THE IMPORTANCE OF DYNAMIC MFA IN SUPPORTING CIRCULARITY

A CASE STUDY OF PVC IN PAKISTAN

Authors: Shiza Aslam, Asma Gul, Jabir Hussain

ACKNOWLEDGMENTS

We are very much grateful to Mr. Hassaan Sipra, Mr. Saad Shah, and Ms. Fatima Hafsa for their kind assistance and support during development of the project proposal and guidance to start the project activities.

FUNDING

This study is part of the APN funded project "CBA2021-12SY-Syed". The project is in collaboration between COMSATS University Islamabad, Circular Plastic Institute at Karachi School of Business and Leadership, Engro Polymers & Chemicals and Engro Foundation.

ASIA-PACIFIC NETWORK FOR GLOBAL CHANGE RESEARCH

AUTHORS

Shiza Aslam is a circular economy expert with over 5 years of experience in industrial ecology, assessments, and creating livelihoods from waste. With a background in Environmental Engineering and a Master's Degree in Environment, Science, and Policy, she has received technical training in landfill design and management as well as lifecycle assessment. Shiza has worked on various national and international projects focused on secondary resource management, social sustainability, life cycle assessments, public health, and economic benefits of inclusive waste management. She serves as the Research Head at Circular Plastic Institute at Karachi School of Business and Leadership.
Email: shiza.aslam@ksbl.edu.pk
Phone: +92 334 1302977

Asma Gul Qazi, an MPhil in Environmental Sciences, focuses on life cycle assessment, circular economy, and municipal solid waste management. She has over 5 years of experience and is an ISWA scholar.

Email: qazi390@hotmail.com
Phone: +92 333 8900938

Dr. Jabir H. Syed, an Assistant Professor of Environmental Studies at COMSATS University Islamabad, focuses on chemicals and waste, their environmental and climate impacts, and monitoring emerging toxic substances. He is the lead author of the Chemical Policy of Pakistan and the Updating National Implementation Plan for Phasing Out and Elimination of POPs under Stockholm Convention.

Email: jabir.syed@comsats.edu.pk
Phone: +92 345 4824777

CONTENTS

INTRODUCTION

Plastic is a widely used material due to its versatility, ease of processing, and relatively low cost – proving itself to be a critical material in modern life. Globally, 8300 metric tons (Mt) of primary plastics been produced and 6300 Mt of plastic waste generated of which only 9% has been recycled and 79% accumulated in the environment[1]. In FY 2020-21, approximately 4,400 kilotons of plastic were consumed annually in Pakistan and only an estimated 20% of the plastic consumed was recovered[2] (Circular Plastic Institute, 2023). It is important to note that quantum or percentage of consumption is not the best metric to measure waste generation and recovery rates, particularly for long-lifespan or durable materials and products and properties of different polymers. Therefore, polymer-specific data and dynamic material flow analysis (MFA) are useful approaches for understanding the metabolism of materials, as it is a quantitative strategy that captures mass balance in an economy.

Material flow analysis (MFA) is based on the principle of materials balance, which allows for various types of analyses. By using MFA, major flows and accumulations can be identified, and trends can be spotted if data is available for several years. Static MFA models can help identify the causes of pollution and assess the effectiveness of measures taken to address the issue. The main difference between static and dynamic MFA models is the inclusion of stocks in society. The presence of stocks of products and materials in use can disrupt the inflow and outflow balance of a system in one year. Ignoring stocks may lead to inaccurate estimates and forecasts of future emissions and waste streams. The majority of MFAs adopt static models that consider a time frame of one year, which means they only provide a singular representation of a particular moment in time. Predictions of past and future material flows can offer valuable information on the drivers of resource utilization and help to identify potential environmental issues early on. Additionally,they can aid in the planning of investments in mining, production, and waste management infrastructure.

> *Today's stocks are tomorrow's emissions and waste flows[3]*

Dynamic MFA models that consider stocks result in more precise predictions of future resource use and waste streams. However, to date, only a few specific substance stock inventories or models have included stocks in their analysis. To maintain a reliable database across the value chain, it is recommended to use dynamic MFA models that consider stocks in their analysis. The growth and decline of substance stocks over time are driven by the dynamics of inflow and outflow of the materials and products that contain them.

Static MFA is suitable for accounting products with a lifespan of less than one year and single use products (see below). In other cases, static MFA is useful if the system boundary is set to assess post-consumer waste flows.

[1]Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. Science Advances, 3(7), e1700782. https://doi.org/10.1126/sciadv.1700782
[2]Circular Plastic Institute. (2023, January 19). Roundtable on "Drivers and Barriers to Plastic Circularity in Pakistan."
[3]Elshkaki, A. (2005). Dynamic stock modelling: A method for the identification and estimation of future waste streams and emissions based on past production and product stock characteristics*1. Energy, 30(8), 1353–1363. https://doi.org/10.1016/j.energy.2004.02.019

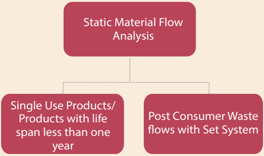


Figure 1: Scenario setting for appropriate use of static MFA

Dynamic Material Flow Analysis

Dynamic material flow analysis (MFA) is a widely used methodology when undertaking consumer behavior and quantifying semi-durable and durable products to account material and products stocks. Products that have a lifespan of more than a year often accumulate during the use phase and do not immediately flow out. Instead, they are stored for a period of time as products-in-use, which are referred to as stocks. For instance, durable items in construction and buildings may become available as secondary resources after as long as 35 to 60 years (in stock for 30 years on average). Dynamic MFA allows us to understand the dynamics of stocks and serves as a size and time buffer to the outflows, critical to understanding the metabolism of materials. For instance, a dynamic MFA can help identify the optimal time to harvest resources from secondary stocks, leading to more efficient resource management and circularity.

The dynamics of the stock can be categorized into three levels:

1. stocks of products, which are handled by producers and users, such as shoes, clothes
2. stocks of materials that comprise these products, such as PVC
3. stocks of substances that are contained within these materials and products, such as chloride.

Each level of stocks has its unique characteristics and dynamic behavior. Wherein, the behavior of the inflow (product placed in market or new product purchases) and outflow (discarding of outdated products) primarily determines the dynamic behavior of the product stock.

In conclusion, polymer-specific data and dynamic MFA are crucial tools in developing effective strategies for circular economy.

Research Methodology

Under the Mapping Metabolism and Identifying End-of-Life Options project, we undertook an exploratory sequential design approach in collaboration with Comsat University, Circular Plastic Institute at Karachi School of Business and Leadership, and Engro Polymers. The project was conducted using two research instruments:

1. Thematic analysis of 36 in-depth interviews and field visits across 4 cities of Pakistan (Lahore, Rawalpindi, Karachi, and Gujrat)
2. Modelling of PVC metabolism to conduct dynamic material flow analysis.

Finally, we approached the calculation/modelling of waste management in a two-tier process; a) reviewing reports on waste audit, recycling, and waste management, and b) field investigation, including extensive interviews with PVC value chain actors to assess the recyclability potential and collection for recycling rate of individual PVC products (e.g., pipes, cables, shoe) to estimate the amount of waste ending up in any respective activity.

The diagram below shows the key informant interviews with stakeholders from different sectors within the value chain:

Figure 2: List of Key informant groups undertaken for the research. The groups represented various sub-sectors including pipes, cables, shoe, and profile manufacturers in Pakistan

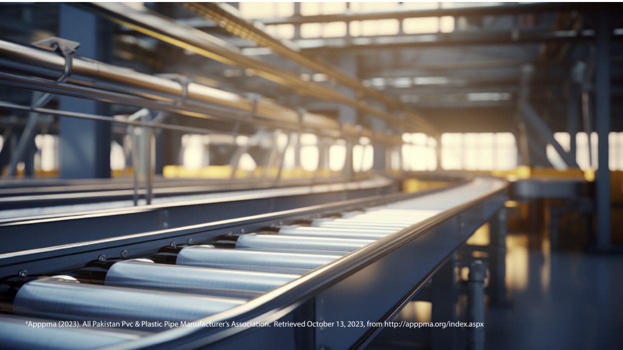
A consensus-building exercise with critical stakeholders such as PVC manufacturers, reprocessors, recyclers, and collectors was conducted to ground-truth the dynamic material flow analysis and polymer specific EoL options.

We considered "closed loop" recycling when secondary material was used in competition with primary PVC. If the secondary material was directed towards other purposes, we classified it as "open loop" recycling.

Case Study: Dynamic MFA on Poly Vinyl Chloride (PVC) in Pakistan

Overview of PVC Industry in Pakistan

In Pakistan, the PVC industry comprises of over 1150 industrial setups of small, medium, and large scales with approximately 28,750 employees (APPPMA, 2023)[4]. Engro Polymer and Chemicals Limited (EPCL) is the sole producer of PVC resin in Pakistan, with a current production capacity of 295,000 KTA. From 2015 to 2021, the PVC demand has risen from 182, 000 tons to 280,000 tons with a compound annual growth rate of 7.4%. PVC has two main types: rigid and flexible PVC. Around 55% of Pakistan's market share is made up of rigid PVC, including PVC pipes (sewerage, drainage), furniture, landscape irrigation, fittings, profiles, wall/door protection and window frames. The rest of 45% of the market share of PVC in Pakistan consists of soft PVC products, i.e., film and sheets, flexible hose, cable compound, PVC geomembrane for canals, flooring, car mats and shoes. The market share of PVC in Pakistan varies among sectors, including building and construction, packaging, agriculture, and consumer goods sectors – see table below:



[4]Apppma (2023). All Pakistan Pvc & Plastic Pipe Manufacturer's Association. Retrieved October 13, 2023, from http://apppma.org/index.aspx

Table 1: Market share of PVC in Pakistan

Sector	Products	Market Share (%)
Building & Construction	**Total**	**70%**
	Pipes and fitting	60%
	Cables	10%
Packaging	**Total**	**14%**
	Rigid sheet	8%
	Flexible & twist shrunk	6%
Agriculture	**Pipes and geomembrane**	**8%**
Consumer & Others	**Total**	**8%**
	Shoes	3%
	Garden Hose	3%
	Others	2%

Dynamic MFA on Poly Vinyl Chloride (PVC)

Figure 3 shows a dynamic material flow analysis of PVC in Pakistan from 2007 to 2020. The Sankey diagram illustrates the cumulative production of PVC, exported PVC products, PVC distributed for domestic consumption, PVC in-use stocks, PVC waste generation, and exported PVC scrap, which amounts to 2696.5 ktons, 81.2 ktons, 3408.3 ktons, 3224.28 ktons, 1400.56 ktons, and 40.7 ktons, respectively. The top three sectors with the highest PVC flows are construction and buildings (2406.9 ktons), packaging (602 ktons), and consumer goods (552.1 ktons).

Construction and buildings, and agriculture sectors are also with largest in-use stock quantities of PVC products i.e., between 2007 – 2020 only 141.1 ktons, and 87.7 ktons amount has been available to market as secondary resource from each sector respectively.

From 2007 to 2020, the collective consumption of PVC across all sectors rose steadily from 0.66 kg/capita (119 ktons) to 1.65 kg/capita (374 ktons). PVC waste generation per capita has increased over the years, ranging from 0.22 kg in 2007 to 0.90 kg in 2020. This is primarily due to consumption behavior and end of useful life of long lifespan products (e.g., pipes and cables). This trend highlights the pressing need for improved waste management practices to minimize the environmental impact of PVC waste.

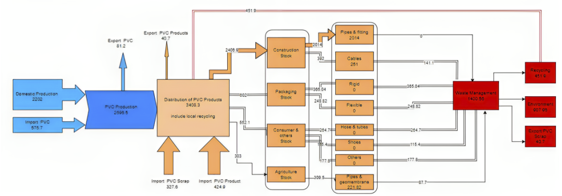


Figure 3: PVC material flow analysis in Pakistan for year 2007 –2020

In dynamic MFA the stocks of products with long lifespans have a significant impact on environmental concerns such as predicting future emissions and waste streams. Thus, it is important to have information about the societal stocks of polymers to provide policymakers with accurate information about future outflows.

Figure 4 shows the inflow and outflow of PVC for the years 2007 to 2030. The inflow represents the amount of PVC that is entering the system, while the outflow represents the amount of PVC that is leaving the system and becoming available to value chain actors as secondary resource. It is important to note that for the years 2020 onwards, the outflow values are not actual predictions of the future, but rather a reflection of the stock of PVC that has accumulated in previous years. This means that the outflow values for these years are not influenced by any forecasting models, but rather serve as a buffer of time for the PVC that has already entered the system in previous years to be used or discarded.

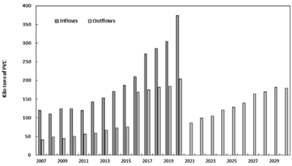


Figure 4: inflow and outflow of PVC in Pakistan

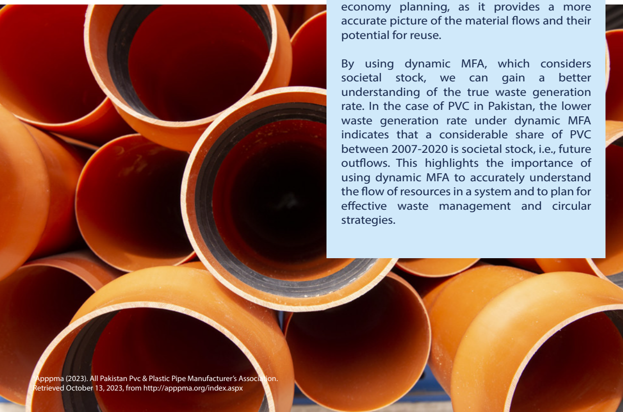
The implication of this information is that it highlights the importance of considering the accumulation of stocks in previous years when planning waste management strategies and circularity measures for PVC products. If waste management and circularity policies only focus on the current year's inflow and outflow, they may not be addressing the full extent of the PVC stock that has accumulated in previous years. This could result in an underestimation of the total amount of polymer waste that needs to be managed, leading to inadequate waste management and circularity measures.

The Importance of Dynamic MFA in Understanding Societal Stock

The traditional static MFA assumes that all PVC consumed within a year becomes waste, regardless of its application in the product. However, this is not always the case. This assumption overlooks the role of societal stock, which is the PVC that has entered the system in previous years and has not yet been used or discarded.

As seen in figure 1, the waste generation values obtained through static and dynamic MFA differ significantly for PVC between 2007-2020. The dynamic MFA estimates suggest that a considerable share of PVC consumed during this period represents societal stock, rather than waste generated in the same year. This finding highlights the need for using dynamic MFA in waste management and circular economy planning, as it provides a more accurate picture of the material flows and their potential for reuse.

By using dynamic MFA, which considers societal stock, we can gain a better understanding of the true waste generation rate. In the case of PVC in Pakistan, the lower waste generation rate under dynamic MFA indicates that a considerable share of PVC between 2007-2020 is societal stock, i.e., future outflows. This highlights the importance of using dynamic MFA to accurately understand the flow of resources in a system and to plan for effective waste management and circular strategies.



Apppma (2023). All Pakistan Pvc & Plastic Pipe Manufacturer's Association. Retrieved October 13, 2023, from http://apppma.org/index.aspx

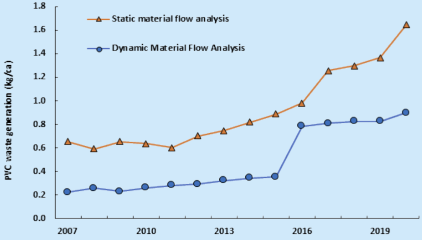


Figure A: Comparison of PVC waste generation quantum using static and dynamic MFA

The collection rates for PVC product recycling in Pakistan are presented in Table 2, which are based on waste characterization reports, key informant interviews, and a consensus building exercise. The estimates consider the material recovered by waste pickers, demolition and rehabilitation waste diverted to junk dealers and aggregators by private contractors, and local secondary material utilized as a feedstock by recyclers and manufacturers. These rates can serve as a starting point for policymakers, manufacturers, and recycling firms to improve the recycling rates of PVC in Pakistan.

Table 2: Recycling rate (%) of various PVC products in Pakistan

Sector	Products	Collection for recycling
Building & Construction	Total	
	Pipes and fitting	95%
	Cables	75%
Packaging	Film & Packaging	
	Rigid sheet	80%
	Flexible & twist shrunk	50%
Agriculture	Pipes and geomembrane	80%
Consumer & Others	Total	
	Shoes	65%
	Garden Hose	70%
	Others (e.g., composite textile, yarn, wallpapers, flooring, penaflex, car mats)	30%

Circularity in PVC: Case Studies

1. A case of shoes

Post consumer shoes are readily recycled into new shoes. The post consumer shoes feedstock is both imported and local. In case of imported shoe supply, the shoes are arranged in pairs when released from lots and containers; the sorting is done based on

1. Pairing: to re-sale as second hand product
2. Material based: for recycling and energy recovery.

Under option 2, the post-consumer shoes are sorted based on their respective materials composition i.e., PU, PVC, TPR, EVA and others in sole (lower part of shoe) and syntheic fabirc or leather in upper part of the shoes. The leftover material from shoes which is not recyclable is sold as a fuel for burning in the kilns or mills – most of which lies in cottage industries and fairly inadequate in managing emissions and pollutants from burning of such feedstock.

The shoes manufacturers on the hand use a mixture of primary PVC, secondary PVC (i.e., PVC scrap materials) and chemical additives (mostly DOP). The secondary PVC are fed into the crusher or cutter machine that crush the old shoes or other seocnday PVC material into small pieces or chunks, getting ready for compounding with primary PVC and additives. Then the material goes to a moulding machine that carries moulds (dyes) of certain designs and gives shoes a shape. The mixture composition usually consist of 3 bags of 25 Kg (75 Kg in total) alongwith DOP which is used to soften the shoes. Shoes are typically manufactured into two qualities, i.e., a) made soly from primary PVC and b) made from secondary PVC material. Shoes industry estimates tell us that demand of shoes made of resin is 80% while that of made from recycled waste is 20%.

2. A case of Flooring

In the PVC flooring/panels industry, it was observed that products made are of three types, rigid, semi-rigid and soft PVC type. The rigid type is used for wall panels. In the flooring, semi-rigid type plastic is used while 100% soft plastic is used in hospital products. There are two processes involved in their manufacturing. First is the one which takes direct raw material and mixes, crushes and extrudes it. The second process is when people take the raw material, extrude it make granules and sell it to the manufacturer. In that case, the manufacturers tells the supplier of certain specifications he needs in the raw material such as hardness, density etc. and then extrudes it and makes a finished product from it.

Marflex flooring company under their closeloop initiative receive recylate from the suppliers and also give incentives to their customers on giving back the old flooring back to the company which is again used in the manufacturing process by cutting, crushing and mixing it with the resin. However, the understanding and relation of products produced from secondary material requires awareness among different strata of population.

According to industry estimates, the market for rigid PVC in Pakistan is 53% and that of flexible PVC is 43%. We can further make a tree of rigid and flexible PVC. In the PVC foam board, door panels and door presses industry, the materials used for production is mainly the PVC resin. The post production waste is also not sold unless it cannot be used anymore. Sometimes the materials are sold when different colors are mixed up as this waste is used in making various household materials.

Based on the above recycling rates, the total amount of PVC waste that underwent metric recycling in Pakistan between 2007 and 2020 are highlighted in figure 5. The percentage of PVC scrap recycled in each sector has generally increased over time. In the packaging sector, the percentage of PVC scrap recycled increased from 9.2% in 2007 to 21.6% in 2020 for rigid sheets, and from 3.3% in 2007 to 8.4% in 2020 for flexible and twist shrunk. Similarly, in the consumer and other sectors, the percentage of PVC scrap recycled increased from 4.8% in 2007 to 12.6% in 2007 for shoes. It is necessary to improve the collection rate for recycling and develop more efficient and cost-effective recycling technologies to encourage the recycling of PVC waste in Pakistan.

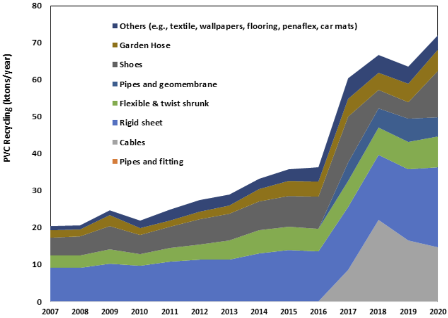
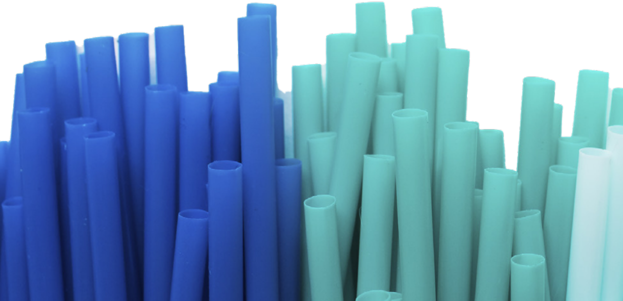


Figure 5: Recycling of PVC scrap per products



Future Enablers of Plastic Circularity

Given the discussion above on the need for polymer specific data and use of appropriate approaches like dynamic material flow analysis, a range of efforts are required to ensure plastic circularity in Pakistan:

Recommendations for Supporting Plastic Circularity through Data and Education

Develop a comprehensive database of polymer-specific data: A database that contains detailed information about individual polymers and their corresponding products will be helpful in developing targeted solutions for their recovery, recycling, and reuse. This database should include information on the properties and characteristics of each polymer, as well as their potential end-of-life options.

Material flow analyses: More studies should be conducted to gain a deeper understanding of the material flows and stocks of different polymers in the value chain. These studies should also consider the different stages in the lifecycle of these polymers, from production to disposal.

Educate consumers about plastic waste: Educating consumers about plastic waste and its impact on the environment is crucial in reducing plastic waste. Awareness campaigns and educational programs should be launched to inform consumers about the proper disposal of plastic waste, the importance of recycling, and the need to reduce single-use plastic products.

Standardization of data collection: Standardization of data collection methods and formats across the value chain is important for ensuring consistency and comparability of data. This could be achieved through the development of industry-wide data collection protocols and guidelines.

Improved data sharing and collaboration: Improved collaboration and data sharing between different actors in the value chain, such as manufacturers, waste management companies, and recyclers, can help to improve the quality and accuracy of data.

Incentives for data quality: Providing incentives for stakeholders to maintain high-quality data, such as financial rewards or recognition, can help to motivate them to prioritize data collection and accuracy.

Regular audits and reviews: Regular audits and reviews of data collection methods and results can help to identify and address any gaps or inconsistencies in the data and ensure that the data remains accurate and up to date over time.

Recommendation to Redirect PVC towards circular pathway

Improving recovery and recycling: To boost PVC product recovery rates in agriculture, it is suggested to enhance their design and installation. Similarly, exploring ways to improve the recovery and recycling of shoes, textiles, and packaging items can benefit the city's waste management system. More research is required to assess the technical challenges and market demand associated with recycling these items.

Extended Producer Responsibility (EPR) for the textile sector: To tackle the issue of low textile waste recycling rates, EPR should be extended to the textile sector. This will involve holding manufacturers responsible for managing the end-of-life of their products and incentivizing closed-loop recycling through government regulations.

Addressing the composite nature of PVC products: Most PVC products are difficult and uneconomical to recycle due to their composite nature. There is a need to research and develop new recycling technologies and processes that can effectively separate and purify composite PVC waste.

Promoting sustainable consumption: The increasing consumption of PVC products has led to an increase in PVC waste generation and environmental pollution. Promoting the use of durable, repairable, and recyclable PVC-based products with longer lifespans can help reduce PVC waste generation. Encouraging second-hand PVC products and refurbishing old PVC products can also contribute to sustainable consumption.

Conclusion

In conclusion, the global plastic industry faces significant challenges with massive production and waste generation, a large portion of which accumulates in the environment due to limited recycling efforts. Dynamic Material Flow Analysis (MFA) emerges as a vital tool, offering precise insights into material metabolism and mass balance. By examining polymer-specific data and employing dynamic MFA, major flows, accumulations, and trends can be identified, facilitating effective pollution control measures.

Shifting the focus to Pakistan's PVC industry, it is a significant player with a multitude of setups and employees, dominated by Engro Polymer and Chemicals Limited (EPCL). The demand for PVC has seen substantial growth over the years, particularly in rigid and flexible PVC products, utilized across various sectors. However, this surge in usage has led to increased PVC waste generation per capita, necessitating improved waste management strategies.

Understanding polymer stocks is pivotal for policymaking, enabling accurate predictions of future outflows. The study delved into PVC's inflow and outflow dynamics, providing essential insights for the industry stakeholders. Standardizing data collection methods and fostering collaboration among value chain participants are critical steps. Incentives, regular audits, and reviews can enhance data accuracy, fostering a culture of meticulous data collection.

Furthermore, the white paper advocates for comprehensive improvements in PVC product recovery and recycling. This includes enhancing product design, exploring recovery and recycling options for items like shoes, textiles, and packaging materials. The implementation of Extended Producer Responsibility (EPR) schemes, especially in the textile sector, can substantially boost recycling rates. Research and development efforts should focus on innovative technologies for recycling composite PVC waste. Additionally, promoting sustainable consumption practices, such as opting for durable, repairable, and recyclable products, encouraging second-hand purchases, and refurbishing old items, can significantly contribute to a circular economy.

This white paper underscores the importance of dynamic material flow assessment, using the PVC industry as a case study. By embracing these strategies and methodologies, the industry can pave the way for a more sustainable future, reducing environmental impact and fostering responsible plastic usage.