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Sustainability Impact Assessment of Increased Plastic Recycling and Future Pathways of Plastic Waste Management in Sweden

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Abstract: Plastic is a versatile material that has contributed to numerous product innovations and convenience in everyday life. However, plastic production is growing at an alarming rate, and so has the generation of plastic waste. Unsound waste management results in plastic leakage to the environment with multiple adverse effects to ecosystems. Incineration of plastic waste produces excessive greenhouse gas (GHG) emissions, while plastic as a material is consumed and cannot be used again as a resource within a circular economy framework. For this reason, the European Union (EU) takes measures to increase plastic recycling, introducing higher targets for recycling in its revised waste legislation. Sweden follows suit, prioritising actions for improving the management of plastic waste. In this contribution, three scenarios of future plastic waste management are analysed for their sustainability impacts by 2030. The analysis is enabled by a plastic waste management flow model that calculates environmental, economic, and social impacts. The indicators used in the model to describe the impacts in each axis of sustainability are (1) GHG emissions, (2) monetary costs and benefits, and (3) number of jobs created. The results indicate several trade-offs between the different scenarios and between the different sustainability aspects of future plastic waste management, with their strengths and weaknesses duly discussed. Concluding, the most promising and sustainable future scenario for plastic waste management in Sweden includes high targets for recycling—in line with EU targets—and a gradual phase-out of plastic incineration as a waste management option.

Keywords: plastic recycling; recycling targets; plastic waste; sustainability assessment

1. Introduction

The prevalence of plastics in modern lifestyles is undisputable. Plastic is a versatile material that can be used in a wide range of applications, from simple single-use packaging to high-tech durable industrial applications. Over the last decades, plastics have been key enablers of innovation and have contributed to the development and progress of society [1]. In the last 50 years, plastic production has increased twenty-fold, reaching 322 million tonnes in 2015 [2], and plastic production is estimated to double by 2036 and might even quadruple by 2050 [3]. This accelerated rate of production, coupled with a rapidly increasing world population and an even higher rate of consumption, ultimately results in significant plastic waste generation.

Despite the multiple benefits of plastic use, plastics raise several environmental concerns throughout their life cycle. Traditionally, production of plastics is fossil-based and uses crude oil and natural gas as raw material, with a bio-based alternative only recently being exploited commercially [4]. Fossil-based resources are finite and impact the environment negatively throughout the extraction, production and utilisation processes [3]. Moreover, unsound waste management practices which cannot contain plastics from leaking to the environment usually result in dispersing the material as litter, which ultimately ends up in the oceans [5]. Currently, there are approximately 150 million tonnes of plastic in the oceans, and every year, 8 million additional tonnes of plastics end up in the marine environment. This could be compared to one garbage truck emptying its entire content into the ocean every minute [3]. Due to the chemical structure of plastic, its degradation is a very slow process and can take over a century. While degrading, the plastic is fragmented into smaller pieces known as macro- and microplastics [6]. These are hazardous because they can easily be ingested by marine fauna. The plastic can then work its way up the food chain and increase in concentration as larger animals feed on lower trophic levels [7].

On the other hand, plastics have the potential to be recycled many times while retaining their value and functional properties, which means that by increasing the recycling of plastics all the above adverse environmental impacts can be avoided. Despite this fact, it is noted that within the EU-28, a large share of this material (70%) is currently wasted, either sent to landfill or incinerated for energy recovery [2]. The situation is not much different in Sweden, where the uptake of higher recycling is hindered by several market and technology-related barriers [8].

Recognising the potential sustainability gains of increased plastic recycling, the European Commission elevated plastic waste to a priority waste stream in its recent Action Plan for the Circular Economy (COM(2015) 614 final), followed by a comprehensive Strategy for Plastics in a Circular Economy (COM(2018) 28 final). The Strategy aims to promote plastic recycling and influence the design of products to be fully and easily recyclable be 2030 and facilitate the creation and functioning of a robust market for plastic recycling products in Europe [9]. In a similar course of action, the Swedish minister of the environment fully supports EU commitments and urges to step up the fight against plastic waste, indicating that Sweden already takes measures by banning the use of microplastics in rinse-off cosmetics and initiating a government commission on plastics [10].

In policy processes, scientifically substantiated evidence can facilitate decision-making and steer the formulation of appropriate policy measures, targeting a specific problem [11]. Increasing plastic recycling seems intuitively as a positive course of action, but potential environmental, economic, and social impacts should be investigated to create the appropriate evidence base. A majority of Life Cycle Assessment (LCA) studies comparing plastic recycling to other waste management options have concluded generally positive results [12–14], with significant reduction of environmental impacts. However, a sensitive topic which influences the results of any impact assessment is the substitution potential of recycling, a fact that has been raised repeatedly within the context of the circular economy [15]. Significant environmental benefits take place only when plastic is replacing virgin plastic in production, while in any other case the results are mixed or negative [12,13]. These findings indicate that a plastic recycling system must be organised with high quality output and high reuse potential in mind. This in turn requires an economic assessment of the potential plastic recycling system.

Far fewer studies have been performed in this field, for example the assessment of the plastic recycling system for packaging in Italy [16], and a combined LCA-LCC (Life Cycle Costing) methodology in a case study in Sweden [17]. Both studies indicated that potential costs of plastic recycling systems may vary in real-life waste management, as operations often diverge from modelled economic systems. Furthermore, [18] illustrated that the cost of collection, sorting and recycling of packaging waste is commonly not covered entirely by industry contributions through Extended Producer Responsibility (EPR) schemes and that state subsidies and/or municipal financial contributions are necessary for the recycling systems to work. This is an issue of concern, since public finances are a central topic of governance and political affairs. Therefore, the economic sustainability of waste management systems must be fully scrutinised before any waste management option is prioritised over another. Social impacts of increased plastic recycling have not been quantified in scientific literature.

Although previous studies are based in solid scientific methodologies and provide a reliable basis for decision making, they are not comparable within an integrated system boundary of a national waste management system, and therefore the results cannot be assessed holistically. LCA studies do not necessarily describe the same boundary conditions as in a cost assessment or social assessment. Therefore, an integrated approach within a single common framework would be most preferable to measure the overall sustainability impacts of increased plastic recycling.

An integrated approach to assess environmental, economic and social impacts was recently published by Plastic Recyclers Europe (PRE) [19], based on a fully quantifiable plastic waste management flow model for post-consumer plastics. The model incorporated waste quantities, operation and investment costs, and employment potential, in different waste management options as input parameters. Output parameters were three indicators of environmental, economic and social aspects of plastic recycling, which are routinely consulted in policy-making processes. The indicators are (1) greenhouse gas emissions (GHGs), expressed in millions tonnes of CO_2e (a carbon dioxide equivalent, commonly abbreviated as CO_2e, is a metric unit used to compare the emission intensity of various greenhouse gases based on their global-warming potential (GWP), by converting the measured amount of other greenhouse gases to the equivalent amount of carbon dioxide); (2) costs, expressed in EUR (euro currency); and (3) direct jobs, expresses in number of jobs created.

Taking all the above into account and in an effort to create the evidence base for policy-making in the field of plastic recycling and circular economy, the aim of this contribution is to quantify the potential impacts of increasing plastic recycling in Sweden. For calculating the impacts, we used the same modelling approach as the PRE study [19] and populated the model with Sweden-specific data. Moreover, we defined three possible future waste management scenarios and we compared the results with a Business-As-Usual (BAU) scenario. The output indicators illustrate the environmental (GHG emissions), economic (costs), and social (jobs generated) impacts of future waste management in Sweden, according to the three different scenarios used, with increased plastic recycling in focus. Considering the results of the waste flow model and impact assessment, potential future pathways of plastic waste management in Sweden are identified and qualitatively assessed in terms of environmental, economic and social sustainability. Ultimately, combining the results and qualitative assessment, we conclude on which future waste management scenario would be the most beneficial pathway for Sweden to achieve high plastic recycling and fulfil the European Union (EU) recycling targets by 2030.

In the following section, we present a brief overview of waste management and policy framework conditions of plastic waste in the EU and in Sweden. Next, we present the results of the plastic recycling waste model and discuss potential implications of the different scenarios for achieving higher plastic recycling in the future. The methodology of this contribution is described in every detail in the section following the results. Lastly, we conclude with identifying a potential future pathway for plastic waste management in Sweden and the requirements for its implementation and suggest future research that will facilitate the transition toward an efficient and effective plastic waste management.

2. Plastic Waste Management and Policy Background

The waste management system and waste policy conditions in Sweden are largely embedded within the EU waste policy framework. In this section, we present the EU waste framework and related legislation to plastic waste, outlining the current situation and recycling performance, followed by the Swedish national policy context and plastic waste management performance.

2.1. Plastic Waste Management and Policy in the EU

Plastic recycling in the EU has been gradually improving over the last 10 years, with the recycling rate of post-consumer plastics having doubled since 2006 [2]. Still, the rate of plastic recycling remains low compared to other materials such as paper and metals. Year 2016 was the breakthrough moment when recycling of plastics surpassed the rate of 30%, reaching 31.1% of the total post-consumer plastic waste collected in the EU, and the first time recorded that recycling surpassed landfilling as an end-of-life (EOL) option [2]. Overall, 27.1 million tonnes of plastic waste was collected from households and businesses in the EU, of which 8.4 million tonnes were recycled [2]. Recycling rates among EU Member States (MS) vary considerably, with recycling rates around 40% in leading MS, i.e., Germany and Sweden, and recycling just below 20% in Malta and Bulgaria [2]. MS with statutory landfill restrictions of recyclable and recoverable waste (e.g., Germany, Sweden, Denmark, The Netherlands) appear to have, on average, higher recycling rates of plastic, which indicates that a landfill ban can act as driver not only for improving the energy capture of waste plastics but also increasing recycling as an alternative waste management option. On the other hand, some MS with limited incineration capacity and no bans on landfilling have been successful in achieving equally high plastic recycling rates, within the range of 35%–40% (e.g., Spain, Portugal, Czechia, Latvia) [2].

Plastic waste in EU policy is addressed through the broad EU waste acquis, regulating different waste streams and general framework conditions, but there is no specific legislation targeting plastic waste. The collection and recycling of plastic waste is indirectly addressed as part of municipal solid waste and construction and demolition waste (Directive 2008/98/EC), waste electrical and electronic equipment (Directive 2012/19/EU), End-of-Life vehicles (Directive 2000/53/EC), packaging waste (Directive 94/62/EC), and following the rules of waste shipments (Regulation (EU) No 660/2014). Plastic waste recycling has a significant role to play in achieving the targets set out in EU Waste Directives mentioned above, e.g., Municipal Solid Waste (MSW) recycling target of 50% by 2020; Construction and Demolition Waste (CDW) recovery target of 70% by 2020; EOL vehicles re-use and recycling target of 85% by 2016. The only plastic specific target set in EU Waste legislation concerns plastic packaging waste and corresponds to a recycling rate of 22.5% by 2008.

However, the policy landscape is gradually changing after the introduction of the EU Action Plan for a Circular Economy (COM(2015) 614 final) that was published in December 2015. In the Action Plan, the Commission recognised plastic waste as a priority area for action, prioritising a variety of actions that will enable the increase of plastics recycling, such as eco-design, a revised EU target on recycling of plastic packaging, quality standards, and actions to facilitate cross-border trade in recyclable plastics [20]. The EU circular economy action plan was bundled with revision proposals for the EU waste related directives, including a proposal for amending Directive 94/62/EC on packaging and packaging waste (COM(2015) 596 final), introducing the significantly higher target for plastic packaging waste of 55% recycling rate by 2030 [21]. In the beginning of 2018, the European Commission followed with the European Strategy for Plastics in a Circular Economy (COM(2018) 28 final) setting up a roadmap for achieving higher re-use and recycling of plastics within a modern, competitive, low-carbon, resource and energy-efficient economy which will contribute to reaching the 2030 Sustainable Development Goals and the Paris Agreement [9].

In May 2018, the proposed revised Directives were approved by the European Council and the new legally binding target for recycling of plastic packaging waste in EU MS becomes 55%, with the respective target of MSW recycling raised to 60% by 2030 [22]. Within two years after the approval of the new targets, all EU MS are obliged to transpose these targets into their national legislation.

2.2. Plastic Waste Management and Policy in Sweden

The recycling rate of post-consumer plastic waste is high compared to other EU MS, at about 40% in 2016, and can be matched only with that of Germany and Czechia at about 38% recycling rate, respectively, in the same year [2]. This rate could be described as remarkable—despite being quite modest compared to other waste materials, e.g., paper—taking into account the fact that Sweden has significant overcapacity and reliance on waste incineration [23,24]. Additionally, Sweden lacks policies specifically targeting the plastic waste stream [25]. Plastic waste is not identified as a priority waste stream in the Swedish Waste Management Plan [26] and in the Swedish Waste Prevention Plan [27], which likely puts actions for improving plastic waste recycling at a lower priority than food waste and textile waste, for instance, which are clearly defined as high priorities in the aforementioned strategic policy documents.

Sweden is obliged to fulfil the EU mandated targets, related to plastic, which are transposed to Swedish legislation, especially the Waste Ordinance (2011:927), Ordinance on producer responsibility for packaging (2014:1073), and Ordinance on producer responsibility for electrical equipment (2014:1075). It is interesting to note that Sweden has introduced higher targets in the Packaging Ordinance (2014:1073), compared the EU legislation, setting the target for plastic packaging recycling at 30% by 2020 [28]. The Ordinance (2014:1073) also stipulated a higher target to be set after 2020 at 50%, however a timeframe for achieving this target is not provided in the legal document. Interestingly, this target provision in the text seems fully aligned with the recent revision of EU targets for plastic packaging recycling of 50% by 2025, and 55% by 2030 [21].

The plastic waste recycling rate in 2016 can be mainly attributed to the high recycling of plastic packaging, which peaked at nearly 49% [2], indicating a well performing Extended Producer Responsibility (EPR) scheme for plastic packaging waste in Sweden. According to the Waste Ordinance (2011:927) Swedish municipalities hold the responsibility of managing the collection of household waste [29]. Packaging waste however, and therefore also plastic packaging waste, falls under the producers' responsibility Ordinance 2014:1073, which means that it is the producers' responsibility to make sure that all plastic packaging that they have placed on the Swedish market is collected and then treated appropriately [30]. Every physical or legal entity that handles packaging waste is by law 2011:927 (article 24) required to separate these from other waste types. The majority of Swedish plastic producers and importers are part of the Producer Responsibility Organisation (PRO) Förpacknings- och tidningsinsamlingen (FTI), which is responsible for the operation and collection of plastic packaging [31]. FTI has approximately 6000 unmanned bring sites across Sweden where households can dispose of their plastic packaging waste. The bring sites consist of separate containers that are emptied on a regular basis and then transported to sorting facilities contracted by FTI [30].

Another option for the collection of plastic packaging from households, which is increasingly gaining popularity in Sweden, is kerbside collection directly from residential and commercial buildings [30]. Kerbside collection is operated by the municipalities, in some cases they are contracted by FTI and in other cases they are under agreement with the producers. Since the producer responsibility still applies, the municipalities receive compensation for the collection of the plastic waste [30]. Municipalities also operate recycling centres for the disposal of larger plastic items such as furniture, but only a small amount of these are recycled due to limitations in recycling capacity in Sweden [30].

PET bottles are collected and treated in a separate system according to Ordinance 2005:220, which states that all bottles containing ready-to-drink beverages, excluding products containing a certain amount of dairy or fruit juice, must be deposited into a deposit system [30]. Responsible for the operation of the PET bottle and aluminium can deposit system is Returpack. Their customers consist primarily of grocery stores across Sweden. Returpack has a list of approved reverse vending machines that any store in the retail food market can purchase. As a member of Returpack, the stores are then given financial compensation for the deposits and handling fees [30,32]. In 2016, the total recycling rate of both aluminium cans and PET bottles was 85% [33].

Electronic waste classified as Waste Electrical and Electronic Equipment (WEEE) is separated from other types of plastic waste due to producer responsibility Ordinance 2005:209 (as amended by Ordinance 2017:1075). The PRO El-Kretsen, in collaboration with producers and municipalities across Sweden, is responsible for the collection and treatment of WEEE [34]. Plastics from WEEE are recycled at a high rate, reaching 44% [34], while other plastic waste from households (not packaging), EOL vehicles and construction and demolition are primarily incinerated for energy recovery [35]. There is a voluntary agreement within the agricultural sector in Sweden [36] for the collection and recycling of agricultural plastic waste with reportedly high rates of collection for recycling (>80%) [37].

When post-consumer plastic waste is collected from residential and commercial areas it is transported to sorting facilities, where the plastic goes through a rough initial sorting and baling process [38]. The sorted waste is then transported to recycling facilities where the plastic is further sorted and treated depending on type of plastic [38].

Swerec AB is the main actor in Sweden when it comes to recycling of plastic. The facility receives 53,000 tonnes of plastic (48,000 tonnes of plastic packaging waste and 5000 tonnes of other plastics) [39]. In total, only 50% of the collected plastic packaging is transported to Swerec, the rest is exported to recycling facilities in Germany. This is due to the fact that Swerec does not have sufficient capacity to handle more plastic waste [34]. FTI is currently in the process of building a brand-new recycling facility with the capacity to handle substantially more plastic waste than Swerec can today [40].

PET-bottles from the deposit system, however, are treated separately from other kinds of plastic. They are transported by Returpack to their own sorting facility in Norrköping and then they are recycled at Cleanaway, a recycling facility that lies in conjunction with their sorting facility, or sold further to other reprocessors [30].

3. Results and Discussion

In this section, we present the results of the plastic waste flow model and discuss the different future scenarios and their sustainability potential based on the quantified impacts provided by the model.

3.1. Defining the Scenarios

For assessing the potential sustainability impacts of increased plastic recycling under different future waste management configurations in Sweden, we introduce three distinct future scenarios and analyse their particular conditions. By developing alternate possible futures and comparing the model outcomes, possible future pathways for increasing plastic recycling in Sweden may be identified. However, the scenario analysis does not predict the future, it is simply a tool to explore and compare different future pathways [41]. Furthermore, it helps decreasing potential over- and underestimations of future developments [42].

To perform the analysis of future scenarios, first a baseline scenario is developed including data about the current situation of plastic recycling in Sweden (for a full list of current data, see the Method section and supplementary material). Using the baseline as a reference scenario, four possible future scenarios were developed, which refer to the year 2030. The specific year of the future scenarios is set to 2030, which is the year of farthest target setting in time found at the revised EU Waste Directives [21,43]. The first scenario is a Business-As-Usual (BAU) scenario, where no changes take place and all parameters are similar to the baseline situation, except that the quantities of plastic waste generated are projected in the future year 2030. This scenario will not be analysed, as no significant changes are taking place, but it will be used for comparing the associated benefits or costs of the other three scenarios, based on our chosen indicators (GHG emissions, costs, and jobs generated), in order to determine the best future pathway for Sweden [19]. The following three scenarios will be compared to the BAU scenario, all of which are set in 2030:

Scenario A: Sweden fulfils all targets set by the EU

This scenario represents the minimum required effort by all Swedish stakeholders involved in waste management and plastic recycling operations to just fulfil the legally binding targets set out in the EU Directives. In case no binding recycling target exists, the scenario defines minimum targets based on industry voluntary agreements and/or good practices, which makes these targets feasible and acceptable. Table 1 lists the targets, stating the source and the rationale behind the specific targets selection.

Table 1. Plastic recycling targets for 2030, by waste stream.

Target	2030	Source
Packaging recycling	55%	COM (2015) 596 final, target for plastic packaging [21].
Waste Electrical and Electronic Equipment (WEEE) recycling	50%	Directive 2012/19/EU, weighted average of the different targets by WEEE categories. The rate presented here represents the share of plastics in WEEE that needs to be recycled for reaching the overall target in the Directive. For calculation method, refer to the PRE report [19]. In the PRE report this rate is calculated at 45% for 2020, but in this contribution we assume progression of the target to 50% by 2030.
End of Life Vehicles (ELV) recycling	30%	Directive 2000/53/EC, based on plastic content in ELV. The rate presented here represents the share of plastics in ELV that needs to be recycled for reaching the overall target in the Directive. For the calculation method refer to the PRE report [19].
Building & Construction plastic recycling	30%	No target, legal or voluntary, was found for this waste stream, and therefore we assume a 30% target in line with other waste streams (e.g., ELV and Agri.), as a measure of good practice and ambition within the construction sector.
Agricultural plastic recycling	30%	Voluntary industry target, set at sectoral level by Swepretur—an industry association for manufacturers, importers and retailers of silage film, plastic bags and horticultural foil [44].
Other plastic waste recycling	7%	Plastic content in municipal solid waste (except packaging waste) that needs to be recycled for achieving the revised municipal waste target of 60% by 2030 (COM(2015) 595 final) [43]. For the calculation method refer to the PRE report [19].

Scenario B: Sweden fulfils all targets set by the EU, with additional actions retaining plastic waste domestically for recycling and limited exports

This scenario assumes as a given the fulfilment of the targets, as presented in Scenario A, and includes considerations for further actions to increase the supply of plastics for recycling. Previous studies have indicated the lack of both supply of waste plastics and demand of recycled plastics [8,25]. Therefore, it is considered important to increase the supply of plastic waste to recyclers which would eventually lead to economies of scale for improving their recycling output. A raise in quantity of recycled plastics, coupled with improvements in quality, could spur demand of the recycled product from industry, which favours steady supply and homogeneity of input raw materials. This in return could create a virtuous cycle of increasing demand and improving recycling processes while reducing the overall costs in the long run. Furthermore, trade restrictions on plastic waste imposed by China [45], which is the second target destination of plastic waste from Sweden [46], would put a pressure on Swedish waste managers to either increase capacity and limit exports or find alternative trade partners. An outright limit of exports is not considered realistic, especially due to free trade agreements that apply in Sweden and the growing global waste trade. However, the scenario assumes that progressively the exports will be limited, and once capacity is installed in Sweden, the economic advantage of exports would diminish, and domestic recycling of plastics would be the most favourable option among Swedish waste managers. Concluding, this scenario assumes that by 2030 no exports for plastic recycling will take place from Sweden, while imports to Sweden continue like BAU.

Scenario C: Sweden fulfils all targets set by the EU, including a statutory ban on the incineration of recyclable plastic waste

This scenario assumes as a given the fulfilment of the targets, as presented in Scenario A, and includes considerations for introducing a statutory ban on incineration of all recyclable plastic waste. Similarly to Scenario B, this action aims to increase supply of plastic waste to domestic recyclers and thus improve their operations and output. The scenario assumes that all recyclable plastic waste collected by municipal or commercial actors is not allowed anymore to enter incineration treatment facilities in Sweden. Plastic waste that is rejected from sorting or/and recycling operations is eligible to be diverted towards incineration. Moreover, the scenario does not assume any changes in imports or exports of waste, and plastic waste collected can be diverted to exports. However, it is expected that the significantly increased amount of plastic waste resulting from the incineration ban, would instigate high interest for building infrastructure domestically to capitalise on this opportunity of surplus material for recycling.

This scenario is specifically addressed in this contribution due to the strategic vision of the Swedish government to minimise fossil CO_2 emissions by 2045 [47]. The incineration of plastic waste results in CO_2 emissions of fossil origin, since plastic is a petroleum-based product. This means that if Sweden genuinely wishes to transition to no fossil CO_2 emissions, then inevitably the incineration of plastic waste needs to be banned.

3.2. Model Outputs

The results of the model simulations are presented in this section. These represent the future associated benefits and costs of increased plastic recycling of each of the three scenarios (A, B, and C) compared to the BAU future situation of plastic waste management in Sweden.

3.2.1. Environmental

Figure 1 shows the results of the scenario comparisons regarding the greenhouse gas (GHG) emission savings from increased plastic recycling in Sweden. Scenario C results in the highest reduction of GHG emissions, with 544.6 kt CO_2e less emitted compared to the BAU scenario. Scenarios A and B show a substantial GHG reduction compared to the BAU, of 214.8 kt CO_2e and 272.4 kt CO_2e, respectively. However, Scenarios A and B do not show significantly high difference between them, making Scenario C appear to be clearly the most environmentally beneficial scenario for a future plastic waste management, showing double savings of GHG emissions compared to the other two scenarios. To bring this number into perspective, Scenario C could save as much GHG emissions as 1/3 of the total amount of GHGs produced by the city of Malmö [48], the third larger urban area in Sweden (population: 322,574 people [49]; gross city product: approx. 15.2 million EUR [50]; reference year 2015).

3.2.2. Social

Figure 2 shows the results of the scenario comparisons regarding the number of direct employment from increasing plastic recycling in Sweden. Scenario C results in the highest generation of net directs jobs with 1621 jobs, compared to the BAU scenario. Scenario B shows the second highest generation of net direct jobs at 601 jobs, followed by Scenario A with the lowest generation of net direct jobs at 560 jobs. Scenarios A and B are relatively even in the respective waste management operations, except for recycling, for which Scenario B shows a moderate increase in employment due to higher processing capacity required in the absence of exports. Notably, Scenario C results in the highest number of jobs created in the majority of waste management operations across the value chain (from collection to sorting, transport and recycling) and respectively results in the highest number of jobs lost in the currently dominant waste management option of plastics in Sweden—incineration with energy recovery.

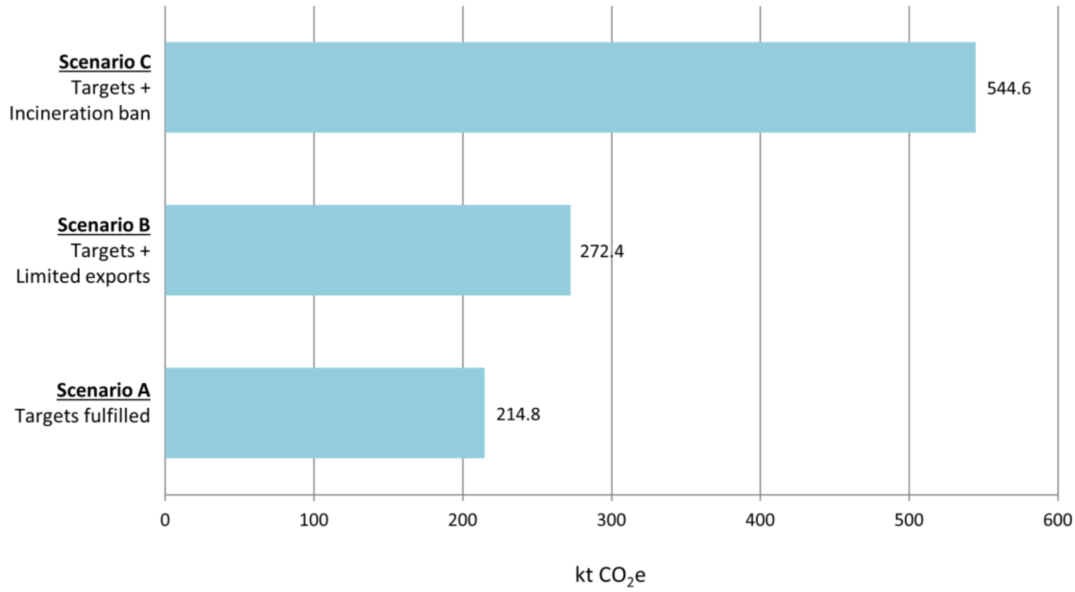

Figure 1. Greenhouse gas (GHG) savings of increased plastic recycling in Sweden.

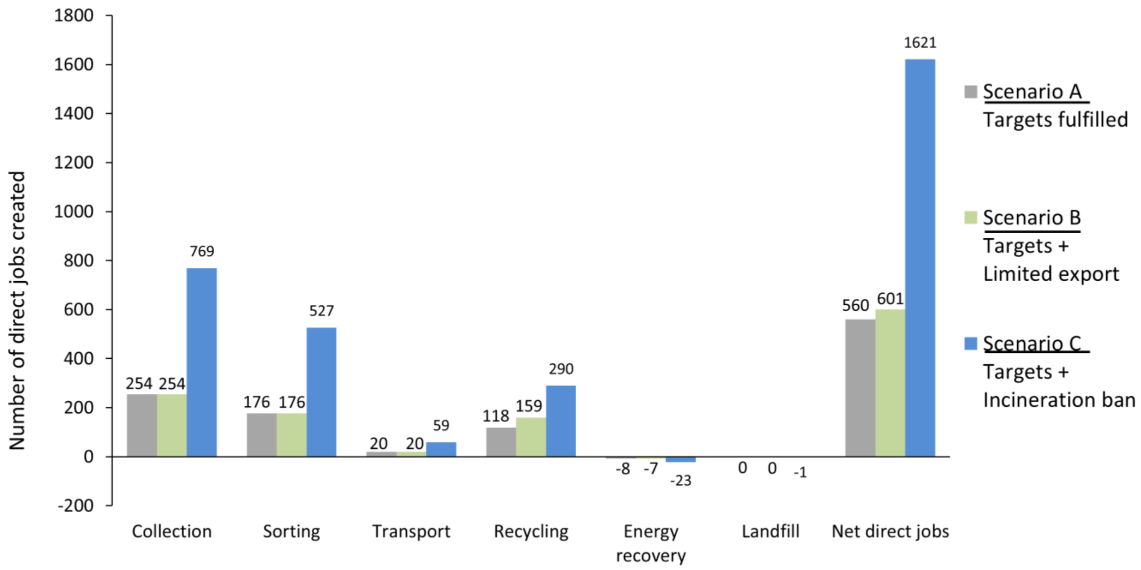

Figure 2. Number of direct jobs created (or lost) at each waste operation.

In addition to the direct employment in the plastics recycling value chain, there is potential for the creation of indirect jobs linked to supporting operations, such as construction of new recycling facilities, manufacturing of equipment for recycling, maintenance and repair of recycling facilities and equipment, and administrative and management positions. It is generally difficult to quantify indirect employment and little evidence is available that can support this assessment. Previous research in this area resorted to the use of so-called 'multipliers' which determine the indirect employment attached to the direct employment of various waste management operations [19]. The multiplier of 1.5 for indirect employment is used in this research, based on a review of relevant sources [51,52]. This multiplier is considered conservative by the sources, since it is lower than those generally applied in other economic sectors such as mining, construction, manufacturing, transport, communication and utilities. Applying this multiplier to the results of the model, the number of indirect jobs for Scenario A is 840, for Scenario B is 902, and Scenarios C results in additional 2430 indirect jobs. This means that the total number of jobs created in Scenario A is 1400 new jobs, in Scenario B 1503 new jobs, and in Scenario C 4050 new jobs.

3.2.3. Economic

Finally, concerning the economic perspective of transitioning to a higher degree of plastic recycling in the Swedish waste management system, Figure 3 shows the associated costs of increased recycling across the plastic waste value chain. Costs presented in Figure 3 represent operational and investment payback costs of waste management operations from the collection stage to the final recycling. Revenues in Figure 3 represent the earnings from plastic waste and/or recyclate transactions through the various stages of the value chain. For the full data sources of costs and revenues, please see the supplementary material.

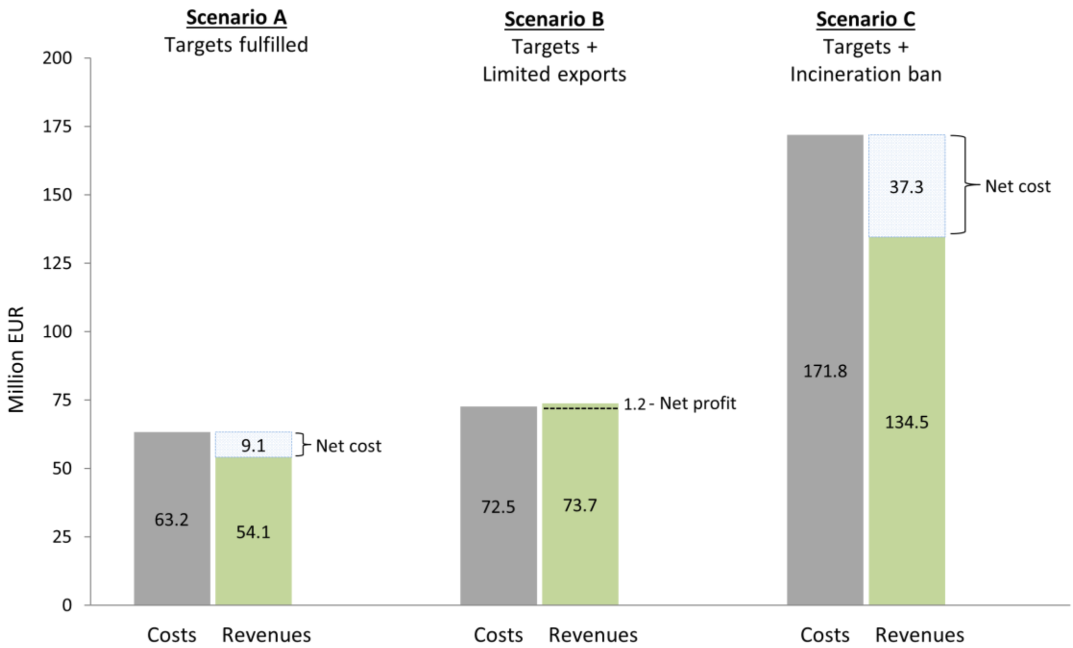

Figure 3. Economic costs and benefits of increased plastic recycling across the value chain.

Scenario B shows a net profit of 1.2 million EUR per year, indicating that increasing domestic recycling and avoiding the export of plastic waste can lead to an overall profitable situation. Currently, waste exported abroad for recycling have a minimum value. The recycler abroad who receives the waste can profit from selling the final product (recycled plastic) at competitive prices in the market, while the sender (Swedish waste company) loses the opportunity to retain the value embedded in the end of life plastic. The apparent profit in Scenario B can attract business interest and further investment for increasing capacity and developing a sound domestic recycling industry in Sweden. Scenarios A and C appear to be rather costly, with Scenario C showing a significantly higher cost at around 37.3 million EUR per year by 2030. This is due to the significantly higher amount of plastic waste that would require processing in the sorting, transportation and recycling stages. Eliminating the alternative option of incineration with energy recovery for recyclable plastic waste, Scenario C requires further expansion of recycling capacity to cope with increased amounts of plastic waste. Recycling operations are much more expensive per unit of treated waste (1 tonne) than incineration [25,53]. However, with increased supply of waste and deployment of technology, treatment cost per unit is expected to lower in the long run [19].

Just fulfilling the minimum recycling targets, in Scenario A, will have an overall cost of 9.1 million EUR. Scenario C costs roughly four times higher than Scenario A, which might result in political and socio-economic resistance when considering about adopting an incineration ban in the future. On the other hand, Scenario B seems to be profitable and can be seen as a promising alternative for the future. The only weak point in Scenario B is how exactly to motivate the shift towards domestic recycling instead of exports, as significant upfront investment would be required to build the necessary capacity to accommodate the increased volume of plastic that remains within the country. So, despite being profitable in the future, Scenario B might face resistance from actors that are sceptical or unwilling to invest.

3.3. Analysis of Findings

Comparison of the results in all three impact categories does not give a decisive and clear-cut image for designing future waste management of plastics in Sweden. There are mixed signals, with significant trade-offs between economic and environmental impacts of the scenarios. Scenario C appears to have the highest GHG savings potential compared to the other two scenarios, saving roughly the double amount of GHG emissions across the value chain of plastics. On the other hand, Scenario C is four to five times more expensive to implement compared to the other two scenarios. The increased cost in Scenario C, however, contributes to increasing social benefits domestically in Sweden, by creating three times higher number of jobs than the other two scenarios. Consequently, the interpretation of the results requires extreme caution and consideration of all relevant aspects that could influence and prioritise the implementation of one future pathway over another. In Table 2, the quantitative results of the three modelled scenarios are summarised in cross-comparison and are coupled to their respective qualitative effect, i.e., the level of perceived benefit, assigned by the authors.

Table 2. Summary of quantitative findings and qualitative assessment.

	Environmental Impact (GHG Emmisions)		**Economic Impact (Costs)**		**Social Impact (Number of Jobs)**		**Sustainability Assessment**
	Quant.	**Qual.**	**Quant.**	**Qual.**	**Quant.**	**Qual.**	
Scenario A	−214.8 kt CO_2e	+	9.1 mEUR	−	560 jobs	+	0/+
Scenario B	−272.4 kt CO_2e	+	−1.2 mEUR	+	601 jobs	+	+
Scenario C	−544.6 kt CO_2e	++	37.3 mEUR	−−	1621 jobs	++	+/++

Note: The qualitative assignment is indicated by the symbols ++ (very positive); + (positive); 0 (insignificant effect); − (negative); −− (very negative).

Weighting the results of the model, Scenario A does not appear to hold any significance, as it only illustrates marginal improvements in the system, having modest environmental benefits and social impact, while not decreasing the overall cost of operation. Practically, most of the GHG savings and a significant part of the costs in Scenario A are attributed to the increase of recycling in other waste streams than packaging—which in Sweden it was already as high as 49% in 2016. However, raising the initial recycling rate of plastics, for instance from construction, automotive, or electronics, represents a "low-hanging fruit" approach. A recycling rate increase from 0% to 30% can be challenging to achieve but it is certainly feasible [2,54], while the increase of recycling to higher rates requires much more concentrated effort, not only on waste management options and policy decisions, but also in technology development and logistics optimisation. Therefore, Scenario A can be described as "conservative", not really moving far away from the BAU situation.

Scenarios B and C appear to be more promising approaches for plastic recycling and indicate that a progressive domestic re-organisation of plastic waste value chains is needed. Scenario B reflects an increase in domestic recycling capacity and redirection of recycling processes internally, instead of exporting for recycling, which is the dominant option currently. In terms of environmental and social impacts, Scenario B does not appear to be far superior to Scenario A, but it shows significantly lower costs, resulting in net benefits by 2030. This point of comparison is enough to prioritise Scenario B over Scenario A. However, a comparison of Scenario B with Scenario C is not as straight forward. Scenario B can be criticised due to the fact that illustrates a rather protectionist domestic approach—limiting exports—and due to the high initial investment that is required for increasing recycling capacity in Sweden. There needs to be investment confidence and security for relevant actors to commit funds towards the recycling sector. To increase confidence and reduce the risks of investment, ideally, public interventions (governmental/regional/municipal) would be required by establishing public-private partnerships and ensuring the supply of plastic waste for recycling. This has been discussed in literature as a prerequisite for a sound functioning of recycling markets and a way to increase confidence in the sector [55], together with an increase in the demand of recycled plastics by industrial actors [8,55].

Scenario C shows the highest environmental benefit, by saving more than double GHG emissions through the plastic waste management value chain. Further, it generates three times more jobs, but costs four to five times higher compared to the other two scenarios. Central condition of Scenario C is the restriction of incineration of recyclable plastics and the redirection of this waste stream to recycling. This special condition would solve one of the main barriers of plastic recycling in Sweden, the supply of waste plastic to recyclers [8,25]. Banning incineration of recyclable plastics is a way of decreasing the linearity of plastic production and is seen as being fundamental for the entire plastic industry to transition to a circular economy [9]. Since plastic waste is fossil-based, it is no longer sustainable to continue extracting crude oil to accommodate the constantly growing plastic industry [3].

Due to its petroleum origin, plastic at its end of life can be used very effectively for the production of energy, having the highest calorific value of any other end of life material. Consequently, plastic waste plays a key role in Waste to Energy (WtE) facilities for the production of high energy output. Sweden has historically invested in WtE technology primarily to cover its demand of heat energy for heating urban areas [24]. Currently, Sweden has an overcapacity of WtE facilities and the trend of constructing new incinerators is increasing [56], resulting in a strong lock-in effect in WtE technologies at the expense of the nascent recycling industry in Sweden [24].

This brings plastic waste in the epicentre of a pressing and controversial debate whether it is preferential to recycle or incinerate. Generally, there is trade-off between recycling and energy generation. Low quality recycling might not be the preferred option for plastic waste management, because there is a high chance that the recyclate will not be used to substitute virgin plastic. Manufacturers set specific standards on the raw materials they would prefer to use in their production operation, and if the recycled plastics cannot fulfil the standard requirements, then they will not be used. This means that even if plastic waste is recycled in high rates, but does not substitute virgin plastic, then the GHG savings calculated by the model will not be realised, and the higher recycling rates would not justify the costs of Scenario C. On the other hand, energy from incineration of plastic waste (especially heat) is highly needed for providing heating to housing areas (district heating), for a large part of the year in Sweden. If no plastic is incinerated, then another source of heating would be required to fulfil district heating needs, which is likely to be of fossil origin. Consequently, to materialise the benefits of higher recycling, as illustrated by the model, it is important to establish the technology for high quality recycling before the potential incineration ban can effectively divert plastic from incineration to recycling. High quality recycling can ensure higher uptake of recycled plastic material for use in manufacturing, and therefore contribute to lowering the environmental impacts of the plastic industry as a whole.

In reality, a complete ban on incineration of recyclable plastics might not be feasible to implement in a short period of time and will most likely require a gradual adaptation. This could be done initially through implementing economic instruments, such as taxes. An effective way to decrease incineration in Sweden could be to implement a carbon dioxide tax specifically for incineration of plastics, alternatively taxing plastic that is going to incineration by weight [53]. This would increase the prices of incineration of plastic, and if the tax is high enough it might no longer be profitable to cover the costs of incineration by the revenues of energy sales. Consequently, this could favour the plastic recycling industry as it will become more beneficial to recycle and re-use plastic, which constitute the first instances in the EU waste hierarchy. Moreover, this could in turn increase competitiveness in the sector, which could boost operational improvements within the recycling industry [53]. Once the effect of economic instruments establishes a gradual redirection of plastic waste to recycling, then the phasing out of recyclable plastics from incineration could be introduced.

Scenario C is the most costly compared to the other two, predicting annual costs of about 37.3 million EUR. This shows that plastic recycling in the future would not be entirely financially self-standing, given that the operating costs across the whole value chain are higher than the revenues from the sales of secondary raw materials. This illustrates the fact that, like in the current situation, there needs to be support by other revenue streams than the sales from the materials, including Producer Responsibility Organisations' schemes and local waste management taxes which are required in order to supplement collection and sorting costs. Therefore, in Scenario C, the objective of the plastic recycling chain should be to reduce this "external" financing gradually, in order to improve its economic sustainability in the long run. Economy of scale resulting from the increased supply of recyclable plastics and logistics optimisation of separately collected plastic waste can result in short-term cost adjustments and eventual reductions. Moreover, [57] illustrated that implementing a tariff system and regulation of waste facilities, as in the case of Portugal, encourages performance improvements over time and gives incentives to overcome the defined regulatory targets. In this way, waste management companies engaged in separate collection and recycling could make profit and distribute higher dividends to their shareholders.

Finally, concerning employment numbers, Scenario C clearly outperforms the other two scenarios and shows a dynamically growing recycling sector by 2030, providing over 4000 new jobs. The significance of job creation in the recycling sector, and other associated waste management and support functions, is not only based on the number of jobs but also on the opportunity for social cohesion of diverse demographic groups. Employment in waste management is mostly attached to low-skilled jobs that could be performed by workers who may have fewer options available elsewhere in the economy, a fact that contributes to social integration and poverty alleviation. Especially in Sweden, recycling can offer a unique opportunity to absorb workers who recently arrived in the country and have not build their competences yet at a level to be competitive in the domestic job market. Direct employment in recycling can provide a safety net for these workers and their dependents.

4. Method

4.1. The Model

The quantification of increased recycling impacts was enabled using a plastic waste management flow model, developed for Plastic Recyclers Europe [19]. The model outlines the different parameters and criteria influencing the amount of plastic waste that is recycled, together with the associated costs and labour required for the different scenarios defined. The model enables a full quantification of impacts throughout the value chain of plastic waste. The value chain steps included in the model are (1) the collection of plastic waste, (2) the following pre-treatment/sorting, (3) the transportation to waste management facilities, and (4) finally, the recycling of the collected waste, incineration, or landfilling.

The model is populated with key data, such as costs for operation, collection and transportation, employment data and GHG emission data, and the model output enables an environmental (GHG emissions), economic (costs), and social (jobs generated) impact assessment [19]. The overall structure of the model, the associated parameters, and all necessary assumptions are presented in the following sections. The model is constructed in a simple and comprehensive way, avoiding over-complication of the value chain. The full methodology and details of data points are presented in great detail and full transparency in a report by Plastics Recyclers Europe [19] and the supplementary material of this article.

In this contribution, specific data for the Swedish situation was used and a modification of the model was performed. The original model did not include exports and imports of plastic waste due to data constrains, and therefore presented a more "simple" linear representation of the waste management system. In this study, we have developed an additional module that includes the amount of plastic waste that goes in and out of the country for recycling. The original model, by precluding exports and imports assumed a mass flow balance in a closed system, while in the model version of this study we use an open system approach, where the recycling capacity is dynamic dependent on imported and exported volumes.

4.2. Limitations of the Model

Model outputs are to be considered with caution, since the quality and confidence of the results can be as good as the underlying assumptions of the model. A lot of underlying assumptions are related to future projections, which means that there is a certain amount of uncertainty and unpredictability. We used primarily secondary sources, avoiding making our own assumptions, and thus the results of the model are dependent on the quality of the data sources. Furthermore, due to company confidentiality issues but also due to difficulties of getting timely responses from the actors contacted, a number of data points specific to Sweden were not successfully acquired. The missing data points were instead replaced with EU average values from a previous study conducted for Plastic Recyclers Europe [19]. This results to a slightly decreased level of confidence in the results and therefore they might not be fully accurate for Sweden.

4.3. Model Baseline Assumptions and Calculations

The baseline situation of plastic waste management and plastic waste flows in Sweden is based on a previous investigation by SMED (Svenska MiljöEmissionsData), published in 2012, using as reference the year 2010 [34]. SMED is a consortium of public institutions in Sweden with the aim of collecting and developing skills regarding the long-term emission statistics in the areas of air and water pollution, and waste and hazardous substances generation. Members of the consortium are the Swedish Environment Institute (IVL), the Swedish Statistics Agency (SCB), the Swedish Agricultural University (SLU), and the Swedish Meteorological and Hydrological Institute (SMHI). The report 'Mapping of plastic waste streams in Sweden' [34] presents the most comprehensive mapping of plastic waste flows in Sweden so far, and it contains rich contextual information that satisfy nearly all baseline data requirements of the plastic waste management model used in this study.

4.3.1. Plastic Waste Generation by Waste Stream

The SMED report provides quantitative data on plastic waste generation and management by source [34]. 'Manufacturing' and 'Medical' plastic waste is out of the scope of this study, so they are not modelled, and we did not use the respective amounts of plastic waste found in the SMED report. Without these two waste fractions, the breakdown of post-consumer plastic waste generation used in the model is presented in Table 3. The amounts presented in the table below are rounded.

Table 3. Share of plastic waste generation, by waste stream [34].

Ref. Year 2010	Packaging	WEEE	ELV	B&C	Agricultural	Other	TOTAL
Post-consumer plastic waste (tonnes)	299,000	34,000	18,000	43,000	18,000	81,000	493,000
Proportion of post-consumer plastic waste	61%	7%	4%	9%	4%	16%	100%

Note: WEEE: Waste Electrical and Electronic Equipment; ELV: End of Life Vehicles; B&C: Building and Construction.

4.3.2. Plastic Waste Collection Mode Differentiation

In the case of household waste, the data is broken down according to collection method. In the model, we distinguish between the different modes of collection according to the data found in the SMED report [34]. 'Sorted plastic packaging' is mainly attributed to 'bring site' collection, as 'kerbside' collection was not widely developed at the time of the study. ‘Plastic packaging in the residual waste’ is attributed to the ‘kerbside’ collection system in the model. ‘Sorted deposit bottles’ corresponds to the ‘Deposit’ system of collection in the model. Further, we have attributed a share of the ‘Services’ plastic waste to commercial post-consumer packaging, using the percentage defined by Plastic Recyclers Europe [19]. For the waste stream ‘Other plastic waste’ in the model, we included the data ‘Other plastics in the residual waste’ (kerbside collection) and ‘Bulky waste’ (delivery to recycling centres) from the SMED report. There is a separate mention in the SMED report about ‘Plastic packaging in the sorted food waste’, which we integrated into the ‘kerbside’ plastic packaging waste collection in the model. The rest of the waste streams in the SMED report correspond 1:1 to the defined categories of the model, so the attribution of data to respective categories is evident.

4.3.3. Plastic Waste Treatment by Waste Stream

SMED also specifies the plastic waste treatment in each waste stream, and this breakdown is used in the model to define the treatment shares of plastic waste by waste stream in the model baseline, as presented in Table 4.

Table 4. Share of plastic waste generation, by waste stream [34].

Ref. 2010	Collection for Recycling Rate	Incineration Rate	Landfilling Rate
Packaging	37%	63%	0%
WEEE	43%	44%	13%
ELV	0%	67%	33%
B&C	0%	100%	0%
Agricultural	89%	11%	0%
Others	4%	96%	0%
Total	29.13%	68.75%	2.12%

Note: The ‘Total’ treatment rate in the last row is a weighted average taking into account the share of each waste stream in the total plastic waste generation (see Table 3).

In Table 4, the column ‘Collection for recycling’ refers to the amounts of plastic waste collected and sent to recycling. However, the actual recycling is lower as a certain percentage of plastic is rejected in the subsequent processes (sorting and recycling), which is then redirected to other treatment options (most notably, incineration). This particularity is important in calculating the environmental impacts of plastic recycling, but it has little or no effect when calculating the economic and social impacts.

4.3.4. Plastic Waste Imports and Exports

The SMED report presents data regarding imports and exports of plastic waste. However, it does not specify countries of origin and destination, waste stream and plastic waste type. For this reason, we used the international trade databases ‘UN comtrade’ [46] and ‘Eurostat comext’ [58] to triangulate the data and identify the missing information. Plastic waste corresponds to CN8 code 3915, which is further subdivided by plastic waste type, 391510 for polymers of ethylene (PE); 391520 for polymers of styrene (PS); 391530 for polymers of vinyl chloride (PVC); 391590 for polymers of propylene (PP) etc. The data proved to be very consistent across all databases, which gives a strong indication of good quality data. We extracted data time series (2010–2015) and concluded that the type of waste traded and the trade partner countries remained relatively stable. About 25% of exports had Hong-Kong and China as destination, while the remaining 75% was trade was among EU partners with Germany being a dominant end market (30%–35% of the exports). A slight change over the years was observed with trade in EU shifting from earlier partners Netherlands and Belgium to later partners Poland and Lithuania, at the same percent of exports (15%–20%). In terms of modelling, this change has no effect, since the distance and mode of transport are approximately the same. For imports, Norway consistently accounts for over 90% of imports of plastic waste to Sweden for the whole period 2010–2015. The projections of imports and exports of plastic waste in the model are represented by a percentage of the amount compared to the total plastic waste generation in Sweden. In this assumption, the percentage of exports and imports is kept constant for all future scenarios. For example, if the export of PET bottles for recycling is 8% of the total plastic waste generated in Sweden in 2010, then the percentage of export of PET bottles for recycling in 2030 will be 8% of the total plastic waste generated in Sweden in 2030. This is an inherent assumption of the model, since it is not possible to predict actual amounts of plastic waste traded in a hypothetical situation in the future.

4.3.5. Projections of Future Plastic Waste Generation

For calculating the future plastic waste generation in Sweden, we used the baseline data from Table 3 and applied the annual growth rates proposed by the Swedish National Institute of Economic Research (Konjunkturinstitutet) in the report 'Environment, economy and policy 2016' [59]. The growth rates are based on the general equilibrium model EMEC, which is used by the Swedish government for long-term projections of the economy and for policy development. These projections have been criticised by another report from SMED [60] for being too "gross" and not accounting for possible waste prevention measures that would take place in the meantime and keep the growth rates at lower levels. However, in this study we will use the growth rates by KI for a number of reasons. Firstly, we ran time series (2008–2015) analyses on statistical data on waste generation [61–65] for 'Total waste generation', 'Packaging waste generation', and 'Municipal waste generation', and concluded that the projections by KI are valid, especially concerning plastic waste. When analysing 'Total waste' and 'Municipal waste' generation the trend was practically flat, with very low growth rate, which made us doubt the projections by KI. However, the trends in packaging waste in general, and plastic packaging waste in particular, were strongly correlated with the rate 2.4% proposed by KI. Secondly, a recent evaluation of the Swedish National Waste Prevention Programme by the Swedish Environment Agency [66] concluded that the programme was not effective in inducing waste prevention and the majority of Swedish stakeholders were unaware of its existence and its actions. Taking into account the weak performance of waste prevention activities in Sweden, the fact that packaging waste consists 61% of the total plastic waste, and that it is the waste stream with the most significant influence in the model, we concluded keeping the original projections made by KI and the EMEC model for all waste streams in the waste flow model. Table 5 presents the future amounts of plastic waste generated in 2030 which form the basis of calculations for all future scenarios in this study.

Table 5. Annual growth rate of waste generation and future waste amounts, by waste stream.

	Packaging	WEEE	ELV	B&C	Agricultural	Other	TOTAL
Post-consumer plastic waste (2010) (tonnes)	299,000	34,000	18,000	43,000	18,000	81,000	493,000
Annual growth (%)	2.4%	2.5%	2.5%	2.6%	1.0%	2.4%	-
Post-consumer plastic waste (2030) (tonnes)	480,474	55,713	29,495	71,848	21,963	130,162	789,656

Note: WEEE: Waste Electrical and Electronic Equipment; ELV: End of Life Vehicles; B&C: Building and Construction.

4.4. Data Collection

Specific data for use in the model was gathered through online literature sources, as well as expert interviews through phone calls and e-mails sent to relevant authorities and waste management organisations. The data needed for the quantification of the different impact categories in the model were operation and investment costs, employment numbers, transport distances, and weights related to the collection, transport, sorting and recycling of plastic. To get an overview of the data, a data protocol was constructed before the gathering was initiated. All cost data points collected were in Swedish currency (SEK), but were recalculated to EUR using a conversion rate of 1 EUR = 10.15 SEK. This is the average exchange rate over the period March–May 2018. The currency conversion was necessary for gap filling, in case of missing data, to harmonise the data points found specifically for Sweden with the ones that were used straight from the previous study [19].

The online literature search was conducted through search engines, such as Google Scholar. The search was done in both Swedish and English to make sure that no relevant literature was overlooked. In order to collect data that could not be retrieved from literature, expert interviews with different authorities connected to the plastic waste industry were done. Detailed data specifications retrieved from literature and interviews are provided as supplementary material in the on-line version of this article.

5. Conclusions and Future Research

The production, use and waste generation of plastic products is expected to increase in the future [3,60] and thus it is urgent to increase the re-use and recycling of plastic waste for transitioning to a resource efficient circular economy in Sweden. For increasing plastic recycling, there is a number of pre-conditions that need to be met [8,55], summarised in the following: (1) appropriately established schemes for the separate collection of plastic waste, (2) steady supply of plastic waste in adequately high volumes, (3) well-functioning markets for plastic waste with clear signals of secondary raw material demand, and (4) quality guarantees by the recycling industry for uptake in plastic manufacturing processes.

This contribution examined three potential future pathways for plastic waste management in Sweden, reflecting the above preconditions, and providing a way out of the inefficiencies of the current plastic waste management system. Among the three scenarios examined, Scenario C resulted in significantly positive environmental and social impacts with a high associated cost. Scenario B was the only scenario that resulted in economic benefits, but the environmental and social impacts were rather moderate. Purely on financial terms and cost considerations Scenario B might seem as the most desirable future option for Sweden. However, taking a more balanced approach, including cost-benefit and trade-off considerations, Scenario C might be the one to prioritise as a highly resource efficient and forward-looking option for transitioning to a low carbon circular economy in Sweden.

Sweden has set ambitious goals for transitioning to a fossil-free economy and contributing to the Paris agreement climate targets [67]. To achieve this, recyclable plastic waste would have to be gradually phased out from incineration facilities for energy production. This would be a great challenge, as incineration plants contribute significantly to the heating needs of municipalities. However, prohibiting the incineration of recyclable plastic waste would lift one of the major barriers of plastic recycling, the supply of waste plastic. It could provide a large quantity of waste of variable quality. Therefore, a ban on incineration would necessarily need complementary measures of sorting and recycling technology development, as well as capacity expansion. Additionally, a certification scheme or industry-wide standards (preferable at EU or global level) for guaranteeing the quality of plastics would be required to increase the confidence to and uptake of recyclable plastics.

Public policies that could promote demand from consumers could be addressed by improved public procurement criteria for resource efficiency, or by a preferential taxation framework for secondary raw materials. Apart from these defined policy instruments, stakeholders in plastic waste management prioritise additional policy interventions (at local, national or international level), such as value chain coordination and gradual integration, followed by the need for increased investment for innovation in the sector [8].

The results of this study, together with the identified barriers in the Swedish market of plastic waste [8], can form the basis of future research on the appropriate policy measures required to increase plastic recycling in Sweden. Policy instruments, such as the ones mentioned above, need to be thoroughly analysed and evaluated in order to provide potential solutions and policy tools that will enable the transition to a low carbon circular economy in Sweden.

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