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DOI 10.1016/j.jclepro.2022.132876
ISSN 0959-6526

Publisher: Elsevier

Journal of Cleaner Production 366 (2022) 132876

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

The impacts of safety on sustainable production performance in the chemical industry: A systematic review of literature and conceptual framework

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ARTICLE INFO

Handling Editor: Dr. Govindan Kannan

Keywords:
Safety
Safety performance
Sustainable production performance
Chemical industry
Systematic literature review

ABSTRACT

The chemical industry is a fundamental component of how countries function and, as such, can be both an enabler and inhibitor of sustainability. Given its importance, it is unsurprising that the sector has received increasing attention in the extant literature base in recent times, although less consideration has been given to the importance of safety in sustainable production and how this may challenge performance in the sector. The purpose of this paper is to close this gap and provide a comprehensive understanding of how safety challenges sustainable production performance. Using the systematic literature review methodology, 62 peer-reviewed articles were carefully selected, mapped, and assessed. Thematic analysis was performed to unravel the relationship mechanisms between safety performance and sustainable production performance, synthesised into five propositions. One of the important contributions of this work is the development of a conceptual framework that formalises the relationships between safety and sustainable production performance in the chemical industry. The framework can act a theoretical lens that subsequently enables future research in both safety and sustainability to be conducted in a more robust and credible manner.

1. Introduction

Sustainable production was first introduced during the United Nations Conference on Environment and Development (UNCED) in 1992 (Veleva and Ellenbecker, 2001). The conference discussed non-renewable processes of consumption and production in industrialised countries and pointed them out as the main reason for the world's environmental problems. While sustainable consumption takes into consideration the utilisation of goods and services, sustainable production places the focus on the raw material extraction and other natural resources used in the production processes, production throughput, and the waste generated during the production cycles (Pusavec et al., 2010). Sustainable production systems also strive for emission and pollution prevention, often by combining the use of renewable energy (Gavrilescu and Chisti, 2005). The benefits are thus not only in terms of the environmental aspects, but also in terms of cost savings, increased product quality and healthier working environments (Abou-Elela et al., 2007). For this reason, attaining sustainable production continues to be an important objective of modern industry sectors (Baah et al., 2020).

The chemical industry is a strategic industrial sector that is indispensable in many countries, thus vital for both the global economy and society's well-being (Alkaya and Demirer, 2015; Ruiz-Mercado et al., 2014). However, these massive contributions, to global economy and society's well-being, comprise a negative impact to both the environment and human health and safety. Despite attempts to achieve sustainable production, most of the efforts have been focused on the financial benefits and overlook safety, causing the decrease of safety in many cases (Stephanopoulos and Reklaitis, 2011). An industry is not fully sustainable just because it is economically viable, but it also needs to be environmentally compatible, and socially responsible (Gavrilescu and Chisti, 2005). Among those three pillars of sustainability, the social pillar is perhaps the one that is most overlooked (Ruiz-Mercado et al., 2014). As important as the two other pillars, the social pillar is essential in achieving sustainability, being the indicator of the chemical industry's impact on society's well-being. The environment and workers' health and safety are among the indicators of the social pillar

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https://doi.org/10.1016/j.jclepro.2022.132876
Received 6 May 2021; Received in revised form 13 June 2022; Accepted 23 June 2022
Available online 28 June 2022

(Ruiz-Mercado et al., 2012), which the chemical industry has been struggling to provide within its sustainable production process.

Even though a great deal of discussion on the importance of safety in the context of sustainable development has taken place, safety is often considered to be a part of the social pillar (Nawaz et al., 2019). Kishimoto (2013) noted that the effort that has been devoted to achieving sustainability might be contradictory to the effort made on health and safety. Many cases have shown that the absence of safety will also harm the economic and environmental pillars of sustainability. Thus, there is a need to understand the impacts of safety on sustainable production, and how exactly safety can influence sustainable production performance in the chemical industry. Additionally, how the characteristics of the chemical industry play their role in influencing the relationship between safety and sustainable production performance needs to be made clearer.

Inspired by the above-mentioned phenomena, we attempt to structure our line of enquiries and thoughts, by setting out the first research questions:

RQ1. To what extent does safety impact the performance of sustainable production in the chemical industry, and what is the mechanism?

Compared to other industries, the chemical industry has its unique characteristics, which subsequently has received increased attention in the extant literature base in recent years (Lee et al., 2015). Research by Lee et al. (2015) details that the chemical industry typically utilises high technology as a core component of its operations, adding greater complexity and a higher likelihood that more accidents occur, as well as being capital-intensive. Champion et al. (2017) noted the rare occurrence of major accidents in chemical production, but the effects are typically catastrophic when they do occur with numerous examples of major incidents happening in recent times. Some of the most prominent incidents include the vapour cloud explosion of the BP Texas City Refinery in March 2005, the dust explosion of the Imperial Sugar Refinery in October 2008, and the explosion and oil spill of the Deepwater Horizon oil rig in April 2010. Considering how the chemical industry has its own unique characteristics that influence safety performance of the industry, we set our second research question as follow:

RQ2. To what extent do the chemical industry's characteristics affect the relationship between safety and sustainable production performance?

Our study offers several contributions to the safety and sustainability literature. First, it shows the research gaps for further study, in order to understand the extent of the relationship between safety and sustainable production performance in the chemical industry. Second, it also uncovers the mechanism of the relationship between the two. Lastly, it offers practical suggestions to the chemical industry and other industry sectors with similar characteristic. The framework proposed in this study could be deployed into a practical workbook consisting of self-assessment procedures. Although this is not the first study that relates safety and sustainability, this is considered the first literature review that produces framework to explain the mechanisms of the relationship between the two.

In the next section, we first present the theoretical perspectives by explaining the related research areas in sustainable production, and the relationship between safety and the chemical industry. Then we present the method chosen to conduct the literature review, comprising the mechanism of data generation from databases, the selection process, and data analysis. This is followed by the descriptive and thematic analyses respectively, leading to the interpretation of findings that aim to answer the research questions. Based on the findings, the research gaps are then described, which underpin the development of a conceptual framework and the research propositions. The paper concludes with a brief summary of the contributions to knowledge, limitations and opportunities for future research.

2. Theoretical perspectives

This section will explain related theoretical perspective regarding themes of our study: safety, sustainable production performance, and chemical industry. The first section describes the sustainable production and sustainable production performance, their definition, the differences and the relationship between the two. The second section describes safety, safety culture, and their implications for the chemical industry. The third section highlight the relationship between safety and sustainability, which is core topic in this paper.

2.1. Sustainable production and sustainable production performance

Sustainable production is hereby defined as the development of products and services by processes and procedures that are pollution free, energy and natural resource efficient, economically viable, secure and safe for workers, communities and consumers, and socially and creatively beneficial to all the stakeholders (Macchi et al., 2020; Veleva and Ellenbecker, 2001).

The principles of sustainable production encompass the ties between the environmental, social, and economic frameworks within which the development and consumption take place (Machado et al., 2020). These principles provide a vision and long-term objectives for industries intending to become more sustainable, although for some, it is considered inadequate for a sustainable production in industries if they rely on vision and long-term objectives alone (Gani et al., 2022). Tools, methods and techniques are needed to help industries identify the issues with their current production processes and to establish specific measures of progress along with the direction of the sustainable production (Lin et al., 2020).

There exist several international standards that companies can use to measure their sustainable production performance. Among others, the ISO 14000 series for environmental management standard by International Organisation for Standardization (ISO) is perhaps the most recognized one (Hillary, 2017). The ISO 14001 and ISO 14031 standard provides guidance for organisations to manage their environmental systems and performances (British Standards Institution, 2015)(British Standards Institution, 2021). ISO also published ISO 26000 as a guidance for social responsibilities (Moratis and Cochius, 2017). Pertinent to the abovementioned standards are the Indicators of Sustainable Production (ISPs), that can be specifically used to measure the sustainable production (Veleva et al., 2001). Such indicators are, for instance, used to measure sustainable production performance are the usage of energy (Choy et al., 2016; Veleva and Ellenbecker, 2001) and material usage (Pusavec et al., 2010; Veleva and Ellenbecker, 2001), the impacts to environment (Nikolopoulou and Ierapetritou, 2012; Veleva and Ellenbecker, 2001), the workers' health and safety (McQuaid, 2000; Veleva and Ellenbecker, 2001), and the impacts to community (Lv et al., 2020; Veleva and Ellenbecker, 2001). Consequently, those indicators can also be used as input parameters to manage the production environment, social and economic aspects.

2.2. Safety, safety culture, and safety issue in the chemical industry

The US Agency for Healthcare Research and Quality defines safety as the 'freedom from accidental injury', while the International Civil Aviation Organisation defines it as 'the state in which harm to persons or of property damage is reduced to, and maintained at or below, an acceptable level through a continuing process of hazard identification and risk management'. The American National Standards Institute similarly defines safety as 'freedom from unacceptable risk'. Consequently, safety goals are usually defined in terms of a reduction in the measured outcomes over a given period of time. The fact that safety has become a global concern that instigate the publication of ISO 45001 standard containing as a framework to manage health and safety in the workplace (Soltanifar, 2022). This standard provides guidelines for

organisations to prevent both injury and ill health, and create safe and healthy workplaces (British Standards Institution, 2018).

Guldenmund (2000) pertinently summarised definitions of safety culture from various researches. Guldenmund (2000) highlight definitions by ACSNI, "The safety culture of an organisation is the product of individual and group values, attitudes, perceptions, competencies, and patterns of behaviour that determine the commitment to, and the style and proficiency of, and organisation's health and safety management", as the most explicit, outlining most of the assumed contents of safety culture.

During the 1980s, and even more intensively in the 1990s, the EU Member States, industry, environmental groups, NGOs (Non-Governmental Organisations) and academia worked more closely to develop regulations and risk assessments pertinent to chemical management. In addition, there were noticeable drivers that have caused these changes: the requirements of the regulations that have noticeably increased (REACH Directive contributed greatly), the growing interest in sustainable development around the world (including in the EU), and the increased public awareness of environmental risk (Kallenberg, 2009).

The increased awareness and attention to safety regulations were partly triggered by some well-known incidents of hazardous chemicals in products, for instance brominated flame retardants (BFRs) in several products such as electronics and textiles (Kallenberg, 2007), China-produced plastic toys that contain lead in dangerous levels, dioxin in animal feed and benzene in Perrier (Wiener, 2006), and phthalates in plastics (Wiener and Rogers, 2002). Those and many other unspecified cases, which have been covered extensively by the media, have been the topic of discussion in many forums, both formal and informal, and become the reason for the growing interest from the EU Member States and also the general public (Kallenberg, 2009).

Currently, there are tens of thousands of chemicals in the European market that have not been assessed and regulated. Continuous exposure to those chemicals is dangerous and can potentially be catastrophic to the health of both humans and the environment (Hansen et al., 2007).

2.3. Safety and sustainable production performance

Linking safety and sustainability is not a novel idea. There has been many research that suggested the importance of safety in supporting sustainable development. The earliest research that studied the connection might be McQuaid (2000), who argued that improving organisations' health and safety condition will increase the achievement of sustainable development. Meshkati (2007) reviewed the Chernobyl accident and concluded that to ensure a sustainable energy system, an organisation's safety culture needs to be regarded as the most important. Kishimoto (2013) voiced concern regarding new unknown risk. Noticing that the latest development to achieve sustainability may bring regarding new unknown risk, Kishimoto (2013) suggested developing a new framework for risk assessment that can be used for creating sustainability-related designs. Nawaz et al. (2019) also argued that safety and sustainability are closely linked. Furthermore, safety can offer operationalisation for sustainability, since both fields share the same pillars (i.e., economy, environment and society).

Although many have studied the relationship between safety and sustainability, those studies discussed only the broad topic of safety and sustainability. Studies that focused on more specific topic such as sustainable production performance are still lacking. Furthermore, how exactly safety can influence sustainability still remain untouched. A study that uncovers the mechanism of the relationship between those two fields is needed.

3. Research method

To understand the status of safety and its correlation with sustainable production performance in the chemical industry within the literature, this study carried out a systematic literature review (SLR) in line with the same methods as Tranfield et al. (2003). There are other literature review methods such as semi-systematic review (which is considered suitable for research with broader topic within a diverse discipline that use a broad research question) and integrative review (suited for study aiming to combine different perspectives). However, SLR is deemed more suited for this study, which has specific research question and aims at synthesizing the collection of studies (Snyder, 2019). The SLR has several advantages, such as the ability to deliver rigorous and transparent process, cover studies that are relevant and have explanatory findings, and produce empirical output that potentially could lead to the next improvement in research (Denyer and Tranfield, 2009). These advantages differentiate SLR from other literature review methods, which frequently lack rigour and audit trails, resulting in biased results.

3.1. Data collection

Even though the safety of each individual is very important, the focus of this study is safety at an organisational level, while primarily discussing safety issues in the system, or in the management system, either in the design or at an operational level. The last criterion is that articles selected were required to explicitly or implicitly discuss the correlation between safety and sustainable production performance within the scope of the chemical industry.

Five research databases – EBSCO Academic Complete, EBSCO Business Complete, EBSCO GreenFile, ABI/Inform and Scopus – were used to collect relevant articles and to ensure that all related papers were included and accommodated the interdisciplinary view of the subject under review. Search strings (SS - a combination of keywords) were created for each online database to retrieve as many publications as possible related to safety, sustainable production, and the chemical industry (see Table 1). During the search process, the publication dates were limited to until 2020, while there was no limitation for the earlier publication date in order to capture all relevant articles.

The search for relevant articles was limited to articles that were peer-reviewed, published in academic journals and the full text written in English. However, articles whose abstracts are written in English but not the full text, were not included.

Having retrieved the meta-data from publication databases, the title, abstract and full text of the articles were then screened manually using two sets of assessment criteria (Denyer and Tranfield, 2009). The assessment criteria are shown in Table 2. Articles that met all the criteria are included in this study.

3.2. Data analysis

After applying the inclusion and consistency evaluation criteria, 1991 titles and abstracts were retrieved, and 374 duplicates were removed. For the remaining 1617 articles, the title and abstract screening was then carried out, resulting in 111 articles ready for full-text screening. The full text screening resulted in 62 articles (Fig. 1), which were then exported to NVivo 12 for content analysis.

Each article was read in detail, and first-order coding was

Table 1
Search strings used in the study.

Code used	Formula used in this study for search strings
SS-1	"Safe*" OR "accident" OR "error" OR "incident" OR "near miss"
SS-2	"Sustainable product*" OR "sustainable manufactur*" OR "sustainable design" OR "non-polluting product*" OR "non-polluting manufactur*" OR "green design" OR "green product*" OR "green manufactur*" OR "sustainab*"
SS-3	"Chemical industr*" OR "chemical plant*" OR "process industr*" OR "process plant*" OR "process manufactur*" OR "chemical manufactur*" OR "petrochemical"
SS	SS-1 AND SS-2 AND SS-3

Table 2
Screening criteria used to select papers.

Title and abstract assessment criteria	Full text assessment criteria
• Peer-reviewed article only. • Only articles written in English. • The purpose of the article, the finding, and/or the implication is about safety and/or sustainable production performance. • The context of the article is the chemical industry.	• The focus of the article is safety and its correlation with sustainable production performance (failure, error, accident, etc. that can have negative effect/impact on the health/well-being of both humans and the environment). • The article concerns safety at an organisational level, regardless of its size, and not at the individual level. • The context of the article is the chemical industry, i.e. addressing a safety issue that is within the scope of the chemical industry.

established. Referring to the research questions, relevant data were then extracted through the coding process. To capture and extract the relevant data in the articles, an *a priori* set of codes was developed. These 62 articles are published in 39 peer-reviewed academic journals across a number of disciplines, covering a range of research methodological approaches that passed this quality assessment. See Appendix for the full list of articles being reviewed.

The coded articles were then analysed using the template analysis technique (Brooks and King, 2014). This technique has been proved effective to analyse textual data thematically and allowed a flexibility in structuring the themes. This will subsequently assist the extraction of the relevant information. The codes can evolve due to the newly found codes, or as a result of deleting or merging existing codes throughout the process of theme formation.

3.3. Synthesis

Once the articles had been coded, the next step was to analyse the emerging themes as the basis of the synthesis of the research propositions. The first order coding process then commenced to allow the collection of detailed information on explicit and/or implicit primary dimensions of safety performance, secondary dimensions, antecedents, consequences, moderating dimensions, mediating dimensions, underlying mechanisms of safety performance, and sustainable production performance. This terminology, henceforth referred to as relationship mechanisms, reflects the different ways safety performance is positioned amongst other distinctly defined constructs or variables in the literature.

Primary dimensions apply to the main constructs or variables, while in the reviewed literature, secondary dimensions or sub-dimensions represent supporting constructs or variables studied. Secondary dimensions can also represent objects of measurement used to describe primary dimensions. The definition of primary and secondary dimensions is adapted from Watts et al. (1993), as quoted in D'Souza and Williams (2000), in line with Podsakoff et al. (2006), who use the term 'dimensions' with their specific measures or variables to cover various facets of constructs. This paper adapts the definition of a construct as "a broad mental configuration of a given phenomenon" by Bacharach (1989), while a variable is "an operational configuration derived from a construct". Performance, for example, is a construct, while a variable representing performance is product safety or quality. Therefore, a variable is the more concrete manifestation of a construct (Bacharach, 1989).

In this study, the antecedents refer to primary dimension interventions, drivers, or determinants; they are constructs or variables that trigger primary dimension existence. The consequences are the implications or results of primary dimensions. The relationship between primary dimensions and consequences is strengthened or weakened by moderating dimensions, while mediating dimensions function as a

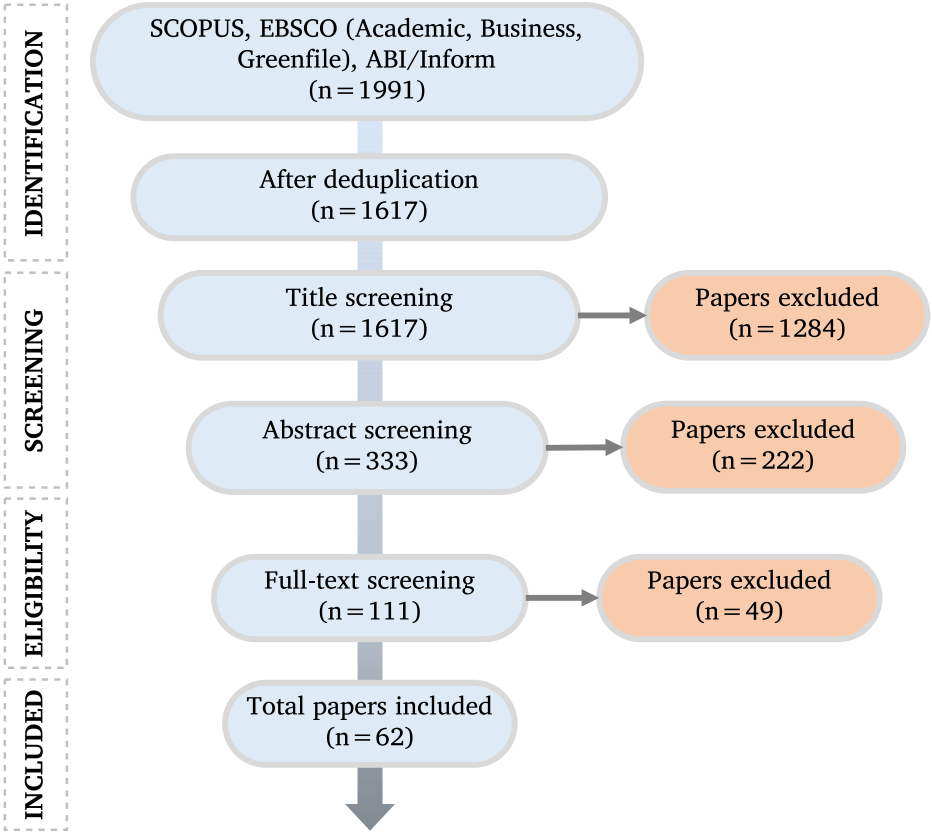


Fig. 1. Article screening (based on the PRISMA flow diagram (Liberati et al., 2009)).

bridge in this relationship. The relationship between primary dimensions and implications cannot occur when mediating dimensions are taken away. Finally, underlying safety performance mechanisms apply to mechanisms that generate the outcomes of safety performance and describe how safety performance influences the outcomes. The notion of underlying mechanisms differs from mediating dimensions as they are not the constructs or variables, but factors that make up the relationship between constructs or variables.

4. Findings

4.1. Bibliometric analysis

A bibliometric analysis was first conducted on the 62 articles being reviewed to understand the different topics and trends emerging in the areas of safety and sustainable production from 1995 to 2020. The keywords of these articles were uploaded to VOSviewer (version 1.6.16), a software tool for visualising bibliometric networks. The construction of the networks was carried out using keyword co-occurrence, and the "total link strength attribute" was applied as the weight attribute. Since the themes of this research (safety and sustainability) cut across multiple disciplines, the use of keyword co-occurrence is deemed more suitable for analysis (Gaviria-Marin et al., 2019). The co-occurrence of keywords analysis enables us to quantify and visualise the thematic network underlying this research (Liao et al., 2018). Articles whose keywords occurred more than four times were then included in the analysis. Of the total 698 keywords in the articles, 23 met the threshold. The size of the nodes indicates the frequency of occurrence, and the arcs between the nodes show their co-occurrence within the same articles.

As shown in Fig. 2, three clusters emerged on the map: sustainable development (red cluster), processes that support accident prevention (green cluster) and the chemical industry (blue cluster). The red cluster mainly considers the environmental sustainability issues in the pertinent industry sector. The green cluster represents the effort in ensuring the safety procedures are being upheld including the risk assessment and the decision-making processes. Finally, the blue cluster provides an industrial context on which this research is focused.

4.2. Profiles of the articles

As can be seen in Fig. 3, the oldest article found, using the chosen criteria, was published in 1995, followed by one published in 2000. After 2007, in which the chosen criteria found three published articles, articles were found in every year. The highest number is recorded in 2019 with 11 articles, which highlights the significance and relevance of the topic under discussion. The overall increased trend shows that more and more people are concerned with the same issue and have shown an interest in the topic; 2019 being the peak, shows that the topic is very current and relevant to the latest developments.

Fig. 4 shows the number of articles grouped by contribution. Of the

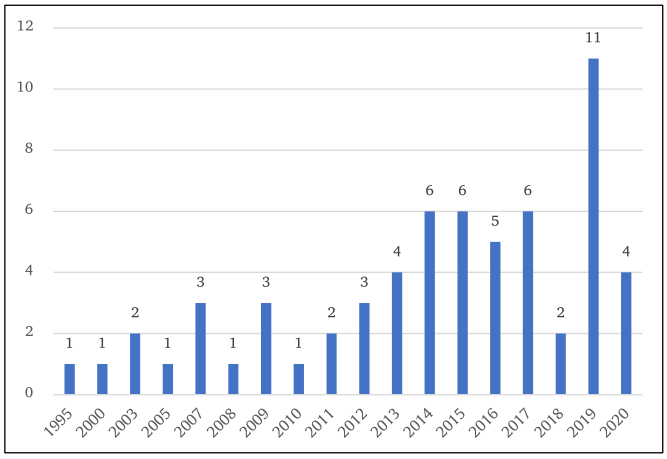


Fig. 3. Number of articles over the year.

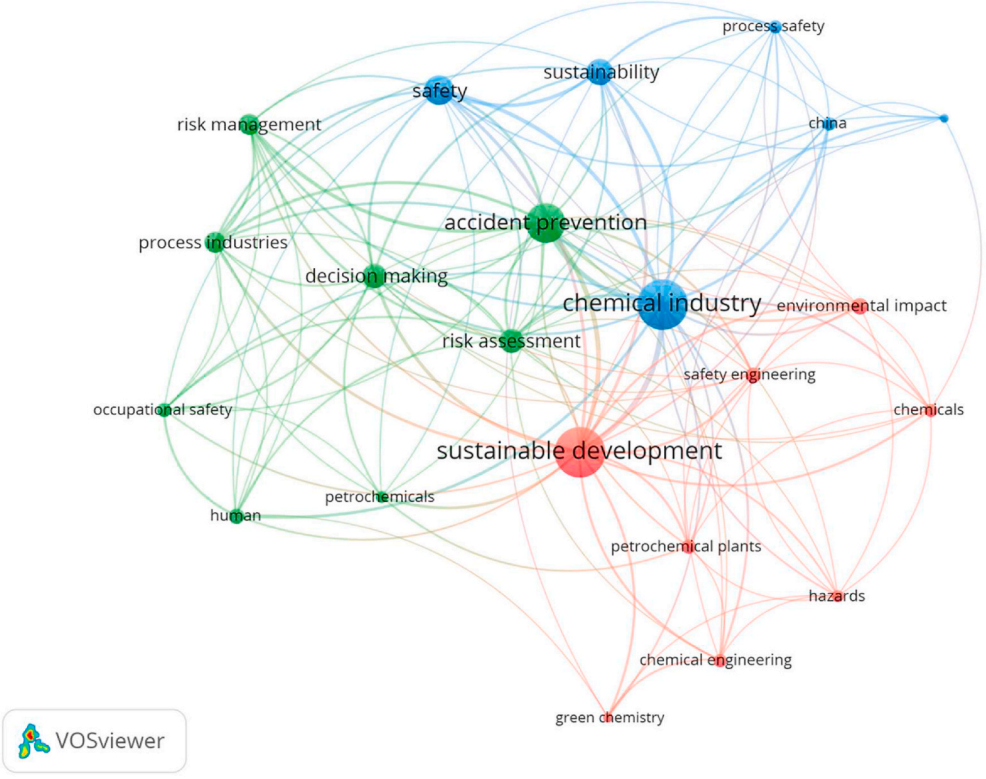


Fig. 2. Distribution of the keyword themes from the selected journal articles.

final 62 articles, 17 contributed to designing new tools/strategy/framework, making it the highest on the list. Process industries are considered as high risk. Accidents, minor or major, can occur in process industries due to many causes: either related to chemicals, operational issues, human error, or inadequate process design. Despite many efforts to decrease the number of accidents, it remains high and major industrial accidents usually result in a big loss of both property and lives. This situation is probably what has caused many scholars to design, develop, and propose new tools/strategy/framework. Looking further into the articles, one finding shows that the majority of articles showed concern for error/failure. Fig. 5 shows the number of articles grouped by concern for failure discussed in their study. Among the total 62 articles, only 15 do not show any concern towards error/failure, while the remainder are clearly concerned. Detecting possible failure in the current method/system is the most popular concern shown, having eight articles that discuss such concern.

One similarity shared by all articles is that they all make recommendations for improvement. Fig. 6 shows the number of articles grouped by type of recommendation for improvement. In the field of chemical engineering, process design is considered as a core element. Many have argued that process design is the centre point, which can bring all components of chemical engineering together. Therefore, many believe that the most effective way to eliminate or diminish the hazards to the lowest possible level is the design approach.

Fig. 7 shows the number of articles being reviewed grouped by the journal theme. The 62 journal titles are grouped into eight themes: Chemical Science/Engineering/Sustainability, Engineering, Environment, Safety and/or Health, Sustainability, Economics, Resources, and Policy. Of the eight themes, Safety and/or Health has the highest number of articles published (22 articles). Chemical Science/Engineering/Sustainability is the second highest, followed by Environment, Sustainability and Engineering.

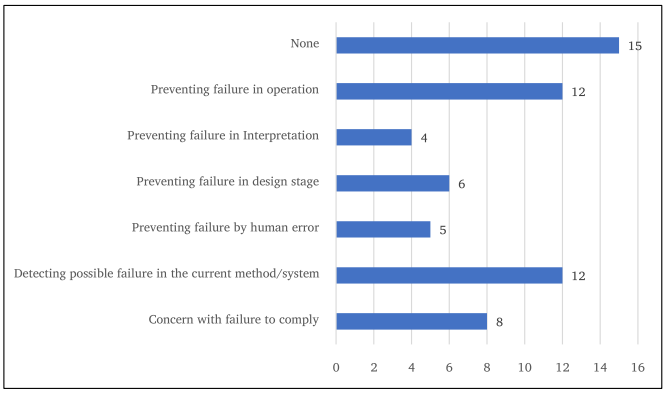


Fig. 5. Number of articles according to failure concern.

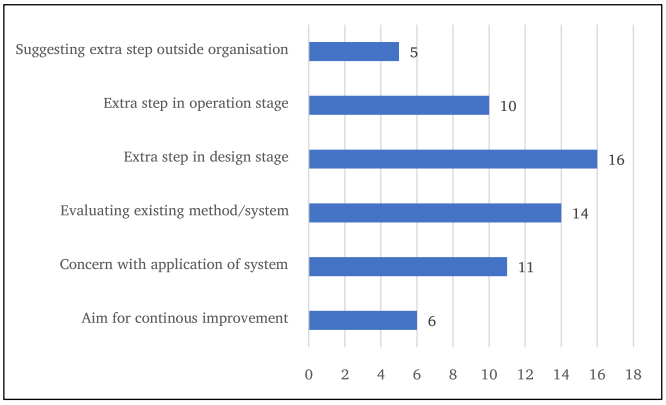


Fig. 6. Number of articles according to suggested improvement.

4.3. Safety performance and sustainable production performance

Safety is a relative concept that must be understood in the presence of hazard or risk. The concept of risk is related both to hazards created by humans and those created by nature; consequently, safety constitutes an ability to reduce or eliminate the likelihood of hazardous events occurring (Gobbo et al., 2018). In the context of the chemical industry, where the risk is high, both to humans and the environment, safety plays a very important role.

There are several ways to measure the level of safety in an organisation, or in other words, safety performance. Griffin and Neal (2000) summarised previous studies and reported their findings. The actual safety performance of individual at workplace can be defined by the components of performance. To distinguish safety performance at workplace there are two component that can be used: safety compliance and safety participation. The fundamental safety activities that must be done by each worker to maintain workplace safety are defined as safety compliance. While the voluntary activities that are related to safety are distinguished as safety participation.

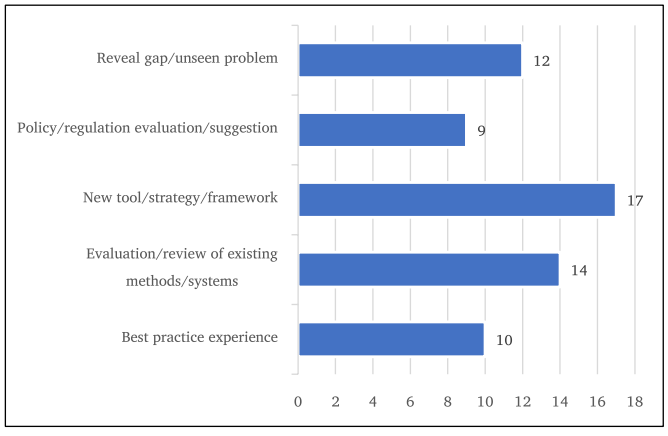


Fig. 4. Number of articles according to journal contribution.

There are several issues regarding safety performance in the chemical industry. One of the issues is the human factor, which is an essential for safety. As Sikorova et al. (2017) aptly summarised, the majority of accidents involving runaway reactions in the process industry are associated with the failure of controls and safeguards, or with human error. Akyuz and Celik (2015) also studied how to minimise human error in liquefied petroleum gas (LPG) storage and handling processes. Chidambaram (2016) highlighted how significant human and organisational factors are involved in accidents in all sectors of industry. An accident study in the Greek Petrochemical Industry from 1997 to 2003 showed that 73% of the accident causes were related to human factors (46%) and organisational factors (37%). A close study of incidents in Korea between 1988 and 1997 showed that most accidents (46%) occurred mainly due to operational failures, which were rooted in human factors, including lack of maintenance and lack of a culture of safety-consciousness. These statistics illustrate how significant the human safety factor is.

Another issue is how many companies in chemical industry mainly only consider safety aspect at the later/final stages. However, the cost of process improvement and operational risks can be significantly reduced if safety aspect is considered at the preliminary stage compared to the later stage. Thus, the safety aspect should be reviewed on the earlier stage, as also stated in Teh et al. (2019). Brzezińska et al. (2019) shared the same concern, noting that although fire can result from a growing range of threats, many fire strategies still do not include a proper hazard

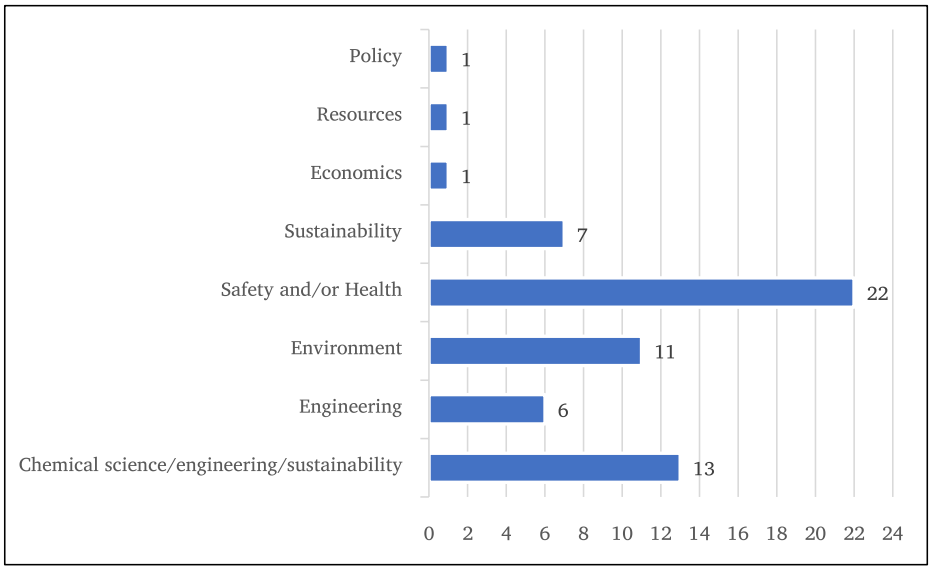


Fig. 7. Number of articles according to journal themes.

analysis in the early stages of the project. Chidambaram (2016) also noted the inclusion of design errors and that the contribution of process defects would produce a similar degree of contribution, as found in the incident review of the Greek petrochemical industry. Athar et al. (2019a) and Fernandez-Dacosta et al. (2019) also argued that industrial disaster can be avoided through sustainable process designing at the design stage, while Kallenberg (2009) summarised several cases that have highlighted the issue of how chemicals in products are potentially hazardous, as a result of ignoring safety at design stage.

Many research in the literature noted how poor safety performance results in low sustainable production performance. When companies have low safety compliance to environmental policies, industrial practices result in the production of vast amounts of waste, the misuse of natural resources and unnecessary energy use (Chris and Khaled, 2019; Marhavilas et al., 2020; Teh et al., 2019; Yang et al., 2020). This entails designing and implementing sustainability policies in the manufacturing sector (Abdul-Rashid et al., 2017). Shamim et al. (2019) added that the development of a safety performance index can achieve a sustainable chemical process.

Poor safety performance can have impact on sustainable production performance in wider scope. Trasande et al. (2011) noted that as chemicals have become widespread in the environment in industrialised countries, the prevalence and incidences of chronic health conditions have increased. One in six US children is now obese and 2–8% are now affected by developmental disabilities. Although scientific evidence to supplement the temporal association of increasing chemical exposures with obesity is lacking, the National Research Council has estimated that 28%t of developmental disabilities are due, at least in part, to environmental factors. Casson Moreno and Cozzani (2015) also reported several accidents, resulting in human, environmental and economic loss.

4.4. Chemical industry characteristics

The chemical industry has its own characteristics that are unique, compared to other industries. Several researchers have described these characteristics in their studies. Song et al. (2019) described the chemical industry as an high risk industry, uses high technology (Marhavilas et al., 2020), involves complex processes (Brzezińska et al., 2019) and capital-intensive (Teh et al., 2019). Additionally, it also has very strong connections to virtually every other sector of the economy (Lee et al., 2015; Pashapour et al., 2019; Tong et al., 2019, 2020). These characteristics require highly trained and skilled talent for the industry's operation (Lee et al., 2015). Reniers and Amyotte (2012) observed that if we examine the first few decades of the preceding century, the number of plants that handle hazardous chemicals in the world has increased significantly. This is a direct result of the variety of chemical products and processes that keep increasing. At the same time, due to increasing densities of population, those plants must be located closer to each other and consequently, closer to highly populated neighbourhoods.

4.5. The importance of safety culture

Hajmohammad and Vachon (2014) investigated the potential benefits of a strong safety culture for organisations. Their study concluded that a safety culture is linked to several indicators of organisational performance related to sustainable development. Guldenmund (2000) defined safety culture as follows: "those aspects of the organisational culture which will impact on attitudes and behaviour related to increasing or decreasing risk". Following his definition, the culture of an organisation plays an important role in determining the level of risk within that organisation. The absence of a safety culture will cause the level of risk to be high, and therefore it is more likely that its safety performance to be low.

McQuaid (2000) noted that making a company safe is all about order, control, and good behaviour. In recent years, many researchers have shared the same concern as McQuaid. Pasman et al. (2020) stressed the importance of safety culture and leadership in the process industry, highlighting that the lack of those factors can increase failure and reduce an organisation's resilience. Chen and Reniers (2020) also noted that lack of a safety culture and safety awareness of workers in Chinese chemical plants is the direct cause of accidents. Considering its importance, Amaya-Gómez et al. (2019) even added that every future process engineer needs to have safety culture "planted" in their education.

De Rademaeker et al. (2014) also supported this argument, stressing that safety culture is critical in reducing the numbers of accidents. Their study suggested that promoting safety culture in an organisation will help develop a critical thinking, prevent complacency in the workplace, aim for excellence and grow responsibility in safety matters. De Rademaeker et al. (2014) noted that a well-developed safety culture can give the organisation the right response to safety-related situations and an ability to act that has considered several perspectives.

Despite its importance, the level of safety culture in an organisation

is not easy to define. Safety culture is not easy to measure because it entails the assumptions and beliefs that are shared by every worker in the organisation. Sudarmo and Arifin (2018) proposed a tool to measure the level of safety culture in an organisation based on Loughborough University's Safety Climate Survey (Loughborough Safety Climate Assessment Toolkit - LSCAT). Their study suggested that important factors in measuring safety culture are management value, risk perception, safety system, work pressure, and competence level.

4.6. Answering the research questions

RQ1 in this study seeks to understand to what extent does safety impact the performance of sustainable production in chemical industry. In the previous section, it has been discussed how, in the context of the chemical industry, where the risk is high to both human life and the environment, safety plays a very important role. There is many research that highlight the importance of safety, and where safety is absent the consequences can be catastrophic, causing heavy loss of life, health, property, and the environment (Nawaz et al., 2019). For example, Sovacool et al. (2016) analysed accidents that occurred in the low-carbon energy sector from 1950 until 2014. They studied the literature and found that during that period, there were 686 accidents recorded. Those 686 accidents caused a staggering 182,794 fatalities and property damage losses as high as $265.1 billion. On average, each time an accident occurred in the low-carbon energy sector there would be 267 human lives lost and $389 million of property damage. Those numbers are definitely not small. No matter how good the sustainability performance in energy production, it can be argued that the loss caused by the accidents is offsetting the sustainability performance. The consequences of the absence of safety are not only felt by humans, but also the environment. Sikorova et al. (2017) noted that, aside from the impact on human health, the consequences of the most major accidents were also shown to have a significant impact on the environment, social well-being and also on the biotic components of the environment. In certain cases, surface water and groundwater pollution occur which could pollute drinking water supplies in the affected area.

RQ2 aims to understand the role of the chemical industry's characteristics in the relationship between safety and sustainable production performance. The unique characteristics of chemical industry have been discussed by many researches. Lee et al. (2015) described the chemical industry as an industry that uses high technology and is capital-intensive. Additionally, it also has very strong connections to virtually every other sector of the economy. Casson Moreno and Cozzani (2015) noted how, in the case of biomass, which is part of chemical industry, the more complex the processing, the more likely it is to cause more incidents or accidents with major consequences.

The discussion arising from RQ1 and RQ2 has resulted in several conclusions. First, in the context of the chemical industry, where the risk is high both to humans and the environment, safety plays a very important role (Amaya-Gómez et al., 2019; Chen and Reniers, 2020; Klein and Viard, 2013; Marhavilas et al., 2020; Song et al., 2019). Second, the unique characteristics of the chemical industry play a critical role in sustainability performance (Al-Sharrah et al., 2010; Chidambaram, 2016; Pasman et al., 2020; Sikorova et al., 2017; Srivastava and Gupta, 2010). However, despite the extensive discussion in the literature, accidents in the chemical industry are still considered high, resulting in the decrease in the sustainable production performance (Casson Moreno and Cozzani, 2015; De Rademaeker et al., 2014; Phimister et al., 2003; Reniers et al., 2005; Trasande et al., 2011).

Nonetheless, as safety and sustainability share the same pillars (economic, environmental, and social), it can be argued that there is a strong linkage between the safety performance and the sustainability performance. The mechanism of how safety performance influences sustainable production performance in the chemical industry will be discussed in the following section.

5. Discussion

5.1. Analysis and synthesis of the literature

In order to have an understanding about how safety performance influences sustainable production performance, this research examines how the safety-sustainability literature addresses safety performance. To make the relationship clearer, the relationship mechanism between safety performance and sustainable production performance, either stated explicitly or implicitly (Lusiantoro et al., 2018), is mapped and classified into Table 3. The columns in Table 3, categorise the relationship mechanism according to the positioning of the safety performance construct, either as antecedent, primary dimension, secondary dimension, moderating dimension, mediating dimension, or consequences, depending on how it influences sustainable production performance. The row shows how each literature described the relationship mechanism, either 'explicitly' or 'implicitly'. Thus, the first row mens "*safety performance as the explicit antecedent*" and the second, "*safety performance as the implicit antecedent*", and so on. The words/phrases in each cell are the terms used by the literature to describe safety performance and sustainable production performance and the number in bracket shows how many times a particular term appears in different articles.

For example, row 3 of Table 3 shows that this research identifies a correlation between safety performance and sustainable production performance as a primary dimension, and the literature addressed this explicitly (Akyuz and Celik, 2015). Through safety compliance, safety performance directly influences workers' health and safety (Champion et al., 2017); therefore, safety performance is a primary dimension of sustainable production performance. Row 3 of Table 3 further identifies that safety compliance can lead to a better natural environment and use of resources (Jacobs et al., 2016); therefore, better sustainable production performance is a consequence of safety compliance.

Another example in row 3 is that this study identifies safety performance as a primary dimension, affecting the clean environment as a consequence, and this is also stated explicitly in the literature (Raksanam et al., 2012). This row shows that the lower the chemical consumption, the stronger the impact of safety performance on the clean environment; therefore, chemical consumption is considered as a moderating variable (Raksanam et al., 2012).

This study further identifies, in row 7, that the relationship between safety performance and sustainable production is indirect and only exists when the improvement of technology influences the efficiency of resource consumption (e.g. amplifying the extent of technology improvement can influence sustainable production) (Accardi et al., 2013). This example shows that safety performance is a mediating variable. The method of categorising the positioning of the safety performance construct is really helpful in order to have a better understanding regarding the safety-sustainability literature, and how the literature indicates how safety performance affects sustainable production performance.

5.2. Positioning of the safety performance constructs

Following Table 3, a summary of articles and their author(s) that position safety performance amongst other constructs in the safety-sustainable production performance literature, either explicitly or implicitly, is given in Table 4. From Table 4, it can be concluded that safety performance is positioned as either a primary or secondary dimension by an overwhelming majority. As shown in Table 3, as a primary dimension, safety performance can improve economic performance, health, safety and environmental impact (Teh et al., 2019). The relationship between safety performance as a primary dimension and sustainable production performance as the consequence is mediated by consumption or usage of hazardous chemicals (Raksanam et al., 2012). The relationship is also moderated by hazardous process, level of

Table 3
Positioning safety-sustainable production performance constructs and variables.

Ex/Implicitly mentioned in the literature	Antecedents (number of articles)	Primary dimensions (number of articles)	Secondary dimensions (number of articles)	Moderating dimensions (number of articles)	Mediating dimensions (number of articles)	Underlying Mechanism (number of articles)	Consequences (number of articles)	Sustainable production performance (number of articles)
Explicit	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Implicit	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Explicit	Safety culture (3), safety system (4), management commitment (3), risk perception (1)	Safe handling and storage (1), accident rate (4), safety performance (7), safe design (4), safe chemicals (2), risk control (1), risk awareness (1), risk management (3), major accident (6), process safety (1)	Assessment method (1), chemical exposure (1)		Industry characteristics (6), management commitment (2), hazard identification (2), development stage (1), hazardous materials (3), technology (2), occupational risk (6), high consumption (1), accident prevention (2), hazardous process (3), supplier selection (1)	Human factors (2), sustainability assessment (1), risk assessment (3), fire strategy (1)	Sustainable transportation (1), sustainable production (13), sustainable development (9), green production (1), economic value (2), clean environment (1), major accident (1), economic resilience (1)	Accident rate (5), workers' safety and health (10), waste production (3), economic value (11)
Explicit		Sustainable production (1), sustainable policy (1), technology (1), sustainable indicators (3), innovation (1), chemical usage (1), green chemistry (1)	Safety performance (9)		Industry characteristics (3), company participation (1), waste production (1), occupational risk (1)	Operation strategy (1)	Economic value (1), sustainable production (2), sustainable development (6)	Economic viability (6), social performance (2)
Implicit	Sustainable awareness (1)	Sustainable funding (1), green chemistry (1), chemical usage (2), sustainable policy (1), sustainable design (1), sustainable assessment (1)	Safety performance (7)		Sustainable policy (1), chemical usage (1), environmental business market (1)	Production cost (1), chemical management (1), safe design (1), factors trade-off (1), closed life cycle (1), green metric (1)	Sustainable development (2), sustainable production (2), children's health (1), waste production (2)	Clean environment (6), economic viability (1)
Explicit	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ex/Implicitly mentioned in the literature	Antecedents (number of articles)	Primary dimensions (number of articles)	Secondary dimensions (number of articles)	Moderating dimensions (number of articles)	Mediating dimensions (number of articles)	Underlying Mechanism (number of articles)	Consequences (number of articles)	Sustainable production performance (number of articles)
Explicit		Technology (2), innovation (1), process industry (1)			Risk assessment (1), safety performance (3)		Sustainable production (3), economic value (1)	Clean environment (1), high consumption (1), economic viability (2)
Implicit		Hazardous process (1)			risk assessment (1)		Sustainable production (1)	Economic viability (1)
Explicit		Risk assessment (1)			Industry characteristics (1)		Safety performance (1)	Accident rate (1)
Implicit	Awareness (1)	Sustainability policy (1)			Law requirements (1)	Political support (1)	Chemical risk management (1)	

Table 4
Respective authors of safety – sustainable production performance relationship.

Safety – sustainable production performance relationship	Number of articles	Authors
Safety performance as explicit antecedent	N/A	N/A
Safety performance as implicit antecedent	N/A	N/A
Safety performance as explicit primary dimensions	28	(Barghava and Welford, 1995); (McQuaid, 2000); (Phimister et al., 2003); (García-Serna et al., 2007); (Wilding and Lewis, 2007); (Narayan, 2012); (Raksanam et al., 2012); (Reniers and Amyotte, 2012); (Klein and Viard, 2013); (De Rademaeker et al., 2014); (Akyuz and Celik, 2015); (Remoundou et al., 2015); (Chidambaram, 2016); (Ghasemi and Nadiri, 2016); (Jacobs et al., 2016); (Champion et al., 2017); (Teh et al., 2019); (Brzezińska et al., 2019); (Athar et al., 2019a); (Athar et al., 2019b); (Fernandez-Dacosta et al., 2019); (Shamim et al., 2019); (Song et al., 2019); (Chen et al., 2019); (Tong et al., 2019); (Pashapour et al., 2019); (Chen and Reniers, 2020); (Yang et al., 2020)
Safety performance as implicit primary dimensions	8	(Hansen et al., 2007); (Goossens et al., 2008); (Xie et al., 2010); (Liew et al., 2014); (Casson Moreno and Cozzani, 2015); (Kim et al., 2017); (Sikorova et al., 2017); (Amaya-Gómez et al., 2019)
Safety performance as explicit secondary dimensions	12	(Kidwai and Mohan, 2005); (Lange, 2009); (Al-Sharrah et al., 2010); (Tan et al., 2015); (Husgafvel et al., 2015); (Lee et al., 2015); (Choy et al., 2016); (Blum et al., 2017); (Iles et al., 2017); (Chris and Khaled, 2019); (Tong et al., 2020); (Marhavilas et al., 2020)
Safety performance as implicit secondary dimensions	7	(Fiorini and Vasile, 2011); (Trasande et al., 2011); (Fujii and Managi, 2012); (Phan et al., 2012); (Holt et al., 2016); (Dunjó et al., 2019); (Pasman et al., 2020)
Safety performance as explicit moderating dimensions	N/A	N/A
Safety performance as implicit moderating dimensions	N/A	N/A
Safety performance as explicit mediating dimensions	4	(Srivastava and Gupta, 2010); (González-Moreno et al., 2013); (Accardi et al., 2013); (Iavicoli et al., 2017)
Safety performance as implicit mediating dimensions	1	Mohsin et al. (2019)
Safety performance as explicit consequences	1	Reniers et al. (2005)
Safety performance as implicit consequences	1	Kallenberg (2009)

technology, and occupational risk. The benefits of safety performance are highest when hazardous chemical usage is low, production process is less hazardous, and the level of technology is high.

As a primary dimension, safety performance is driven by other constructs including a safety system and management commitment as its antecedents. A good safety system in an organisation can improve safety culture and therefore safety performance, thus increasing the value of the safety performance (Athar et al., 2019a). Low levels of management commitment decrease the safety culture, and therefore safety performance (Wilding and Lewis, 2007). This argument implies that once safety culture is established, safety performance will then occur.

5.3. Classification of constructs and variables

Following the previous step, the constructs and variables of safety-sustainable production performance identified in Table 3 were further classified into higher level themes (see Table 5). This is done in order to have the patterns and relationships amongst constructs and variables that explain how safety performance affecting sustainable production performance is characterised. In line with Griffin and Neal (2000), this research classified management value, safety system, risk perception, work pressure and competence as safety culture. All constructs and variables related to knowledge and skill motivation were classified as determinants of that safety culture.

This research classified constructs and variables, such as energy and material used, natural environment, workers' health and safety, economic viability and community development, under sustainable production performance, whereas hazardous material, hazardous process, high risk, high resource consumption and waste production are classified as chemical industry characteristics. In line with Veleva and

Table 5
Classification of Safety-Sustainable Production Performance constructs and variables.

Central Themes	Categories	Constructs and Variables
Safety Culture	Management Value	Management commitment, organisational improvement, management priority
	Safety System	Safety system, system safety, safety management
	Risk Perception	Risk perception, self-protection, risk awareness
	Work Pressure	Work pressure, stressful environment
	Competence	Competence, worker's ability
Safety Performance	Safety Compliance	Safe handling and storage, accident rate, safety performance, safe design, safe chemicals, major accident, process safety, risk assessment
	Safety Participation	Precautionary principles, health and safety, chemical management, risk control, risk awareness, risk management
Sustainable Production Performance	Energy and Material Used	Sustainable transportation, sustainable production, sustainable development
	Natural Environment	Green production, clean environment, waste production
	Workers' Health and Safety	Major accident, accident rate, workers' safety and health
	Economic Viability	Economic resilience, economic value
	Community Development	Collective action, welfare improvement
Chemical Industry Characteristics	Hazardous Material	Industry characteristics, management commitment, hazardous materials, technology, supplier selection
	Hazardous Process	Hazard identification, development stage, hazardous process
	High Risk	Occupational risk, accident prevention
	High Resource Consumption	Resource consumption, energy consumption
	Waste Production	High emission, hazardous waste

Ellenbecker (2001), these categories were further classified as indicators of sustainable production. Afterwards, all constructs and variables in relation to safety compliance and safety participation were classified as safety performance, in accordance with Griffin and Neal (2000). Having determined all the categories, constructs and variables of safety-sustainable production performance identified in Table 3 were then grouped according to their similarities, and were subsequently put in the respective columns.

5.4. Development of the theoretical framework

The purpose of Table 3 is to show how the positioning of the safety performance construct, either as antecedent, primary dimension, secondary dimension, moderating dimension, mediating dimension, or consequences, depending on how it influences sustainable production performance, can give a clearer picture regarding the difference in relationship mechanisms. By understanding the relationship between safety performance and sustainable production performance, followed by grouping these relationships, the influence of safety performance to sustainable production performance can be understood.

Safety culture has been determined as the antecedent of safety performance in the literature. Champion et al. (2017) argued that the key to success for the Dow Chemical Company in reducing its accident rate between 2013 and 2015 was built on a strong foundation of safety culture and leadership. A strong management system and constant devotion to process safety at all levels of the organisation are necessary to drive the reduction of process safety incidents. Athar et al. (2019a) found that managerial aspects are considered key contributors to accidents. Similarly, McQuaid (2000) argued that the emphasis placed on senior management involvement may result in the ownership of health and safety being removed from the shop floor. For this reason, we postulate our first proposition that,

Proposition 1. *Safety culture is the antecedent of safety performance. The higher the safety culture, the higher the safety performance will be.*

Studies in the literature have shown that a characteristic of the chemical industry is mediating the relationship between safety culture and safety performance. In a very sensitive and complex work environment, such as LPG tanker operations, the risk to safety for workers, facilities, and the environment will become even higher (Akyuz and Celik, 2015). There is no doubt that if there were any operational failure during critical processes (i.e. cargo loading), it would lead to a catastrophic accident such as a massive explosion. Athar et al. (2019b) noted that chemical process manufacturing is associated with risks that cannot be eliminated. This condition requires a better safety process strategy in order to prevent accidents, which can be catastrophic when they happen in the chemical industry. This is postulated by the following proposition:

Proposition 2. *Chemical industry characteristics moderate the relationship between safety culture and safety performance. The harsher the characteristics of the chemical industry, the weaker the influence of safety culture on safety performance will be.*

Many have argued that safety performance is the primary dimension in influencing safety production performance. Choy et al. (2016) argued that safety is a critical issue for sustainable consumption and production. Casson Moreno and Cozzani (2015) carried out a survey of major accidents related to the production of bioenergy (intended as biomass, bioliquids/biofuels and biogas) based on past accident reports available in the open literature and in specific databases, and built a data repository. Data analysis shows that major accidents have increased in recent years and their number keeps on growing, resulting in relevant human, environmental and economic losses. Kim et al. (2017) particularly noted that proper assessment and management of hydrogen fluoride is essential for a safe and sustainable chemical industry.

Griffin and Neal (2000) described safety compliance and safety participation as indicators for safety performance. González-Moreno et al. (2013) described how a more efficient and responsible use of natural resources, including energy, is an important factor in increasing sustainable production performance. Their study involved a sample of 544 companies in the Spanish chemical industry and concluded that safety compliance and participation are needed to achieve their goals.

Proposition 3. Safety performance directly influences sustainable production performance. The higher the safety performance, the higher the sustainable production performance will be.

Griffin and Neal (2000) proposed that safety culture is the antecedent of safety performance, with management value being one of the indicators of a safety culture. Mearns et al. (2003) added risk perception and safety system as two other indicators. Klein and Viard (2013) stressed leader and management commitment as an important factor for successful process safety performance. Industrial regulation and standard compliance cannot be achieved without strong commitment from top level management. Barghava and Welford (1995) noted how the failure of the safety system was the main cause for the catastrophic incident at Bhopal. Additionally, Remoundou et al. (2015) described how the risk perception of operators, workers, residents and bystanders potentially influences the extent to which different stakeholders adopt self-protective behaviour.

Proposition 4. *Management value, risk perception, and safety systems are the antecedents of safety compliance.*

Guldenmund (2000) proposed work pressure and competence as other indicators of a safety culture. Xie et al. (2010) noted that the characteristics of the coal chemical industry, i.e. labour intensive, harsh environment and intensive material handling, has increased the work pressure for their workers, which in turn has influenced the safety culture within the industry. Xie et al. (2010) also noted that new coal-based chemical technologies such as coal liquefaction, coal gasification, coal-to-methanol including its derived products, and co-production based on the coal chemical industry were carried out rapidly in China. This situation requires high competence from their workers.

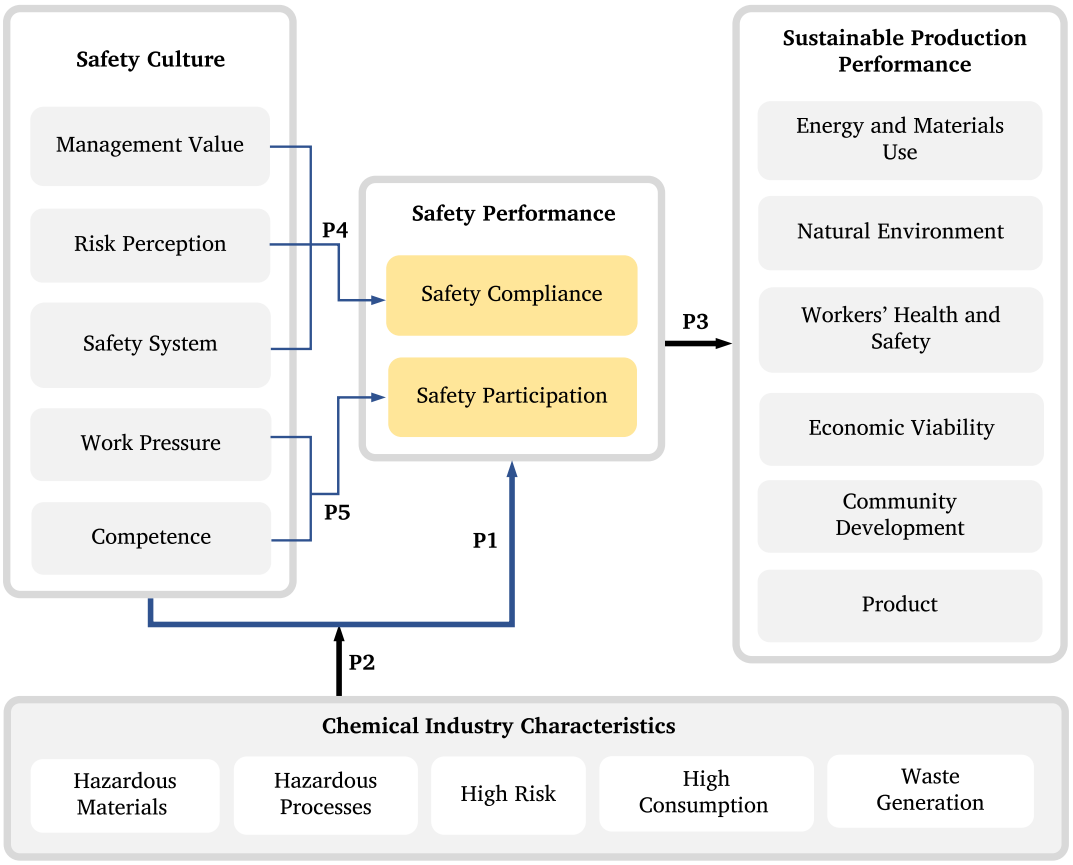
Proposition 5. *Work pressure and competence are the antecedents of safety participation.*

The discussion above has allowed this study to recognise and become familiar with how the variables interact with each other. Finally, based on the propositions above, it enables the construction of an initial theoretical framework which formalises the relationship between safety and sustainable production performance in the chemical industry, as shown in Fig. 8.

6. Conclusions

The first research question (RQ1) in this study aims to understand how safety can influence sustainable production performance in the chemical industry. Previous sections have indicated that in the context of the chemical industry, where the risk is high both to humans and the environment, safety plays a very important role. Not only can improving safety performance keep both humans and the environment safe, but it can also improve sustainable production performance at the same time, producing two-pronged benefits.

The second research question (RQ2) then investigates in the depth the extent to which the chemical industry's characteristics affect the relationship between safety and sustainable production performance. The chemical industry has several inherent characteristics that are unique, compared to other industries. Since the unique characteristics of the chemical industry make managing safety more challenging, and the absence of safety causes harm to sustainability performance, it can be concluded that those unique characteristics of the chemical industry play a critical role in sustainability performance, and improving safety performance will produce a double benefit: reducing the safety risks of the chemical industry, and improving sustainability performance at the



P1 – P5: Proposition 1 - Proposition 5

Fig. 8. Theoretical framework of Safety-Sustainable Production Performance.

same time. It is generally perceived that implementing sustainable manufacturing will improve environmental performance. Today, industrial performance metrics are shifting from economic-centric performance measures to those of sustainability. The term "sustainability" is defined as the expansion of the corporate perspective, which considers environmental, social, and economic aspects. Hence, to assess the performance of sustainable production, it is important to assess all three aspects instead of just economics, with higher emphasis being placed on the assessment of the safety aspect in the industry.

6.1. *Theoretical contributions*

This study offers a valuable contribution by showing the research gaps for further study in order to understand the relationship between safety and sustainable production performance in the chemical industry. There is a need to refine the relationship between those two, and there are two specific gaps that are identified in the literature. The first one remains unclear on how precisely safety can influence the sustainable production performance in the chemical industry. The second one is that there is inconsistency in the positioning of safety in supporting sustainable production performance in the chemical industry.

Another valuable contribution from this research is that it shows the relationship between safety and sustainable production performance in the chemical industry and uncovers the link between the two. The framework and proposition produced from this research will help in opening new possible paths for safety research. Other than the obvious benefit of safety, keeping humans and the environment safe, improving safety can also result in other advantages, with improving sustainability being one of them.

6.2. *Practical contributions*

Although the framework was developed using the context of the chemical industry, it is open to customisation for other industry sectors with similar characteristics, with some adjustments to the components of sustainable production performance. In our opinion, the framework could be deployed into a practical workbook consisting of self-assessment procedures, so that practitioners can further explore their capabilities, allowing a fuller understanding of how to increase their sustainable production performance, relevant to the specific application of this framework (possibly) beyond the chemical industry sector.

6.3. *Future work*

We are mindful that our work could generate different interpretations and opinions simply because of the way our framework is formulated. Nonetheless, we hope that this paper can stimulate a healthy discourse on the practical realities of sustainability performance in the chemical industry where safety, until now, remains a topical research concern.

There are several limitations in this study. First, this study is based on an SLR to unravel the relationships between safety and sustainable production performance, particularly in the chemical industry. Second, the initial framework was developed from an amalgamation of multiple theories, mainly from the perspectives of safety. As a further work, we will conduct an empirical study in the context of chemical industry to validate the proposed framework.

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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