The Roadmap for Improving Sustainability in Remanufacturing Operations

Paulina Golinska-Dawson, Monika Kosacka and Karolina Werner-Lewandowska

1 Introduction

Experts are aware of the fact that remanufacturing allows to recover a big proportion of the resources, which were used to produce a product. The environmental and economic benefits of remanufacturing are, as follows:

- It recovers a product to useful life at low cost (up to 85% of the weight of remanufactured products can be reused), thus reducing the price of the product (Ijomah et al. 2004; Sundin and Bras 2005),
- it allows to reduce the raw materials and energy usage compared to primary production(Ijomah et al. 2004; Kerr and Ryan 2001),
- it allows closing the materials loop and reducing landfilling (Seitz and Peattie 2004; Abbey et al. 2014).

Remanufacturing is often perceived as a key strategy to achieve goals of the sustainable development policy (e.g. Ijomah et al. 2004). When proofing the importance of remanufacturing for the sustainable development, the researcher mainly apply the life cycle design and the life cycle engineering approach. There is a research gap regarding the assessment of remanufacturing operational excellence, as far as sustainability issues are concerned. In the previous research we have elaborated qualitative (Golinska and Kübler 2014) and quantitative (Golinska et al. 2015a) method for maturity assessment regarding sustainable usage of resources in a remanufacturing process. We defined three sustainable maturity levels. The assumption was made that small and medium sized remanufacturers (RSMEs) want to perform their operations and used their resources in the most efficient way, regarding economics, environmental and social aspects. Companies can achieve the maturity level, as follows (Golinska et al. 2015a):

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- class k = 1 (in green)—there is an acceptable level of sustainability of remanufacturing operations and no improvement actions are needed;
- class k = 2 (in yellow)—there is a conditionally acceptable level of sustainability of remanufacturing operations, which requires corrective actions, as soon as it is economically and organizationally possible;
- class k = 3 (in red)—there is an unacceptable level of sustainability of remanufacturing operations, which requires corrective actions.

The designed by the authors roadmap provides the guidelines on how to improve the current level of maturity regarding the sustainable usage of resources in remanufacturing operations. It helps to identify the area of operations which need improvements. In the next sections we present the process of creating the roadmap and its application potential.

2 Methodology

The roadmap was developed based on the data collected from small and medium sized Polish automotive parts remanufacturers. The aim was to first identify the drivers and facilitators which help the companies to improve their operations with regard to the sustainability. The roadmap is aiming also to provide some action plan towards implementation of necessary measures.

Roadmap is a useful tool, which is used to capture and communicate the outputs from the strategic planning process towards their implementation (Holmes et al. 2004). Technological roadmap presents the relationship between the market, products and technology parameters and identifies the objectives related to the required effort (Kappel 2001). Phaal et al. (2004) identified 8 purposes for preparing roadmaps:

- Product planning—where roadmaps are used to link planned technology and product development,
- Service/capability planning—where roadmaps focus on how technology supports organizational capabilities. It is mostly used in service–based enterprises,
- Strategic planning—where roadmaps are used to support evaluation of different opportunities and threats,
- Long-range planning—where roadmaps are elaborated at sectorial or national level and act as an radar to discover disruptive technologies and markets,
- Knowledge asset planning—where roadmap links the skills, technologies and competencies required to meet future markets demand,
- Programme planning—where roadmap focuses on implementation of general strategy to particular project development, it shows relationships between technology development and project’s milestones,
- Process planning—where roadmap supports new product development by incorporating both technical and commercial aspects,

- Integration planning—this type roadmap focuses on integration and evolution of technology shows how different technologies can be combined to form new technology or system.

In order to create a technology roadmap the two basic dimensions need to be defined, as follows (Phaal et al. 2004): timeframes and amount of layers. The timeframe depends on the industry. For example in case of industries where the technology and market conditions are changing in very short cycles (e.g. electronics), there is no point in building roadmap for 10 years. Phaal and Muller (2009) recommend five main timeframes:

- The past—in this perspective it can be determined which events and factors have led to the current situation. It can be learning point for future actions.
- A short time horizon (now)—this is usually a one year horizon. This is a very important part of the map as it will be converted into real plans and activities, which will influence the future.
- The medium time horizon (plans)—the period between 1 and 3 years (usually), combined with the strategic plan, featuring the main directions and actions affecting the plans and decisions in the short term.
- A long-term perspective (future)—usually a period of between 3 and 10 years, a combination between the average time horizon and the vision and aspirations of the organization. In this horizon should be identified uncertainties and future scenarios, technological changes, the market and the market environment should be identified in order to establish a mechanism radar that can detect and assess certain phenomena that affect current decisions.
- The vision—it is long-time aspirations of the organization, including the definition of the mission.

The layers of the proposed system must be customized and suited to the analysis of the specific organization and problem. The first stage of work on the map is to define the layers and sublayers. Characteristics of the layers is presented in Table 1.

The multi-layer roadmap is presented in Fig. 1. The top layer relates trends and economic, environmental, social drivers with the goal of the roadmap. The middle layer is focused on mechanism through which goals are achieved, like: products, services, performance, requirements, operations (Phaal et al. 2005). The last layer presents resources which are needed to achieve the defined goal.

The literature review has showed that in case of remanufacturing the road map is applied very seldom. The search through databases: Science Direct, Business Source Premier and Google scholar databases were used with criterion "*remanufacturing*" + "*roadmaps*" and "*roadmapping in remanufacturing*", showed very limited results. We grouped the relevant papers into four categories:

- Technology roadmaps for sustainable manufacturing (remanufacturing included marginally) (Mishima and Umeda 2012; Seliger et al. 2008; Valkokari et al. 2014; IMS2020 2010)

Table 1 Characteristics of layers of technology roadmap

Layer	Sub-layer	The main issue	Qualifying question
L1 Market drivers	Market, customers, competition, Environment, business, trends, threats, strategy	The purpose with some factors affecting it	Know—why?
L2 Products/process	Features, functions, performance, services, processes, systems, capabilities	The mechanism of achieving the purpose	Know—what?
L3 Technology/ resources	Technology, competences, knowledge, science, resources, infrastructure, finance, standards, R&D projects	Everything what is required to develop products/services/systems	Know—how?

The own studies based on (Phaal and Muller 2009; Phaal et al. 2005)

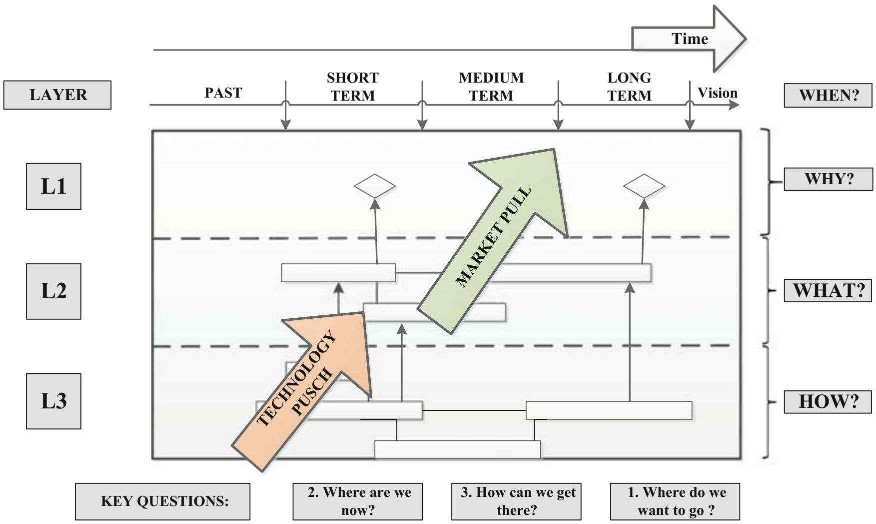

Fig. 1 Multi-layer scheme roadmap. Own study based on Phaal and Muller (2009), Phaal et al. (2005)

- Technology roadmaps for sustainable supply chain (remanufacturing included marginally) (Glenn et al. 2005; Dev and Shankar 2015)
- Technology roadmaps for end-of-life management (Cheung et al. 2015; Wang and Cheng 2013; Juehling et al. 2010)
- Technology roadmaps for design for remanufacturing (Cunha et al. 2011).

The most relevant to our research is the paper of Cunha et al. (2011). The authors applied T-Plan methodology to elaborate technology roadmap in order to identify

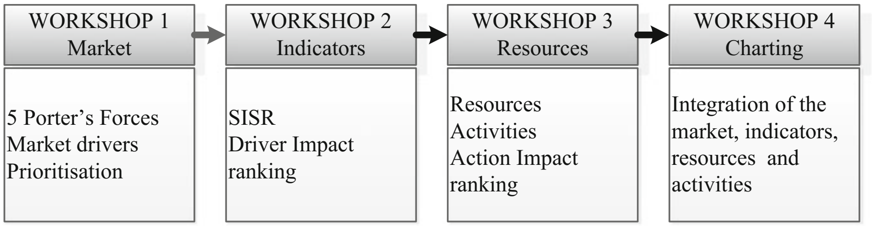

Fig. 2 Research methodology

how to improve the remanufacturing of production equipment, and to develop the new technologies to satisfy the market drivers.

Based on the findings from literature review we decided to also applied the T-plan roadmapping approach. The main advantage of the T-plan is its simplicity, and ability to be used for strategic and tactical planning.

The T-plan methodology recommends to make 4 workshops on: (1) market, (2) product, (3) technology and (4) roadmapping through linking technology resources to the future market opportunities and marking the existing gaps (Phaal et al. 2004).

Our aim was to developed the roadmaps which to guide RSMEs through decision-making process to improve usage of resources in the remanufacturing operations (with focus on automotive parts remanufacturing). We also aimed to link the roadmapinkg with the concepts of the maturity level of sustainable resource utilization. For these reasons we have modified the initial T-plan method as presented in Fig. 2.

In the first workshop (W1), as suggested by Phall et al. (2004) were identified the market drivers, which showed market trends. The second workshop (W2) aimed to identify the links between indicators which were used to described the maturity level of resources utilization (SISR—Sustainability Indicators System for Remanufacturing) and the market drivers. The third workshop (W3) focused on identification of the necessary resources and actions that affected the indicators values. The fourth workshop (W4) aimed to visualize the relationship between the effects of previous workshops, and to show the holistic perspective including the time dimension. The results of the each workshop are discussed in the next section.

3 The Development of the Technology Roadmap for Remanufacturing

3.1 Market Workshop

The main goal of the Market Workshop (W1) was to identify which markets trends are most influential and are driving the development of more sustainable remanufacturing operations in Poland. The basic characteristic of the first workshop is presented in Table 2.

T-Plan methodology recommends a set of tools to perform market drivers analysis. We decided to use common tool for strategic analysis, which was the Porter's five forces analysis. In order to find the drivers which were relevant in the context of sustainability, we examined the dimensions, as follows: suppliers, buyers, substitutes, competitive rivalry, market conditions for potential new entry (as presented in Fig. 3).

In the next stage of the analysis the designated drivers from the Porter's model were assessed. Each driver (d_i) was analyzed from the perspective of its importance level (z) (Table 3). The importance level (z) was evaluated on simple scale, as follows: z = 1—low impact, z = 2—moderate impact, z = 3—high impact.

For the further analysis only drivers with the importance level z = 3 were taken into consideration.

Table 2 Characteristic of the workshop W1

Characteristic	Description
Workshop name	Market
Objective	Identification of the most important market drivers for RSME's
Input data	Market analysis for remanufacturing SME's
Process steps	1. 5 Porter's forces analysis 2. Identification of market drivers 3. Drivers impact ranking 4. Identification of the most powerful drivers

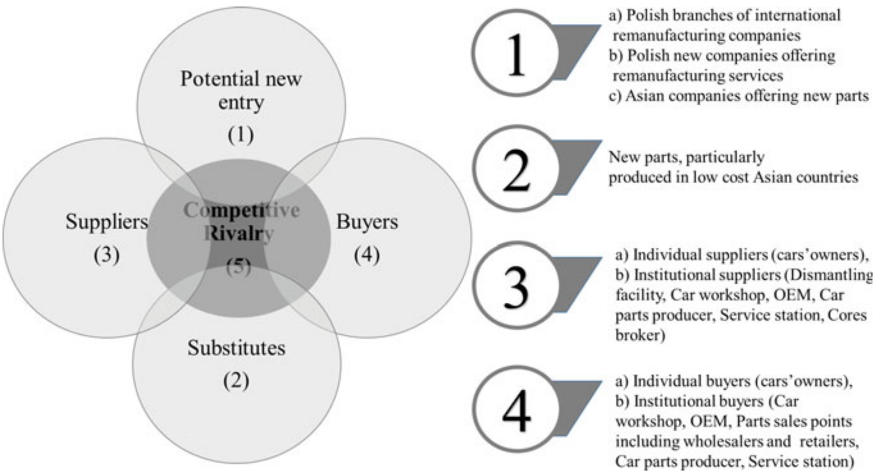

Fig. 3 Porter's model

3.2 Indicators Workshop

In roadmapping the common second step is to assess the influence of the identified markets drivers (from W1) on the product, process or service. In case of our roadmap the second workshop was dedicated to identify the sensitivity levels of the sustainability indicators, which we developed in the previous research. We used so called SISR (Sustainability Indicators System for Remanufacturing). The system is described in detailed in the Chapter Determining the Importance of the Criteria for Assessment of Sustainability in Remanufacturing Companies of this book. These indicators are designed to evaluate the resource utilization of a company taking into consideration 3 dimensions of sustainability. The definitions of each indicator is also presented in work of Golinska et al. (2015a). The basic characteristic of the workshop W2 is presented in Table 4.

We made assumption that companies use their resources efficiently and in more sustainable way when they achieve higher level of remanufacturing process maturity (Golinska and Kübler 2014). The company maturity level assessment results from the value of the 15 indicators in SISR. We created the matrix of influence (see Table 5) to find out which indicators values are most sensitive to changes of the most important market drivers (from W1). Every participant of the workshops W2 graded each factor with the following scale:

- i = 0—no effect;
- i = 1—low impact;
- i = 2—moderate impact;
- i = 3—large impact;
- i = 4—a very big impact.

The summary of the assessment process is presented in Table 5. In order to identify the most sensitive indicators to changes in the market driver the results were normalized by scaling between 0 and 1. The most sensitive (results over 0.75) are indicators: Overall out of stock (OOS), Employment, Overall equipment effectiveness (OEE) and Material recovery rate (MRR). This findings corresponds with the results of our previous survey on group of over 40 RSMEs in automotive sector in Poland (see Golinska et al. 2015b). The majority of respondents there stated (87.5%) that they struggle to reach lot size bigger 1 piece. The very high variety of products variants make impossible to automate most of the operations in the remanufacturing process. The manual operations required advanced technical skills of employees. The respondents were complaining about the difficulty to find suitable employees because of the demographics trends and also shift on the job market towards service and high-tech industries. Lack of economy of scale also negatively influence the overall equipment effectiveness. The respondents also stated that the constant flow of cheap automotive parts from emerging markets (e.g. China) negatively influence the availability of cores for remanufacturing (impact on OOS value).

Table 3 Identification of drivers with the use of Porter's five forces analysis

No	Driver (d_i)	z	Dimension of the Porter's model
1.1	New technologies are relatively rarely used by the RMEs (mainly manual work – relatively low equipment's cost)	3	1. Threat of new entry
1.2	The companies are very similar in their structure and business model	1	
1.3	Increasing importance of sustainable purchasing models	3	
1.4	Similar products portfolio (most of the RMEs provide services for others so brand identity is low)	1	
1.5	Difficulties to achieve economy of scale	2	
1.6.	Global companies (including OEMs) entering the market	3	
2.1.	Low price of new parts from Asian markets	2	2. Threat of substitutes
2.2.	Frequent changes of products' version (shorter lifecycles and models' proliferation)	2	
3.1.	Trend for closing material loops (the purchaser of new products, as well as the remanufacturing) become suppliers for remanufacturers (e.g. repair services, car owners)	2	3. Bargaining power of suppliers
3.2.	Mismatch between supply and demand	1	
3.3.	Insufficient quality and quantity of cores	3	
3.4	Grey zone extinction—because of more strict laws and better databases (e.g. central register of vehicles) and growing environmental awareness it will be more difficult to operate in the grey zone (e.g. unauthorized vehicle dismantling). The disappearance of the grey zone should increase the input stream to the remanufacturing process	3	
4.1.	Dispersion of buyers	1	4. Bargaining power of customers
4.2.	Insufficient scale of purchases	1	
4.3.	Growing products' standardization	3	
4.4	More sustainable utilization model	3	
4.5	PULL paradigm—the buyer starts the process, since in RMSEs mainly remanufacture-to-order (buyer after delivery of the core starts the process)	3	
4.6	Growing environmental awareness of buyers	2	
5.1.	More restrict and common end of life laws	3	5. Competitive rivalry
5.2.	Increasing environmental awareness of society	1	
5.3	Certification of remanufacturing processes and products —it means that workers are trained and processes are well described, which brings benefits to enterprises (including less defects—fewer complaints) The process requires lower materials and energy consumption, which also translates into lower labor intensity resulting in greater comfort of employees	3	

(continued)

Table 3 (continued)

No	Driver (d_i)	z	Dimension of the Porter's model
5.4	Increasing importance of design for remanufacturing	3	
5.5	Growing remanufactured products' attractiveness	3	
5.6	Shortage of qualified staff for highly manual remanufacturing operations	3	

Table 4 Characteristic of the workshop W2

Characteristic	Description
Workshop name	Indicators
Objective	Identification the sensitivity level of the indicators (s)
Input data	• SISR • Market Drivers with the highest importance (from W1)
Process steps	1. Evaluation of the impact of market drivers on indicators 2. Creating the matrix of influence 3. Normalization of the results 4. Identification of the most sensitive indicators to changes in the market

Source Own elaboration

The sensitivity level analysis shows which indicators are most exposed to change their values when the market conditions might change. For this reason they should be monitored more carefully. The actions taken in case of the positive change of the market conditions, should result in the improvement of the maturity level of the remanufacturing process and more efficient use of resources.

3.3 Resources Workshop

In T-plan methodology usually the third Workshop (W3) focused on technology. In case of our roadmap the focus was placed on more sustainable utilization of resources. During W3 we reviewed the results from the market and indictors workshops. After the brainstorming session on how resources can be used more sustainable in remanufacturing process we created a list of potential actions which might be taken to improve the values of the SISR in order to achieve a higher level of remanufacturing process maturity. We made classification of the activities according to their impact on sustainability indicators. Finally we were able to identify the most influential actions for increasing maturity level of sustainable recourse utilization. The basic characteristic of the workshop is presented in Table 6.

Table 5 Evaluation of the impact of the drivers on the indicators SISR

Indicator	Market drivers							
	1. New technology	2. Sustain able purchasing model	3. Competition in the sector	4. Cores' supplies	5. Grey zone extinction	6. Products' standardization	7. Sustainable utilization model	8. PULL Paradigm
1. Over equipment effectiveness (OEE)	4	2	3	2	2	4	3	4
2. Remanufacturing process flow (RPF)	2	2	2	2	2	4	3	4
3. Planning adequacy (PA)	2	2	2	2	2	4	3	3
4. Availability of machines & tools (AMT)	4	2	2	2	2	3	3	3
5. Service level (SL)	1	4	2	4	4	2	3	2
6. Overall out of stock (OOS)	1	4	4	4	4	2	4	4
7. Energy consumption level (ECL)	3	2	2	2	2	3	3	2
8. Waste generation level (WGE)	3	2	2	3	3	3	3	2
9. Material recovery rate (MRR)	2	2	2	4	4	3	4	4
10. Generated emissions level (GEL)	4	2	2	2	2	3	3	2
11. Employment (E)	4	4	4	3	3	2	2	3
12. Staff Training (ST)	2	2	4	2	2	3	3	2
13. Harmfulness of the remanufacturing process (HRP)	3	1	2	2	2	2	2	2
14. Average level of comfort at work (AVC)	3	2	3	3	3	3	3	3
15. Innovation level (I)	2	1	2	2	2	3	2	2

(continued)

Table 5 (continued)

Indicator	Market drivers					
	9. End of life laws	10. Certification of processes & products	11. Design for remanufacturing	12. Products' attractiveness	13. Shortage of qualified staff	Results (sensitivity levels)
1. Over equipment effectiveness (OEE)	1	3	4	3	3	0.75
2. Remanufacturing process flow (RPF)	1	4	3	2	3	0.50
3. Planning adequacy (PA)	1	2	3	3	3	0.38
4. Availability of machines & tools (AMT)	1	3	2	2	1	0.25
5. Service level (SL)	1	4	3	3	1	0.50
6. Overall out of stock (OOS)	4	2	4	4	1	1.00
7. Energy consumption level (ECL)	4	4	3	2	1	0.44
8. Waste generation level (WGE)	4	3	4	3	1	0.63
9. Material recovery rate (MRR)	2	2	4	4	1	0.75
10. Generated emissions level (GEL)	4	4	3	2	1	0.50
11. Employment (E)	3	2	2	3	4	0.81
12. Staff Training (ST)	1	4	2	2	3	0.38
13. Harmfulness of the remanufacturing process (HRP)	3	3	2	2	3	0.19
14. Average level of comfort at work (AVC)	2	3	4	3	2	0.69
15. Innovation level (I)	2	3	1	2	2	0.00

Table 6 Characteristic of the workshop W3

Characteristic	Description
Workshop name	Resources
Objective	Identification of the actions which should be taken in order to achieve a higher level of remanufacturing process maturity in terms of sustainability
Input data	Case study results using RPA method (rapid plant assessment) Results of the conducted ReMC analysis (remanufacturing operations muda checklist) Sensitivity level of each indicator (from W2)
Process steps	1. Resource identification 2. Resource categorization 3. Definition of improvement actions in remanufacturing (providing higher process maturity level) 4. Linking actions with resources 5. Ranking the impact of each action on each indicator (influence matrix) 6. Normalization of the results 7. Classification of the activities according to the greatest impact on sustainability indicators 8. Identification of the most influential activities for increasing maturity level of sustainability

Table 7 Categorization of improvement actions

Resource category	Subcategory				
	Availability (A)	Standardization (S)	Effectiveness		
			Eco	Econ	Soc
Materials (M)	M–A	M–S	M–Eco	M–Econ	M–Soc
Information (I)	I–A	I–S	I–Eco	I–Econ	I–Soc
Employee (E)	E–A	E–S	E–Eco	E–Econ	E–Soc
Machines and tools (MT)	MT–A	MT–S	MT–Eco	MT–Eco	MT–Soc

The resources used in the remanufacturing process in small and medium sized enterprises were divided into four categories: materials, information, employee, machines and tools.

During the brainstorming sessions we created list of the 64 actions which contributing to the more sustainable resources utilization in remanufacturing process. Then they were allocated to subcategories, depending whether they might focus on improving availability, standardization or effectiveness of the resources (see Table 7). The list of actions is presented in Table 8.

The distribution of the improvement actions between the subcategories is presented Fig. 4.

In case of resources, like materials and information most of the suggested improvements actions focused on standardization. The remanufacturing process in small and medium sized enterprises is "difficult to standardize partly due to the

Table 8 Identified actions and their classification

No.	Actions	Category
1	Simplifying dismantling operations	E–S
2	Creating information feedback mechanism between the RSMEs and OEMS	I–Econ
3	Creating system of measurement and reporting of energy consumption for remanufacturing process	MT–Eco
4	Reducing idling time and setups	MT–A
5	Optimizing layout	E–A
6	Designating of places of storage of the waste and the works in progress	M–Econ
7	Isolating of equipment and surfaces in order to minimize heat loss	MT–Eco
8	Using air filters	MT–Eco
9	Applying of water soluble cleaners	MT–Eco
10	Optimizing parameters and the temperature of the washing and the choice of suitable cleaners	MT–Eco
11	Monitoring of the lighting levels	E–Soc
12	Job scheduling in advance	MT–A
13	Optimizing the lot size	MT–A
14	Reducing friction in machines	MT–A
15	Optimizing times and temperature of drying	MT–Eco
16	Eliminating the storage of materials in the production hall	M–A
17	Implementing ISO standards	I–S
18	Creating work stand's instructions and working standards for each operations	E–S
19	Implementing 5S	E–S
20	Limiting the number of operations performed in a standing position	E–Soc
21	Implementing tools for demand forecasting	M–A
22	Implementation of the plan of preventive maintenance	MT–A
23	Improving machine setups (SMED)	MT–A
24	Establishing a system of clear orders' marking and monitoring of their movement through the process	M–S
25	Introducing of Checklist for the proper verification of the quality of the core at the entrance to the process (disassembly checklist)	M–S
26	Introducing of the principles of maintenance tools and periodic quality control of tools	MT–S
27	Introducing idea boxes	E–Soc
28	Paying incentives for employees, who improvements are implemented	E–Soc
29	Internal training (e.g. relating to the complaint, the quality issues)	E–Soc
30	Verifying of complaints in order to prevent future shortcomings	P–Econ
31	Limiting distances between workstations (line system if possible)	E–A
32	Describing the operational goals & providing their transparent measuring system	I–S
33	Job rotation	E–Soc
34	Active participation in the practical training of future employees (training options for pupils on site)	E–Soc

(continued)

Table 8 (continued)

No.	Actions	Category
35	Using exclusively the waterborne paints and varnishes	MT–Eco
36	Using safe spraying booths	MT–Eco
37	Creating instructions for separating waste	M–S
38	Determining of safe storage of waste in the production hall	M–S
39	Using mainly reusable transport containers (both internal and external)	M–S
40	Applying KANBAN	M–S
41	Applying FMEA	M–S
42	Analysis and elimination of waste using Muda checklists	M–S
43	Applying ISO 140001	MT–Eco
44	Use mainly materials suitable for recycling or other reuse options	M–Eco
45	Avoiding/reducing usage of toxic substances	M–Eco
46	Local sourcing	M–Econ
47	Creating manuals for operators to facilitate components' substitution.	I–S
48	Creating system of transparency orders and components indexing	I–S
49	Creating visual data base for easy products' types identification	I–S
50	Networking with other RSMEs	I–S
51	Periodic reviews of the cores' inventory and establishing guidelines to scrap them	M–S
52	Verifying the cores at the process entrance for assessment of the potential profitability (gatekeeping)	M–Econ
53	Creating guidelines for verifying the cores after disassembly to assess the usage rate of particular components	M–Econ
54	Designating clear and undistributed transportation ways at the production hall	MT–S
55	Setting system for transparent work monitoring	P–S
56	Training employees to multi tasks work (a minimum of 2 workstation)	E–Soc
57	Training of workers to self-control of quality	E–Soc
58	Rationalizing of the material needs	M–A
59	Eliminating of unnecessary movements while working	E–Soc
60	Elaboration of principles of the materials feeding for each workplace	I–S
61	Standardizing of production documents (for example, production order)	I–S
62	Monitoring of the training needs of employees	E–Soc
63	Noise monitoring and reduction	MT–Eco
64	Products' portfolio optimizing	M–Econ

variability of components parts, products and processes" (Guidat et al. 2015). The Polish small remanufacturers suffer from very high variability of products variants, which influence the profitability of their operations and limits the application of more efficient organization and resources utilization (Golinska et al. 2015b). The standardization of operations, the information exchange and work routines help to reach better utilization level of resources.

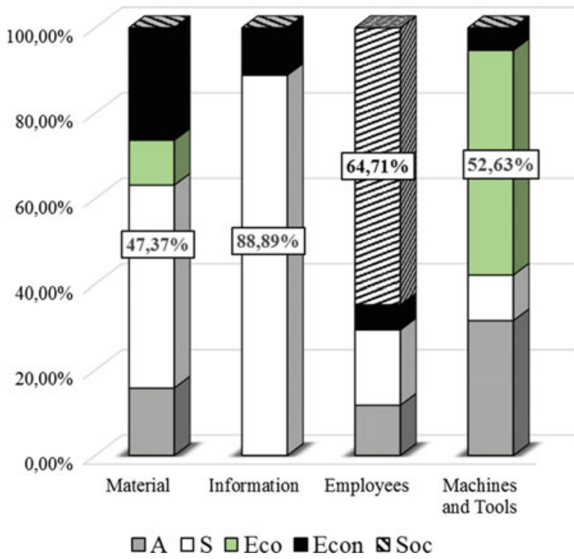

Fig. 4 Sectional activity analysis

In the case of human resources most of the actions (over 60%) focus on improving the effectiveness by creating more friendly and safe work environment.

The actions which focus on improvements of usage of Machines and Tools are aiming on improving of the ecological effectiveness. However about 30% of proposed actions also include introduction of standardization procedures.

After the actions were linked with appropriate resources then we ranked the impact of each action on each indicator from SISR (influence matrix). The Influence matrix is presented in Table 9. The numbering of the actions respond to those presented in Table 8, and numbering of the indicators responds to those presented in Table 5. At the intersection of the column (indicators) and line (action) is analyzed the impact of the actions on the indicators and are presented the evaluation according to the previously described scale (i = {0, 1, 2, 3, 4}). The results (last column) were normalized by scaling between 0 and 1 to facilitate comparisons of the scores. In the result there is obtained the answer for the previous question about the most desirable actions which have the greatest impact on sustainability indicators.

Authors divided all actions into 7 classes according to the normalized results (Table 10).

Class boundaries were estimated with the use of the statistics method. Authors made calculations with the different class number from 3 till 7. The best results were achieved when dividing actions into 7 classes. The analysis showed that there were 13 actions, which had a high impact on the SISR.

These were the actions no: 5, 10, 12, 13, 14, 16, 23, 24, 25, 26, 43, 45, 47, which accounts for about 20% of all relevant activities. There can be applied Pareto rule that 20% of all actions may cause 80% effect in sustainability improvement.

Table 9 Influence matrix: activity—indicators

Sensitivity (s)	0.75	0.50	0.38	0.25	0.50	1.00	0.44	0.63	0.75	0.50	0.81	0.38	0.19	0.69	0.00	Result	Normalized result
Indicator No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
Activity																	
1	1	1	1	1	1	1	1	1	3	1	2	2	4	4	3	13.06	0.01
2	3	2	3	3	2	2	1	1	2	1	1	1	1	1	1	19.81	0.38
3	2	2	2	3	1	1	4	2	1	4	1	1	2	1	1	15.75	0.16
4	4	3	3	3	1	1	2	2	2	2	1	1	1	1	1	15.69	0.16
5	3	3	2	2	1	1	3	2	1	3	1	1	1	4	1	26.13	0.73
6	3	3	2	3	2	4	1	4	2	1	1	1	2	2	1	19.69	0.38
7	2	2	1	2	1	1	4	2	1	4	1	1	2	2	1	23.81	0.60
8	2	2	1	2	1	1	4	2	1	4	1	1	2	2	1	15.81	0.16
9	2	2	1	2	1	1	3	2	1	4	1	1	2	2	1	23.81	0.60
10	2	2	1	2	1	1	4	2	1	4	1	1	2	2	1	27.81	0.89
11	2	2	1	2	1	1	4	2	2	3	1	1	4	4	1	25.81	0.83
12	4	4	4	4	2	2	3	2	2	3	2	1	1	3	1	31.00	1.00
13	4	4	4	4	2	2	3	2	2	3	2	1	1	3	1	31.00	1.00
14	4	3	2	4	2	2	4	3	3	3	2	1	1	2	1	30.44	0.98
15	2	2	1	2	1	1	4	2	1	4	1	1	2	2	1	23.81	0.76
16	3	4	2	2	2	4	2	3	2	2	1	1	1	3	1	26.31	0.84
17	2	2	2	2	2	2	2	2	2	2	2	4	2	2	2	23.38	0.75
18	3	3	3	3	3	2	2	2	2	2	2	3	3	4	3	22.94	0.73
19	3	3	3	3	3	2	2	2	2	2	2	3	3	4	3	22.94	0.73
20	1	1	1	1	2	1	1	2	2	1	2	3	3	4	3	15.19	0.47
21	3	4	3	2	2	4	2	3	2	2	2	2	1	3	1	23.88	0.76
22	4	4	3	4	2	3	3	3	3	3	2	2	3	3	1	24.75	0.79

(continued)

Table 9 (continued)

Sensitivity (s)	0.75	0.50	0.38	0.25	0.50	1.00	0.44	0.63	0.75	0.50	0.81	0.38	0.19	0.69	0.00	Result	Normalized result
Indicator No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
Activity																	
23	4	4	3	4	2	3	3	3	3	3	2	2	3	3	1	27.75	0.89
24	3	4	3	2	2	3	3	3	3	2	2	2	2	2	2	28.13	0.90
25	3	4	4	2	3	3	3	4	4	2	2	2	2	2	2	30.38	0.98
26	4	4	3	4	2	3	3	3	3	3	2	2	3	3	1	30.75	0.99
27	2	2	2	2	2	2	2	2	2	2	2	3	2	3	4	21.69	0.69
28	2	2	2	2	2	2	2	2	2	2	2	3	2	3	4	21.69	0.69
29	2	2	2	2	2	2	2	2	2	2	3	3	2	3	4	20.50	0.65
30	2	2	2	2	4	2	2	2	3	2	2	2	2	2	2	20.38	0.65
31	4	4	3	3	2	3	2	2	2	2	2	2	2	2	1	22.75	0.73
32	3	2	4	3	3	2	2	2	3	2	2	2	2	2	2	21.63	0.69
33	3	2	2	4	2	2	2	2	2	2	3	3	3	4	3	22.63	0.72
34	2	2	2	2	2	2	2	2	2	2	4	3	1	3	3	21.13	0.67
35	1	1	1	1	1	1	3	3	3	4	1	1	3	3	1	19.31	0.61
36	1	1	1	1	1	1	3	3	3	4	1	1	3	3	1	19.31	0.61
37	1	1	1	1	1	1	3	4	3	3	1	1	2	3	1	22.25	0.71
38	1	1	1	1	1	1	3	4	3	3	1	1	4	3	1	22.63	0.72
39	1	3	1	1	1	3	2	2	3	2	1	1	2	3	1	20.50	0.65
40	2	3	1	1	4	3	2	2	3	2	1	2	2	3	1	23.13	0.74
41	2	3	1	2	3	2	2	2	3	2	1	2	3	3	2	20.06	0.64
42	4	3	3	3	3	3	2	2	3	2	1	2	3	4	3	24.25	0.78
43	2	2	1	2	4	2	4	4	3	4	1	3	3	3	2	26.69	0.86
44	2	2	1	1	2	3	3	4	3	4	1	1	3	3	2	23.69	0.76

(continued)

Table 9 (continued)

Sensitivity (s)	0.75	0.50	0.38	0.25	0.50	1.00	0.44	0.63	0.75	0.50	0.81	0.38	0.19	0.69	0.00	Result	Normalized result
Indicator No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
Activity																	
45	2	2	1	1	2	3	3	4	2	4	1	1	4	3	2	29.13	0.94
46	3	3	3	1	3	4	2	2	2	2	2	2	2	2	1	24.50	0.78
47	3	3	3	2	4	4	2	2	2	2	2	2	2	3	1	25.94	0.83
48	3	3	3	2	4	4	2	2	2	2	2	2	2	3	1	23.94	0.76
49	3	3	3	2	4	4	2	2	2	2	3	3	2	3	3	25.13	0.80
50	2	2	2	2	3	3	2	2	2	2	3	4	2	3	3	22.38	0.71
51	2	3	3	2	3	4	2	3	4	2	2	2	2	2	2	24.13	0.77
52	2	3	3	2	3	4	2	3	4	2	2	2	2	2	2	24.13	0.77
53	2	3	3	2	3	4	2	3	4	2	2	2	2	2	2	24.13	0.77
54	4	3	3	2	3	3	2	2	2	2	2	2	3	4	1	24.06	0.77
55	4	3	4	3	3	2	2	2	2	2	2	2	2	4	1	23.50	0.75
56	3	2	2	4	2	2	2	2	2	2	3	3	2	3	3	21.75	0.69
57	4	2	2	2	4	2	2	3	2	2	2	3	2	3	2	22.81	0.73
58	4	3	3	3	3	4	2	3	1	1	1	1	1	1	1	21.06	0.67
59	3	1	1	1	1	1	1	1	1	1	2	2	3	4	2	14.44	0.45
60	4	3	3	3	2	4	2	2	2	2	2	2	2	3	1	23.94	0.76
61	1	3	3	3	2	4	2	2	2	2	2	3	2	4	2	20.75	0.66
62	1	1	1	1	1	1	1	1	1	1	2	4	2	3	1	12.81	0.39
63	1	1	1	1	1	1	1	1	1	2	2	1	4	4	1	13.25	0.41
64	3	3	3	3	3	2	2	2	2	2	2	1	1	3	1	19.13	0.60

Table 10 Class intervals for actions

Class	Impact on SISR	Class boundaries		Frequency	Frequency accumulated	Percentage share (%)
1	Low	<0.000	0.143)	5	5	7.81
2	Low	<0.143	0.286)	3	8	12.50
3	Medium	<0.286	0.429)	8	16	25.00
4	Medium	<0.429	0.571)	17	33	51.56
5	Medium	<0.571	0.714)	18	51	79.69
6	High	<0.714	0.857)	7	58	90.63
7	High	<0.857	1.000)	6	64	100.00

Table 11 Characteristic of the workshop W4

Characteristic	Description
Workshop name	Charting
Objective	Roadmap for remanufacturing SME's
Input data	• Market Drivers with the highest importance (from W1) • SISR • Activities categorized from the perspective of the resources in remanufacturing company (from W3)
Process steps	1. Layers definition 2. Determination relationship between Market drivers and SISR 3. Linking relationships 4. Determination relationship between actions and SISR 5. Linking relationships 6. Visualization of the roadmap for remanufacturing 7. Establishment of the implementation plan

It can be assumed with high probability that when a company takes such actions, it will improve the SISR indicators values to such an extent that it would reach a higher maturity level of a remanufacturing process in terms of sustainability and would benefit from market-based drivers.

3.4 *Charting Workshop*

During the last workshop we reviewed the results from previous workshops. Then we focused on the layers definition and determination of the relations between market drivers and SISR. In the next step the actions were linked to the indicators. All the links were visualized in the roadmap The basic characteristic of the workshop W4 is presented in Table 11.

The prepared roadmap aims to help companies to implement actions which will result in more sustainable resources utilization in RSMEs and operations higher maturity level. According to the presented methodology a company has a long road to achieve that target. Firstly, a company has to know how do the market drivers influence the indicators (SISR). Moreover the resources should be identify (what is available, what is the resources' quality). In the result company is able to select proper set of actions leading to higher resources utilization (Fig. 5).

In Fig. 6 are presented the layers, which were identified in the previous workshops, namely: market drivers, indicators, resources. The next step was to establish links between layers. The result of the linking layers in the roadmap is illustrated in Fig. 6.

Fig. 5 Concept of the technology roadmap for remanufacturing

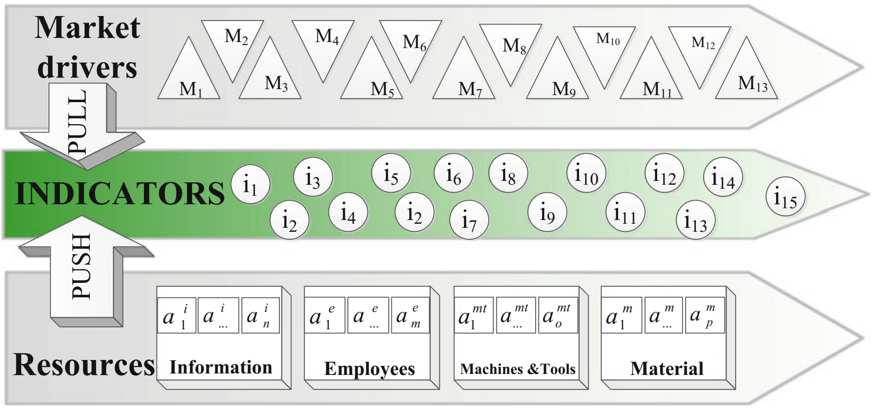

Fig. 6 Roadmap

In the proposed approach the relevant market drivers (M_1–M_{13}) have a direct impact on indicators (i) (PULL). The middle layer contained indicators, which are affected by the resources (PUSH).

Resources are divided into four groups including: information (I), employees (E), machines (M), tools and material (MT). In each appropriate activities according to the formula:

$$a_z^y \quad (1)$$

where

- y—resource group, $y \in \{$i (information); e (employees), mt (machines & tools), m (material)$\}$,
- z—number of activity in the resource group.

By taking appropriate measures the company can improve the value of the indicators. Map shows the relationship and direction of influence between the resources and indicators.

4 Conclusions

The aim of the chapter was to present the process of elaboration of the roadmap for improving the resources utilization in the remanufacturing operations. In the process of the roadmap construction were identified the relations among the market drivers, process indicators and resources in the RSMEs. The map provides a decision support for small and medium sized enterprises in the remanufacturing sector. It visualizes the relations between actions which might be taken and their effects on resources utilization in long term perspective. It presents the actions which can be taken in order to achieve a higher level of maturity in the remanufacturing process.

The study has some limitations. The proposed actions are rather general. Due the fact that each company can be initially at different levels of maturity of remanufacturing process in terms of sustainable resources utilization, therefore timeframe was not included in this roadmap. The chapter rather provides a framework and guidelines for detailed roadmap elaboration in a RSME.

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