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Multi-stakeholder perspectives on indicators for sustainable maintenance performance in production contexts: an exploratory study

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Abstract

Purpose – Poor maintenance management leads to non-negligible economic, environmental and social impacts and obstacles to the sustainable manufacturing paradigm. Studies evaluating maintenance impacts on sustainability underline growing interest in the topic, but reports on the industrial field are lacking. Therefore, this paper investigates the industrial environment and the indicators that manufacturing companies use for measuring their maintenance impacts.

Design/methodology/approach – In this pilot survey study, several stakeholders of production enterprises in the south of Italy were interviewed to unveil the spread of the measurement of maintenance impacts on sustainability and the indicators used by those companies.

Findings – The interview results showed a low level of awareness among stakeholders about maintenance impacts on sustainability. Maintenance stakeholders are mainly focused on technical and economic factors, whereas environmental, quality and safety stakeholders are becoming more aware of maintenance impacts on environmental and social factors. However, both groups need guidelines to define sustainability indicators to assess such impacts.

Originality/value – This exploratory study allowed us to investigate the current situation in industrial organisations and achieve the first variegated and diversified vision of the awareness of company stakeholders on maintenance impacts on the sustainability of several business functions. This paper provides a valuable contribution to "maintenance and sustainability" research area in production contexts and sheds light on non-negligible maintenance impacts on sustainability, providing preliminary insights on the topic and an effective basis for defining future research opportunities. Moreover, this study enables increased awareness among internal and external manufacturing company stakeholders on the role of maintenance in sustainable production.

Keywords Maintenance measurement, Maintenance performance, Sustainable manufacturing, Indicators

Paper type Research paper

1. Introduction and motivation of the study

Manufacturing enterprises have a huge impact on the surrounding environment, society and economy and, consequently, on sustainable development (Garetti and Taisch, 2012). Accordingly, the sustainable manufacturing paradigm has attracted a great deal of interest in the last years as an approach that aims to empower companies to cope with several challenges, such as the depletion of physical resources, customer requests for higher product quality and stricter laws and regulations (Eslami *et al.*, 2018). In today's competitive environment, maintenance is a fundamental lever of organisational efficiency because it allows organisations to guarantee the accurate operation of production systems and provide

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products at the required quality level (Jasiulewicz-Kaczmarek, 2013). In the near future, maintenance will be increasingly influenced by social and environmental factors, which will inevitably lead to a greater focus on education and training, new smart work procedures, sustainable management and the integration of new technologies (Bokrantz *et al.*, 2017).

Maintenance is defined as the combination of all technical, administrative and managerial actions during the life cycle of an item required to retain or restore it to a state in which it can perform its required function (EN 13306, 2001). Given its impact on other company processes, the maintenance process has great potential in terms of the pursuit of sustainable manufacturing; as such, it is becoming an increasingly important business function (Franciosi *et al.*, 2017, 2018; Iung and Levrat, 2014). Maintenance impacts not only the technical conditions of assets and equipment (reliability and availability performance) but also sustainability issues (safety performance, environmental damage, high energy and resource consumption, etc.). Maintenance affects sustainability in various ways, including direct impacts due to the execution of maintenance activities and indirect impacts on the assets and equipment to be maintained and manufactured products due to maintenance efficiency/inefficiency.

Poor maintenance quality and ill-defined maintenance practices lead to various problems and negative economic, environmental and social impacts (Liyanage and Badurdenn, 2010; Raouf, 2009). The economic impacts are mainly related to costs, downtime, breakdowns, waste, low performance, waiting times, defects, extra inventory and extra transportation, which also affect product quality and plant productivity (Jasiulewicz-Kaczmarek and Stachowiak, 2016; Raouf, 2009; Sutrisno *et al.*, 2015). Ill-defined maintenance practices for manufacturing assets lead to several environmental impacts, such as hazardous emissions, production waste due to system malfunctions, inefficient energy usage, ineffective resource consumption and wastage of stored materials (Ajukumar and Ghandi, 2013; Kazemi, 2013; Keivanpour and Kavi, 2015; Liyanage and Badurdeen, 2010; Raouf, 2009). The maintenance-related social impacts concern human health and safety; bad maintenance practices, as well as incorrect maintenance employee performance, could cause unsafe and unhealthy working conditions, accidents and incidents (Amrina and Aridharma, 2016; Di Pasquale *et al.*, 2017; Franciosi *et al.*, 2019; Jasiulewicz-Kaczmarek and Drozyner, 2013). Maintenance can affect employees directly involved in maintenance tasks, those involved in the production process and customers if poor maintenance strategies or poorly performed procedures lead to unsafe working conditions or low-quality manufactured products.

Proper maintenance and management of physical assets has positive effects on the economic, environmental and social performance of corporate sustainability (Durán and Durán, 2019; Maletič *et al.*, 2018), and sustainable maintenance management contributes to the reduction of maintenance impacts on sustainability (Franciosi *et al.*, 2018). Maintenance impacts and performance should be measured to evaluate and control the gap between the actual and desired sustainable performance. However, the current norm on the topic, EN 15341:2007, *Maintenance Key Performance Indicators*, presents technical, economic and organisational indicators, but only goes into detail on the economic dimension of sustainability. Moreover, industrial stakeholders are generally focused on the visible impacts of maintenance on production performance, measuring only the technical and economic indicators directly affected by maintenance activities.

Therefore, considering the huge impacts of maintenance on industrial sustainability and the lack of a norm or detailed indicators for measuring sustainable maintenance performance, the present exploratory study was conducted to investigate if such impacts are assessed and measured in production contexts and to identify the indicators adopted for evaluating sustainable maintenance performance. Specifically, an interview protocol was designed and a sample of stakeholders from different areas of several companies in different industrial sectors in the south of Italy were interviewed. This allowed us to investigate the current situation in industrial firms and achieve the first variegated and diversified vision of the

awareness of company stakeholders of maintenance impacts on several business functions and the contribution of maintenance to sustainable production.

This paper is structured as follows. Section 2 provides a brief literature review of indicators for measuring sustainable maintenance performance in production contexts, while Section 3 presents the semi-structured interview methodology used to reach the study purpose, the characteristics of the sample and the data collection and analysis process. Section 4 provides the detailed results of the interviews, while Section 5 presents the discussion of the results and the main conclusions of the interviews.

2. Literature review

Some studies reviewed maintenance performance measurement systems and indicators (Kumar *et al.*, 2013; Muchiri *et al.*, 2010, 2011; Simões *et al.*, 2011; Parida *et al.*, 2015; Van Horenbeek and Pintelon, 2014) highlighting that the maintenance indicators assessing maintenance performance are still mainly technical and economic.

Maintenance cost, overall equipment effectiveness (OEE), mean time between failure (MTBF), mean time to repair (MTTR), downtime, number of failures, productivity, availability, maintenance quality and number of maintenance employees were the most recurrent indicators reported in the aforementioned literature, covering mainly the economic and technical aspects of maintenance performance. Nevertheless, as Parida *et al.* (2015) highlighted, changes in business goals, new technologies and organisational aspects can affect the success of measuring performance. In fact, performance measurement systems need to be proactive and dynamic, and the associated indicators need to change based on company goals, stakeholder needs and external regulations.

Recently, Sénéchal (2017) discussed weaknesses in maintenance decision support systems for the assessment of sustainable performance, highlighting that current indicators do not sufficiently address the social and environmental impacts of maintenance. Therefore, despite the relevance and increasing interest in research concerning maintenance impacts on sustainability in the last decade, few recent studies proposing indicators for measuring sustainability performance and maintenance impacts were found in literature.

Sari *et al.*'s (2015) study was the first one found in literature to propose a limited set of measures for sustainable maintenance performance measurement systems of automotive industries, broken down into different hierarchical levels, that is corporate, tactical and functional. They introduced some indicators from the economic, environmental and social dimensions of sustainability that should be considered from the maintenance department perspective to assess the direct impact of maintenance on sustainability. In particular, concerning the economic dimension, they provided cost-effectiveness, quality and productivity indicators, for example maintenance budget, OEE, MTTR, MTBF, availability, number of failures, maintenance costs and response time for maintenance, considering measures deeply addressed in the conventional literature on maintenance indicators. They also provided environmental indicators, such as the number and type of spare parts used; the number of lubricants; energy, water and land consumption; hazardous waste; air and water pollution; and land contamination. Finally, they proposed social impact indicators belonging to the following categories: (1) learning and growth, for example training topics and hours per employee, innovations suggested and small group meetings/teamwork; (2) health and safety, for example recordable injury rate, workplace noise level, lighting and ventilation; (3) employee satisfaction, for example employee satisfaction rate and employee complaints; and (4) stakeholder satisfaction, for example stakeholder complaints.

Domingo and Aguado (2015) tried to consider the environmental impact of the conventional OEE and presented overall environmental equipment effectiveness (OEEE), while Pires *et al.* (2016) analysed some sustainability aspects with respect to OEE and demonstrated the

existence of relations between sustainability and the three OEE indexes: availability, performance and quality. Amrina and Aridharma (2016) provided 16 economic, environmental and social indicators for evaluating the sustainable performance of maintenance in the cement industry. However, the measures presented in their study were defined approximately and only allowed a glimpse of the importance of considering sustainability aspects in the conventional measurement and management of maintenance performance.

Some studies focused on specific aspects of sustainability affected by maintenance activities, such as Hoang *et al.* (2017) and Do *et al.* (2018), who first proposed the remaining energy-efficiency lifetime (REEL) instead of the conventional remaining useful life (RUL) as an indicator for appropriate maintenance management. Then, they proposed a new energy efficiency- and condition-based maintenance model, including the energy efficiency indicator, highlighting the today's need to integrate energy efficiency indicators into maintenance decision-making processes in order to support sustainability requirements.

A few other recent studies proposed models integrating some sustainable indicators to assess the sustainable performance of maintenance functions. For instance, Jasiulewicz-Kaczmarek and Zywica (2018) provided a methodology to assess maintenance performance and its impacts on sustainability but mainly focused on the maintenance department perspective, highlighting the need to extend the scope of the research and understand the perspectives of different departments of a company to achieve reliable results. Meanwhile, Amrina and Yulianto (2018) and Amrina *et al.* (2019) provided a model for finding relationships among indicators by measuring sustainable maintenance performance in the rubber industry. Finally, Sénéchal and Trentesaux (2019) presented a framework for helping decision makers be environmentally aware of maintenance activities by assessing a new key indicator they proposed—remaining sustainable life (RSL)—which focuses on the environmental dimension of sustainability.

Despite the recent efforts of the aforementioned authors to assess the sustainable performance of maintenance, they focused on a single topic and did not apply a holistic vision. Some focused on the maintenance department's vision, others on very specific industrial contexts and still others on specific aspects of sustainability. However, different stakeholders are affected by maintenance activities in different ways, impacting the sustainability performance of several departments in companies. As defined by ISO/IEC 15288, 2002, a stakeholder is an individual or organization with a right, share or claim to a system or in possession of characteristics that meet their needs and expectations. Active maintenance stakeholders include people who perform technical and administrative maintenance actions, as well as those who are external to the maintenance process but interested in the required functions of the item being retained or restored (Soderholm *et al.*, 2007). Therefore, a diverse group of stakeholders can be interested in sustainable maintenance management. Furthermore, it is relevant to understand the indicators needed for overall assessments of maintenance impacts on economic, environmental and social dimensions of sustainability from different perspectives, that is different stakeholders and different industrial contexts.

Therefore, this study explored several industrial contexts and stakeholder perspectives to understand the indicators affected by maintenance activities and adopted in the field for measuring sustainable maintenance performance. This approach offers a multi-sector perspective and a comprehensive understanding of stakeholder and industry awareness about maintenance impacts on economic, environmental and social sustainability. Moreover, to the best of our knowledge, this the first exploratory study investigating the current maintenance management practices and indicators adopted by manufacturing enterprises to contribute to sustainable development.

3. Methodology

A pilot survey study methodology was adopted to achieve the purpose of the paper. Specifically, an empirical investigation using face-to-face and conference call interviews of

production company stakeholders was conducted to unveil the indicators used to measure and monitor maintenance impacts on sustainability.

3.1 Structure of the interview

This sub-section presents the structure of the interviews, which were designed to reach the purpose defined in the previous section. To formulate the interview questions correctly, unambiguously and in the ideal chronological order, the guidelines of Synodinos (2003) were followed. The interview format was characterized by open questions divided into an introductory and a core section. To avoid possible misalignment, the interviewees were given the definitions of maintenance policies according to the ISO standard 13306. Figure 1 provides a flowchart of the interview and its main elements, which are reported in detail in the Appendix. The two interview sections are described in the sub-sections below.

3.1.1 Introductory section of the interview. The interview was designed for stakeholders from maintenance areas or other company areas affected by maintenance activities in order to analyse the main impacts of maintenance from various perspectives. The interviewees were asked about the general objectives of the area to which they belonged; if an interviewee belonged to a maintenance area, the strategies and the policies adopted by that area were also investigated. This first section of the interview was merely introductory and allowed us to understand the specific industrial context and area (Figure 1).

3.1.2 Path 1 core section of the interview. In the core section of the interview, we asked respondents whether maintenance impacts were measured or managed through specific indicators and whether the indicators used were affected by maintenance processes. Based on the answer, each interview continued along one of two paths.

If the stakeholder did not measure or manage maintenance performance and impacts, i.e. the "no" output of the rhombus in the flowchart in Figure 1, the corresponding path (the first

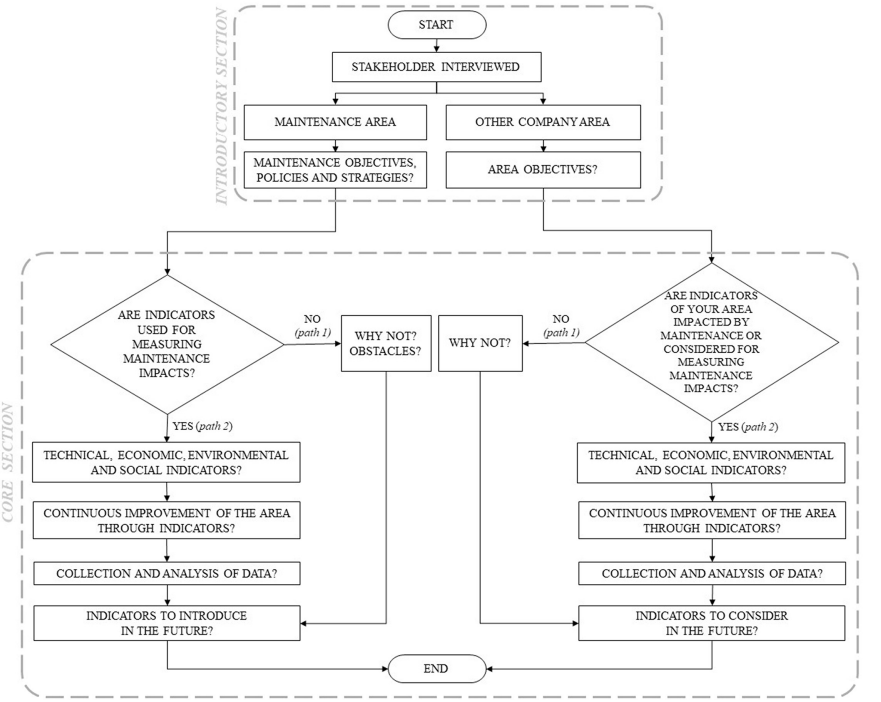

Figure 1.
Structure of the interview

path) was followed. In this case, if the respondent was in the maintenance area, he/she was asked about obstacles to using the indicators and then asked if his/her area intends to introduce measures for evaluating maintenance performance in the near future. Therefore, the interview included a discussion about maintenance impacts and the possibility or convenience of introducing indicators to measure maintenance impacts. If the respondent belonged to another company area, he/she was asked his/her opinion on why the indicators were not impacted by maintenance and not considered for measuring maintenance impacts, as well as about the possibility of introducing new indicators.

3.1.3 Path 2 core section of the interview. If the stakeholder measured maintenance impacts or considered indicators to be impacted by maintenance, that is the "yes" output of the rhombus in the flowchart in Figure 1, the corresponding path (the second path) was followed. In this case, each respondent was asked about the indicators used or affected by maintenance processes, and if these were into technical, economic, environmental and social indicators. Then, the interviewees were asked if and how the indicators were used for the continuous improvement of the company area to which they belonged. Then, questions on the collection and analysis of the data needed for the calculation of the indicators were asked, including who collects and analyses the data and how and when the collection and analysis are performed. Finally, each interviewee was asked whether the area to which he/she belonged intended to introduce new indicators, as well as the possibility or convenience of introducing new indicators for the measurement of direct or indirect maintenance impacts.

3.2 Recruiting process and data collection

Stakeholders from different business areas in several industrial sectors, such as maintenance managers, maintenance specialists, plant managers and environmental and safety managers, were contacted to determine their willingness to take part in the interviews. The main data on the interviewed companies were collected using AIDA (Analisi Informatizzata Delle Aziende) database (van Dijk, 2013), which contains comprehensive information on companies in Italy.

The interviews were conducted face-to-face or, when that was not possible, via conference call. All interviews were recorded digitally and lasted from half an hour to two hours, based on the availability of the stakeholders to offer details beyond specific answers to the questions. The interview questions were very general, giving the stakeholders the opportunity to answer broadly and share information with the researchers relatively freely. With some interviewees, this enabled the collection of information beyond the goals of their company areas or the specific indicators they used to measure maintenance impacts, such as company problems related to maintenance impacts on economic, environmental and social aspects of sustainability.

Following the interviews, the recordings were transcribed, and detailed notes were made. Then a detailed qualitative analysis of each of the three possible interview sections (introductory, path 1 and path 2) was undertaken. The stakeholders' answers were reported in an electronic spreadsheet and aggregated according to specific topics identified through the analysis.

In the core section of the interview, the indicators used in the stakeholders' industrial contexts were classified into technical, economic, environmental and social indicators. Moreover, the indicators were classified into two categories: directly and indirectly affected by maintenance. The ones belonging to the first category were strictly connected to the execution and management of maintenance processes, i.e. change in an indicator's value was a direct output of the execution of maintenance processes. Meanwhile, the ones belonging to the second category were indirectly influenced by the poor or good quality/management of maintenance processes, and the evolution of each indicator's value depended on several company areas, for example maintenance, production and quality.

4. Sample features

During the recruiting process, several small, medium and large production companies were contacted to participate in the interviews. We inquired about the availability of stakeholders

from various corporate functions, such as maintenance, production, health, safety and environment, to take part in the study. Due to the exploratory nature of this study, we contacted 25 companies to fulfil the purpose of the paper, i.e. to achieve a variegated and diversified vision of the awareness of company stakeholders of maintenance impacts on several business functions and the contribution of maintenance to sustainable production.

By the end of the recruiting process, 18 stakeholders from 15 production companies in the south of Italy agreed to be interviewed. As shown in Table 1, stakeholders from various industrial areas were interviewed, including maintenance managers, maintenance specialists, plant managers and environmental pillar managers. In total, 10 stakeholders held maintenance positions, five were plant managers and three held environment and safety positions. In small and medium companies, there is very often no maintenance manager position. In such cases, we asked to interview plant or production managers who were able to answer questions related to maintenance activities and their impacts. Each stakeholder was assigned a letter of the alphabet for coding purposes; when two stakeholders belonged to the same company, a letter and a number were assigned to them. The details of the stakeholders and their companies are reported in Table 1.

5. Results

The interview results are reported below according to the structure of the interviews and the three interview sections identified in Section 3.1.

5.1 Results of the introductory section of the interview

In the introductory section of the interview, each interviewee was asked about the goals of the department to which he/she belonged. If the interviewee was an employee or manager in the maintenance area, he/she was also asked about maintenance strategies and policies.

Table 2 shows the classification of the goals identified by the respondents into technical, economic, environmental and social categories. Most of the answers of the interviewees working in or managing maintenance areas were related to guaranteeing the reliability and productivity of the operations, equipment and machines (technical goals). Meanwhile, the goals of the interviewees belonging to environmental or safety departments were related to environmental, health and safety (EHS) compliance or zero impact activities (environmental goals). Social goals were considered as well and referred to the guarantee of safety standards for employees and customer satisfaction. Finally, economic goals were taken into account by several interviewees, especially A and I whose company missions involved providing excellent maintenance services in specific industrial sectors to achieve the desired profit levels. They explained how the role of maintenance has changed over the years, becoming more and more essential for new technologies available on the market.

Going into detail about the answers provided by other interviewees, B, E1 and Q1, a technical area manager, professional maintenance manager and maintenance manager with high levels of experience in the maintenance field, respectively, provided detailed maintenance goals related to reliability, productivity and economic factors. The main objective of E1's maintenance department was maintaining plant efficiency to produce compliant and non-compliant products at the minimum cost, whereas the main goal of Q1's maintenance department and manager B's technical department was meeting indicators' target values. Those indicators were mainly technical and economic, such as MTTR, MTBF, budgets for internal and external maintenance employees, spare parts and warehousing, investments and non-compliant products.

D, E1, F and L reported that their maintenance functions were composed of various activities that needed to be standardised to guarantee reliability and good machine operation

Case	Interviewed stakeholder	Company dimension	Company sector	Company core business
A	Senior system O & M manager	Large	Railway	Railway signalling and integrated transport systems for passenger and freight rail operations
B	Technical area manager	Large	Food	Production and trade of foodstuffs, in particular, pasta
C	Plant manager	Medium	Engine	Manufacture of electric motors, generators and transformers
D	Maintenance manager	Medium	Mechanical parts and structures	Metal structural works, steel dyeing and plastic moulding. The company is also engaged in the manufacturing of mechanical products, dies and abrasive products
E1	Professional maintenance manager	Large	Automotive	Manufacturing, assembly and selling of motor vehicles and spare parts
E2	Environmental pillar manager			
F	Maintenance specialist	Large	Automotive	Manufacturing, assembly and selling of motor vehicles and spare parts
G1	Maintenance manager	Large	Steel	Production of laminates and electro-welded structures; metal products in iron and steel
G2	Environment and safety manager			
H	Plant manager	Small	Mechanical machining	Treatment and coating of metals
I	Maintenance and safety manager	Medium	Oil	Manufacture of machines and equipment for chemical, petrochemical and oil industries (including parts and accessories)
L	Plant manager	Small	Naval	Building of pleasure and sporting boats
M	Plant manager	Medium	Mechanical machining	Forging, pressing, stamping and roll-forming of metal; powder metallurgy
N	Plant manager	Medium	Mechanical machining	Machining
O	Maintenance and quality manager	Small	Plastic moulding	Plastic moulding
P	Maintenance and part warehouse manager	Large	Mechanical machining	Treatment and coating of metals; machining
Q1	Maintenance manager	Large	Automotive	Door Panels, Instrument Panels and Cockpits, Floor Consoles, Overhead Consoles, Decorative Trim and Lighting Technologies
Q2	Environment and Safety manager			

Table 1.
Studied companies and stakeholders

with zero failures. G1, N, O and P highlighted that the maintenance department must guarantee proper operation of the plant, reliability and productivity; therefore, they prioritized zero failures and stops and placed a high value on OEE. C, H and M considered reliability and productivity, as well as the safety of the people involved in the maintenance activities and high quality.

Respondent E2, that is an environmental pillar manager, shared his department goals, that is zero impact and reduction of losses, highlighting that he was aware that these objectives are affected by maintenance performance but that his company had taken no action to reduce maintenance impacts on the environmental pillar or increase environmental performance through maintenance. This manager had considerable maintenance and

Case	Goal			
	Technical	Economic	Environmental	Social
A		X		
B	X	X		
C	X			X
D	X			
E1	X	X		
E2			X	
F	X			
G1	X			
G2			X	X
H	X			X
I		X		
L	X			X
M	X			X
N	X			
O	X			
P	X			
Q1	X	X		
Q2			X	
Total	13	5	3	5

Table 2. Classification of the goals identified by the interviewees

environmental/energy experience and provided detailed answers on the types of losses connected to maintenance performance, mainly related to energy and material consumption and the absence of parameter optimization.

Finally, G2 and Q2, both environmental and safety managers, had goals related to EHS compliance. G2 aimed to respect and maintain the safety and environmental targets imposed by external certification bodies, highlighting that both targets could be affected by maintenance. Meanwhile, Q2 listed several goals of his department at corporate and operational levels, which were measured using several indicators that needed to stay on target. He showed his awareness about the influence of maintenance on some goals and indicators of his department.

Maintenance area stakeholders were asked about currently adopted maintenance policies and ones they would adopt in the near future. No industry used predictive, real-time or proactive maintenance and only six adopted condition-based maintenance (23%), while the most frequent policies were periodic maintenance (46%) and corrective maintenance after failures (31%). In the near future, most of the companies aimed to adopt predictive (67%), proactive (11%), real-time (11%) or periodic maintenance (11%).

Periodic maintenance was the most used policy (according to A, B, C, E1, F, G1, H, I, L, M, N, O, P and Q1). Plant-wide planned stops allowed the execution of periodic maintenance interventions by internal maintenance operators and specialists or external maintenance entities. Otherwise, periodic maintenance was executed based on the operation time of the components or a fixed number of manufactured products. Some companies acted periodically based on the technical component sheet or an internal checklist. Other companies divided components into priority classes and acted periodically according to the priority of each component based on the impact of failure or malfunction of the component.

Corrective maintenance after failures was used as well (according to A, B, D, E1, F, G1, M, N and O). Every time a failure occurred, the internal maintenance operators or external maintenance entities would fix the problem and restore the basic condition of the machine or equipment based on the difficulty level of the failure. B reported that his company used a

system to tag problems and failures on the production lines; professional maintenance employees read those warnings and signals and organised their activities based on the seriousness of the problem/failure and the consequences of the stop line.

Five companies (according to B, E1, F, G1 and Q1) adopted condition-based maintenance (CBM) by monitoring vibrations or temperature or using cameras for thermographic inspections. L reported that his company used a very simple CBM in which the maintenance operator performed necessary actions through visual control of the machines used for the production process. Meanwhile, A reported that his company tried to use CBM, but the monitoring was too expensive.

Some interviewees (A, C, D, I, N and P) aimed to adopt predictive maintenance in the future and were studying how to integrate sensors for predicting failures or advising maintenance operators in a timely manner. This would allow the use of the component as much as possible but avoid complications connected with unexpected failures, thus avoiding sustainability-related impacts. E1 and G1 aimed to implement real-time or proactive maintenance.

Each interviewee thought about the future in terms of industry 4.0, smart factories or sustainable industries even though most of them did not have deep awareness and knowledge of the topic. The enabling technologies of industry 4.0 could help with the adoption of predictive, real-time and proactive maintenance policies for smart and sustainable industries.

5.2 Results of the path 1 core section of the interview

Following the methodology steps, interviewees in this path were asked whether maintenance impacts were managed or measured using indicators. Four stakeholders (22%), all maintenance area respondents, said no, while 14 stakeholders (78%) measured maintenance impacts using indicators or were aware of maintenance impacts on several indicators. In this section, we focus on the four stakeholders (C, D, L and N) that did not measure maintenance impacts, investigating the different ways they managed maintenance impacts, as well as the obstacles and limits preventing the use of indicators.

These four stakeholders belonged to growing small- and medium-sized companies, which were not yet well-structured. C and L explained that maintenance activities were managed through external maintenance contracts with periodic maintenance. They explained that their companies did not measure maintenance impacts because their made-to-order production processes did not require monitoring machine performance. Moreover, L noted that the main obstacles to the use of indicators were the structure of the organisation and its small size. Maintenance was mainly managed by failure through the prompt intervention of the parent company within the 24 h following the failure and by periodic maintenance according to the maintenance booklets of the machines. For this reason, the only indicators considered were the MTBF indicated in each maintenance booklet. The monitoring of this indicator on each machine was conducted by the responsible employee, and the production manager coordinated all periodic maintenance activities.

Neither C nor L's company intended to adopt indicators for measuring maintenance impacts in the future. Such companies see maintenance in terms of ensuring the availability of the machine and do not consider machine availability to be an important indicator to monitor because of their made-to-order production processes. This represents the vision of small companies that are unaware of several aspects of the impact of maintenance, such as on the quality of the production process and the final product.

In contrast, D and N were interested in measuring maintenance impacts but could not enact this practice due to the lack of defined structures in their companies. They were trying to introduce indicators to measure maintenance performance, and they noted that a support tool could help them identify which indicators to use in their industrial context. In particular, D acknowledged the lack of organisation of the maintenance function in his company;

he explained that his company mainly works on failures, intervening when necessary, even at very high costs. There are no accurate indicators, and some data are collected but in a disorganised and careless manner. The maintenance employees write paper reports at the end of each intervention, but the data are neither transcribed in a general system nor analysed. On the contrary, N reported that, in his company, maintenance is carried out by external companies, and only minor maintenance interventions are entrusted to the production employees. They just collect analysis reports for each intervention carried out by the external companies and archive them for possible future consultations in case of premature failures or other issues. Moreover, he noted that the data collected in the reports are analysed only superficially.

5.3 Results of the path 2 core section of the interview

The second path concerned the 14 stakeholders (A, B, E1, E2, F, G1, G2, H, I, M, O, P, Q1 and Q2) who measured maintenance performance through indicators or were aware about maintenance impacts on the sustainability of their industrial context. This sample included respondents from maintenance areas and other company areas.

In total, 115 indicators were collected through these interviews: 35 technical, 43 economic, 15 environmental and 22 social indicators. Figure 2 reports the total number of indicators used by each respondent, divided by category. However, analysis of the indicators identified overlap in many indicators. Therefore, the actual number of indicators was 47, as shown in Table 3.

Table 3 summarizes the actual number of indicators divided by category (technical, economic, environmental and social) and classifies the indicators depending on whether they were directly and indirectly affected by maintenance.

The 47 indicators are described below in several tables, divided by category. Specifically, Tables 4, 5, 6 and 7 provide the technical, economic, environmental and social indicators, respectively, the associated recognition number, the type of maintenance impact (direct/indirect) of each indicator and the frequency of indicator utilisation in each case.

Finally, Figure 3 summarises the prevalence of the use of technical, economic, environmental and social indicators considered by the company's interviewees. Figure 3 highlights the large number of technical (16) and economic (14) indicators against the environmental (7) and social (10) indicators. Moreover, the histogram underlines the

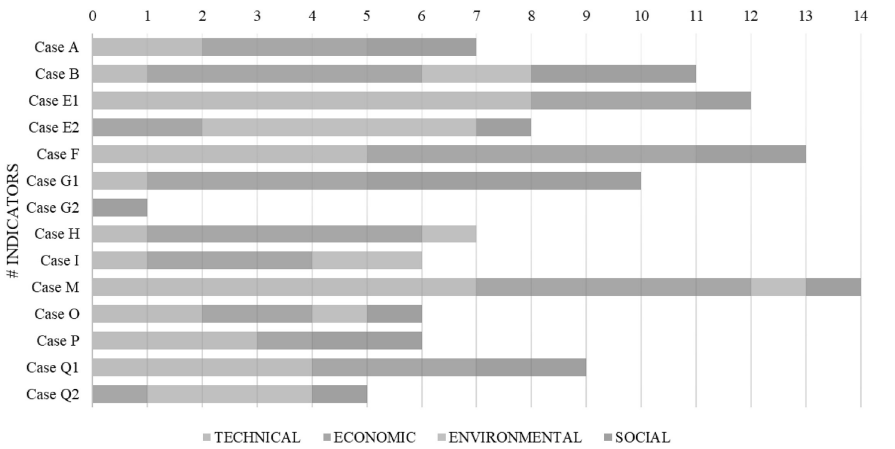

Figure 2.
Total number of indicators used by each interviewed stakeholder, divided by category

inhomogeneity of the frequency of the indicators' occurrence, as shown by the peaks. For example, only three indicators (EC1, EC2 and T1) were considered by more than 50% of the interviewees, and these belonged to the economic and technical categories, whereas 25 indicators (53%) were each considered by only one interviewee.

Category	#Indicators	#Indicators (direct impact)	#Indicators (indirect impact)
Technical	16	12	4
Economic	14	10	4
Environmental	7	1	6
Social	10	7	3
Total	47	30	17

Table 3. Actual number of indicators divided by category

#	Technical indicator name	Definition /Description	Type of impact	Case		
				Large	Small and medium	Total
T1	MTTR	Mean time to repair	Direct	5	3	8
T2	MTBF	Mean time between failure	Direct	4	1	5
T3	OEE	Overall equipment effectiveness	Indirect	2	2	4
T4	MTTr	Mean time to repair – specific for preventive maintenance action	Direct	3		3
T5	#Failures	Number of failures on machines	Direct	1	2	3
T6	#Semi-manufactured items non-complaints		Indirect	1	1	2
T7	%Downtime	Periods in which a system is unavailable	Direct	1		1
T8	%Hours corrective maintenance/tot hours of maintenance	–	Direct	1		1
T9	%Hours preventive maintenance/tot hours of maintenance	–	Direct	1		1
T10	Availability of the machine		Direct	1		1
T11	Mechanical efficiency of the line	–	Indirect	1		1
T12	Minimum number of available spare parts	–	Direct	1		1
T13	#Inefficient maintenance interventions	–	Direct		1	1
T14	#Performed maintenance interventions/number of planned maintenance interventions	–	Direct	1		1
T15	OLE	Overall line effectiveness	Indirect	1		1
T16	Time between maintenance request and maintenance intervention	–	Direct		1	1

Table 4. Technical indicators: recognition number, name, description/ definition, type of impact and frequency of occurrence

#	Economic indicator name	Type of impact	Case		
			Large	Small and Medium	Total
EC1	Costs of spare parts	Direct	7	4	11
EC2	Costs of maintenance employees	Direct	6	3	9
EC3	Costs of external maintenance	Direct	1	3	4
EC4	Costs of lost production for failure	Direct	1	2	3
EC5	Costs of reworking	Indirect	1	2	3
EC6	Budget for maintenance activities	Direct	2		2
EC7	Costs of production employees	Indirect	2		2
EC8	Costs for waste treatment of production process	Indirect	2		2
EC9	Costs of energy used by production process	Indirect	2		2
EC10	Maintenance cost per machine	Direct	1		1
EC11	Costs of external training	Direct	1		1
EC12	Costs of recycled materials	Direct	1		1
EC13	Costs of storage for spare parts and tools used in maintenance activities	Direct		1	1
EC14	Investments in energy efficiency instruments and initiatives taken by maintenance processes	Direct	1		1

Table 5.
Economic indicators: recognition number, name, type of impact and frequency of occurrence

As noted in section 3.1.3, we asked the respondents if and how the indicators were used for continuous improvement. We received several answers; some were generic and others more specific, but, regardless, most stakeholders reported that indicators were essential for continuous improvement and that they make decisions on future developments based on indicator values. For instance, B said he monitors indicators to understand possible connections to failures that have occurred and the quality/cost of the final product; B's department proposed investments or improvement activities to change indicator values in the future. G1 and O noted that they use kaizen for continuous improvement. In particular, G1 explained that the company made indicator values available to all employees in order to share information and make employees feel part of the organisation and more aware of indicator values, which are an intrinsic aspect of continuous improvement. Moreover, G1 gave examples of indicators used for continuous improvement, such as percentage of downtime and number of accidents, which are used to improve maintenance procedures and the plant design, as well as for awareness and training of maintenance employees.

G2 and Q2 belonged to the environmental and safety area, and they reported that all indicators in their area were inserted in general documentation for the evaluation of the safety and environmental system and the development of possible improvements. Some of these improvements could be related to the maintenance area that affected environmental and safety indicators of this area through direct and indirect maintenance impacts.

Some stakeholders (E1, E2, F, H, I, M and Q1) said that they analyse indicator values and the root causes of those values in order to decide what action to take in the maintenance area and what improvements to make. For example, E1 and E2 noted that, when there is a failure or a defect, their company analyses the defect modes using FMEA (Failure Mode and Effect Analysis) procedures, determines which parameters to control to avoid defects or failures and chooses the most appropriate type of maintenance employee according to his/her skills and level of training. E1 and F reported that the maintenance costs associated with different components are periodically analysed; design modifications are proposed to component providers or grouping of maintenance interventions or investments in new components are proposed, to reduce the costs associated with specific machine components. An example of continuous improvement through water and energy indicators related to the production

#	Environmental indicator name	Definition/description	Type of impact	Case		
				Large	Small and medium	Total
EN1	Amount of wastes generated by production process	Amount of wastes generated by production process specified by waste type and disposal method (i.e. hazardous and non-hazardous, recyclable, reusable, remanufacturable, disposable)	Indirect	2	3	5
EN2	Energy consumption for production process	–	Indirect	3	1	4
EN3	Volume of recorded significant spills	(i.e. accidental release of hazardous substances that can affect human health – land, vegetation, waterbodies, and groundwater)	Indirect	1	1	2
EN4	Energy efficiency for production process	–	Indirect	1		1
EN5	Materials used for production process	Materials used for the production process (e.g. raw materials, semi-manufactured goods or parts, auxiliary materials) divided in renewable and non-renewable materials or with a breakdown on type of used materials (virgin, reused, recycled, remanufactured, repurposed)	Indirect	1		1
EN6	Volume of water withdrawn for production process	Volume of water withdrawn for production process with a breakdown by the sources (*e.g. lakes, rivers, ground water, rainwater*)	Indirect	1		1
EN7	Amount of wastes generated by maintenance process	Amount of wastes generated by maintenance processes (e.g. replaced items, used tools, lubricants, oils, documentation) specified by waste type and disposal method (i.e. hazardous and non-hazardous, recyclable, reusable, remanufacturable, disposable)	Direct	1		1

Table 6. Environmental indicators: recognition number, name, description/definition, type of impact and frequency of occurrence

process was relayed by E2. He realised that these indicator values increased due to failures and non-operation of the machines; the production process continued to consume energy and water even if it was not producing. Therefore, his company determined that, after a defined period of non-production, machines must be stopped to avoid useless energy and water consumption. Meanwhile, I and P reported that indicators were analysed through periodic meetings to decide which improvement actions to undertake or by using management software that automatically suggested improvements.

Concerning the interview questions dealing with the collection and analysis of the data needed for the calculation of the indicators, the stakeholders reported on who collects and analyses the data, and how and when collection and analysis activities are performed. They relayed that data are collected by maintenance staff or other employees and recorded in

#	Social indicator name	Definition/description	Type of impact	Case		
				Large	Small and medium	Total
S1	Average hours of training per maintenance employees	Average hours of training defined as the ratio between #training hours and #maintenance employees. e.g. Training for maintenance procedures, safety courses, upgrading skills.	Direct	6		6
S2	Type and scope of training programs	Type and scope of training programs provided by maintenance for upgrading employees' skills	Direct	3	1	4
S3	Product quality assurance and management: incidents of product recalls and customer complaints and resolution met from these incidents	–	Indirect	2	1	3
S4	Type of injury and injury rate due to maintenance activities	Type of injury and injury rate (*e.g. through #maintenance accidents requiring first aid)*	Direct	3		3
S5	Bonus salary for good maintenance employee performance	–	Direct	1		1
S6	Customer satisfaction	Number of practices (*e.g. surveys*) to assess customer satisfaction	Indirect	1		1
S7	Lost workday rate due to maintenance accidents	–	Direct	1		1
S8	#Customer complaints concerning a manufacturing product	–	Indirect	1		1
S9	Personal protective equipment	Personal protective equipment and safety equipment provided by maintenance processes	Direct	1		1
S10	Absentee rate	–	Direct	1		1

Table 7.
Social indicators: recognition number, name, description/ definition, type of impact and frequency of occurrence

specific types of reports (A, E1, G2, H, I, O, P and Q2) or specific devices (B, E2, F, G1, M, P, Q1 and Q2); otherwise, the data are automatically collected by software and devices. The methods used to collect data depend on the data type (whether the data are related to maintenance interventions, the system to be maintained or other systems) and the structure and automation level of the organisation. Moreover, the data are collected daily (B, E1, E2, F, G1, H, M, P and Q1), weekly (G1), monthly (G1 and Q2) or based on a specific condition/event (F and G2).

According to all respondents, the data are analysed by a specific person: an analyst (A, H, I and M), a manager (B, G1, H, M, Q1 and Q2), an employee (O) or a controller of several plants in the same organisation (B). In other cases, a team composed of various company stakeholders (G1, G2, P and Q2) or a company team combined with bodies external stakeholders (Q2)

discusses and analyses the data. F reported that data analysis is only performed if some monitored parameters are out of control. The data analysis is performed daily (B, E1, E2, G1 and P), weekly (B and G1), monthly (B, G1, O, Q1 and Q2), every six months (Q2) or annually (G2). In the future, stakeholders E1, E2 and F aimed to analyse data automatically through the enabling technologies of industry 4.0.

Finally, we asked if new indicators will be used, and the possibility or convenience of introducing new indicators to measure direct and indirect maintenance impacts was discussed. E1, F, G1, P and Q1 did not intend to introduce new indicators in the future; some interviewees were convinced that they already monitored too many indicators. E1 and M aimed to eliminate indicators related to the number of failures (their companies aimed for zero failures so they felt this indicator was unnecessary) and the number of incidents of non-compliant products (they felt it would be more important to monitor the value of each non-compliant product incident rather than the number of incidents).

Meanwhile, H and M aimed to introduce new indicators but did not specify which types, and B intended to introduce an economic indicator related to the cost of different types of production lines. Several stakeholders intended to integrate some technical indicators; B aimed to introduce MTBF and the number of failures per line and per machine (fixing a target), respondent I wanted to introduce the repetitiveness of the intervention, and O wanted to introduce MTTR and MTBF.

After a long discussion with E2 on the sustainability problems of his plant, he agreed that four environmental indicators that should be introduced: chemical product consumption caused by machine failure, energy consumption caused by machine failure, resource consumption caused by machine failure and water consumption caused by machine failure. Only in the last years, has stakeholder A become aware of the relevance of highly skilled maintenance workers, and he aims to introduce a new indicator related to this social aspect. G2 was mainly focused on safety aspects and aimed to collect data related to incidents of "missing injuries", covering all occasions in which an accident could occur. Q2 was more interested in ergonomics and aimed to introduce indicators to evaluate the response time for stakeholder requests to fix ergonomic problems and the number of requests to address ergonomic issues.

Moreover, during the discussions, some stakeholders highlighted that some sustainability indicators were introduced in their companies only recently, as they became aware of the necessity to measure the sustainable performance of organisations. However, it appears that most of the stakeholders, even if they belonged to well-structured and innovative companies, were not aware of how much the maintenance area affects sustainability. Therefore, the necessity to introduce a larger number of specific indicators to measure maintenance impacts on sustainability was discussed.

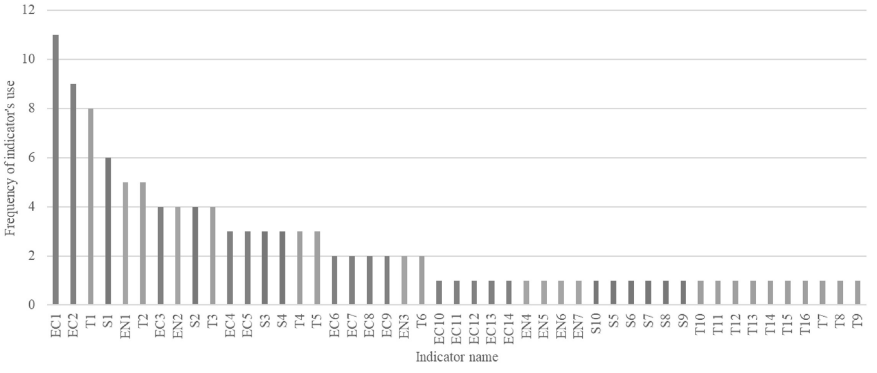

Figure 3.
Spread of technical, economic, environmental and social indicators considered by the interviewees

6. Discussion and conclusions

Maintenance processes can ensure the reliable and sustainable operation of assets and equipment, becoming a key contributor to sustainable manufacturing. Maintenance functions can substantially help industries achieve such goals, and the measurement of maintenance performance and its impacts on the sustainability of a company can help to control the gap between the actual and desired performance.

However, only recent studies addressed the role of maintenance in promoting industrial sustainability. Moreover, the literature review showed that few studies on indicators for sustainable maintenance performance are available, and those studies mainly focused on measuring the direct impacts of maintenance activities and only considered maintenance stakeholder perspectives.

In contrast, the present exploratory study considered different stakeholder perspectives, resulting in several interesting findings:

(1) Even though indicators and maintenance measurement systems are widely recognised as necessary tools for detecting problems, highlighting opportunities for improvement and creating added value for organisations, there are still companies that do not measure maintenance performance. Such companies are generally small or medium sized and not well structured.

(2) Most interviewees measured maintenance performance and were aware of several maintenance impacts. Many indicators were adopted by the respondents' companies, some of which were context specific. However, the considered indicators were not always coherent or exhaustive in terms of the objectives of the company or specific departments.

In fact, regardless of the company objectives, maintenance stakeholders were focused on technical and economic factors with a low level of awareness about the relationship between maintenance and sustainability, while environmental, quality and safety stakeholders were becoming aware but did not share this insight with maintenance stakeholders in their companies; consequently, pro-sustainability maintenance management proposals were not undertaken.

Even if most of the interviewed stakeholders were aware of the general sustainability goals that their companies must reach to cope with the challenges imposed by today's competitive environment, they had a restrictive view of their business function. In other words, they are were unaware of maintenance impacts on general sustainability goals.

For example, H mainly adopted economic indicators even though his company's maintenance objectives included ensuring process reliability and customer quality. In this case, social indicators could be introduced to assess customer satisfaction and other technical measures.

For most of the maintenance interviewees, maintenance activities were very often considered only in terms of the reliability and productivity of the plant; therefore, the adopted indicators measured the technical and economic performance aspects of maintenance. This was particularly evident among E1, F and Q1, who belonged to maintenance departments of large companies. In their companies, even when several types of indicators were used to monitor maintenance activities, they were only economic and technical ones; environmental and social dimensions of sustainability were not considered or measured except in terms of employee training indicators. It is noteworthy that E2 and Q2 belonged to the same companies as E1 and Q1, respectively, but they were from environmental and EHS departments and were aware of some of the maintenance effects on the environmental and social indicators they monitored and the fact that some of those indicators should be considered more deeply to evaluate the maintenance impacts on those sustainability pillars. However, those indicators were not used to perform detailed analysis aimed at monitoring

maintenance effects on sustainability indicators or eventually intervening in maintenance management practices.

What emerged during the interviews was that the stakeholders belonging to the same company very often had contrasting views on the topic of maintenance and sustainability due to the lack of inter-departmental meetings, which represent the basis for achieving sustainable operations and sharing and discovering relationships among economic, environmental and social factors.

However, the case of the environmental and safety manager, G2, was different; although his department's objectives were related to EHS compliance, he used several environmental and social indicators to assess the performance of business processes, but his department did not consider in practice that maintenance can influence indicator values except for injury rate and accident type. Therefore, during the interview, we discussed several impacts of maintenance that should affect sustainability performance and that inevitably lead to increasing/decreasing sustainable indicator values, which should be considered to increase sustainability performance. Even though G1, the maintenance manager of the same company, adopted some social indicators to measure maintenance performance, they were strictly connected maintenance process execution, and no environmental indicators were considered. Therefore, major communication and information sharing practices are needed by the departments of this company to create a general vision that is in line with sustainability requirements.

Often, the main obstacle to achieving sustainability goals is the way of thinking of the stakeholders. One finding that emerged from several discussions was that a tool offering guidance in identifying which indicators to monitor to guarantee sustainable maintenance performance could be appreciated by companies. Such a tool would also make them more aware and show evidence of several sustainable aspects affected by maintenance.

(3) While, as could be expected, the most recurrent technical and economic indicators adopted by maintenance stakeholders correspond to the measures provided in the consolidated literature, the few environmental indicators considered by the interviewed stakeholders mainly address the production process perspective, highlighting the need to monitor indicators related to other company departments to measure sustainable maintenance performance. In addition, the interview results offer a glimpse into the future relevance of social indicators for measuring maintenance performance from perspectives beyond the maintenance employee view. In fact, customer satisfaction is a fundamental lever of organisational survivability and sustainability, and the present results indicate the need to consider new indicators to evaluate maintenance impacts on this area. Social indicators affected by maintenance activities have been roughly considered in the literature, only from the maintenance department perspective, in terms of health and safety or training maintenance employees. Therefore, future studies should consider that new indicators are needed to measure maintenance performance from other perspectives. In addition, indicators could be identified from various stakeholder perspectives to identify all indirect and non-negligible impacts of maintenance on sustainable production.

Based on the lessons learnt from the present analysis, we believe that organisations must become more aware of the importance of addressing maintenance as a set of processes that (1) must sustain equipment/assets during their operation in order to guarantee compliant production processes for manufactured products and reduce industrial impacts on the economy, society and the surrounding environment and (2) must be a sustainable business function in order to limit the impacts generated during maintenance activities.

Furthermore, the present exploratory study yielded the following implications for further research:

(1) A structured questionnaire designed to achieve large-scale quantitative results should be submitted to different types of stakeholders of companies in several industrial sectors at the national level in Italy and the international level to provide a wider and more exhaustive view of the spread of the measurement of maintenance impacts on sustainability. This will also allow deep comprehension of the current management practices for such issues and an in-depth mapping of different industrial sectors, geographical areas, stakeholder points of view.

(2) Taking into account the different maturity levels of companies in terms of the relationships between maintenance and sustainability that emerged in this exploratory study, further research should develop a maturity assessment model for maintenance and sustainability to individuate companies with high maturity levels and understand their management strategies for such issues, performance measurement systems and the sustainability indicators used to assess maintenance impacts on sustainability. The development of good maintenance management practices addressing sustainability issues by high-performing, sustainable industrial companies could inspire other stakeholders to implement similar actions, leading to the consideration of maintenance as a key contributor to enhancing sustainability performance. In this way, the most mature companies could guide other firms towards the improvement of maintenance processes and the strategic organisation of maintenance functions for sustainable production.

(3) A natural evolution of this study would be a conceptual framework to help different types of stakeholders assess sustainable maintenance performance and address the effects of maintenance processes on economic, environmental and social dimensions of sustainability. This would allow stakeholders to have a global vision and correctly adopt indicators for sustainable maintenance and production management. Indeed, if organisations were aware of maintenance impacts on sustainability, they could easily rearrange the management of their processes and use the available information for detailed analysis to achieve sustainable goals.

(4) Based on the stakeholder needs that emerged during the interviews, tools guiding companies in the identification of indicators to measure maintenance impacts on sustainability should be implemented as decision support systems. Based on each enterprise's goals, the tools should be able to suggest sustainable indicators to address the specific industrial context and benefits of the deeper involvement of maintenance in decision-making processes and plant operations.

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Appendix

INTRODUCTORY SECTION	
To which company department does the interviewed stakeholder belong?	
MAINTENANCE AREA	OTHER COMPANY AREA
✓ What are your maintenance objectives (technical, economic, environmental and social)?* ✓ What are the maintenance policies/strategies used in your company?**	✓ What are your department (environment, safety, production, etc.) objectives (technical, economic, environmental and social)? Do you think they are influenced by maintenance?*

CORE SECTION			
IF MAINTENANCE AREA: Are indicators used to measure maintenance impacts? IF OTHER COMPANY AREA: Are indicators in your area impacted by maintenance or used to measure maintenance impacts?			
NO **PATH 1**		YES **PATH 2**	
MAINTENANCE AREA	OTHER COMPANY AREA	MAINTENANCE AREA	OTHER COMPANY AREA
✓ Why not? How is your area's performance managed? ✓ What are the obstacles to using indicators? ✓ In your opinion, what indicators should be introduced in the future?	✓ Why not? How is your area's performance managed? ✓ In your opinion, what indicators should be introduced for measuring maintenance impact in your area?	✓ What technical indicators are used to measure maintenance impacts? ✓ What economic indicators are used to measure maintenance impacts? ✓ What environmental indicators are used to measure maintenance impacts? ✓ What social indicators are used to measure maintenance impacts? ✓ How are these indicators used for the continuous improvement of maintenance and production performance? ✓ How is the data needed for indicator calculations collected? Who (an individual) or what (an informative instrument) collects the information/data needed for the indicators? When?	✓ Which technical indicators in your area are impacted by maintenance or used to measure maintenance impacts? ✓ Which economic indicators in your area are impacted by maintenance or used to measure maintenance impacts? ✓ Which environmental indicators in your area are impacted by maintenance or used to measure maintenance impacts? ✓ Which social indicators in your area are impacted by maintenance or used to measure maintenance impacts? ✓ How are these indicators used for the continuous improvement of your area and maintenance performance? ✓ How is the data needed for indicator calculations collected? Who (an individual) or what (an informative

Table A1.
Interview guide

		✓ How is the data analysis performed and who does it? When? ✓ In your opinion, what indicators should be introduced in the future?	instrument) collects the information/data needed for the indicators? When? ✓ How is the data analysis performed and who does it? When? ✓ In your opinion, what indicators should be introduced for measuring maintenance impact in your area?

Note(s):
* MAINTENANCE = "combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function" (ISO 13306).
* MAINTENANCE OBJECTIVE = "target assigned and accepted for the maintenance activities" (ISO 13306).
** MAINTENANCE STRATEGY = "management method used in order to achieve the maintenance objectives" (ISO 13306).
** PREVENTIVE MAINTENANCE = "maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item" (ISO 13306).
** CONDITION BASED MAINTENANCE = "preventive maintenance which includes a combination of condition monitoring and/or inspection and/or testing, analysis and the ensuing maintenance actions" (ISO 13306).
** PREDICTIVE MAINTENANCE = "condition-based maintenance carried out following a forecast derived from repeated analysis or known characteristics and evaluation of the significant parameters of the degradation of the item" (ISO 13306).
** CORRECTIVE MAINTENANCE = "maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function" (ISO 13306)

Table A1.

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