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Application of the MFA methodology for the analysis of paper and cardboard waste in Italy and a focus on the waste management in Apulia

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**Abstract (English)**

The raw materials crisis has put a strain on the paper market leading to a real supply race forcing recycled paper suppliers to decrease their production capacity. In recent year, the paper recovery market has undergone significant changes: just think how waste paper from the recycling cycle in Italy had a cost of zero euros in February 2020, at the Milan Chamber of Commerce, compared to 68 euros in February 2022. These figures drive home the importance of rethinking production cycles from the perspective of the circular economy.

In this study, the authors have studied the paper value chain to analyze the sustainability of the paper sector in Italy with a focus on the Apulian region using the Material Flow Analysis (MFA) tool, to identify critical points in the regional system. The authors' goal is to identify critical aspects of the current system as a starting point for future improvement scenarios aimed at greater circularity while responding to the logistical and economic needs of the sector.

1. **Introduction**

The guiding principle of the EU Waste Framework Directive (EU Directive 2008/98/EC) places a hierarchy in waste management outlining the prevention, and recycling, actions with a minimum threshold of 50% of waste recovery through separate collection. Differently, landfill represents the least sustainable management of MSW (municipal solid waste); on the contrary it has been the most widely used option in Europe and the most widely used in the world. The idea that maximizing waste collection leads to increased levels of recycling is often misleading. This is since there isn't a market for secondary materials, hence, the supply and demand for recycled materials are unbalanced, and recycled materials continue to be present in the market despite the lack of supply. It should be emphasized the importance of investing both in upgrading the old recycling plants and in the construction of recycling facilities as an alternative to landfills or to promote operative actions, such as a tax credit for recyclers and tax breaks for those who purchase recycled materials. Concerning waste recycling, the current scenario is divided into established supply chains (glass, paper, metal, wood, plastic) and still embryonic supply chains (electronic waste, aggregates, organic fraction, photovoltaic panels, etc.), for which there is enormous potential for development.

In this study, the authors have studied the paper value chain to analyze the sustainability of the paper sector in Italy with a focus on the Apulian region using the Material Flow Analysis (MFA) tool, to identify critical points in the regional system.

The rising costs of wastepaper and the absence in the Apulian territory of a paper mill, which therefore avoids an internal circularity of waste, have been the main reasons that led the authors to examine cardboard waste.

1. **The main literature review analyzed for the case study**

MFA tool is a methodology that provides useful information on direct flows to disposal and/or recovery that represent potential sources of secondary materials. For this reason, literature is often used to understand the life cycle to monitor wastes in and between the processes in the system. In waste management, there are different examples of research studies. [Stanisavljevic](https://journals.sagepub.com/doi/full/10.1177/0734242X15587735" \t "_blank) et al, 2015, evaluated different solid waste management scenarios at the regional scale, whereas Deshpande et al, 2020 show the importance to adopt MFA in the fish industry for supporting both industry and policymakers in realizing improvements. Villalba, 2020 developed a mass balance table to calculate and examine indicators for waste sub-circuits; Hsu, 2021 analyzed inefficiency and potential [leakage](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/leakage" \t "_blank) to natural systems of the plastic sector in Eu 28, and Amicarelli et al (2021) tested MFA to verify the reliability in sustainability assessments of the meat industry in Italy whereas Caldeira et al. 2021, assessed food waste through a combination of MFA and statistical information.

1. **Material and Methods**

3.1 Material flow analysis

The MFA is based on the mass balancing principle, and it is the central methodology of Industrial ecology. The MFA is a tool that measures incoming and outgoing materials while examining and measuring the flows of each material in the entire process. The application of MFA has recently increased in waste management, becoming a tool to support decisions at the policy and administrative levels. According to Brunner and Rechberger, (2004) the "MFA is a systematic assessment of material flows and stocks within a system defined in space and time”. In the current case study, the authors applied a top-down approach, collecting data through national reports, databases as well as a specific interview with local managers operating in the sector of paper and cardboard waste recycling, in Italy with a focus on Apulia. To evaluate the performance of collection, sorting, and recycling of recovered paper, the following indicators were defined: recovery rate (RR), recovery utilization rate (RUR), recovery import rate (RIR), and recovery export rate (RER).

As underlined in the literature there are different performance indicators, and the authors have chosen two material cycle indicators: the “Direct material input” (DMI) which measures the direct and actual input of materials into a well-defined national economy as the sum of domestic extraction plus physical imports and the “Material use efficiency” (MUE) which represents an appropriate value for quantifying the recovery of by-products (Hashimoto S. and Moriguchi Y. 2003). In addition, the "Total material input productivity" indicator was calculated to assess eco-efficiency.

Table 1 describes the methods of calculating the selected indicators.

Tab. 1 The methods of calculating wastepaper performance indicators.



Based on : Sevignè-Itoiz et al., 2014; Amicarelli et al., 2021

* 1. *Paper recycling in Italy and comparison with Apulia*

All data comes from official national reports of 2019, the year is taken as a reference for the study. In 2019, the value of the paper industry's turnover in Italy was 7.26 billion euros, down 6 percent from 2018. Paper production requires fibrous materials, such as virgin fiber and pulp, and non-fibrous materials, such as minerals and starches, as inputs. Paper recycling is a classic example of the circular economy both because of the features of the finished product, which is easily recyclable and biodegradable in the environment, and because fibers are currently fed back into the production cycle about 3.6 times. In Italy in 2019, there was a raw materials consumption of 10,085,000 t to produce 8,901,000 t of paper, where roughly more than 50% is represented by secondary material (Assocarta, 2020). In 2019, the paper collection for recycling was 6,564,000 t; import of paper for recycling is 311,000 t and export is 1,815,000 t, leading to paper recycling of 5,060,000 t.

Figure 1: Italy's paper recycling collection phase



The Apulian separate wastepaper collection is 198,750 t, which represents 10% of the total municipal waste (ISPRA, 2020). Of 198,750 of wastepaper 95% is sent to the selection platform, and successively transferred to different paper mills outside the region. Figure 2 depicts the cycle paper collection phase in Apulia in 2019. Wastepaper represents 43% of the total waste produced in Apulia.

Figure 2: Apulia paper recycling collection phase



**4. Discussion and conclusions**

The authors compared the results obtained in Italy with the results of Sevignè-Itoiz et al., 2014 for some performance indicators.

Table 1: Comparison of environmental performance indicators on wastepaper collection between Italy and Spain

***ITALY***

|  |  |  |  |
| --- | --- | --- | --- |
| *RR* | *RUR* | *RIR* | *RER* |
| *82,54%* | *73,74%* | *4,73%* | *27,65%* |

***SPAIN***

|  |  |  |  |
| --- | --- | --- | --- |
| *RR* | *RUR* | *RIR* | *RER* |
| *69,1%* | *78,5%* | *28,6%* | *19,4%* |

*RR: Recovery Rate; RUR: Recovered Utilization Rate; RIR: Recovered Import Rate; RER: Recovered Export Rate.*

Personal elaboration of the authors

The comparison between the Spanish and Italy paper collection system highlights that Italy has a higher RR compared with Spain, and this is representative of a high grade of circularity of the paper in Italy. From the comparison it emerges that the Recovered Utilization Rate shows a value of 73.74%, which is lower than the value of the Spanish system equal to 78.5%; the reason for this data is attributable to the use of virgin fiber for the production of paper. Hence, the RIR and RER values show that Italy has a significant paper collection phase and differently from Spain a smaller phase of importing waste paper.

Regarding the TMIP and MUE indicators, since there is no research at the European level that has computed the values of these indicators, the authors calculated them in 2014 (Assocarta 2015) and 2019 in Italy, and successively compared the results (see table 2).

Table 2: Comparison of MUE DMI and DMIP at the domestic level

|  |  |  |
| --- | --- | --- |
| Indicators | 2014 | 2019 |
| TMIP | 691,81 € | 686 € |
| MUE | Missing data | 82,5% |

The results showed a general improvement in TMIP in 2019, passing from 691,81 € to 686 €. The MUE in 2014 was not possible to compute since there are only aggregated data that cannot allow calculation.

It was difficult to calculate the RR, RER, RIR, and RUR performance indicators in Apulia because some initial data are missing. Mainly, the calculation of RR, RER, RIR, and RUR was not possible because data on *paper production and consumption* in Apulia are not available. The main problem is due to the absence of some regionally broken-down data that do not allow some allocations.

The same critical issue was found for the calculation of the MUE and TMIP because the lack of data for calculating *the regional paper DMI*.

It is therefore important to have disaggregated data at the regional level, in order to be able to evaluate and make regional estimates on consumption.

As figure 2 shows, most of the wastepaper collected in Apulia is sent outside the region and this leads to the contradiction that, the increase in the collection phase does not correspond to a regional circularity of the paper sector. For example, in 2001 Apulia region collected a total of 48,930 t of paper whereas, in 2019, collected 198,750 t, with a total increase of 406.2% (figure 3). The increase of the collection phase has not provided any environmental benefit in the region considering the increase of the environmental aspects due to transport outside the region and the development of some business circular models.

Figure 3: Tons of paper waste collected in Apulia from 2001-2019.



Future projections to 2025, indicate an amount of recycled paper waste of 220,000 t, bringing the recycling rate to 98% from the current 95 %. Considering the future projections, the presence of a paper mill in Apulia is necessary. The construction of a paper mill will create an internal circularity system reducing, at the same time, environmental impacts due to road transport that is unavoidable today.

This work stands as a basis for future research aimed at assessing the impacts of the Apulian waste collection system using the LCA methodology by subsequently imagining improved scenarios of a paper mill, supplementing the current work with surveys aimed at quantifying regional paper consumption to fill the current lack of data necessary for a national comparison.

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