tools can play in this context. Thus, it has been adopted a methodology that combines SRL and Action research approaches to propose a novel tool tailored to support TT in the CI. The results of the SLR on existing assessments and roadmapping tools for the TT in manufacturing revealed that out of 268 analysed works, only 21 propose a model, a framework, or a roadmap to assist manufacturing companies in the TT. Notably, the majority of the models and roadmaps present in the literature are conceived to be generic and not specific for a certain industry. While this characteristic provides flexibility, it may also lead to overlooking critical industry-specific aspects, potentially reducing their effectiveness.

Furthermore, it was observed that only in few works a precise technical support for companies is provided ((Kristoffersen et al., 2020; Lopes de Sousa Jabbour et al., 2018; Miranda et al., 2019; Nascimento et al., 2022)). Nonetheless, two of these focus solely on CE, and do not encompass other ESP aspects (Kristoffersen et al., 2020; Lopes de Sousa Jabbour et al., 2018). In the remaining two cases, only specific digital technologies are considered: , technologies applicable in product development and Additive Manufacturing (Miranda et al., 2019; Nascimento et al., 2022). A tool to fill the identified literature gap, called TTCRT, is proposed, which has both theoretical and practical implications.

On the theoretical side, it amalgamates two concepts: the assessment of the current ESP and TT of a cosmetic company and the roadmapping of a cosmetic company in terms of TT. This union also holds significant practical implications as the TTCRT facilitates roadmap development based on the results of a structured assessment, ensuring alignment with company current contingencies and needs.

The TTCRT connects all possible mechanisms for improving Industrial ES of a cosmetic product throughout its life cycle with the opportunities for ESP through digitalisation. The possible mechanisms for ESP improvement are identified and classified to be tailored for the CI. The TTCRT also specifies the digital technologies that can be addressed to perform ESP enhancement. They are classified into three categories according to their role in a company.

All typologies of technologies relatable to the TT are included. TTCRT introduces (i) a new scale for assessing a product ESP across its life cycle encompassing all pertinent SBMAs and (ii) a new scale for evaluating a company technological implementation dedicated to ESP improvement. Improvement in the latter is instrumental in enhancing the former, since within the TT framework, superior technological implementation leads to improved ESP. Finally, the TTCRT is, at extent of the authors’ knowledge, the first management tool supporting companies in the TT specifically for the CI.

From a practical standpoint, the TTCRT can offer substantial benefits to CI manufacturing companies, particularly SMEs, by supporting them through the TT. The tool assists in identifying the most suitable digital technologies for implementation. It also helps to identify their area (in terms of PLPs) and purpose (in terms of SBMAs) of implementation. It does so consistently with identified opportunities, threats, strengths, and weaknesses of the companies themselves. Furthermore, through the know-why section, companies can better define and understand their own drivers towards the GT and the TT. Through both know-why and know-what sections, companies can acquire a more defined view of the overall opportunities, threats, strengths, and weaknesses they have to face in terms of ES. The roadmap phase, enabled by the compilation of all the three TTCRT sections, provides companies step-by-step guidance, as proved by the real-world application case. This approach assists companies in devising a roadmap that aligns with their ES drivers and objectives while targeting areas in need of ESP and digitalisation enhancements. This step-by-step guidance is particularly valuable for SMEs, supporting them in overcoming barriers related to a lack of technical knowledge and expertise (Horváth and Szabó, 2019; Stentoft et al., 2019).

However, a notable limitation was observed during the application case. The know-why and know-what sections of the tool are designed to be applied to one product typology at a time. Therefore, if a company offers a wide array of products, applying the TTCRT to each product may be time-consuming. Thus, it is advisable to prioritise the TTCRT usage by applying it to products of greater strategic importance or to those whose sustainability is more relevant for the market (e.g., the natural products). Alternatively, partial application of the TTCRT, considering only one or few PLPs shared among more than one product may be feasible. For instance, if a few products share very similar packaging phases, going through very similar processes with the same machinery, it may be possible to apply the TTCRT to all of them concurrently, considering only the packaging phase.

Nonetheless, this limitation may hinder the TTCRT application in micro-enterprises. Furthermore, even if the tool streamlines complexity, and even if from the industrial application it did not emerge as too complicated to be understood, still it may be too technically intricate for micro-enterprises to use it independently. Indeed, the company the TTCRT was applied to is a medium enterprise that benefitted of the crucial support of the authors throughout the application.

7. Conclusions and future research

In this work it was addressed the research objective of developing a tool to support practitioners in cosmetics SMEs in performing TT. In the proposed contribution the current state of the art of practical managerial tools and roadmaps to support enterprises in facing the challenge of the TT is investigated.

The findings of this research revealed that, while some interesting and useful tools are available, none comprehensively assist enterprises in both assessing their current state and facilitating improvements across the entire spectrum of possible digital technologies implementation and ESP improvement modalities. Furthermore, no tools were identified focusing specifically on the CI.

To address this gap, a tool called TTCRT, integrating the principles of maturity models and roadmapping tools, has been developed. The development of the TTCRT follows Design Science methodology, by designing and testing an artifact to solve a defined problem. Specifically, the approach followed to implement Design Science methodology amalgamates SLR and Action Research. By doing so, it was possible to comprehend the state of the art of assessment tools, maturity models, roadmaps and frameworks supporting companies in performing the TT. Then, the findings of the SLR supported the tool development. The proposed tool is conceived to support CI companies, moreover SMEs, through four main phases: (i) the know-why phase, involving an analysis of the objectives and drivers of the company, (ii) the know-what phase, encompassing an assessment of the current level of implementation of ES strategies across the PLPs, (iii) the know-how phase, entailing an analysis of the digital technologies supporting sustainability implemented across PLPs, and (iv) the roadmapping phase, where improvement actions for the company can be defined based on the results of the preceding phases. The TTCRT underwent validation through an industrial case, leading to refinements and improvements in the tool.

Some potential avenues for future improvement emerged during the testing of the tool. One promising direction is to develop a mechanism that can automate and customise the application process of the know-how section to suit the specific company. This could involve creating a mechanism to link different company processes with digital technologies that are appliable to them. This approach would result in a more tailored roadmap aligned with the unique features of the company.

Another avenue for automation could involve correlating targets of the company and areas of improvement (PLPs and SBMAs). This mechanism can reduce the element of human subjectivity in the TTCRT application, empowering SMEs to use the tool more effectively autonomously, without support by external experts. Indeed, during the testing of the tool the company board relied intensively on external support. To address concerns about accessibility for micro-enterprises mentioned in the limitations paragraph, an alternative less precise but simplified version of the TTCRT could be d considered for future development. Another avenue for future developments may be the adaptation of the TTCRT to create alternative versions of it customised to other industries.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used OpenAI ChatGPT in order to improve the syntax and grammar of the manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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.

Data availability

No data was used for the research described in the article.

References

Acerbi, F., Rocca, R., Fumagalli, L., Taisch, M., 2023. Enhancing the cosmetics industry sustainability through a renewed sustainable supplier selection model. Prod. Manuf. Res. 11 https://doi.org/10.1080/21693277.2022.2161021.

Acerbi, F., Taisch, M., 2020. A literature review on circular economy adoption in the manufacturing sector. J. Clean. Prod. 273, 123086 https://doi.org/10.1016/j.jclepro.2020.123086.

Battistella, C., De Toni, A.F., Pillon, R., 2015. The Extended Map methodology: technology roadmapping for SMES clusters. J. Eng. Technol. Manag. - JET-M 38, 1–23. https://doi.org/10.1016/j.jengtecman.2015.05.006.

Baumgartner, R.J., Ebner, D., 2010. Corporate sustainability strategies: sustainability profiles and maturity levels. Sustain. Dev. 18, 76–89. https://doi.org/10.1002/sd.447.

Bhatia, P., Diaz-Elsayed, N., 2023. Facilitating decision-making for the adoption of smart manufacturing technologies by SMEs via fuzzy TOPSIS. Int. J. Prod. Econ. 257, 108762 https://doi.org/10.1016/j.ijpe.2022.108762.

Bloem da Silveira Junior, L.A., Vasconcellos, E., Vasconcellos Guedes, L., Costa, R.M., Guedes, L.F.A., 2018. Technology roadmapping: a methodological proposition to refine Delphi results. Technol. Forecast. Soc. Change 126, 194–206. https://doi.org/10.1016/j.techfore.2017.08.011.

Bocken, N.M.P., Short, S.W., Rana, P., Evans, S., 2014. A literature and practice review to develop sustainable business model archetypes. J. Clean. Prod. 65, 42–56. https://doi.org/10.1016/j.jclepro.2013.11.039.

Bom, S., Jorge, J., Ribeiro, H.M., Marto, J., 2019. A step forward on sustainability in the cosmetics industry: a review. J. Clean. Prod. 225, 270–290. https://doi.org/10.1016/j.jclepro.2019.03.255.

Böttcher, T.P., Empelmann, S., Weking, J., Hein, A., Krcmar, H., 2023. Digital sustainable business models: using digital technology to integrate ecological sustainability into the core of business models. Inf. Syst. J. 1–26 https://doi.org/10.1111/isj.12436.

Bozza, A., Campi, C., Garelli, S., Ugazio, E., Battaglia, L., 2022. Current regulatory and market frameworks in green cosmetics: the role of certification. Sustain. Chem. Pharm. 30, 100851 https://doi.org/10.1016/j.scp.2022.100851.

Ching, N.T., Ghobakhloo, M., Iranmanesh, M., Maroufkhani, P., Asadi, S., 2022. Industry 4.0 applications for sustainable manufacturing: a systematic literature review and a roadmap to sustainable development. J. Clean. Prod. 334, 130133 https://doi.org/10.1016/j.jclepro.2021.130133.

Cinelli, P., Coltelli, M.B., Signori, F., Morganti, P., Lazzeri, A., 2019. Cosmetic packaging to save the environment: future perspectives. Cosmetics 6, 1–14. https://doi.org/10.3390/COSMETICS6020026.

Cosmetics Europe, 2022. https://cosmeticseurope.eu/files/3116/6746/7597/CE_Socio_Ec_Infographic_2022.pdf. Last visit on 4th July 2023.

Czachorowski, K.V., Haskins, C., 2022. Applying systems engineering to roadmapping for digital transformation in the offshore exploration and production supply chain operations. Syst. Eng. 25, 191–206. https://doi.org/10.1002/sys.21611.

Data Bridge Market Research, 2022. https://www.databridgemarketresearch.com/reports/global-biodegradable-cosmetic-packaging-market. Last visit on 15th September 2023.

Data Intelo, 2022. https://dataintelo.com/report/global-bakuchiol-market/. Last visit on 15th September 2023.

Dikhanbayeva, D., Shaikholla, S., Suleiman, Z., Turkyilmaz, A., 2020. Assessment of industry 4.0 maturity models by design principles. Sustain. Times 12, 1–22. https://doi.org/10.3390/su12239927.

Ferrera, E., Rossini, R., Baptista, A.J., Evans, S., 2017. Toward Industry 4 . 0 : Ef fi Cient and Sustainable Manufacturing Leveraging MAESTRI Total Ef fi Ciency Framework 1. https://doi.org/10.1007/978-3-319-57078-5.

Flumerfelt, S., Wenson, J., 2019. Lean Engineering for Global Development, Lean Engineering for Global Development. Springer International Publishing. https://doi.org/10.1007/978-3-030-13515-7.

Ghobakhloo, M., Iranmanesh, M., Grybauskas, A., Vilkas, M., Petraitė, M., 2021. Industry 4.0, innovation, and sustainable development: a systematic review and a roadmap to sustainable innovation. Bus. Strat. Environ. 30, 4237–4257. https://doi.org/10.1002/bse.2867.

Helms, M.M., Nixon, J., 2010. Exploring SWOT analysis – where are we now?: a review of academic research from the last decade. Journal of Strategy and Management. https://doi.org/10.1108/17554251011064837.

Hettiarachchi, B.D., Brandenburg, M., Seuring, S., 2022. Connecting additive manufacturing to circular economy implementation strategies: links, contingencies and causal loops. Int. J. Prod. Econ. 246, 108414 https://doi.org/10.1016/j.ijpe.2022.108414.

Holmström, J., Ketokivi, M., Hameri, A.P., 2009. Bridging practice and theory: a design science approach. Decis. Sci. J. 40, 65–87. https://doi.org/10.1111/j.1540-5915.2008.00221.x.

Horváth, D., Szabó, R.Z., 2019. Driving forces and barriers of Industry 4.0: do multinational and small and medium-sized companies have equal opportunities? Technol. Forecast. Soc. Change 146, 119–132. https://doi.org/10.1016/j.techfore.2019.05.021.

Kaya, İ., Karaşan, A., Güvercin, Ö., İlbahar, E., Baraçlı, H., 2023. Appraisal of smart factory design for advance manufacturing plants based on transition strategies by using an integrated fuzzy decision-making methodology. Int. J. Comput. Integrated Manuf. https://doi.org/10.1080/0951192X.2023.2177735.

Kenett, R.S., Zonnenshain, A., Fortuna, G., 2018. A road map for applied data sciences supporting sustainability in advanced manufacturing: the information quality dimensions. Procedia Manuf. 21, 141–148. https://doi.org/10.1016/j.promfg.2018.02.104.

Kristoffersen, E., Blomsma, F., Mikalef, P., Li, J., 2020. The smart circular economy: a digital-enabled circular strategies framework for manufacturing companies. J. Bus. Res. 120, 241–261. https://doi.org/10.1016/j.jbusres.2020.07.044.

Kumar, V., Vrat, P., Shankar, R., 2022. Factors influencing the implementation of industry 4.0 for sustainability in manufacturing. Global J. Flex. Syst. Manag. 23, 453–478. https://doi.org/10.1007/s40171-022-00312-1.

Leong, W.D., Teng, S.Y., How, B.S., Ngan, S.L., Rahman, A.A., Tan, C.P., Ponnambalam, S.G., Lam, H.L., 2020. Enhancing the adaptability: lean and green strategy towards the industry revolution 4.0. J. Clean. Prod. 273, 122870 https://doi.org/10.1016/j.jclepro.2020.122870.

Li, J., Tao, F., Cheng, Y., Zhao, L., 2015. Big Data in product lifecycle management. Int. J. Adv. Manuf. Technol. 81, 667–684. https://doi.org/10.1007/s00170-015-7151-x.

Lopes de Sousa Jabbour, A.B., Jabbour, C.J.C., Godinho Filho, M., Roubaud, D., 2018. Industry 4.0 and the circular economy: a proposed research agenda and original roadmap for sustainable operations. Ann. Oper. Res. 270, 273–286. https://doi.org/10.1007/s10479-018-2772-8.

Mabkhot, M.M., Ferreira, P., Maffei, A., Podržaj, P., Mądziel, M., Antonelli, D., Lanzetta, M., Barata, J., Boffa, E., Finžgar, M., Paśko, Ł., Minetola, P., Chelli, R., Nikghadam-Hojjati, S., Wang, X.V., Priarone, P.C., Litwin, P., Stadnicka, D., Lohse, N., Lupi, F., 2021. Mapping industry 4.0 enabling technologies into united nations sustainability development goals. Sustain. Times 13, 1–35. https://doi.org/10.3390/su13052560.

Machado, C.G., Pinheiro de Lima, E., Gouvea da Costa, S.E., Angelis, J.J., Mattioda, R.A., 2017. Framing maturity based on sustainable operations management principles. Int. J. Prod. Econ. 190, 3–21. https://doi.org/10.1016/j.ijpe.2017.01.020.

Miranda, J., Pérez-Rodríguez, R., Borja, V., Wright, P.K., Molina, A., 2019. Sensing, smart and sustainable product development (S3 product) reference framework. Int. J. Prod. Res. 57, 4391–4412. https://doi.org/10.1080/00207543.2017.1401237.

Mohamed, N., Al-Jaroodi, J., Lazarova-Molnar, S., 2019. Leveraging the capabilities of industry 4.0 for improving energy efficiency in smart factories. IEEE Access 7, 18008–18020. https://doi.org/10.1109/ACCESS.2019.2897045.

Montresor, S., Vezzani, A., 2022. Digital technologies and eco-innovation. Evidence of the twin transition from Italian firms. DRUID Conf 1–29, 2022.

Münnich, M., Stange, M., Süße, M., Ihlenfeldt, S., 2022. Integration of Digitization and SustainabilityObjectives in a Maturity Model-Based Strategy Development Process, Springer, Manufacturing Driving Circular Economy. https://doi.org/10.1007/978-3-031-28839-5.

Nascimento, D.L. de M., Quelhas, O.L.G., Moyano-Fuentes, J., Tortorella, G.L., Maqueira, J.M., 2022. Circular value stream mapping 4.0: proposed general model and application to a digital 3D printing recycling factory. Sustain. Prod. Consum. 34, 600–612. https://doi.org/10.1016/j.spc.2022.10.012.

Ortega-Gras, J.J., Bueno-Delgado, M.V., Cañavate-Cruzado, G., Garrido-Lova, J., 2021. Twin transition through the implementation of industry 4.0 technologies: desk-research analysis and practical use cases in europe. Sustain. Times 13. https://doi.org/10.3390/su132413601.

Panayiotou, N.A., Stergiou, K.E., Stavrou, V.P., 2019. Development of a Modeling Architecture Incorporating the Industry 4.0 View for a Company in the Gas Sector, IFIP Advances in Information and Communication Technology. https://doi.org/10.1007/978-3-030-29996-5_46.

Peffers, K., Tuunanen, T., Rothenberger, M.A., Chatterjee, S., 2007. A design science research methodology for information systems research. J. Manag. Inf. Syst. 24, 45–77. https://doi.org/10.2753/MIS0742-1222240302.

Prakash, G., Ambedkar, K., 2023. Digitalization of manufacturing for implanting value, configuring circularity and achieving sustainability. J. Adv. Manag. Res. 20, 116–139. https://doi.org/10.1108/JAMR-01-2022-0010.

PXR, 2022. Italy People Experience Research. https://pxritaly.com/en/blog/sustainable-cosmetics-market-data/. Last visit on 15th September 2023.

Researchandmarkets.com, 2023. https://www.researchandmarkets.com/reports/5302375/natural-and-organic-cosmetics-global-strategic. Last visit on 5th July 2023.

Rocca, R., Acerbi, F., Fumagalli, L., Taisch, M., 2022. Sustainability Paradigm in the Cosmetics Industry : State of the Art 3. https://doi.org/10.1016/j.clwas.2022.100057.

Rocca, R., Sassanelli, C., Rosa, P., Terzi, S., 2021. Circular economy performance assessment. In: SpringerBriefs in Applied Sciences and Technology. Springer Science and Business Media Deutschland GmbH, pp. 17–33. https://doi.org/10.1007/978-3-030-74886-9_3.

Rosa, P., Sassanelli, C., Terzi, S., 2018. Circular economy in action: uncovering the relation between circular business models and their expected benefits. Proc. Summer Sch. Fr. Turco 2018-Septe 228–235.

Rossi, E., Hoffman, R., 2007. A Study of the European Cosmetics Industry. http://edz.bib.uni-mannheim.de/daten/edz-h/gdb/07/study_eu_cosmetics_industry.pdf. May 2015.

Sahu, A., Agrawal, S., Kumar, G., 2022. Integrating Industry 4.0 and circular economy: a review. J. Enterprise Inf. Manag. 35, 885–917. https://doi.org/10.1108/JEIM-11-2020-0465.

Santos, R.C., Martinho, J.L., 2020. An Industry 4.0 maturity model proposal. J. Manuf. Technol. Manag. 31, 1023–1043. https://doi.org/10.1108/JMTM-09-2018-0284.

Sassanelli, C., Pezzotta, G., Pirola, F., Rossi, M., Terzi, S., 2019. The PSS design GuRu methodology: guidelines and rules generation to enhance PSS detailed design. J. Des. Res. 17, 125–162. https://doi.org/10.1504/JDR.2019.105756.

Schaltegger, S., Lüdeke-Freund, F., Hansen, E.G., 2012. Business cases for sustainability: the role of business model innovation for corporate sustainability. Int. J. Innovat. Sustain. Dev. 6, 95–119. https://doi.org/10.1504/IJISD.2012.046944.

Schumacher, A., Nemeth, T., Sihn, W., 2019. Roadmapping towards industrial digitalization based on an Industry 4.0 maturity model for manufacturing enterprises. Procedia CIRP 79, 409–414. https://doi.org/10.1016/j.procir.2019.02.110.

Stawiarska, E., Szwajca, D., Matusek, M., Wolniak, R., 2021. Diagnosis of the maturity level of implementing industry 4.0 solutions in selected functional areas of management of automotive companies in Poland. Sustain. Times 13. https://doi.org/10.3390/su13094867.

Stentoft, J., Jensen, K.W., Philipsen, K., Haug, A., 2019. Drivers and barriers for industry 4.0 readiness and practice: a SME perspective with empirical evidence. Proc. Annu. Hawaii Int. Conf. Syst. Sci. 2019-Janua 5155–5164. https://doi.org/10.24251/hicss.2019.619.

Sun, X., Yu, H., Solvang, W.D., 2022. Towards the smart and sustainable transformation of Reverse Logistics 4.0: a conceptualization and research agenda. Environ. Sci. Pollut. Res. 29, 69275–69293. https://doi.org/10.1007/s11356-022-22473-3.

Uçar, E., Le Dain, M.A., Joly, I., 2020. Digital technologies in circular economy transition: evidence from case studies. Procedia CIRP 90, 133–136. https://doi.org/10.1016/j.procir.2020.01.058.

United Nations, 2020. The Sustainable Development Goals Report 2020. https://doi.org/10.29171/azu_acku_pamphlet_k3240_s878_2016.

Wagire, A.A., Joshi, R., Rathore, A.P.S., Jain, R., 2021. Development of maturity model for assessing the implementation of Industry 4.0: learning from theory and practice. Prod. Plann. Control 32, 603–622. https://doi.org/10.1080/09537287.2020.1744763.

World Economic Forum, 2019. Global Risks Report 2019. Geneva Switzerland.

Worrell, E., Bernstein, L., Roy, J., Price, L., Harnisch, J., 2009. Industrial energy efficiency and climate change mitigation. Energy Effic 2, 109–123. https://doi.org/10.1007/s12053-008-9032-8.

Xiao, Y., Watson, M., 2019. Guidance on conducting a systematic literature review. J. Plann. Educ. Res. 39, 93–112. https://doi.org/10.1177/0739456X17723971.

Zoubek, M., Poor, P., Broum, T., Basl, J., Simon, M., 2021. Industry 4.0 maturity model assessing environmental attributes of manufacturing company. Appl. Sci. 11 https://doi.org/10.3390/app11115151.