Sustainability performance evaluation for selecting the Best Recycling Pathway During its Design Phase

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Abstract As the end of life products are becoming more and more complex, the recycling systems encountered many difficulties in valuing all the materials contained in each product. This involves not only recovering a large number of materials but also doing so with the minimal environmental impact. Although the benefits of recycling are well established, the industrial processes need to be designed in regard with their environmental impacts. That is why recyclers need robust assessment tools to make the right choices during the design of recycling processes. This evaluation's work should enable them to choose the right recycling solutions for a wide range of end of life products. In this article, we present how we develop a methodology for evaluating the performance of recycling processes during their design phase. This methodology is our answer to help optimize the recycling of multi materials products based on the evaluation of the sustainability performance of the processes chosen.

Keywords Recycling, ETV, design phase, Decision support tool, Performance Evaluation

1 Introduction

The rise of the world's population and its life conditions go hand in hand with the growth of energy and raw material consumption as well as the steady growth of CO2 concentration in the atmosphere [1, 2]. As the economy is mostly linear, the consumption's growth comes with an increase in the amount of waste produced annually [3]. Because the primary resources used are consumed and lost, the demand is not tenable in a long-term [4, 5]. It is therefore vital to find industrial

solutions to maintain standards of living equivalent while also decoupling resource use and demand [6]. The circular economy offers a partial answer to resource depletion [7]. Recycling is inherent in the circular economy strategies that is why industrial companies look for stepping recycling rates up. To do so they implement product centric End-of-Life (EoL) strategy using closed loop recycling [8]. Those strategies show good environmental performances but they rely on specific EoL processes. Furthermore, those EoL strategies require a suitable and efficient supply chain to reach the recycling plant. The different steps of an EoL scenario are shown on the Fig. 1. Unfortunately, the generalization of closed loop recycling is slowed down, if the economic balance is not favorable [9–11].

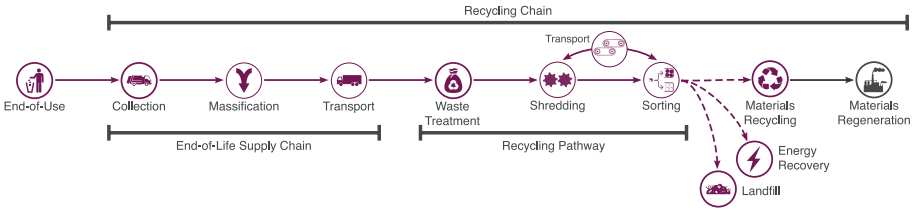


Fig. 1 Main steps of the End-of-Life chain including recycling pathway

MTB company, an international manufacturer of recycling technologies and a recycling operator in France, has launched a sustainability strategy. The aim of the strategy is to reduce the environmental impact of its industrial activities. To do so, MTB started to evaluate its environmental performance with evaluation tools such as Life Cycle Assessment (LCA) and Materials Flow Analysis (MFA). The first evaluation has been realized on an aluminum recycling process using only mechanical separation process instead of smelting. Results show the advantages of mechanical processes [12]. Based on these results from environmental evaluations, MTB implemented corrective measures to increase its environmental performance level [13]. Beyond optimizing recycling pathways in operation, these results also helped us to guide the research for new recycling processes which have been designed to be more sustainable [14]. All these steps help to enrich the company's own knowledge, but the evaluation process is long and requires strong stakeholder involvement at each assessment step.

To systematize this new practice and provide data relevancy to decision makers, a methodology was needed to integrate the Life Cycle Management (LCM) approach during the design phase. The technologies used for pre-recycling processes are multiple and it is important to determine the best combination according to different categories of indicators and not only financial performance. The purpose of our work is to provide the engineering team with the results of the environmental evaluation during the design phase. Based on this information, the engineering team

will be able to select the best recycling pathway. This method is intended more specifically to the wastes that are not recycled so far.
The construction of our approach has been broken up into several key stages. First, the evaluation tools (LCA, MFA) were used to characterize technologies and to identify the key impact category indicators. Next, the Environmental Technology Verification (ETV) was used to draw the evaluation framework for recycling pathway. Then, the final stage is the implementation of a decision-making tool for the engineering team. In this article, we present the interlinking of tools to conduct an evaluation during the design phase of recycling processes.

2 Methodological framework

2.1 Segmentation of recycling processes

The recycling pathways are mostly based on common elementary technologies. The elementary technology selection and order have a strong influence on the overall performance of the recycling chain [15]. This assembly achieves the targets of purity and quality specific to processed waste. The performances largely depend on the pathway rather than technological innovations [16], hence, the assembly choices of common sub-processes are one of the key points to design efficient recycling pathways. The Fig. 2 shows EoL's pathway alternatives for the same waste. The technologies used and the streams vary with recycling process choices. We have determined that recycling processes can be classified in three types [17]: shredding, separation and transport. In addition to these three families of process unit, there is the flow unit family.

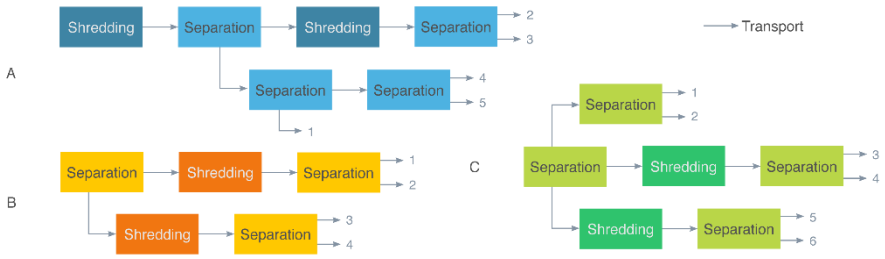


Fig. 2 Presentation of different pathways for the same waste

2.2 Unit process database

To support the evaluation, we launched the construction of a database for recycling processes. This database includes technical, environmental and economic dataset. On the one hand, for each data a part of the values is fixed. They are invariant data regardless the type of transformation performed by the unit process. This is mainly the impact of manufacturing, its price without the options or the weight of the equipment. On the other hand, in addition to these fixed values, the engineering team define values to adjust the unit process to the specificities of the customer needs. These are the operating variables. These actions will have a direct effect on the performance of the recycling pathway. Each unit process and its associate in/output flows can be modeling as shown on the Fig. 3.



Fig. 3 Modeling of a recycling pathway step with a separation unit process

To define the technical characterization of each unit process, we have chosen to implement the Environmental Technology Verification (ETV) protocol [18,19]. The main steps of the ETV program are given on Fig. 4. The whole ETV verification steps combine together last eight to eighteen months [20]. In comparison, the average designing time for a recycling pathway is between three and six months. Although ETV's verification time is too long for designers, the program provided general requirements, allowing to develop a self-assessment framework [21].

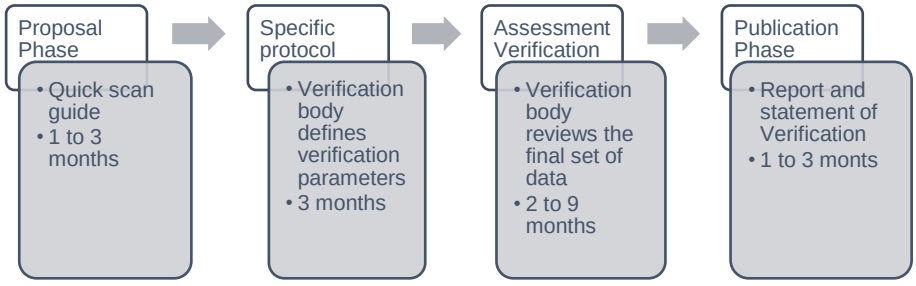


Fig. 4 Main steps of the European Environmental Technology Verification process

For the three families of unit process, the Tab. 1 gives the associate operational details and the technical characterization define using the ETV program. For each specific unit process, technical characterization will help to define the most suitable process for each purpose of the recycling pathway step.

Tab. 1 Variables and characterization for recycling each unit process family

Type	Operational Details	Characterization
Shredding	Type of technology (constraint) Cost of purchase Material losses Capacity	Reduction rate/Fineness
Separation	Type of technology (constraint) Cost of purchase Material losses Capacity	Effectiveness/Separation quality
Transport	Type of technology (constraint) Environmental characterization Cost of purchase Material losses Capacity	Rate flow
Elementary flow	Composition flow Physical properties Input or Output Market price	Purity

3 Results

3.1 Step by step evaluation methodology

Our assessment methodology has been developed to provide a coarse result in early design phases and to promote sustainable solutions. The methodology can be divided into several key steps. First, the general framework is built based on the customer needs and with the waste type specifications. This step allows to determine the specific constraints, delays and costs of the project in order to determine the initial specifications for the recycling pathway. In the continuity, the customer

provides its main orientations for the recycling process purpose. The customer defines the purpose and objectives for the recycling pathway. Next, the engineering team validate or not the main orientation of the recycling chain. From this orientation, the engineering team starts working on the recycling pathway proposal. The aim is to provide: treatment synoptic definition, selection of the main steps and the choice of technological bricks.

According to the recycling chain synoptic, for each step of the recycling pathway, MTB's Sales Team needs to select the appropriate technology and thanks to the expertise from MTB's Engineering Team the operating variables are selected. It is from this point that the database makes it possible to calculate the unit performances. This calculation is made according to the general settings, the specific information flow and the variables. At the end, a synthetic evaluation of the global process and unit steps is provided to allow discussion.

3.2 Unit process performance calculation

3.2.1 Technical performances

The technical performance indicators are oriented towards the capacity of the pathway to recycle the waste, so each unit process is described by three indicators. The calculation of these rates is made according to the standard [22].

- Recycling rate
- Recovery rate
- Landfill rate

3.2.2 Economic performances

For the economic dataset, data is easily accessible through the information provided by manufacturers and recyclers feedback. The Life Cycle Cost (LCC) analysis is used to determine the economic performance of each unit process. The LCC methodology used to consider both the costs of each system in addition to the profit from the sales of the sorted materials. However we do not include the costs of the environmental impact [23]. The economic performance is described by using three results:

- Initial investment costs
- Operating costs (cost per ton)

- Profit from recycled materials sales

3.2.3 Environmental performances

On the contrary, environmental data are rare and not available in the current Life Cycle Inventory database (ELCD, Gabi, Ecoinvent). Inventory data remains to be collected and assessed to build a strong dataset. Our team has started to build an environmental database for recycling processes. The result of environmental performance is given with one inventory indicator and two impact factor indicators (using ILCD methodology [24]):

- Total energy consumption
- Climate change
- Non-renewable resource depletion

4 Discussion

The decision tool aims to help the design team to implement more sustainable recycling pathway. It is not a matter of providing a comprehensive assessment for each recycling pathway during the design phase, but it is to communicate to industrial customers the performance indicators in addition to the economic indicators. These additional performance indicators should allow designers to propose optimization on recycling pathways and give a quantified result of the improvements. With an iterative approach, designers could optimize the flows and processes to contain impacts.

Although recycling lines are not new, industrial optimization has not been fully conducted [25]. The unconstructive approach, the complexity of waste and the lack of control over incoming flows limit the drafting of theoretical principles. The increasing interest in waste recycling and the evolving regulations in force steer the waste sector to adopt an increasingly industrial approach. To accompany this transition, it is a question of advancing the design methods with specific tools.

5 Conclusion

Even though plenty of technical options exist for developing recycling products, the recycling solutions selecting motivations are too often led by the pursuit of profit

growth which leads to a greater inefficiency [26]. By communicating additional performance indicators, we are convinced that this approach can evolve. And that new issues will be introduced in trade negotiations for recycling pathway.

As a next step, we need to build a sufficiently complete and robust database to support the evaluation of recycling pathway. This approach must be enriched in the future. It is also required to facilitate the improvement of the quality of results during the refining process variables and input parameters.

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