TECHNOLOGY INFRASTRUCTURE, MANUFACTURING TECHNOLOGY AND SUSTAINABLE MANUFACTURING PRACTICE IN SMES

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ABSTRACT

Nowadays, sustainability practices in manufacturing are required for the business environment, especially for SMEs. In particular, technology capabilities are essential to enhance firms' capacity. This paper explores the relationship between technology infrastructure, manufacturing technology and sustainable manufacturing practice (SMP) in the context of SMEs. The data were collected through questionnaires using purposive sampling in Thailand, with completed 237 surveys being returned. We used structural equation modeling to test the research framework. The results reveal that the implementation of SMP in SMEs is still at a medium level, thus demonstrating that there is still substantial room for enhancement. Moreover, the findings show that technology infrastructure has an impact on SMP, while manufacturing technology also significantly mediates the relationship between technology infrastructure and SMP. These findings imply that SMEs in the manufacturing industry can develop technology capabilities as essential resources to gain higher SMP for sustainability in the competitive business environment and to accomplish the Sustainable Development Goals (SDGs).

***Keywords*:** Manufacturing Technology; Sustainable Manufacturing Practice; SMEs; Technology Infrastructure.

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1. INTRODUCTION

Small and medium enterprises (SMEs) are key drivers of economic development, accounting for 33% of GDP in emerging economies (Gherghina et al., 2020; Organisation for Economic Cooperation and Development, 2017; Prasetyo, 2019). These constitute over 90% of the total number of firms, with employment and production representing 60-70%, and 50% of the total, respectively (Urata, 2021). In Thailand, manufacturers in SMEs generate 31.1% of the total GDP contributed by SMEs. On the one hand, the manufacturing sector consumes a lot of energy and other resources, leading to environmental problems that hinder sustainable development (Kitisittichai, & Aruninta, 2015; Mittal & Sangwan, 2014). On the other hand, sustainability in manufacturing has been acknowledged by some firms, recognizing how this can deliver competitive advantage for their industry (Chege & Wang, 2020; Bazan et al., 2017; Millar & Russell, 2011). Market forces as well as social and environmental factors have also started to drive manufacturers to realize the importance of sustainability for their firms' continuous growth and expansion (Yuan et al., 2012; Seidel et al., 2007; Seidel et al., 2006). Thus, SMEs are required to manage sustainable development issues inevitably (Yacob et al., 2021).

Nevertheless, SMEs are lagging behind larger firms in their environmentally friendly behavior, being responsible for 70% of all industrial pollution (Masurel, 2007; Hillary, 1999) and they often fail to engage with sustainable development (Revell & Rutherfoord, 2003). In Thailand, a large number of SMEs realize that they are major sources of pollution. Due to the limitations of technology capabilities, it is difficult for Thai SMEs to deal with environmental pollution and natural resource inefficiencies (Jaroenroy and Chompunth, 2019). Moreover, the rapid growth in food industrial development has brought about Thailand's environmental issues through air and water pollution (Wattanapinyo and Mol, 2012). In particular, food business industries involve harmful environmental tasks at every stage of the operation, from upstream to downstream (Saenchaiyathon and Wongthongchai, 2021). Besides, the food industry is key importance as a major component in the SME industrialization of the Thai economy, the food sector represents as the best case, seen as vital for further development (Wattanapinyo & Mol, 2013; Siriphattrasophon, 2014).

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The lack of awareness regarding new technology and sustainability by SMEs has contributed to the problem of low productivity (Singh et al., 2014). Furthermore, the COVID-19 crisis has impacted many SMEs for business operation, struggling to remain sustainability due to resource constraints (Alraja et al., 2022; Baral et al., 2021). To address this, sustainable manufacturing practice (SMP) is increasingly being turned to for overhauling traditional practices and dealing with new regulations, in accordance with stakeholder demand (Singh et al., 2014; Despeisse et al., 2012). SMP involves an industrial activity that develops products for society's needs in relation to sustainability (Alayón et al., 2022) which responses to meet the Sustainable Development Goals (SDGs), adopted by all United Nations Member States in 2015 (Moldavska & Welo, 2017; United Nations, 2022). Business firms are integrating SMP into their core activities (Muangmee et al., 2021). SMP refers to the sustainability of human presence by balancing social, environmental and economic domain in such a way as to contribute positively to competitive advantage (Aboelmaged, 2018; Moktadir et al., 2018; Hartini & Ciptomulyono, 2015; Rusinko, 2007), which is in line with a natural-resource-based-view (NRBV), holding that environmentally sustainable economic activity can be a key source of competitive advantage (Hart, 1995). Sustainable manufacturing provides benefits, including cost reduction through natural resource efficiency and regulatory compliance improvement, that contribute to sustainable development (Machado et al., 2020). In order to manage sustainability, therefore, it is essential for SMEs to implement SMP as a significant part of the manufacturing sector (Hami et al., 2018).

However, there is still a gap in understanding in that SMP has not been explored in terms of the technology capability from an NRBV of the firm in enhancing sustainability. In particular, research on the technology aspects as substantial resources in SMEs and their influence on SMP has not received much attention. There is a lack of empirical evidence on what challenges SMEs face in the area of technology and how they should address these. The study by Ghobakhloo et al. (2022) revealed that the adoption rate of technologies among SMEs has been at a low level, lagging behind large enterprises. Besides, the implementation of manufacturing technology is significant for the food industry to gain benefits in terms of sustainability (Ng et al., 2022).

To address this gap, the aim of this study is to examine how technology capabilities relate to SMP in SMEs. This paper consists of four parts. The first contains a literature review and introduces the new research framework. Then, the research methodology is explained. The next part presents the findings from the empirical results based on statistical analysis. Finally, we provide discussion and conclusions, with theoretical and managerial implications.

2. LITERATURE REVIEW

2.1. Sustainable manufacturing practice for SMEs

Sustainable manufacturing is defined by the US Department of Commerce (The U.S. Department of Commerce, 2009) as 'the manufacturing processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities and consumers and are economically sound'. Initially, SMP begins with the treatment of pollution during the first stage of production (Ali & Suleiman, 2016; Organisation for Economic Cooperation and Development, 2009). SMP can enable manufacturing firms to achieve improved competitiveness in the business environment and gain an advantage from this approach (Vinodh & Joy, 2012; Pichagonakesit et al., 2019), relating to NRBV theory (Hart, 1995). It is quite a new approach that involves adopting innovative processes from a social environmental and economic perspective aimed at having no detrimental impact on natural resources (Ceptureanu et al., 2018). It has been adopted mainly by large enterprises, for example, Coca-Cola, Daimler, BMW, General Motors and General Electric (Singh et al., 2016), whereas its implementation by SMEs remains low, because they lack experience, knowledge, resources and expertise (Hami et al., 2018; Millar & Russell, 2011; Seidel et al., 2007; Seidel et al., 2006). SMEs have also failed to manage sustainable manufacturing practice due to low literacy and knowledge among management level (Yacob et al., 2021).

In addition, sustainable manufacturing practice relates to one of the SDGs, developed by the United Nations. This involves SDG 9, focusing on resilient infrastructure and sustainable industrialization (Moldavska & Welo, 2017; United Nations, 2022). Therefore, promoting sustainable manufacturing in Thailand is required by government agencies to achieve the sustainable management and efficient use of natural resources by 2030.

2.2. Technology infrastructure and SMP

Technology infrastructure refers to shared technology across the organization, involving ICT infrastructure, communication systems and tools, that can deliver the technology competency essential for implementing sustainability (Aboelmaged, 2018; Aboelmaged, 2014; Angeles, 2014). According to the SDGs, improving industry infrastructure is also critical to sustainability and resource efficiency (United Nations, 2022). Despite the recognition of the relationship between technology infrastructure and SMP in SMEs, these firms lack the required technology for delivering such practice. Notably, Hami et al. (2018) found that SMEs are not able to implement SMP due to a lack of technology capabilities (e.g. infrastructure, clen technology/equipment). However, such companies have been encouraged to explore new technology aimed at supporting sustainability (Millar & Russell, 2011; Korhonen, 2000). Alraja et al. (2022) found that technologies for SMEs are important factor for green practices that lead to sustainable performance. Manufacturing SMEs need technology infrastructure to adopt sustainable manufacturing practice (Alayón et al., 2022). However, in contrast another previous study by Ceptureanu et al. (2018) found that technology infrastructure has no impact on SMP in SMEs. Hence, we then develop Hypothesis 1 as follows:

H1*: Technology infrastructure has an impact on SMP.*

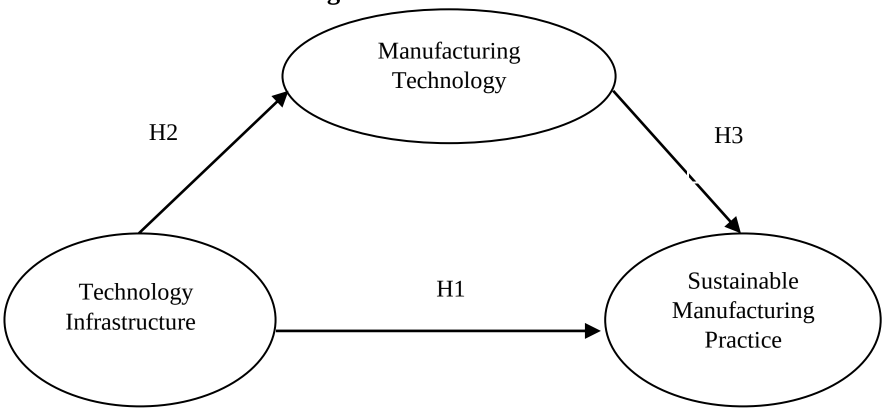
2.3. The role of manufacturing technology on the relationship between technology infrastructure and SMP

Manufacturing technology is considered as being important for supporting design, control, management and delivery, thereby delivery greater efficiency (Association for Manufacturing Technology, 2019; Adeyeri et al., 2019; Khanchanapong et al., 2014; Turban, 2008; Boyer et al., 1997). Technology infrastructure can support manufacturing technology in such matters as waste management/control, materials management, and energy consumption during manufacturing operations (Routroy & Kumar, 2016). For the agri-food industry, the implementation of manufacturing technology provides benefits through the use of modern tools and technology methods for sustainable manufacturing practice (Miranda et al., 2019). Ng et al. (2022) found that digital technologies in the application of Industry 4.0 are beneficial to sustainable manufacturing. With advanced manufacturing technologies, they are associated with Industry 4.0, linking to smart factories that can support sustainable manufacturing for industry development (Machado et al., 2020). Furthermore, green manufacturing technology is essential for implementing SMP (Sharma et al., 2017). In addition, SMEs need to invest in manufacturing technology to enhance the capacity and flexibility of manufacturing processes (Seidel et al., 2007). Based on the previous studies, Hypothesis 2 and Hypothesis 3 are presented as follows:

H2*: Technology infrastructure has an impact on manufacturing technology.*
H3*: Manufacturing technology has an impact on SMP.*

Based on hypothesis development, the research framework is shown in Figure 1.

Figure 1: Research framework



3. RESEARCH METHODOLOGY

3.1. Survey instrument

The questionnaire was developed by selecting survey items for each latent construct from previous validated measures. For our research framework, 12 survey items of technology infrastructure were adopted from surveys developed by Aboelmaged (2018), Aboelmaged (2014) and Angeles (2014). To measure the degree of technology manufacturing, we adopted eight survey items from Association for Manufacturing Technology (2019), Khanchanapong et al. (2014) and Turban (2008). We took 16 survey items regarding SMP from Ali and Suleiman (2016) and Organisation for Economic Cooperation and Development (2011). Then, the questionnaire was validated using the averaged-scores of the index of item-objective congruence (ICO) by three experts working in food manufacturing. After revision, the measurement items were those presented in Appendix 1.

The questionnaires used in this research contain three main parts. The first contains the respondents' profiles, whilst the second, relates to firm characteristics. The third part interrogates the degree to which technology infrastructure, technology manufacturing, and SMP are engaged with, respectively, through closed questions on a five-point Likert scale, ranging from the least agree (1) to the most agree (5).

3.2. Sample and data collection

This survey targeted manufacturing SMEs from food sector since they contributed the highest proportion of GDP value of SMEs in the manufacturing sector in 2018 (Office of SMEs Promotion, 2019). This research employed the purposive sampling method to select only samples that were capable of answering the question according to the objectives of this study (Campbell et al., 2020; Saunders et al., 2003). We asked the respondents to complete our questionnaire at a food exhibition arranged by the Office of SMEs Promotion. Among the total number of 320 SMEs, 237 valid responses were gathered (a 74.06% response rate). Information about the respondents' profiles and firm characteristics are presented in Table 1 and Table 2, respectively. 108 (45.57%) of the respondents from the food manufacturing SMEs were owners, followed by managers/supervisors at 26.16%. In terms of work experience, 50.63 % of the respondents had work experience of three years or less. In addition, 45.99% of sampled SMEs had between 15 and 30 employees and 50.63% had total fixed assets of less than 30 million baht.

Table 1: Respondents Profiles (n = 237)

	Number	Percentage
Current Job Position		
Owner	108	45.57%
Manager/Supervisor	62	26.16%
Asst. Manager	23	9.70%
Other	44	18.57%
Work experience		
Less than 1 year	2	0.84%
1-3 years	120	50.63%
4-6 years	71	29.96%
More than 6 years	44	18.57%

Table 2: Firm characteristics (n = 237)

Firm profile	Number	Percentage
Number of Employees (Persons)		
Less than 15	73	30.80%
15-30	109	45.99%
31-50	36	15.19%
51-200	19	8.02%
Amount of Fixed Assets (Baht)		
Less than 30 million	120	50.63%
30-50 million	105	44.30%
51-200 million	12	5.07%

3.3. Data analysis

Based on a research framework developed by authors since October, 2018, an empirical study was conducted to investigate the relationship between technology infrastructure, manufacturing technology, and SMP. We used partial least squares structural equation modelling (PLS-SEM) for the data analysis. The SmartPLS software was employed for the measurement and structural models.

4. RESULTS

4.1. Measurement model

In Table 3, the results indicate that the implementation of SMP by the focal SMEs is at medium level, with technology infrastructure and manufacturing technology also registering at that level. In addition, the analysis of PLS-SEM shows that Cronbach's alpha, composite reliability (CR) and the Dijkstra-Henseler rhoA coefficient for the constructs are not below 0.7, which means they acceptable. Moreover, the average variance extracted (AVE) value of each construct is higher than the critical level of 0.50, thus reporting that the convergent validity is acceptable. While the loading factor of each indicator has a value greater than 0.7, thus showing the construct reliability as being acceptable (Chin, 2010; Kock, 2013).

Regarding discriminant validity, the results in Table 4 show the square root of the AVE is higher than the correlation coefficient in the model. The Heterotrait-Monotrait Ratio (HTMT) of each construct ranges from 0.45 to 0.85, which relates to the threshold level (Hair Jr et al., 2016), thereby indicating the model possesses discriminant validity.

Table 3: Reliability assessment of the measurement model

Construct	Indicators (Appendix 1)	Factor loadings	AVE	Cronbach Alpha	Composite reliability (CR)	rhoA
Technology Infrastructure (TI)						
TI1			0.701	0.787	0.876	0.791
(Mean = 3.59;	TI1.1	0.820				
SD = 0.97)	TI1.2	0.867				

Construct	Indicators (Appendix 1)	Factor loadings	AVE	Cronbach Alpha	Composite reliability (CR)	rhoA
	TI1.3	0.824				
TI2 (Mean = 3.43; SD = 1.05)			0.620	0.846	0.891	0.848
	TI2.1	0.773				
	TI2.2	0.821				
	TI2.3	0.814				
	TI2.4	0.802				
	TI2.5	0.723				
TI3 (Mean = 3.51; SD = 1.06)			0.680	0.842	0.894	0.846
	TI3.1	0.775				
	TI3.2	0.806				
	TI3.3	0.864				
	TI3.4	0.850				
Manufacturing Technology (MT)						
MT1 (Mean = 3.43; SD = 1.01)			0.687	0.886	0.916	0.886
	MT1.1	0.828				
	MT1.2	0.860				
	MT1.3	0.860				
	MT1.4	0.836				
	MT1.5	0.767				
MT2 (Mean = 3.24; SD = 1.08)			0.772	0.852	0.910	0.856
	MT2.1	0.880				
	MT2.2	0.905				
	MT2.3	0.850				
MT3 (Mean = 3.35; SD = 1.06)			0.756	0.892	0.925	0.895
	MT3.1	0.871				
	MT3.2	0.879				
	MT3.3	0.907				
	MT3.4	0.819				
Sustainable Manufacturing Practice (SMP)						
SMP1 (Mean = 3.35; SD = 1.03)			0.693	0.852	0.900	0.854
	SMP1.1	0.780				
	SMP1.2	0.890				
	SMP1.3	0.847				
	SMP1.4	0.810				
SMP2 (Mean = 3.33; SD = 1.08)			0.676	0.839	0.893	0.844
	SMP2.1	0.841				
	SMP2.2	0.879				
	SMP2.3	0.808				
	SMP2.4	0.755				
SMP3 (Mean = 3.53; SD = 1.01)			0.728	0.876	0.915	0.876
	SMP3.1	0.846				
	SMP3.2	0.876				
	SMP3.3	0.865				
	SMP3.4	0.826				
SMP4 (Mean = 3.43; SD = 1.05)			0.755	0.891	0.925	0.892
	SMP4.1	0.890				
	SMP4.2	0.901				
	SMP4.3	0.850				
	SMP4.4	0.832				

Table 4: Discriminant validity

	1	2	3	4	5	6	7	8	9	10
1.MT1	*0.829*									
2.MT2	0.644	*0.879*								
3.MT3	0.657	0.602	*0.869*							
4.SMP1	0.602	0.536	0.691	*0.833*						
5.SMP2	0.470	0.411	0.593	0.686	*0.822*					
6.SMP3	0.536	0.392	0.577	0.652	0.695	*0.853*				
7.SMP4	0.537	0.485	0.617	0.652	0.568	0.679	*0.869*			
8.TI1	0.643	0.525	0.627	0.623	0.506	0.516	0.562	*0.837*		
9.TI2	0.647	0.610	0.640	0.672	0.556	0.493	0.615	0.688	*0.787*	

	1	2	3	4	5	6	7	8	9	10
10.TI3	0.644	0.586	0.641	0.638	0.554	0.501	0.538	0.650	0.727	*0.825*

SD = standard deviation; italicized values (diagonal elements) are the square root of the average variance extracted (AVE); off-diagonal elements are the correlations between the latent constructs.

4.2. Structural model

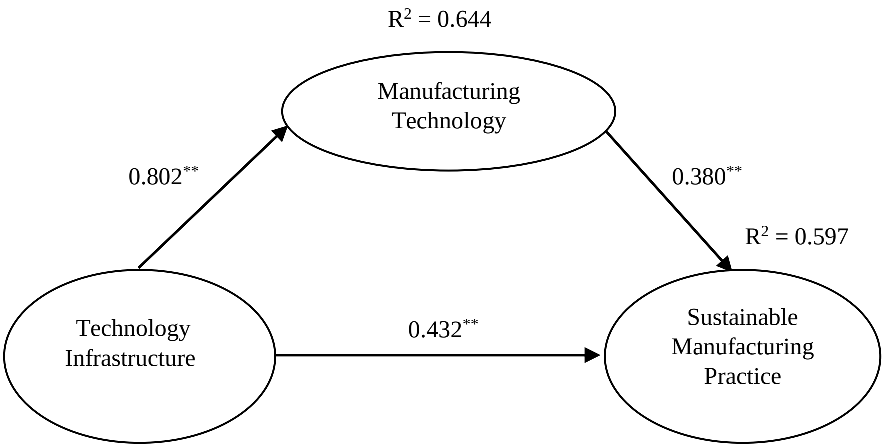
The structural model shows validity, as it can explain 59.7% of the variance in SMP and 64.4% of that in manufacturing technology. For the results of hypotheses testing, as presented in Table 5, the statistical analysis shows that technology infrastructure significantly influences SMP, thus supporting H1. Moreover, the manufacturing technology is a full mediator for the relationship between technology infrastructure and SMP, thereby supporting H2 and H3. Hence, the results of the structural model can be expressed as in Figure 2.

Table 5: Hypotheses Testing

Hypotheses	Paths	Standard Beta	*t*-statistics	f^2	Hypotheses
H1	TI -> SMP	0.432	24.227**	0.164	Supported
H2	TI -> MT	0.802	33.509**	1.807	Supported
H3	MT -> SMP	0.380	5.212**	0.126	Supported

* *p*-value < 0.05, ** *p*-value < 0.01; *TI* technology infrastructure, *MT* manufacturing technology, *SMP* sustainable manufacturing practice

Figure 2: Results of the structural model (** *p* value < 0.01)



5. CONCLUSIONS

In this paper, how technology capabilities can be enablers of SMP for SMEs has been explored. The results reveal that technology infrastructure can encourage the implementation of SMP, which is in accord with the findings of previous studies (Hami et al., 2018; Millar & Russell, 2011; Korhonen, 2000). However, the findings of this paper are different from those of a study by Ceptureanu et al. (2018), which focused on SMEs in the textile industry and found no relation between technology infrastructure and SMP. Moreover, it has emerged from the current study that manufacturing technology mediates the relationship between technology infrastructure and SMP. Thus, the findings can inspire SMEs in Thailand from the food sector to develop their technology capabilities in order to address environmental pollution. Furthermore, the related government agencies involved with environmental management can understand the importance of technology development, which influences Thai SMEs, for enhancing sustainability in the manufacturing sector. Government agencies can also support Thai SMEs in relation to technology development for more SMP, helping to achieve the SDGs by 2030.

For the theoretical contributions regarding NRBV, this study's findings strengthen the view that technology capabilities, including technology infrastructure and manufacturing technology, are the essential resources for supporting the sustainability of SMEs in the manufacturing sector when striving to gain competitive advantage.

Regarding some inherent limitations, there remain substantial gaps for managers/owners in SMEs for developing their technology infrastructure in the manufacturing SMEs. Also, this research has been undertaken using a sample from SMEs in one industry, i.e., food manufacturing. Consequently, more generally on SMEs in other manufacturing industries is required to see if the findings are generalizable. Besides, the analyses explored only technology capability enablers of SMP and hence, future studies should set out to ascertain whether and how other resources regarding NRBV can drive such practice.

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APPENDIX 1

ITEMS OF MEASURES

Technology Infrastructure (TI) *(Aboelmaged, 2018; Aboelmaged, 2014; Angeles, 2014).

ICT infrastructure (TI1)
TI1.1: Company has information communication technology system that is fast and systematic.
TI1.2: The company has a database inside that can help facilitate the work well.
TI1.3: The company has a plan for infrastructure technology in communication, which is systematic and connected.

Energy-saving equipment/tools (TI2)
TI2.1: The company has installed energy-saving equipment in production systems and offices.
TI2.2: The company has a policy to select energy-efficient equipment and appliances.
TI2.3: The company chooses to use equipment or tools to control and support production.
TI2.4: The company has installed equipment for resource management.
TI2.5: The company has installed equipment to help manage the logistics system.

Technology competency (TI3)
TI3.1: Within the company there is an IT support department.
TI3.2: When people and technology have similar performance at a high level, this can result in high sustainable technological competence.
TI3.3: Within the company, there is training and evaluation of employees' knowledge and abilities.
TI3.4: The company supports providing knowledge and technical skills regarding technology to employees.

Manufacturing Technology (MT) *(Association for Manufacturing Technology, 2019; Khanchanapong et al., 2014; Turban, 2008)

Production design technology (MT1)
MT1.1: The company uses technology to assist the design of the production process.
MT1.2: The company uses technology to help design products.
MT1.3: The company uses computer technology to help plan production systems.
MT1.4: The company uses technology to help apportion the proportion of resources appropriately.
MT1.5: The company uses technology to support the production line.

Controlling technology (MT2)
MT2.1: The company has installed an automated production technology system.
MT2.2: The company uses technology to increase the flexibility of its production lines.
MT2.3: There is a real-time control of the production system.

Administration technology (MT3)
M3.1: Technology is used to assist in management and administrative planning.
M3.2: There is internal and external communication for the organization.
M3.3: Technology is used to help plan critical resources of the company.
M3.4: Resource planning technology is used in the production process.

Sustainable Manufacturing Practice (SMP) *(Ali & Suleiman, 2016; Organisation for Economic Cooperation and Development, 2011)

Reduction of energy/resource consumption (SMP1)
SMP1.1: The company has a policy to reduce the use of energy and unnecessary resources.
SMP1.2: The company has designed products to reduce energy consumption and production resources.
SMP1.3: The company has installed equipment to reduce the consumption of resources and energy (water, electricity, main raw materials) in the production process.
SMP1.4: High-quality resources are used to reduce their consumption.

Improvement of the quality of used water (SMP2)
SMP2.1: The company has protection against contamination in the water.
SMP2.2: The company has improved the quality of the water.
SMP2.3: When water resources are used, they are released back to their original sources.
SMP2.4: The company has a wastewater treatment process.

Reduction of waste emissions (SMP3)
SMP3.1: The company has operated the waste system before it is released within the ecosystem.
SMP3.2: The company has a system for dealing with waste or hazardous chemicals.
SMP3.3: The company plans to reduce the amount of waste from the production system.
SMP3.4: The company has a policy to control or reduce the amount of waste.

Pollution prevention (SMP4)
SMP4.1: The production system within the company is planned to take into account pollution.
SMP4.2: The company has a policy or procedure to reduce the amount of pollution.
SMP4.3: The company has a process in the disposal of waste in the production process.

SMP4.4: The company uses raw materials that do not cause pollution.