How China's Foreign Waste Ban Will Reshape the U.S. Recycling Supply Chain: Economic and Environmental Considerations towards a Circular Economy Oriented Paper Recycling Industry

Yali Li,[a,b,*] Franklin Zambrano,[b] Yuhan Wang,[b] and Ronald Marquez [b]

Until recently, China was the largest scrap and unsorted waste importer in the world. Chinese industries sorted the imported wastes and recovered plastic, paper, textiles, and metals, using them as raw materials for manufacturing processes. Since 2013, the Chinese government has imposed measures to ban the import of wastes, the latest one being the "National Sword" policy (fully deployed in January 2021), banning the import of unsorted and recycled wastes. As a result, collecting wastes and recyclables and sending them to China is no longer an option; this has drastically affected the recycling industry supply chain with considerable consequences. This study analyzed the development of Chinese foreign policies on the export of paper waste materials from the U.S. and their specific impact on the recovered paper recycling industry. The economic and environmental consequences of the policy on the U.S. paper recycling industry were analyzed using three scenarios: landfilling (as a baseline), incineration, and recycling. The CO_2 emissions were estimated and then compared. It was found that recycling would result in the largest reduction in greenhouse gases. Although recycling was the best evaluated scenario, it has the greatest costs; therefore, possible solutions towards adding value to paper wastes were analyzed.

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Keywords: Circular economy; Paper recycling industry; National sword policy; Waste management; Sustainability

*Contact information: a: School of Business, Jiangxi University of Science and Technology, Nanchang 330013 China; b: Department of Forest Biomaterials, North Carolina State University, P. O. Box 8005, Raleigh, NC 27695-8005 USA; *Corresponding author: liyali_maxspeci@outlook.com*

INTRODUCTION

The generation and disposal of recyclable solid waste (RSW) has become a major global crisis (Wilson *et al.* 2015; Chen *et al.* 2020). RSW generation is expected to increase at a compounded annual growth rate (CAGR) of 1.6% between 2016 and 2025 and reach a global approximation of 3.4 billion tons annually by 2025 (Gonzalez 2018; The World Bank 2020). This situation is likely to get worse, with emerging economies (such as China) playing an increasingly important role, considering that the global population will generate more solid waste than can be sustainably reused and disposed (Nanda and Berruti 2020; The World Bank 2020).

The United States represents 7.5% of the total global population (U.S. Census Bureau 2018) and generates approximately 14.3% of the global share of RSW (Kaza *et al.* 2018; The World Bank 2020). Throughout the last two decades, the U.S. has exported most

of its RSW to China; this practice represented a trade valued in 11.3 billion dollars (U.S. Census Bureau 2018). Canada, Australia, Japan, and several other countries in the European Union have also traditionally exported their RSW to Asian countries as an approach to managing their waste problem (Olivetti *et al.* 2019; Nanda and Berruti 2020). In 2018, the U.S. exported approximately 90 million tons of recyclable waste to Asian countries (U.S. Census Bureau 2018). Such practices created win-win situations for both importer and exporter countries. This was particularly true for recovered paper; in 2011, the U.S. exported a total of 21 million tons, which later decreased to 16.5 million tons in 2019 and 14.3 million tons in 2020. An unexpected increase of 2 million tons of paper waste exports from the U.S. to the world occurred in 2021, mainly driven by a higher demand for packaging products, although China reported that imports decreased almost to zero (Olivetti *et al.* 2019; U.N. 2022). This decrease in the export of wastepaper is explained by recent restrictive foreign policies on solid waste imports established by China (Parker 2018; Qu *et al.* 2019). In July 2017, the Chinese government issued "the Implementation Plan for Prohibiting the Entry of Foreign Waste: The Reform Plan on Solid Waste Import Management." (GOCSC 2017; Tan *et al.* 2018). In 2018, China implemented the National Sword (NS) policy, which essentially restricted the imports of several recyclable wastes, *i.e.*, a mayor ban on paper and plastics (Wong 2017). This has resulted in a drastic decrease in the U.S. scrap paper and paperboard exports to China from 28.5 million tons in 2016 to approximately 6.4 million tons in 2018, 4.4 million tons in 2020, and 0.5 million tons in 2021 (Staub 2020d; U.N. 2022) (as shown in Fig. 1A). The influence of the restrictive policies has been even more noticeable in plastics (as shown in Fig. 1B). Before the restrictions, China processed the imported waste and subsequently recovered plastics, paper, and electronic parts for industrial utilization, with a considerable portion of the unwanted waste sent to local landfills (Resource Recycling 2020). As a consequence of the implementation of additional governmental restrictions, the importing of U.S. wastepaper and plastics by China reached extremely low values in 2021, according to the 2022 U.N. Comtrade March Report (Xiao *et al.* 2018; Institute of Scrap Recycling Industries 2020; U.N. 2022) (as shown in Fig. 1).

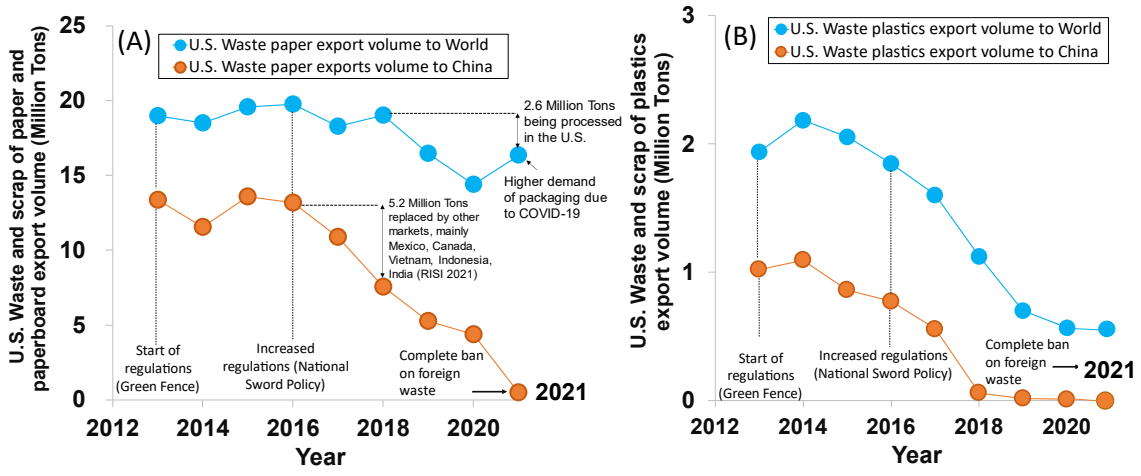


Fig. 1. The U.S. waste and scraps export volume: (A) wastepaper and paperboard; and (B) waste plastics (U.N. 2022)

There are recent studies that outline and model the decrease in U.S exports in waste plastics (Brooks *et al.* 2018; Ren *et al.* 2020; Wang *et al.* 2020). However, in the wastepaper sector, there is a lack of similar reports. In the U.S., wastepaper generation is tenfold the amount of waste plastic; hence, it represents a more severe problem (aggravated by the effect of the 2020 pandemic on corrugated packaging waste generation). It is thus crucial that the U.S. government and the recycling industry find ways to deal with this critical problem right away (U.S. EPA 2020a).

In response to China's NS policy limiting the import of solid waste, the U.S. recycled paper industry established new market destinations for RSW, which included countries in Southeast Asia (Parker 2018; Tan *et al.* 2018; Qu *et al.* 2019; Staub 2020c,d). However, by the end of 2019, several countries, *e.g.*, India, Vietnam, and the Philippines, also implemented similar bans on the importing of scraps, which has resulted in considerable impacts on the exports of U.S. RSW (Resource Recycling 2020). As of the second quarter of 2020, the Chinese government announced a complete ban on the import of solid waste starting in January 2021 (Smalley 2020). Therefore, the export amount of recovered paper from the U.S has fallen to 14.3 million tons annually in 2020, with an overall decrease of 5.3 million tons from 2015 to 2020 (Fastmarkets RISI Intelligence 2022). Consequently, it is of considerable importance for the U.S. to identify and support targeted research focused on the development of effective policies to incentivize recycling operations and transform recyclable wastes, which had previously been exported, into value-added products (Bakshi 2016; Chen *et al.* 2020). Although a considerable amount of research has been accomplished for predicting and modeling the economic and environmental impact of handling municipal solid wastes, these previous analyses do not consider the major effect that China's foreign policies on solid waste imports could have on such handling operations (Shen *et al.* 2011; Cifrian *et al.* 2015; Nabavi-Pelesaraei *et al.* 2017; Tisserant *et al.* 2017; Cremiato *et al.* 2018; ElSaid and Aghezzaf 2018; Chen *et al.* 2020). Regarding this occurrence, a natural question arises: does the U.S. have the capacity to recycle all the RSW that is no longer exported to China starting in 2021? This article aims at assessing the economic and environmental impact of Chinese foreign policies on the U.S. recycled paper industry. This would be a first step in the evaluation of potential alternatives to convert RSW into value-added products and thus reduce the economic and environmental burdens associated with paper recycled waste. The objectives of this paper include:

(i) Discussing the development of Chinese foreign policies affecting the trade of recyclable waste.

(ii) Discussing the economic and environmental effects of the strong restrictions put in place by China on the importing of paper waste and their impact on the U.S. recycling supply chain.

(iii) Outlining preliminary approaches to manage the ongoing recycling crisis in the U.S. (to be further developed in a follow-up paper).

EXPERIMENTAL

Methodology

Literature review

A comprehensive literature review was performed on the following topics: "China's waste and recycling policy", "Green Fence", "National Sword policy", "recyclable waste",

"municipal solid waste", and "recycled paper" (Staub 2017a,b; Green Industries South Australia 2020; Waste 360 2020). The search for these keywords and descriptors included more than 300 scientific articles, reports, and news articles. Documents were analyzed in terms of their relevancy and correlation with the subject of the research (as shown in Fig. 2). News publications were summarized and organized chronologically from 2013 to 2020 to track the development of Chinese foreign policies regulating the trade of recyclable waste.

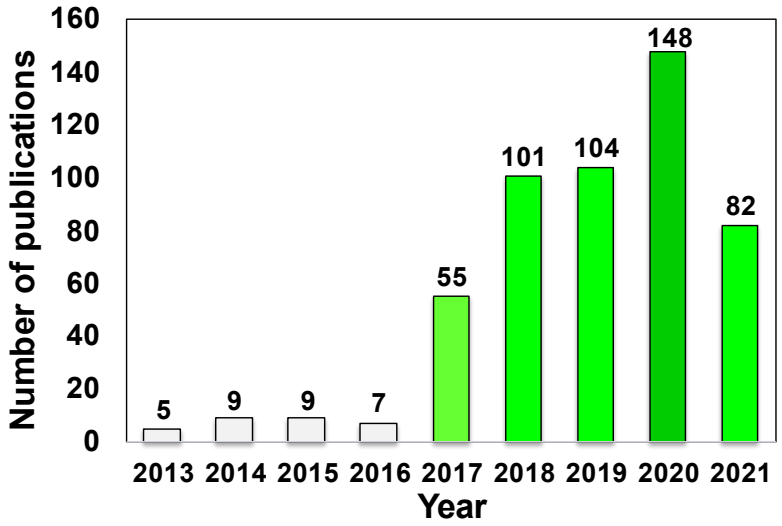


Fig. 2. Evolution of the annual number of publications mentioning "China's foreign import ban policies" since 2013. Descriptors: "China's waste and recycling policy", "Green Fence", "National Sword policy", "recyclable waste", "municipal solid waste", and "recycled paper"

Recyclable and municipal wastes data were sourced from the American Forest & Paper Association, the Institute of Scrap Recycling Industries, and other numerous databases, *i.e.*, RISI, U.S. Environmental Protection Agency (EPA), FAO, U.N. Comtrade, and Statista (EPA 2018; Institute of Scrap Recycling Industries 2019; Fastmarkets RISI Intelligence 2020b; U.N. 2022). Several representative news outlets, *e.g.*, The New York Times and BBC News, were used as sources to understand how news networks were reporting the up-to-date status of the import ban on solid waste by China (Roger 2018; Livia 2020). Scientific papers that cover the impacts of the global recycling industry under Chinese restrictions policy were also included in the review and analyzed (Brooks *et al.* 2018; Tan *et al.* 2018; Qu *et al.* 2019; Chen *et al.* 2020; Ren *et al.* 2020).

Discussion on the effect of Chinese foreign policies on (i) the trade of recovered paper and (ii) the sustainability (economic and environmental) of the U.S. recovered paper recycling supply chain

An evaluation of the economic and environmental impacts resulting from the implementation of Chinese foreign policies was performed to discuss their effects on the U.S. recycling paper industry:

i. Economic impact

Data for the monthly export prices and volumes (Figs. 6a and 6b, respectively) for the different grades of recycled paper, *i.e.*, old corrugated cardboard (OCC), high-grade

de-inked (HD), mixed office waste (MOW), and newsprint (NP), were sourced from RISI Fastmarkets (Fastmarkets RISI Intelligence 2022), and the American Forest & Paper Association (American Forest Paper Association 2020). The revenue for each grade was calculated on a yearly basis by multiplying the export volume and the corresponding price (Fig. 6c).

ii. Environmental impact

The recycled paper landfill amounts and the export amounts for each of the different fiber grades were collected from the American Forest & Paper Association (American Forest Paper Association 2020). Three scenarios were analyzed to evaluate the greenhouse gas (GHG) emissions associated with the end-of-life of 1 ton of the different grades of recycled paper: landfilling (Scenario 1), combustion (Scenario 2), and recycling (Scenario 3). The estimation was performed using EPA WARM Model v15 (U.S. EPA 2020b), which takes into account the complete life cycle of the material, *i.e.*, landfilling total waste transformation. The data associated with recyclable and municipal wastes were sourced from the American Forest & Paper Association (American Forest Paper Association 2020), the Institute of Scrap Recycling Industries (Institute of Scrap Recycling Industries 2019), RISI (Fastmarkets RISI Intelligence 2022), the EPA (U.S. EPA 2020b), and Statista (Statista 2021), as well as news media sources including The New York Times (Yee 2018), BBC News (Roger 2018), South China Morning Post (Huang 2019), and Resource Recycling (Resource Recycling 2018).

RESULTS AND DISCUSSION

The Evolution of Chinese Policies on Solid Waste Importing: Effect of the Chinese Green Fence on Foreign Scrap

The policies of China towards the importation of solid wastes have become more restrictive since the year 2013 (Powell 2013; Tan *et al.* 2018

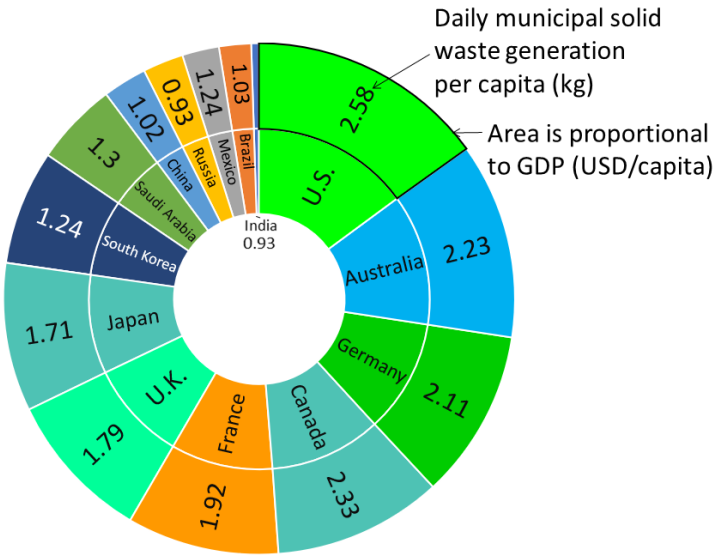


Fig. 3. Daily solid waste generation and its relationship with GDP per capita for selected countries (Hoornweg and Bhada-Tata 2012)

To understand some possible worrisome scenarios related to the generation and disposal of RSW for the next 10 years to 15 years, it is worth reviewing some current facts:

(i) Waste generation is proportionally related to the GDP per capita (Hoornweg and Bhada-Tata 2012; The World Bank 2020) (as shown in Fig. 3). Thus, strong economic growth is typically accompanied by higher RSW generation (Sznajderska 2019).

Based on current economic growth rates, it is estimated that the mixed solid waste (MSW) generation in East Asia (China) would reach up to approximately 602 million tons per year by 2030, twice the value of North America (342 million tons) (Gonzalez 2018; The World Bank 2020).

(ii) In the past, the U.S., Canada, and Europe exported most of their recyclable and municipal wastes to China. The U.S. alone exported nearly 90 million tons of MSW to the China in 2018 (Byrnes and Frohlich 2019). The international trade of MSW has somehow benefited both parties. The U.S. would receive revenue from exporting RSW and avoid the associated handling and disposal costs, while China used its low-cost laborers to sort the RSW to screen usable fibers, plastics, and electronics to manufacture goods for domestic use and exporting (Joyce 2019).

(iii) As the GDP of China keeps increasing, its daily MSW generation is projected to increase from 0.47 billion tons in 2016 to 0.71 billion tons by 2050 (Kaza *et al.* 2018; Sznajderska 2019; Chen *et al.* 2020; The World Bank 2020). Due to the growing internal generation of MSW in China, the need for foreign recycled paper is decreasing. More importantly, China is aware of the environmental burden caused by the import of solid waste and the lack of sustainable disposal strategies. Therefore, China has established foreign policies to regulate the trade of RSW to address environmental issues (Xiao *et al.* 2018; Zhou *et al.* 2019).

The evolution of Chinese trade policies has been progressive with a clear intention to reduce the importation of waste and incentivize internal recycling (as shown in Fig. 4). Back in 2013, China established a regulatory policy on foreign scrap, called "Green Fence," which was precedent to the more recent “National Sword policy”, and placed inspection scrutiny on plastics and paper with high moisture content (Wong, 2017; Brooks *et al.* 2018; Tan *et al.* 2018; Qu *et al.* 2019; Ren *et al.* 2020; Resource Recycling 2020; Wang *et al.* 2020).

A timeline of Chinese foreign policy (as shown in Fig. 4), can be summarized as follows:

1. China launched "Green Fence" in 2013, as a precedent to National Sword; it revised the bale specification by U.S. consumers of fibers and plastics. It also established zero tolerance on e-scrap, textiles, animal waste, *etc.* (Powell 2013).
2. The National Sword policy was established to strike illegal imports of low-grade plastic and paper with high moisture content (Paben 2017).
3. China considers, in addition to striking illegal imports, to considerably reduce the categories and volume of waste imports. Observers were not convinced of a major disruption on Chinese waste imports due to the massive need for raw materials (Staub 2017b).
4. China elaborated on the ban prohibiting the importation of solid waste, covering unsorted mixed paper, textiles, post-consumer plastics, and more, which may cause severe pollution. A policy document issued by the Chinese government planned to domestically recycle for solid waste utilization (The State Council The People’s Republic of China 2017).

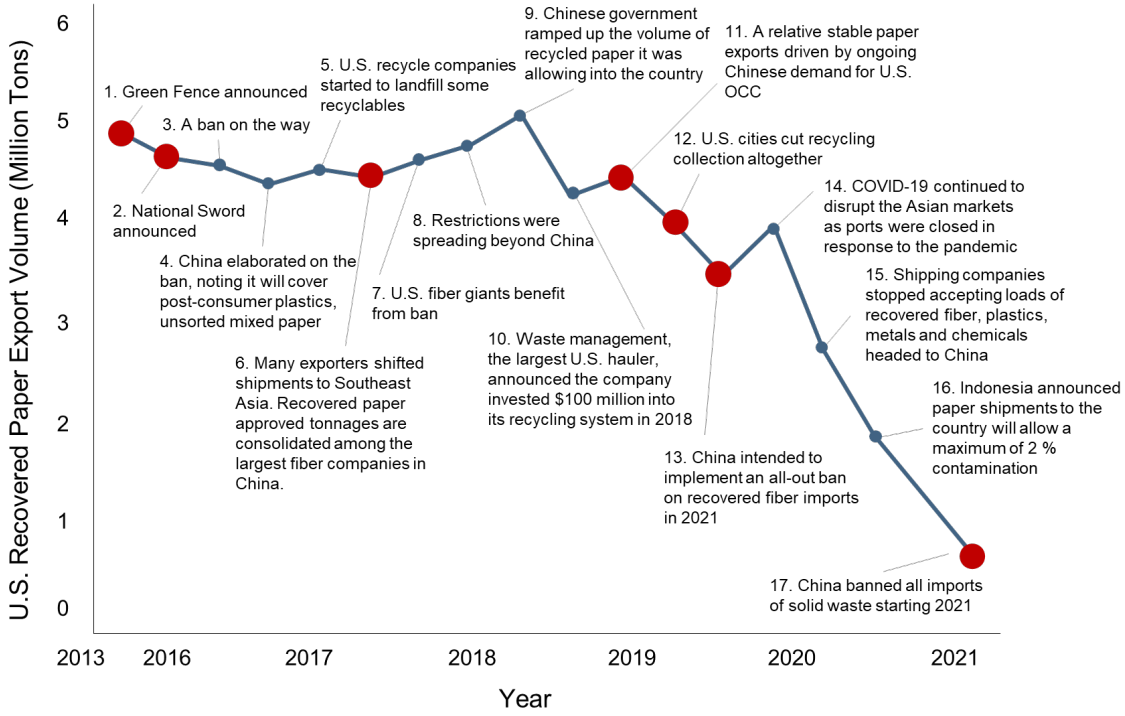


Fig. 4. Evolution of Chinese foreign policy on the import of RSW

5. Municipal programs stopped the acceptance of plastic collections in response to import restrictions. The Solid Waste Association of North America expected repurposes and transformations of U.S. paper mills (Staub 2020f).
6. Big companies in China planned to invest in U.S. processing mills to acquire raw materials. Exporters shifted their shipments to Southeast Asia (Staub 2018c). Recovered paper approved tonnages were consolidated among the largest fiber companies in China. However, the number of licenses issued was drastically reduced under the impact of China's import ban (Staub 2018d).
7. U.S. fiber giants benefited from the price plummet of OCC. Graphic Packaging International saw its fiber cost drop $3 million in the first quarter of 2018 (Staub 2018b).
8. Vietnam announced a temporarily stop in waste imports due to the overloads and numerous permit violations. Thailand planned to permanently ban scrap waste imports (Staub and Paben 2018).
9. The Chinese government increased the large tonnages of recycled paper it was allowing into the country, as the papermaking companies had to take downtime due to the lack of raw materials (Staub 2018a).
10. Waste Management, the largest U.S. hauler, announced an investment of a total of more than $110 million into recycling management systems and material streams in 2018 (Staub 2019c).
11. A relatively stable paper inventory was shipped to China due to ongoing Chinese demand and potential market growth for US OCC (Staub 2019a).
12. Many U.S. communities, *e.g.*, Jackson, Mississippi; Surprise, Arizona, Twin Falls, Idaho; and Hoboken, New Jersey, suspended their curbside recycling programs altogether in response to the restricted recycling management market (Paben 2019).

13. The Chinese government intends to implement an all-out ban on OCC and almost all recovered fiber imports in 2021 (Staub 2019b).
14. COVID-19 continues to disrupt the Asian markets, *e.g.*, Malaysia, the largest importer for U.S. scrap plastic, Vietnam, India, South Korea, *etc*. Numerous ports were shut down, and widespread imports ban were placed in response to the pandemic crisis (Staub 2020c).
15. Major shipping companies suspended accepting loads of scrap plastics, recovered fiber, chemicals, and metals bound for China. This signal anticipates China completely closing the market to any commodities (Staub 2020e).
16. The Indonesian government officially implements the contamination policy for the importation of scrap plastic, recycling paper, and announced paper and plastic shipments to the country would only be allowed a maximum of 2% contamination (Staub 2020b).

The Chinese Ministry of Ecology and Environment (MEE) plans to ban all importation of solid waste from 2021. In response to the ban, Chinese paper and board companies have been preparing to operate and purchase pulp mills from other countries and then legally ship recycled pulp to China (Smalley 2020). The latter could be feasible looking at the current increase in recycled pulp imports by Chinese paper mills as a way to avoid importing paper waste (Waste Paper Trade 2021).

The Economic Impact of the National Sword Policy on the U.S. Recycling Industry

The implementation of the National Sword policy in 2017 resulted in recycled paper import licenses being withdrawn from small Chinese paper mills, which translated in a sharp decrease in the volume of U.S. recycled paper exported to China (Brooks *et al.* 2018). As a consequence of such additional governmental restrictions, the importation of U.S. plastics and paper waste by China considerably decreased (Allan 2018; Stuab 2020g,h). This has led to a considerable reduction in the U.S exportation of recovered paper, which has decreased more than 50% in the last 2 years compared with 2015 levels (as shown in Fig. 4).

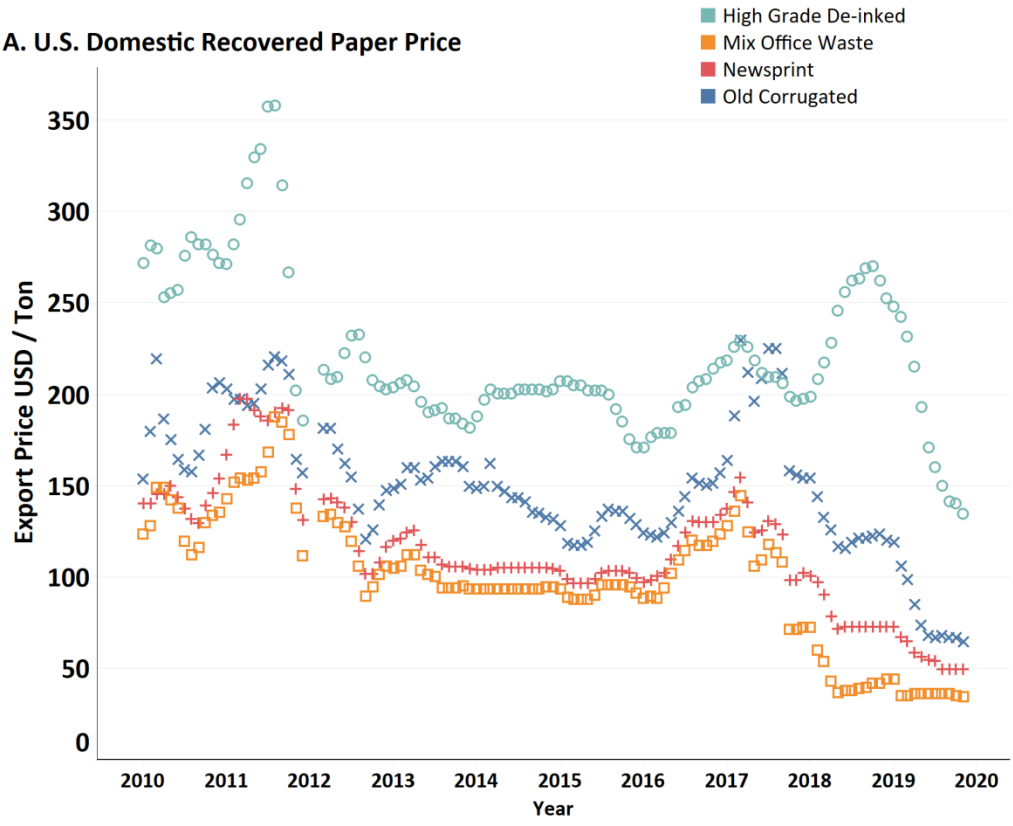
All these policies, aside from being established to address Chinese environmental issues, might also be part of the current trade war between the U.S. and China (Allan 2018; Miles 2018). By restricting imports, the policies are intended to incentivize Chinese domestic recycling business and improve Chinese awareness of the need for recycling and sustainability (Allan 2018; Qu *et al.* 2019). Recently, the Chinese government established waste sorting plans to recycle 35% of the MSW in major cities (Huang 2019). China also planned to retrieve the RSW that was improperly landfilled and use it as raw material (Zhou *et al.* 2019). It is noticeable that the development of these Chinese policies has had a profound impact on the volume of recovered paper (as shown in Fig. 5). Consequently, the U.S. and other countries that shipped most of their recyclable waste to China need to develop effective policies to incentivize recycling operations and transform recyclable wastes, which were once exported for transformation into value-added products (Xiao *et al.* 2018; Ren *et al.* 2020).

Recovered paper (RP) commodities are generally graded into old corrugated cardboard (OCC), high-grade de-inked (HD), newsprint (NP), and mixed office waste (MOW) (Scott 2011). The grades are decided based on the fiber properties, previous usage, and recycling process. Both OCC and HD, with relatively stronger and uniform fibers, are

typically sold at higher prices, and their application is primarily for corrugated paper packaging (Scott 2011; Qu *et al.* 2019). Both NP and MOW, with relatively shorter and weaker fibers, have gone through multiple rounds of recycling and are sold at lower prices; among the products that use these RPs, hygiene tissue and paper towels are included (Scott 2011).

The U.S. domestic prices of all grades of recovered paper have shown considerable declines since 2017 (as shown in Fig. 5A); the prices of MOW, NP, and HD have decreased more than 60% from 2017 to 2019. This scenario has generated an impact on the paper recycling industry due to lower revenue, which disincentives the creation of new paper recycling facilities (Staub 2020d).

The price of OCC reached an all-time high of approximately 229.3 USD/ton in the middle of 2017 and declined quickly to approximately 30 USD/ton in late 2019. In 2020, fluctuations in the prices have been observed, primarily due to increases in the demand for corrugated containerboard and hygiene tissue (Staub 2020g). The price of HD started to decrease in late 2019 from approximately 248 USD/ton to approximately 135 USD/ton in 2019. The price decline of HD started nearly 1 year later than other grades, which was probably due to the low demand for HD (as shown in Fig. 5B).



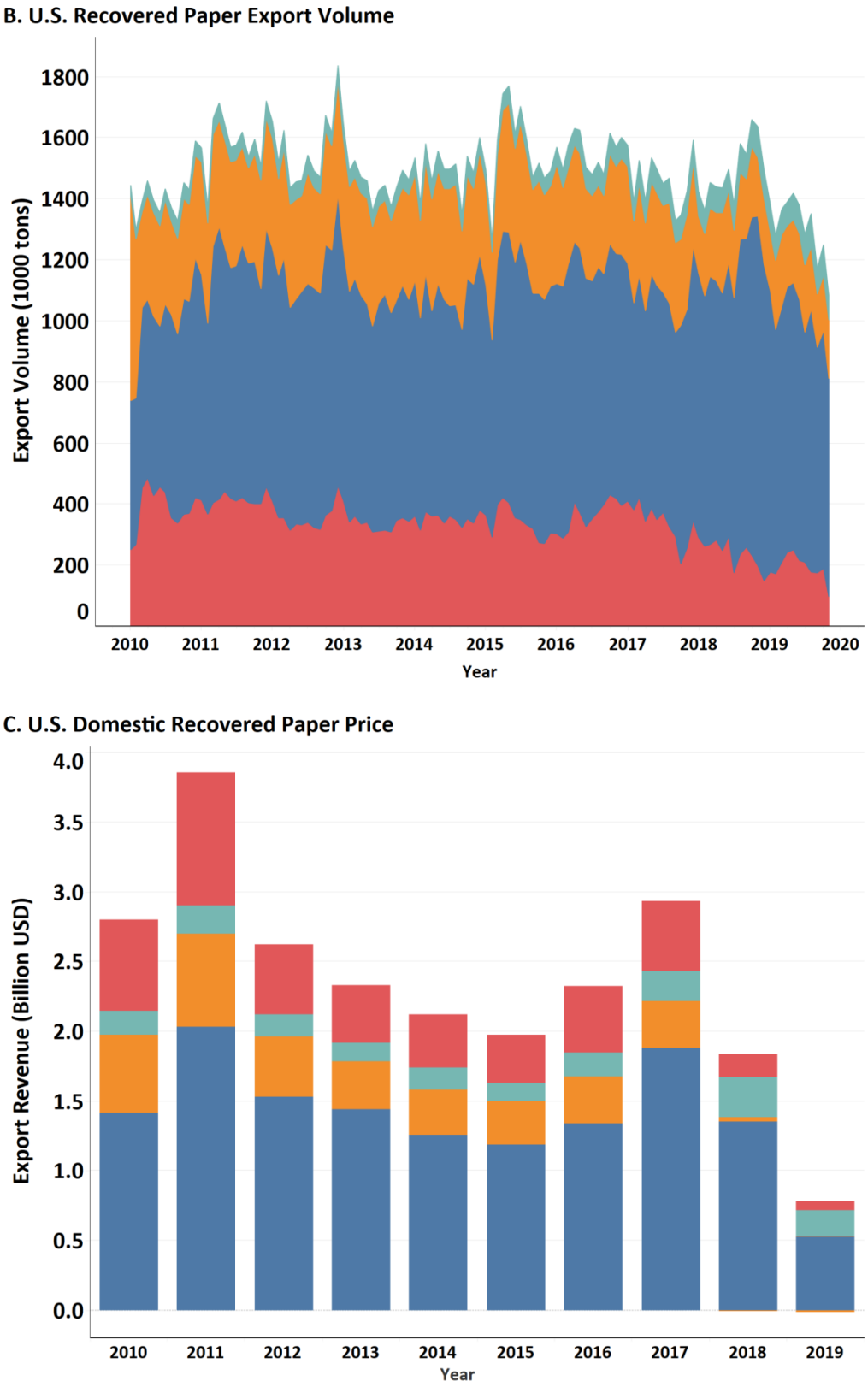


Fig. 5. The economic impact of the National Sword policy on the U.S. recovered paper: (A) the export price; (B) the export volume; and (C) the export revenue, based on OCC, MOW, NP and ND (Roger 2018; Wong 2017)

The total volume of recovered paper exported from the U.S. has decreased by approximately 25% from 2017 to 2019 (as shown in Fig. 5B). The decline has been primarily for MOW and NP, which are specifically banned in the NS Policy, with the restriction on low grades of recovered paper. The export volume of OCC was not considerably affected by the NS policy, which was probably due to the prosperity of Chinese e-commerce and its heavy needs for packaging paper, whereas the needs for writing paper and newspaper have been globally declining (Business Partner 2019; Cornish 2019). The Chinese government might also be assessing the impacts of the NS Policy on the papermaking industry of the country and might adjust the policy based on the needs for imported recycled paper. This may explain the slight increase in 2020 Q2 volume (Staub 2020g). Chinese mills have found alternatives to fiber sourcing; therefore, the government may enforce the ban to a higher level (Staub 2020a).

The export revenue, defined as the export price to foreign countries minus the total costs associated with its production plus shipping, has decreased by 59% yearly from 2017 to 2019 (as shown in Fig. 5C) and was lower for 2020 due to the proximity of the ban enactment and the spreading of the COVID-19 pandemic (Xu and Stanway 2019; Fastmarkets RISI Intelligence 2022; Paben 2022). China has announced it will stop importing any solid waste by 2021 (Smalley 2020). This has caused more problems in the U.S. circular economy, a clear example being MOW, which traded with a negative price for the past 12 months (Roger 2018). The latter imply that there were no domestic buyers for MOW (Staub 2020h).

Besides the revenue loss on exporting, material recycling facilities (MRF) are investing millions of dollars to upgrade the recycling processes to improve the quality of RSW, to meet the more rigorous contamination criteria in each country. International shipping companies were heavily hit by the policy, as the waste shipments to Asia have considerably decreased (Staub 2020e). It is reported that the Mediterranean Shipping Company, the second-largest shipping company in the world, has stopped accepting RSW headed for China (Staub 2020c,e).

The Impact of the National Sword Policy on the U.S. Papermaking Industry

Fiber furnish represents the largest cost for all types of paper product manufacturing. For instance, in tissue manufacturing, fiber accounts for 45% to 60% of the total tissue manufacturing cost (Fastmarkets RISI Intelligence 2022). As aforementioned, the NS policy has generated a dramatic decrease in recovered paper prices. This occurrence has considerably benefited paper giants that use recovered paper as raw materials. An example of this current trend is the behavior of Graphic Packaging International Inc. (GPI) since 2018. In the first quarter of 2018, GPI had a reduction of USD 3 million in costs by purchasing recovered paper, and it was projected that GPI would have saved over 20 million USD in fiber costs in 2018 (Staub 2018b). Fiber prices continued to decrease in 2019 and 2020; therefore, it is expected that companies using recovered paper, *e.g.*, Graphic Packaging International, Cascades, WestRock, *etc.*, have generated considerable savings generating from reduction in fiber costs.

However, the surplus of recovered paper has disrupted other parts of the papermaking industry. Figure 6 shows that some virgin pulp grades experienced price increases by approximately 50% from 2010 to 2019; however, after the establishment of the NS policy, in some cases the price of virgin pulp has fallen to the level of 2010. These price retracements were probably related to the surplus of the recovered fiber in the market. Virgin wood pulps are the resources for various grades of paper products such as consumer

tissue (Assis *et al.* 2018) and linerboard. Going forward, the market of consumer tissue paper will probably remain unaffected from changes in the recovered paper market due to the pursuit of softness and bulkiness by the consumer (Hubbe *et al.* 2016; Wang *et al.* 2019; Li and Xiao 2020; Zambrano *et al.* 2021a). These properties are difficult to achieve by using recovered fiber due to the non-uniform fiber morphology, high fines content, *etc*., which impact the tissue properties, *i.e.*, causes higher strength and lower softness (Peel and Smook 1999). The market for linerboard, however, overlaps with virgin and recycled fibers. The tensile and impact strength are the most important properties for linerboard. These properties can be achieved by using long and flexible virgin fiber or high basis weight old corrugated containers.

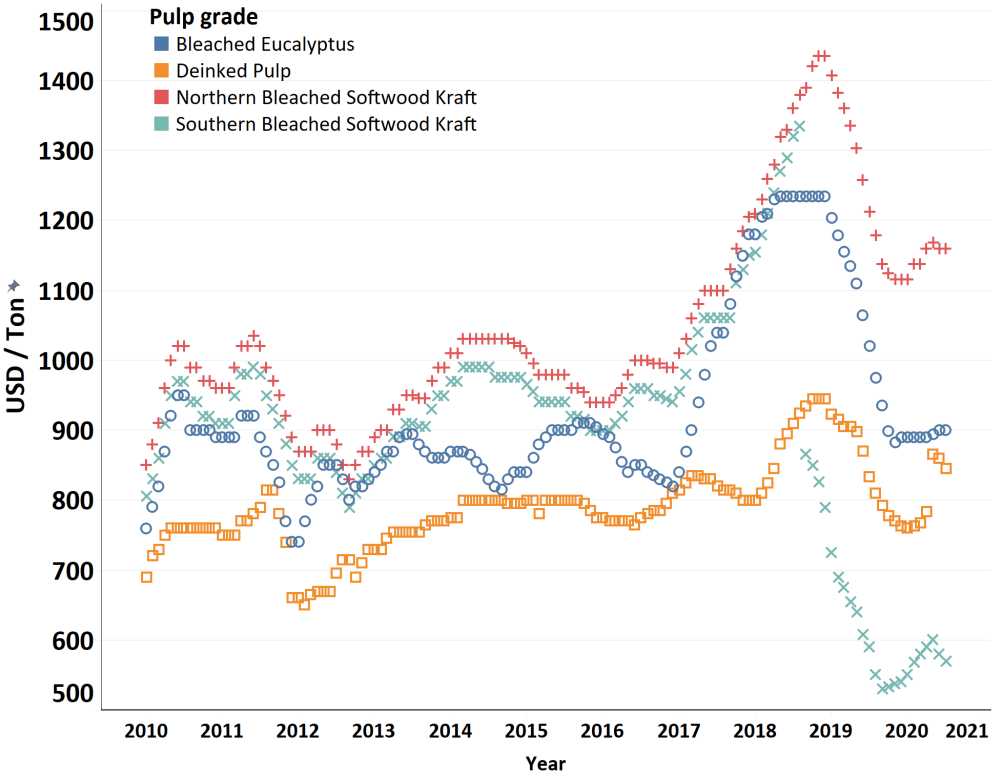


Fig. 6. The U.S. domestic market pulp price from 2010 to 2020

After China confirmed the full ban on recovered fiber from January 1st 2021 (Staub 2020i), the prices of MOW and OCC were held at ~35 and ~80 USD/ ton for the first half of 2021 (Fastmarkets RISI Intelligence 2022). However, disruptions in the supply chain due to the COVID-19 emergency have changed the current composition of recyclables. An increase in e-commerce and home grocery delivery have resulted in a surge of packaging paper, substantially raising OCC and mixed paper prices (Fastmarkets RISI Intelligence 2022). The prices of MOW and OCC have been recovered to ~70 and 140 USD/ton in the first quarter of 2022. The US recovered fiber export also recovered from the lowest of 2020 (~16 million tons) to 18 million tons in 2021. The reduction in China's import by over 90% led to Mexico, India and other Southeast Asian countries to increase their imports. The recovered paper imports for India and Mexico have increased from ~2 million ton to ~ 4 million tons, and ~1.5 million tons to ~ 2.5 million tons, respectively from 2020 to 2021 (Paben 2022).

The Impact of the National Sword Policy on the U.S. Environment

The global supply chain and environmental impact of the NS policy regarding plastics wastes has been recently reported (Brooks *et al.* 2018; Ren *et al.* 2020; Wang *et al.* 2020). In this work, the environmental impact of the NS policy on the U.S. due to the waste and recycled paper ban was assessed. The evaluation was performed by estimating the amount of recovered paper that has been disposed of in the U.S. Then, the export volume of 2015 was used as the baseline scenario, and it was assumed that the domestic generation and consumption of recovered paper remained relatively constant from 2015 to 2021. The authors analyzed three "what if" scenarios, using the differences in the export volume between 2015 and 2018 to 2021, and calculated the amount of additional recovered paper that needs to be either landfilled (baseline, scenario 1), burned (scenario 2), or recycled (scenario 3) (as shown in Fig. 7).

Recycling considerably reduces greenhouse gas (GHG) emissions, more than either landfilling or combustion (as shown in Fig. 7A). Methane emissions from landfilling recovered paper have contributed to more than 90% of $CO_{2equiv.}$ GHGs of paper waste in comparison to combustion without energy recovery, and recycling (U.S. EPA 2020b). The environmental impact caused by methane is thirteen times higher than carbon dioxide (U.S. EPA 2020b). Combustion could decrease GHG emissions by transforming methane to carbon dioxide in comparison to landfilling. Figure 7B shows that recycling the un-exported recovered paper represents energy savings much greater than combustion. The latter results consider the complete life cycle of the recovered paper, as calculated by EPA WARM Model v15. The combustion pathway requires extracting and processing the raw resource, in this case, to produce wood pulp and virgin fibers, which entails high energy expenditure, although a fraction of the energy could be recovered during combustion. Recycling involves other energy-intensive unit operations such as classification and pulping (including possible deinking stages), with energy savings compared to the landfilling and combustion pathways. Nevertheless, the matter is quite complex, since recycling also results in some degradation of the fibers.

The cost of handling recovered paper varies based on the disposal method and recovered paper grade (U.S. EPA 2020a). Material recycling facilities (MRF) must spend more on handling recovered paper (transportation, storage, landfill, *etc.*) due to the new regulations (Cremiato *et al.* 2018). This occurrence has caused dramatic effects on RSW trade; among them, MRF can no longer process or store newly generated recovered paper. Figure 7C shows that a considerable number of MRFs have ceased the recycling business, which has resulted in thousands of households having no access to curbside recycling services (U.S. EPA 2019).

In 2017, there were 60 reported MRFs that had suspended their operations (U.S. EPA 2019). By the end of 2019, the number of suspensions had increased to 85, and it is believed that the actual number is considerably higher than reported. Although the government encourages recycling, tax cuts might not be enough due to the low cost of combustion. Combustion is not a popular disposing method in the U.S. according to stakeholders, as only approximately 12% of the total MSW is combusted (U.S. EPA 2014). Nevertheless, when excess waste is produced, combustion is the first choice for handling recover paper in the U.S., which is probably due to the capacity of incineration facilities (U.S. National Research Council 2000).

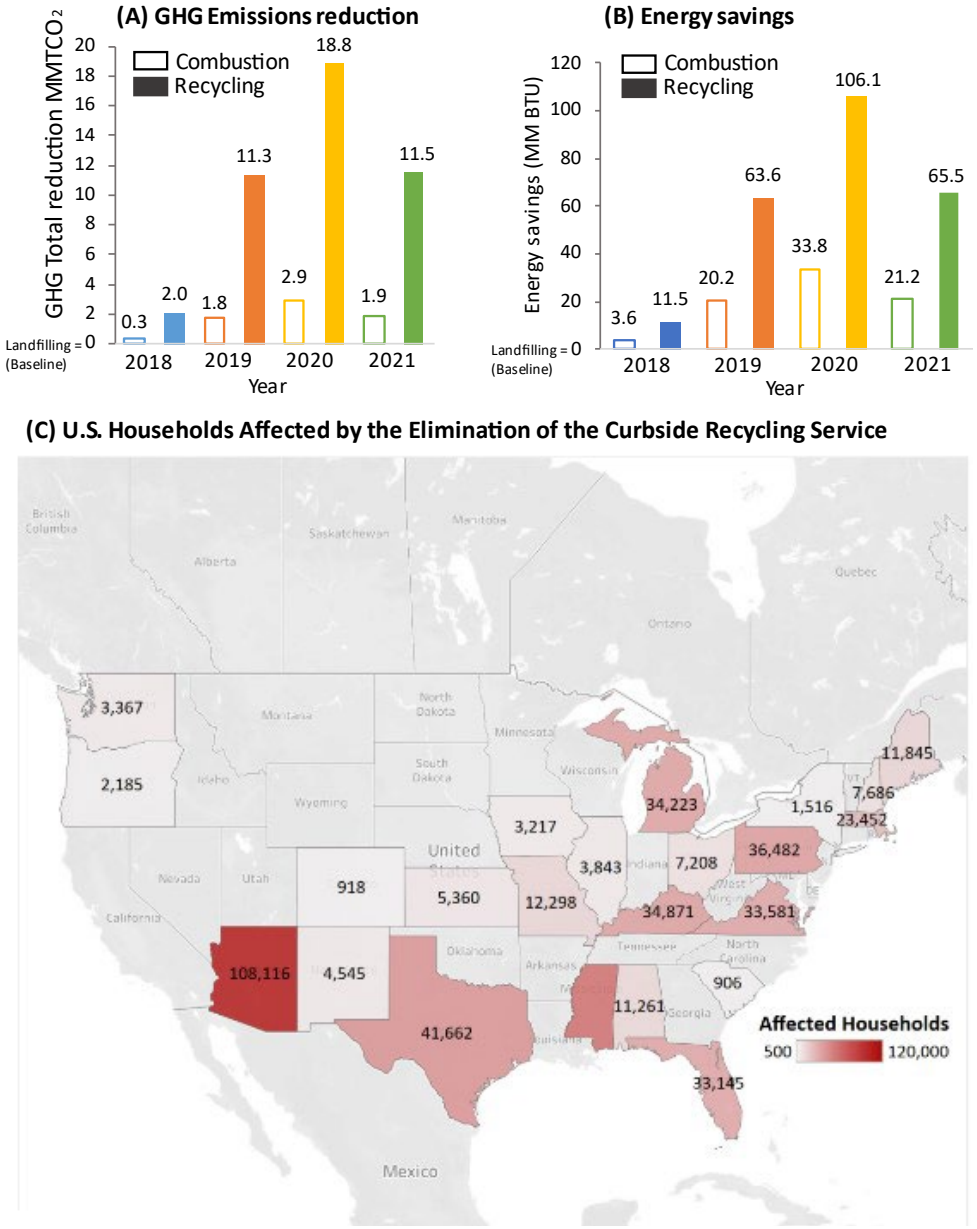


Fig. 7. Summary of the environmental impact of the NS Policy on the U.S.: A) the estimation of potential reduction of GHG emissions *via* combustion and recycling when compared to landfilling (a baseline of 0 metric tons (MT) CO_2 for all non-exported waste landfilled); and B) the energy savings of combustion and recycling of the non-exported paper waste from the U.S. when compared to landfilling (a baseline of 0 M BTU for all non-exported waste landfilled). C) The affected households by the elimination of curbside recycling services;

How Other Countries Handle Waste?

There are a couple of successful stories worth mentioning. In British Columbia, Canada, the government passed the Environmental Management Act, which required manufacturers to recover 75% of the paper and packaging produced (Youden and Stano 2019). In London City, Canada, a program named "Hefty Energy Bag" was implemented to promote the collection of hard-to-recycle plastics. These hard-to-recycle plastics were then sent for energy recovery *via* pyrolysis (Hefty 2020). Another example is Sweden, where only 1% of MSW is sent to landfills (Murphy 2017). In 2002, Sweden banned

organic and combustible waste in landfills (Yee 2018). As a result, thirty-four "waste-to-energy" plants were built to incinerate roughly 50% of the solid wastes, which supply power to over 10 million residents (Lum 2014). Additionally, approximately 49% percent of the waste is used in the manufacturing of new consumer products. The success of waste management in Sweden is, in part, attributed to the strict classification and sorting of waste (organic, paper, glass, tin, *etc.*) and decades of education in the field, along with strategic public policies (Bakshi 2016).

What Are Some Possible Solutions?

Comparing the recycling in other countries, the confederation of European paper industries announced that some MRFs are currently under preparation, which can provide the European market with high-grade paper without exporting any paper waste. It is estimated that each recycling facility will have an investment of at least 500 million euros and a total production capacity greater than 5 million tons within 2 years to 5 years (Confederation of European Paper 2020).

In October 2020, the U.S. EPA published the *National Recycling Strategy* to establish better conditions for the recycling industry. Among the recommendations outlined, the authors can mention the following (U.S. EPA 2020a):

(i) Create a national map of existing recycling infrastructure

(ii) Produce an analysis of the different types of end markets

(iii) Increase the manufacturing usage of feedstocks in the regions where they are generated

As discussed earlier, MRFs refused to continue to recycle due to high operational costs and low income from recycling. Hence, to establish better conditions for the recycling industry, recovered paper must be sorted efficiently domestically and sold at a reasonable price to MRFs. In this case, scenarios for operating linerboard, commercial-grade tissue, and recycled pulp mills using recovered fibers must be established. The cost of fiber, energy, and labor needs to be estimated with literature data and consultation of experts in the field. The corresponding production volume and revenue of an MRF will be calculated in a follow-up publication related to this research.

Figure 8 shows the process flowchart to obtain new products from recovered paper. The flow of recovered paper primarily contributes to the recollection, waste disposal, and manufacturing stages (Swachhcoin 2019). Typically, MRFs sort recovered paper into different grades, where each grade will be priced differently, *i.e.*, MOW, HD, or OCC (European Paper Recycling Council 2020). Depending on the grade of paper being produced, various quantities of virgin pulp from sustainable sources can be added (Zettler 2019). Some papers, *e.g.*, corrugated, mixed office, and newsprint materials, can be made from 100% recycled paper (Kinsella 2012). Recent research work has also shown that recovered grades such as OCC may be upgraded into higher value-added paper products such as hygiene tissue, providing an alternative fiber source for tissue manufacturing and an alternative to deal with excess packaging waste (Zambrano *et al.* 2021b). Once the paper is consumed and used in the market, it will be taken into the sustainable recycled process again (Kinsella 2012).

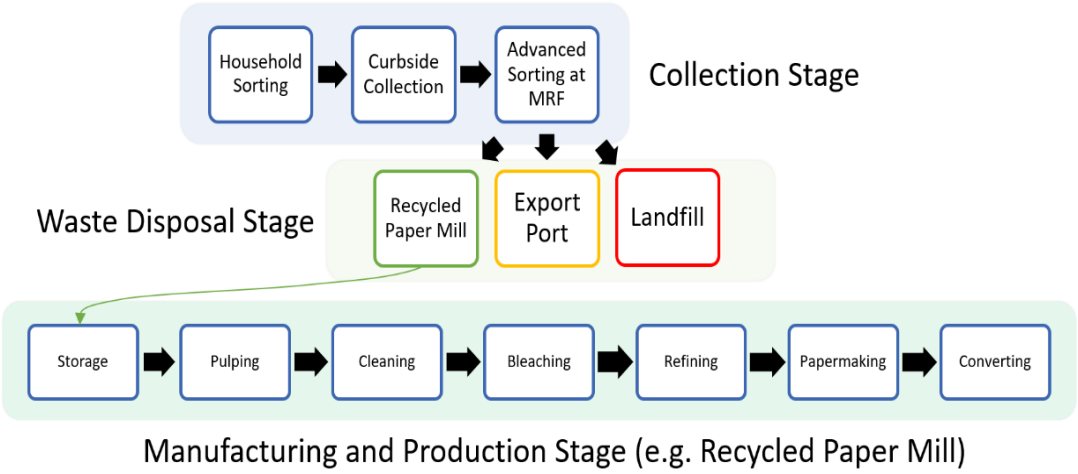


Fig. 8. Process flowchart of recovered paper from recollection to a new product formulation

CONCLUSIONS AND PERSPECTIVE

1. China has been the leading importer of waste and scrap paper worldwide, primarily due to the high imports of solid wastes. The National Sword policy was established to address the domestic environmental issues in China, and the ban on solid waste importation has disrupted the supply chain of the U.S. recycled paper industry.
2. It is believed that there were multiple purposes for establishing the National Sword policy. On the one hand, China was determined to improve its sustainability awareness and integrate its recycling system. For many years, paper raw materials were obtained by importing foreign scraps, resulting in a lack of development of a domestic recycling system. On the other hand, the timing of the establishment was right after the Trade War the U.S. announced against China, as many high-tech products imports were banned from China. Thus, the policy was probably a retaliation against such sanctions.
3. The exporting volume of the U.S. recovered paper to China dropped to almost zero in 2021. Nevertheless, the worldwide increased demand for recycled pulp intended for packaging products generated an unexpected increase in exports from the U.S. The following trends can be mentioned:
   - Total containerboard production in the U.S. in 2021 increased by 5.6% compared to 2020 (American Forest Paper Association 2022).
   - Recycled pulp exports rose significantly, one of the reasons being an increase in recycled pulp imports by Chinese paper mills as a way to avoid importing paper waste (Waste Paper Trade 2021).
   - Packaging consumption increased in the U.S., while cardboard shipments from the U.S. decreased by 2% from February 2021 to 2022 (Paper Export 2022).
   - Although more packaging was produced in 2020 and 2021 in the U.S., the cardboard recycling rate declined from 92.1% at the end of 2019 to 88.8% in 2021, representing an additional 3 million tons of unrecycled waste available in the U.S. (American Forest Paper Association 2021).

4. Therefore, the latter changes, generated in part due to the COVID-19 pandemic disruptions, and the variations in consumer trends, could be crucial to better understand the packaging waste production dilemma in the U.S. Thus, alternative uses for underutilized OCC, *e.g.*, recycling for its use in other paper grades such as hygiene tissue, tailored to deploy feasible solutions are being proposed (Zambrano *et al.* 2021b). According to the estimations presented in the present work, proper recycling of the un-exported mixed paper waste would result in a decrease of at least 18.8 million tons of CO_{2eq} emissions compared to landfilling. This constitutes energy savings of 106.1 MM BTU.
5. The National Sword policy, on the positive side, is a strong stimulus to force transformations in the U.S. recycling industry. The policy may improve consumer awareness of sustainability, particularly in new generational groups, *i.e.*, millennials and generation Z, whose greater environmental awareness might incline them to choose products obtained from recycled fibers. In the short term, the government might need to interfere with setting reasonable prices for domestically selling recovered paper to keep material recycling facilities (MRFs) operating. In the long term, a transformation of the recycling industry to convert recovered paper into new sustainable products is evident.
6. The U.S. government, and particularly the U.S. Environmental Protection Agency has been aware of the increasing recycling problem. The latter cannot be solved simply by the lawmakers. The whole recycling process in the U.S. needs to be improved. This includes educating the residents on the importance of minimizing waste and correct recycling procedures, establishing bills to impose additional plastic/paper tax, expanding the development of sustainable products, and investing in more recycling facilities. Thus, better initial separation discipline is one of the solutions to this problem. Lawmakers must be involved in creating a better recycling business environment. Funds may be collected by imposing a tax on single-use packaging on consumers. The whole integration may take decades to be achieved, but the National Sword policy may stimulate such development.

Declarations

Ethics approval: Not applicable.
Consent to participate: Not applicable.
Consent to publish: Not applicable.
Competing interests: The authors declare that they have no competing interests.

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Authors' Contributions

Yali Li: Conceptualization, Methodology, Data calculation, Formal analysis, Writing the original draft, and Writing the review and editing; Ronald Marquez: Conceptualization, Supervision, Writing the original draft, Writing the review and editing; Yuhan Wang: Conceptualization, Methodology, Data analyzing, Supervision, Formal analysis, Writing the review and editing; Franklin Zambrano: Conceptualization, Supervision, Writing the original draft, Writing the review and editing.

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