"From incineration to recycling – An economic and environmental assessment of circular economy of plastics in Finland"

Version 1.0 / Draft: Not for Publication

Hannu Savolainen[1,2], Juha Honkatukia[3]

[1] Finnish Environment Institute (SYKE), Helsinki, Finland
[2] University of Oulu, Oulu Business School, Department of Economics, Accounting and Finance, Oulu, Finland
[3] The Finnish Institute for Health and Welfare (THL), Helsinki, Finland

ABSTRACT
In circular economy, the value of products, materials and resources is maintained as long as possible. This is done by minimizing the waste generation by using production side flows as resources and reusing and recycling products. The recycling and other waste management actions are in the heart of CE. In this paper we perform a scenario assessment of increased plastic waste recycling in Finland by using environmentally-extended CGE model. Impacts on aggregate economic outcome, growth contributions and value chains are in the focus. We also shed light on the need for policy instruments to enable such a change in plastic waste treatment from incineration to recycling and secondary material manufacturing. Economic indicators are combined with environmental indicators including material use and greenhouse gas emissions. In all three scenarios the costs of increased recycling exceeded the increased production in waste management sector. Overall effect on GDP was negative in every scenario, but least in the case where domestic plastics were subsidized over imported plastics. In this scenario material flow impacts were also favorable, since imported materials were substituted with recycled materials. We could not find a win-win situation where both economic impacts and environmental consequences were simultaneously positive.

KEYWORDS
circular economy, waste, plastics, policy instruments, computable general equilibrium, scenario analysis, material flow analysis, greenhouse gas emissions

1. INTRODUCTION

Some of the grand challenges of today are using the Earth's limited resources in a sustainable and equitable way, whilst preventing negative environmental impacts and tackling climate change. The concept and practice of circular economy (CE) has been proposed to be an essential solution to many challenges our society is currently facing. Additionally, a cleaner, more resource-efficient economy is claimed to be more competitive.

In CE, the value of products, materials and resources is maintained as long as possible. This is done by minimizing the waste generation by using production side flows as resources and reusing and recycling products (European Union, 2015). The overall goal is to move from linear throughput to a closed-loop materials and energy use in the economy. Transition to a circular economy requires changes throughout value chains, from product design to new business and market models, from new ways of turning waste into a resource, and to new modes of consumer behavior.

1.1. The need for CGE approach in assessing CE

For economic policies, the circular economy poses new challenges. New technologies are essentially about discovering and utilising previously neglected material flows, for which there are only limited markets at best. It is therefore almost impossible to use top-down, one-size-fits-all measures to study the role of policies.

The transition to a more circular economy involves structural shifts in the economy. This involves the decline for some sectors and industries and the rise for others (McCarthy et al., 2018). It also means reallocation of capital and labour. There is already a large body of research concentrating on different sectors, actions, measures and policies concerning CE. Research approaches differ ranging from engineering to business studies and material science. The impacts of CE might cover material use, climate change impact or economic outcomes.

The models used in CE studies are often ill-equipped in capturing aggregate economic outcomes, indirect impacts or the essential dynamic nature of the transition. Models might be static, lacking price mechanism, investments or crowding-out effects. Aguilar-Hernandez et al. (2021) find, that there are various modelling limitations in the current literature, most important dealing with public investments, rebound effects and policy interventions. While several models might be able to include various engineering details of recycling technologies, adjustment of the economy, financing of investments, changing relative prices etc. might be missing. This is a considerable pitfall when informing policymakers of economic, environmental and social gains of CE.

Economy-wide quantitative models, such as computable general equilibrium (CGE) or applied general equilibrium (AGE) models, possess elements which make them suitable for analysing CE actions. Price mechanism captures the impacts of changing structures caused by CE actions throughout the economy. Initial effects might be partially offset because of economic agents adapting to changed situation. These models also cover all economic flows, so there are e.g. constraints for economic activity and crowding-out effects in investments. Compared to static or accounting models, CGE/AGE modellers can analyse both aggregate economic outcomes and changes in specific value chains, including direct and indirect effects.

1.2. Waste management and recycling in circular economy - Municipal solid waste, plastic waste and recycling goals in Finland

One of the goals in CE is to keep materials in the economic use as long as possible, thus decreasing the use of virgin raw materials. Prolonging product lifetime and minimizing wastes by refurbishment, re-use, remanufacturing and recycling are important steps and in line with the waste hierarchy. As wastes are inevitable part of economic processes, circular economy emphasizes recycling over other recovery options (backfilling, incineration with energy recovery) or disposal (landfilling or incineration without energy recovery). Figure 1 shows the increase of recycling in European Union countries between 2004–2018.

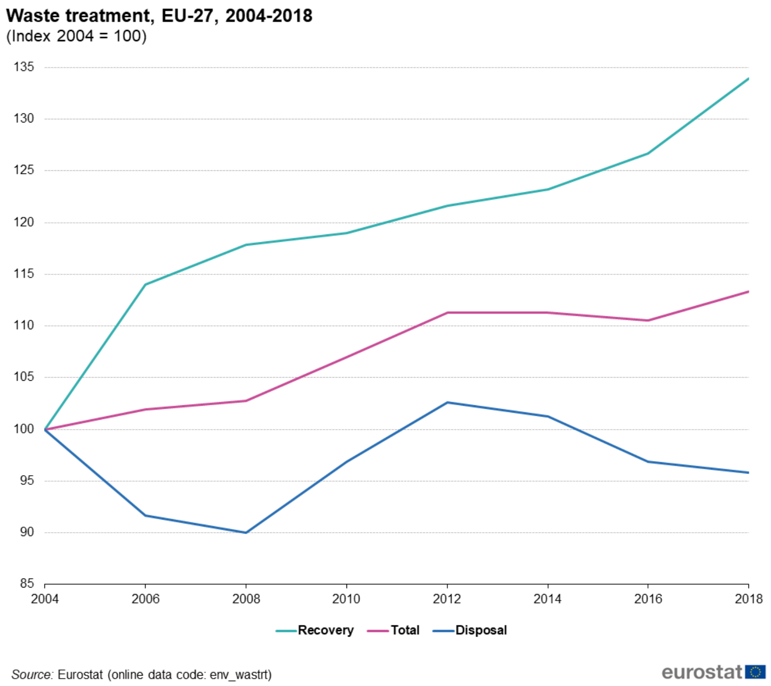


Figure 1. Waste treatment, EU-27, 2004–2018, volume index (Eurostat, 2020).

Municipal solid waste (MSW) is considered one of the most difficult waste fractions to recycle, even though the volumes may not be the highest of all waste flows. MSW is mainly generated by households, but it includes similar wastes from sources such as commerce, offices and public institutions (European Commission, 2016). Usually municipal wastewater treatment sludge, industrial process wastes and construction debris are excluded. Municipal solid waste can be divided into several waste fractions. Source separation means that households and other waste generators sort the waste fractions in real estates or bring those to local sorting stations. Paper and cardboard, biowaste, glass, metal, wood, plastic, disposed electronic devices and so on, are usually collected separately, mainly due to extended producer responsibility (EPR). The rest of MSW can be collected as a mixed municipal waste (MMW) or mixed municipal solid waste. The composition of mixed MSW varies between regions and countries, and it is analyzed by municipal waste authorities and researches alike, in order to determine the energy content, the share of renewable energy and the mass shares of different fractions.

The driving force to recover and recycle municipal solid waste (MSW) stems from three sources. First, the banning of landfilling and/or the lack of space for landfills has raised the need for different waste management schemes. Second, greenhouse gas (GHG) emissions reduction targets put pressure on waste management to cut the emissions and to increase the share of renewable energy sources. Third, the overall need to save natural resources has been widely acknowledged.

The volume of MSW in Finland has been rather constant, increasing from 2.2 million tons (1997) to 3.0 million tons (2018) (Official Statistics of Finland, 2020). From overall waste volume of the Finnish economy (nearly 94 million tons in 2014), MSW covers only 3–4 % (Official Statistics of Finland, 2020). The shares of MSW treatments in 2018 were energy recovery 57 %, material recovery 42 % and disposal 1 %. The most important change in Finnish MSW treatment system has been the decline of landfilling due to tightening waste legislation. In the meantime, rapid and large investment have been made to waste incineration capacity since 2007. As a result, the share of energy recovery of MSW has increased to over 50 %, while material use has stayed quite constant in 1/3 (Official Statistics of Finland, 2020).

As mentioned above, plastic waste is one fraction of MSW[1]. Plastic waste has been in center of waste discussion for some time, at least in EU. There are several reasons for this. Manufacturing of plastic is based mostly on fossil feedstock and incineration of plastic waste contributes to climate change. The use of different plastic types is increasing. Plastic waste and microplastics pose a serious threat to water ecosystems. Some of European Union member states exported most of their plastic wastes to third countries, mainly China. China's decision to cease importing have put pressure on EU to ramp up their recycling capabilities.

In Finland, the share plastic waste is MSW is approximated to be 16-17 %. This amount includes both plastic packages, which are under extended producer responsibility, and other plastics. There were over 135,000 tons of plastic packages in circulation in 2018. The material recovery of that amount was 30 %. Over 2/3 of packages was incinerated. On top of that, 97 % of mixed municipal waste was incinerated and all plastic waste fractions alongside.

European Union has set several goals in order to promote circular economy (European Comission, 2021). Recycling levels of municipal solid waste and different waste fractions are one part of the CE policy package. The national recycling of plastic packages ought to be 50 % in 2025 and 55 % in 2030. Recycling goal of all municipal solid waste (MSW) set by EU directive is 55 % in 2025 and 60 % in 2030. Finland has a high garbage mountain to climb to achieve these goals.

At the moment, there are six secondary material manufacturing companies concentrating on plastic waste recycling and supplying secondary plastics to the market in Finland. Manufacturing capacity is already in full

[1] Here we concentrate on plastic waste in MSW. Plastic waste is generated also in agriculture, manufacturing and construction, but service sector and households generate well over 50 % of it.

use, and some amount of plastic wastes are exported to Central Europe. The need for recycling capacity in waste management sector is urgent, if EU-level recycling goals are to be achieved.

1.3. Our contribution and research task

In this paper we perform a detailed analysis of plastic waste recycling, which is an important part of CE transition pathway for the economy of Finland. Impacts on aggregate economic outcome, growth contributions and value chains are in the focus. We also shed light on the need for policy instruments to enable such a change in plastic waste treatment from incineration to recycling and secondary material manufacturing. Economic indicators are combined with environmental indicators including material use and greenhouse gas emissions.

We use CGE model, which is extended with greenhouse gas emissions and material flow accounting. Few CGE models are able to track environmental effects parallel with economic outcomes (Hatfield-Dodds et al. (2017) and Schandl et al. (2020) use models with material flow extensions). Our end-result is a comprehensive picture of the effects of three plastic recycling scenarios.

Our goal is to critically analyze, whether plastic recycling scenarios imply “win-win” outcomes for both the environment and the Finnish economy or not. The insights from the Finnish case have relevance to policy-planning in other countries, as well.

2. MATERIALS AND METHODS

We perform a scenario assessment of increased plastic waste recycling using environmentally-extended CGE model. We report the effects of the policies as deviations from a baseline extending to 2030. The baseline already contains many measures that could be taken for promotion of the circular economy, stemming from the EU energy and climate policy targets for 2020, and stipulating binding targets for the share of renewables in energy consumption. For 2030, such targets are not yet in place.

We have tried to make full use of the data on new technologies and the changes in value chains and markets they entail by allocating changes in intermediate use, investment and thereby capital-labour or value-added-material ratios by commodity and by industry as closely as possible. It is possible to identify links from investments (in new recycling technologies) to changes in input structure (more efficient or altered material flows). Additionally, it is possible to identify the need for policies for bringing about the changes in waste treatment, for example, by introducing investment subsidies.

2.1. Overview of FINAGE model

We integrate plastic waste CE actions into the FINAGE model to study the impacts of the transition (Honkatukia 2009, Honkatukia 2019). FINAGE is a fairly standard, recursive, VU/MONASH-like AGE model of the Finnish economy which emphasizes the detailed structure of taxes and public sector transfers, as well as the structure of the industries, the labour force, capital stocks, and production. In the core of the model is optimization problems of economic agents that result in the demand and supply functions of goods and primary factors.

The dynamics of the model results in gradual adjustment to policies or external shocks to the baseline development of the economy. Three types of inter-temporal links are connecting the consecutive periods in the model: 1) accumulation of fixed capital; 2) accumulation of financial claims; and (3) lagged adjustment mechanisms, notably in the labour markets. The pace of adjustment depends on several parameters: 1) the rates of depreciation of capital at the industry level; 2) the rate of adjustment of returns to capital; and 3) the rate of adjustment of real wages (when sluggish wage adjustment is assumed). These parameters can be derived from national accounts data and econometric studies of, notably, the labour markets. Policies can also affect the rate of adjustment. Fixed capital is sector-specific meaning that the capital is not malleable.

The model utilises extensive databases describing the transactions between different agents in the economy. A large part of the database uses input-output data to capture the structure of demand for intermediate goods and primary factors by industry and final goods consumption by the consumers, the public sector, and the rest of the world. However, input-output data does not contain data on income flows, which must be obtained from other sources in national accounts. In the current version of the model, data includes 93 industries and 144 commodities following NACE and CPA classifications.

2.2. Modelling waste management and recycling of plastic waste

Waste management is a rather large industry which provides waste management services in the first hand but is also active in many other fields. One of the major commodities it provides is district heating. This is the end-product of conventional waste treatment, i.e., incineration with energy recovery. Plastic waste – both separated plastic waste and a fraction of MMW – is among the feedstocks in this process, and in 2018, it amounted to some 7 M€. The sector is also responsible for recycling wastes and manufacturing secondary materials, among them also plastics. Waste management is a separate industry in the model with specific

To speed up the material recycling of plastic wastes and manufacturing of secondary plastics, both the treatment processes for plastic as well as the collection of plastic waste need to be ramped up. We estimate that this requires an investment of close to 181 M€ in the waste sector alone in waste pretreatment and secondary plastics manufacturing capacity. In addition, waste collection volume has to increase, which increases costs for industrial and service sector users by some 50 M€ yearly. In return, the production of secondary plastic material increases by some 80 M€ yearly. The main users of secondary plastics are potentially outside the waste management sector, mainly in the chemical industries. However, recycled material is in competition with imported materials.

We have differentiated energy nest for waste management sector from other industries and included plastics as one energy type. The rationale behind this is that the sector can either incinerate plastics in waste-to-energy plants to produce district heat or manufacture secondary materials and supply them to the market. We have modified the supply of waste management sector to include secondary plastics.

2.3. Material flow accounting

Use of natural resources is a key element in circular economy. Several actions aim to decrease the extraction of virgin natural resources. In order to analyse the effects of CE actions extensively in our work, we equipped FINAGE model with material flow accounting and indicators. This extension is based on the environmentally-extended input-output model of Finnish economy, ENVIMAT (Seppälä et al., 2011). The model produces estimates of material-intensity coefficients (kg/€) for over 200 domestic, imported and exported products. These coefficients are adjusted for FINAGE commodity classification.

We follow the guidelines of material flow accounting (MFA) of Eurostat in this work (Eurostat, 2018). The domestic extraction of natural resources (DE) in measured in mass (metric tons) and linked with correspondent primary commodities (agriculture, forestry, fishing, mining etc.). Imported and exported commodities are measured in direct mass and raw material equivalent masses.

Since we don't assume any material-intensity changes in extraction or manufacturing, we can report extracted and imported material flows on basis of monetary changes in scenarios. This material flow accounting offers us insights of material inputs, use and consumption.

2.4. Greenhouse gas emissions calculation

GHG emissions calculation follows the production-based calculation (European Environment Agency, 2013), compared for territory-based emissions. Energy-based emissions are calculated via the use of different energy carriers. On top of that, non-energy-based emissions (industry processes, agriculture, product use, waste management etc) are estimated on the basis of economic activity on different industries and sectors. Some additional out-of-the-model calculations are needed to capture e.g. waste incineration emissions. LULUCF emissions are excluded from the model at the moment.

Besides direct emissions, we are able to estimate consumption-based emissions, i.e. embodied emissions of imports. This way we are can keep track on the carbon footprint of Finnish economy. The calculation is similar to material flow accounting. Consumption-based GHG emission of Finnish economy are production-based domestic emissions plus embodied emissions of imports less embodied emissions of exports. The analysis of both production-based and consumption-based emissions is crucial, since Finland is a small open economy, which can outsource its emissions via foreign trade. Since the total effects (direct, indirect and rebound effects) of circular economy actions depend on relative prices, insight of total environmental effects is needed through different indicators.

2.5. Scenario assumptions and data

We examine our research question with different scenarios. Using Börjeson et al. (2006) scenario typologies, our approach is reminds of preserving scenarios, which are part of normative scenarios. They respond to question: how can the target or goat be achieved, by adjustments to current situation? Here we are trying to find out, what economic instruments are needed in order to reach recycling goals of plastic waste in Finland. And what are the economic and environmental consequences of reaching those goals.

We have three different scenarios:

1) Waste pretreatment and secondary plastic manufacturing capacity Investments of 181 M€ starting 2021 with investment subsidies in waste management sector; production of secondary plastics starts in 2023, reaching economic value of 97 M€. In 2023, about 50 million € increase in waste collection costs in industries and services. Use of light of fuel oil and electricity increase by 50-60 % in intermediate use of waste management.
2) As in 1, but a tax on incineration of plastic waste (Power of tax +25%, here also tax rate because no taxes in practice previously)
3) Same as 2, but with a tax cut on domestic plastic to mimic a production subsidy

The main input data and parameters are described in table 1.

Table 1. Main scenario data and parameters.

Variable/parameter	Amount	Unit
Collected plastic waste after CE actions	179,931	tons (annual)
Revenues from secondary plastic material after CE actions	97	M€ (annual)
Capacity investment for secondary manufacturing	438	€ per treated waste ton
Capacity investment for MMW pretreatment	110	€ per treated waste ton
Collection and treatment costs of plastic waste	259	€ per ton (annual)

3. RESULTS AND DISCUSSION

3.1. Main results

3.1.1. Economic impacts

In all scenarios, investment in the new capacity shows initially up as a higher capital contribution to GDP compared to baseline (figures 2-4). But once the new plants begin operating, the increased use of waste management services (collection and recycling treatment) in other industries ends up slightly lowering their productivity (technology effect on GDP). This is due to increasing the use of an intermediate good, which has no effect on production. Industries and services using plastic packages are obligated to pay for the increased recycling rate because of EPR system. Similarly costs of recycling other plastic wastes are borne by industries generating the plastic waste in the first place. The increase in waste management production (secondary plastics) is not enough to compensate for this extra cost, especially as unit costs increase in the waste management sector as well.

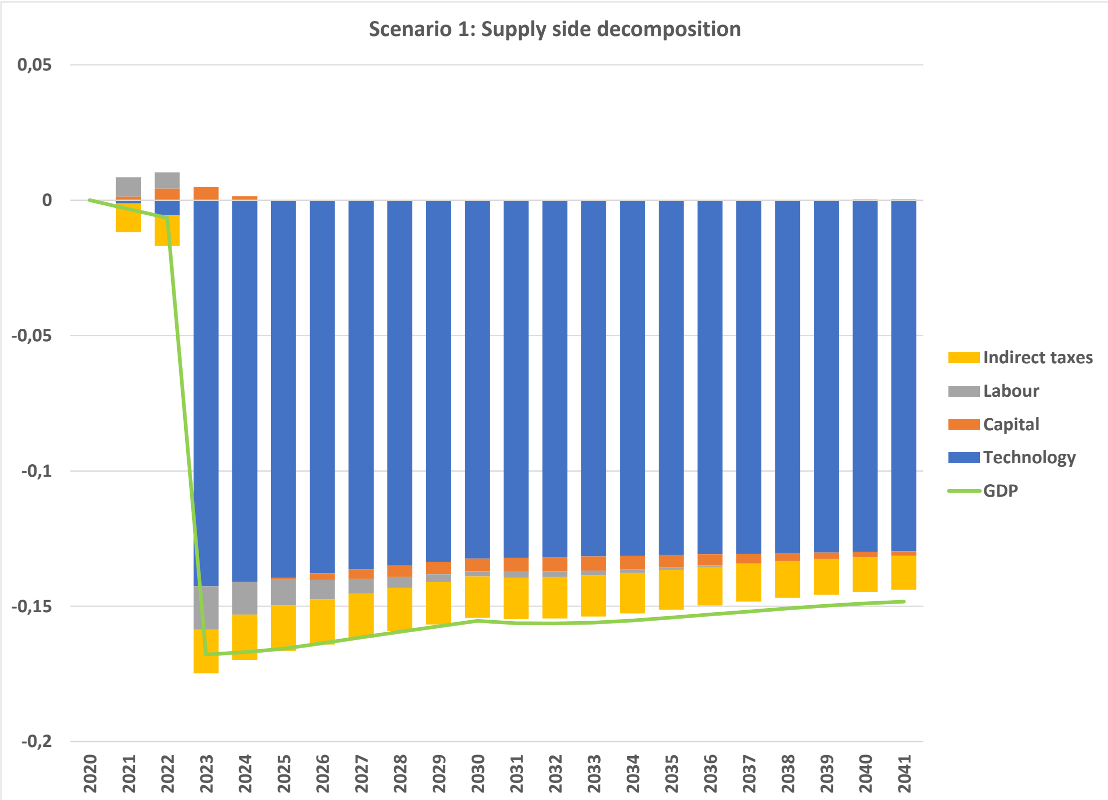


Figure 2. Supply side decomposition of GDP effects in scenario 1 (difference to baseline, percentage points).

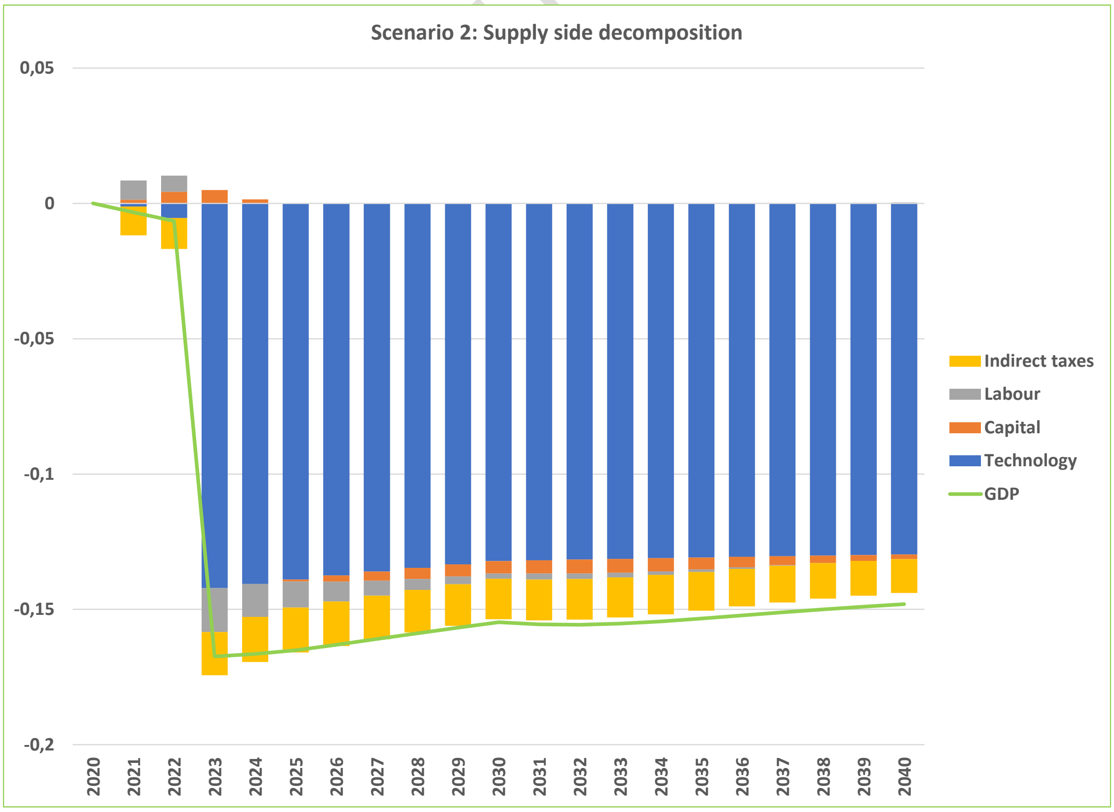


Figure 3. Supply side decomposition of GDP effects in scenario 2 (difference to baseline, percentage points).

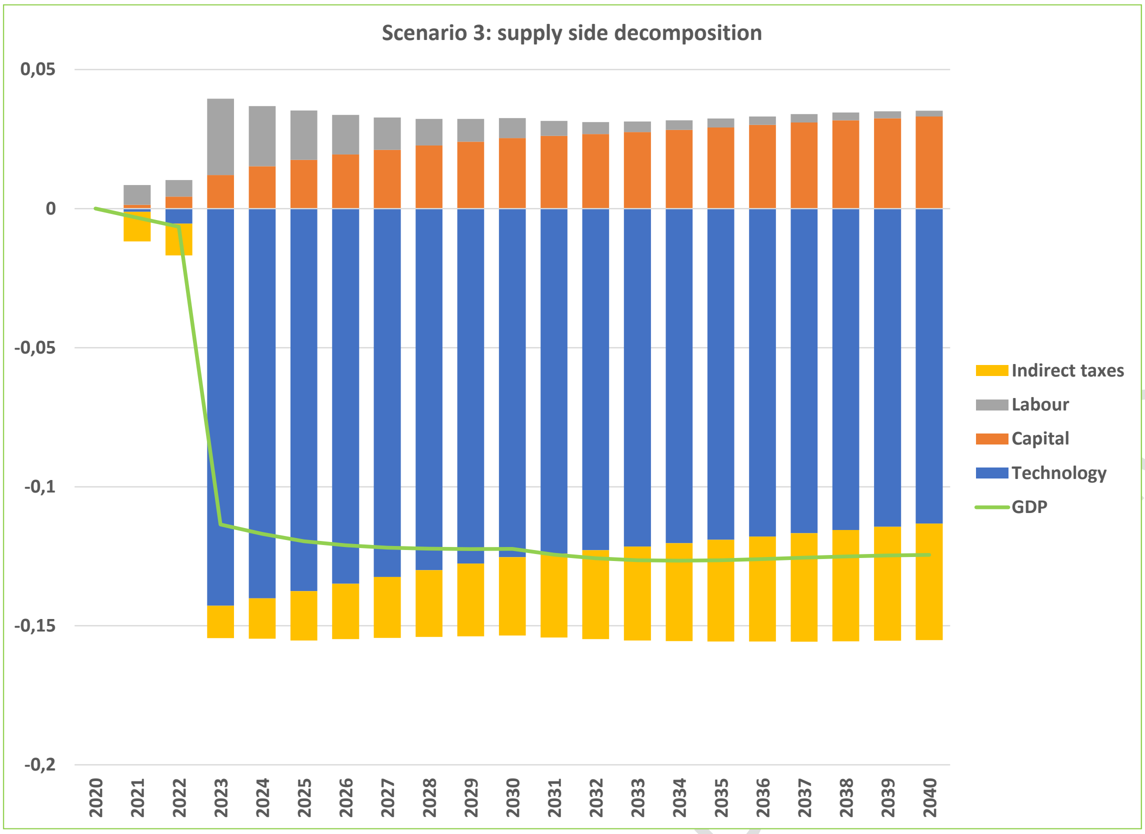


Figure 4. Supply side decomposition of GDP effects in scenario 3 (difference to baseline, percentage points).

It turns out the macroeconomic results depends on how recycled plastic is used. In scenario 1, increased recycling of plastic waste actually increases its incineration. In scenario 2, we introduce a tax to prevent this. This puts an end to incineration, but it also results in even higher prices for the recycled plastic, and its use in other sectors is only slightly improved. In the third scenario, we recognize that the recycled plastic is not competitive and subdue to a tax perk for it. This results in domestic, recycled plastic replacing imported plastic. Figure 8 shows how important plastic user industries (manufacture of pharmaceutical products and manufacture of rubber and plastic products) switch intermediate use of plastics from imported to domestic.

From a GDP point of view scenario 3 turns out to be a slightly more favourable outcome compared to others. Figures 5-7 represents the expenditure effects on GDP growth contributions. Scenario 3 has slightly higher domestic investment and consumption than scenarios 1 and 2. But the cost is a deteriorating trade balance.

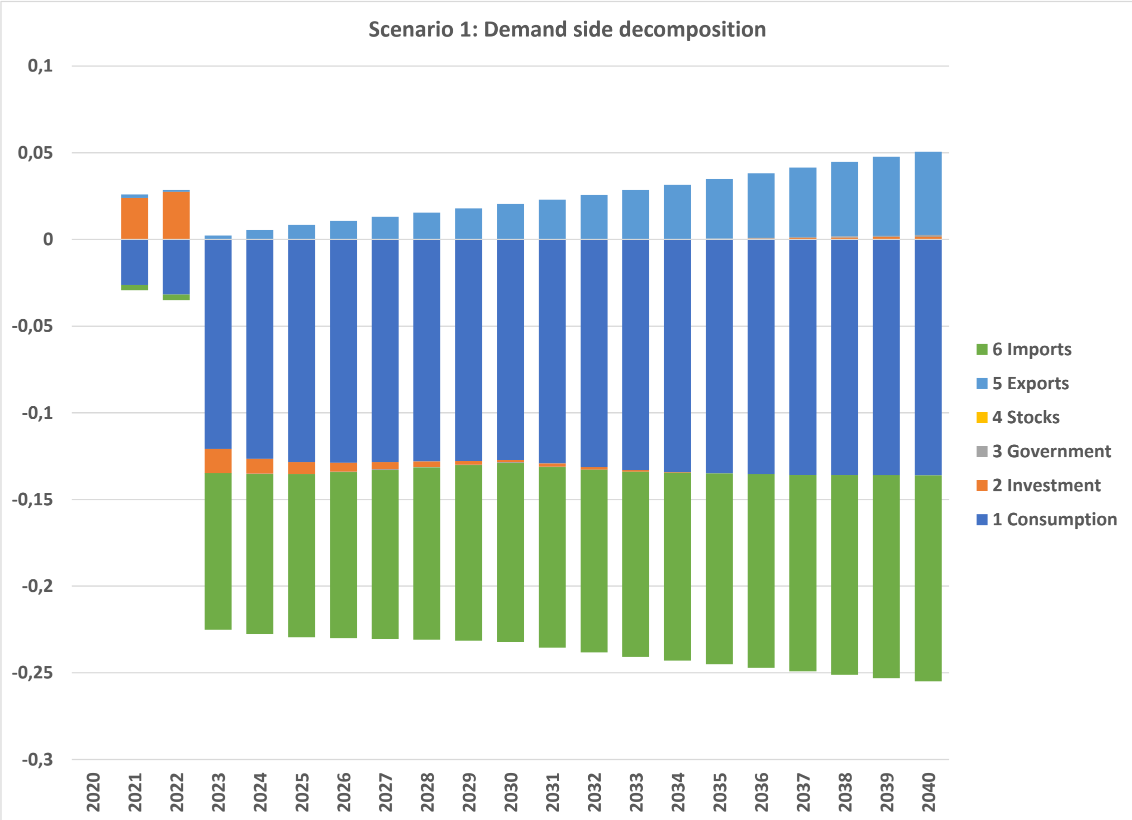


Figure 5. Demand side decomposition of GDP effects in scenario 1 (difference to baseline, percentage points).

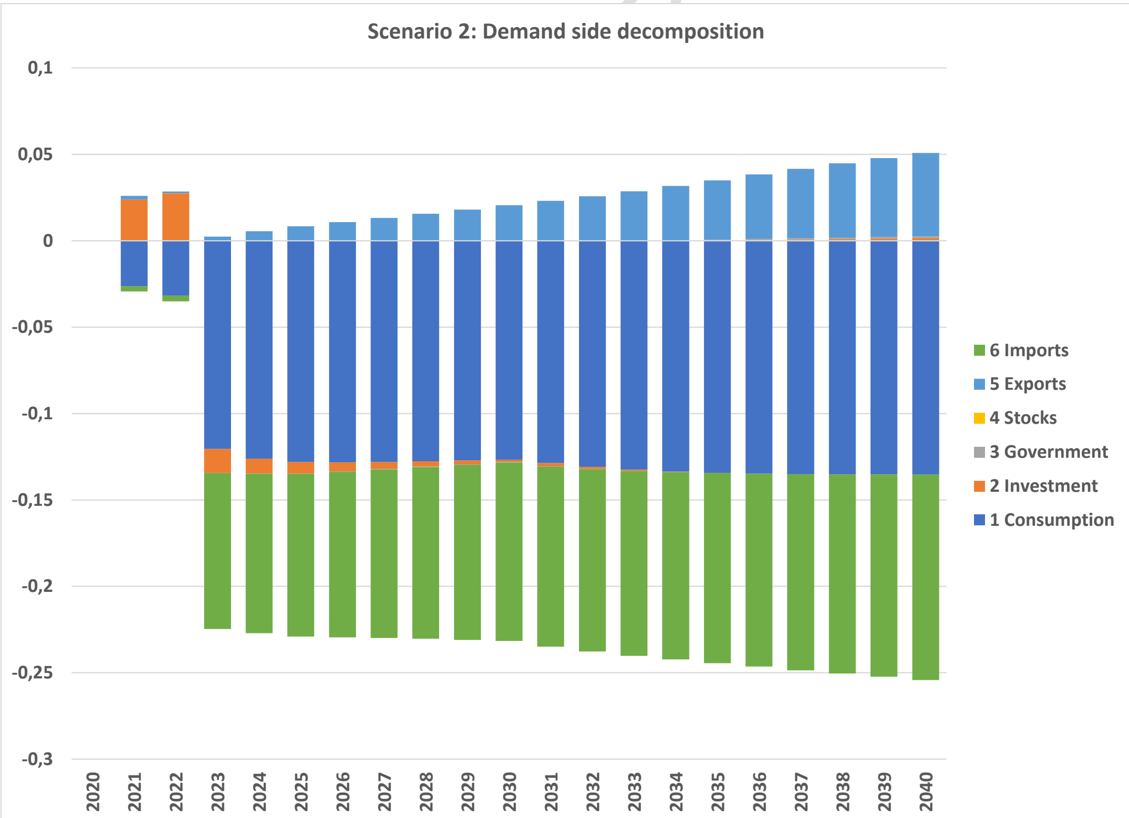


Figure 6. Demand side decomposition of GDP effects in scenario 2 (difference to baseline, percentage points).

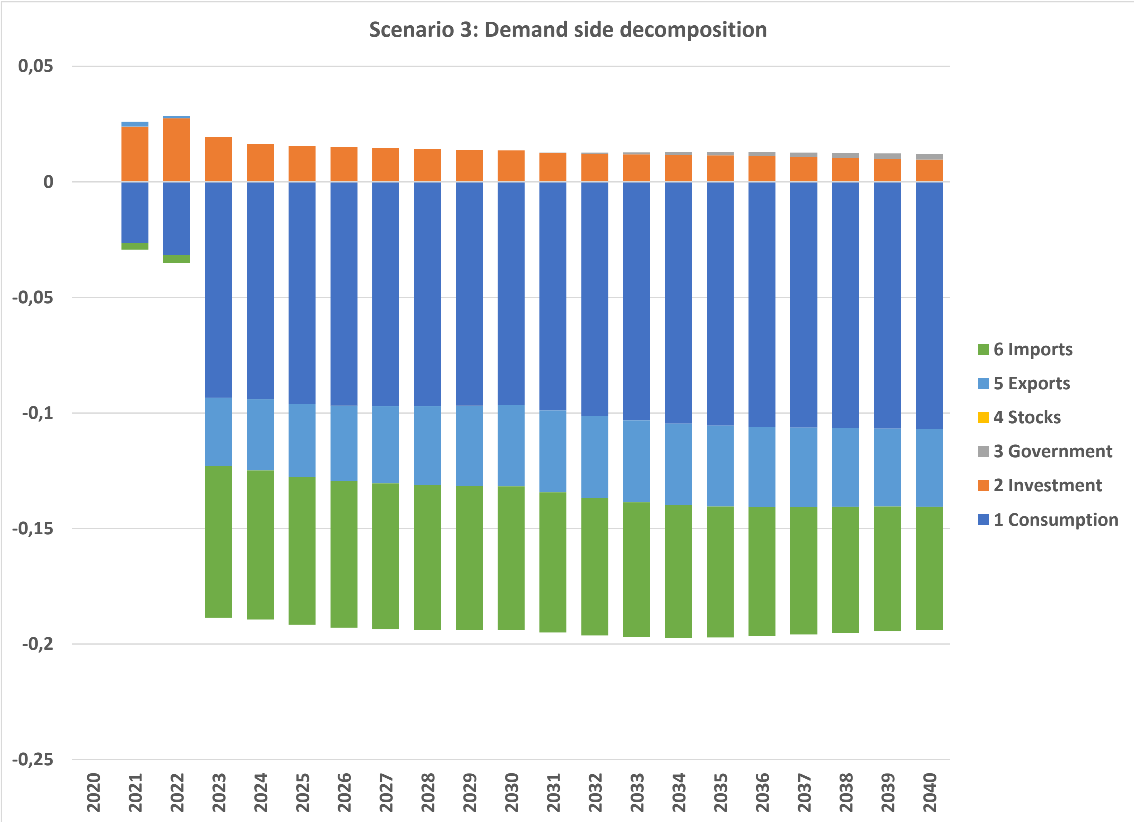


Figure 7. Demand side decomposition of GDP effects in scenario 3 (difference to baseline, percentage points).

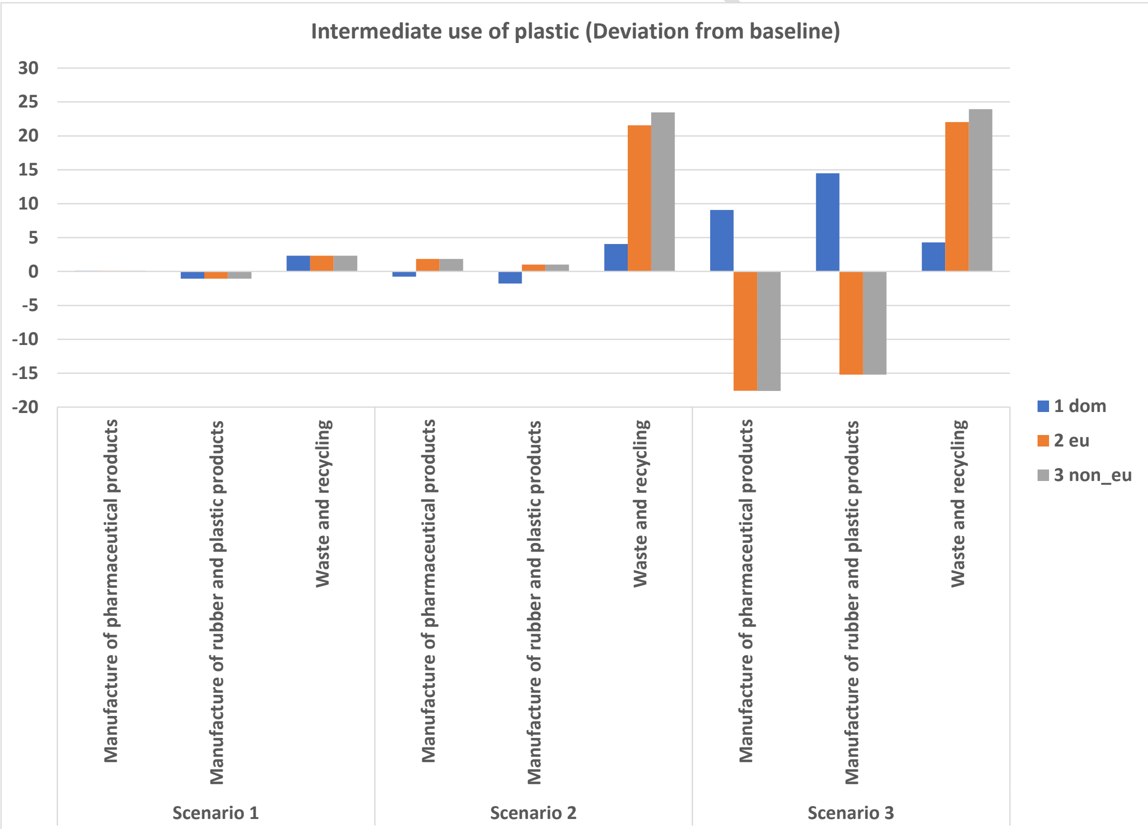
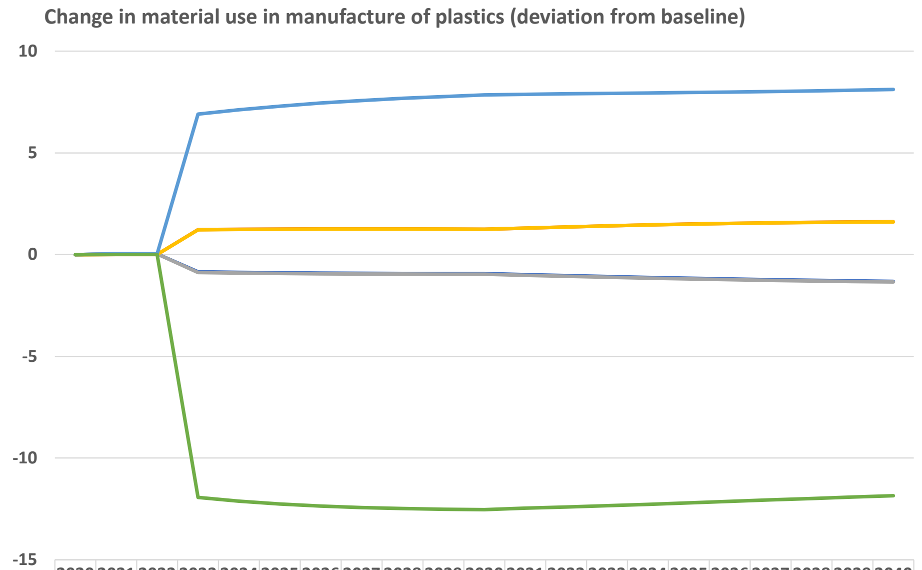


Figure 8. Intermediate use of domestic or imported (EU or outside EU) plastics (deviation from baseline, percentage points).

3.1.2. Impacts on material flows

The material flows linked with plastic products depend on the scenario. When calculating material flows as basic primary raw materials, domestic production and imports have different material intensities per euro worth of product. The material volume depends on both the economic volume and material intensity. Figure 9 depicts the change in material use linked to plastics. In scenarios 1 and 2 imported materials increase due to increased demand for imported plastics. In scenario 3, the change in taxation improves the competitiveness of domestic plastics. It affects material flows so that imported materials decrease over 10 percentage points compared to baseline. The corresponding increase in domestic materials is less than 10 percentage points, since secondary plastics have smaller material intensity compared to plastics manufactured from virgin materials.



	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Scenario 1 DOM	0	0,04	0,04	-0,8	-0,9	-0,9	-0,9	-0,9	-0,9	-0,9	-0,9	-1	-1	-1,1	-1,1	-1,2	-1,2	-1,2	-1,3	-1,3	-1,3
Scenario 1 IMP	0	0,01	0,01	1,22	1,24	1,26	1,26	1,27	1,26	1,26	1,25	1,3	1,36	1,41	1,46	1,5	1,54	1,56	1,59	1,6	1,61
Scenario 2 DOM	0	0,04	0,04	-0,9	-0,9	-0,9	-0,9	-1	-1	-1	-1	-1	-1,1	-1,1	-1,2	-1,2	-1,2	-1,3	-1,3	-1,3	-1,3
Scenario 2 IMP	0	0,01	0,01	1,21	1,23	1,25	1,26	1,26	1,26	1,25	1,24	1,3	1,36	1,41	1,46	1,5	1,53	1,56	1,58	1,6	1,61
Scenario 3 DOM	0	0,04	0,04	6,91	7,12	7,29	7,45	7,58	7,68	7,77	7,85	7,88	7,9	7,92	7,95	7,97	7,99	8,02	8,05	8,08	8,12
Scenario 3 IMP	0	0,01	0,01	-12	-12	-12	-12	-12	-12	-13	-13	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12

Figure 9. Domestic or imported material use in manufacture of plastic products (difference to baseline, percentage points).

3.1.3. Changes in GHG emissions

The results of greenhouse gas emissions shall be added in the next version of this conference paper.

3.2. Overall impacts of recycling plastic wastes

3.2.1. Which policy instruments to use?

3.2.2. Pros & cons at hand – economic and/or environmental?

Chapter 3.2 shall be added in the next version of this conference paper.

3.3. Limitations and uncertainties

3.3.1. Input data of policy scenario

3.3.2. Demand and markets for secondary raw materials of plastics

3.3.3. Material flows and GHG emissions

Chapter 3.3 shall be added in the next version of this conference paper.

4. CONCLUSIONS

The purpose of this paper was to analyze circular economy actions in waste management sector. We used environmentally-extended CGE model in analyzing the scenarios. CGE models have been found well-equipped in assessing macroeconomic impacts of transition needed for circular economy. We concentrated on increased recycling and secondary material manufacture of plastic wastes in Finland. The main research question were: what sort of economic instruments are needed in order to reach EU recycling goals in Finland concerning plastic wastes? Besides that we were interested in macroeconomic and environmental effects of increased recycling.

We could not find a win-win situation where both economic impacts and environmental consequences were simultaneously positive. The costs of increased recycling exceeded the increased production in waste management sector. Overall effect on GDP was negative in every scenario, but least in the case where domestic plastics were subsidized over imported plastics. In this scenario material flow impacts were also favorable, since imported materials were substituted with recycled materials.

REFERENCES

Aguilar-Hernandez, G. A., Dias Rodrigues, J. F., & Tukker, A. (2021). Macroeconomic, social and environmental impacts of a circular economy up to 2050: A meta-analysis of prospective studies. Journal of Cleaner Production, 278, 123421. https://doi.org/10.1016/j.jclepro.2020.123421

Börjeson, L., Höjer, M., Dreborg, K., Ekvall, T., & Finnveden, G. (2006). Scenario types and techniques: Towards a user's guide. Futures, 38(7), 723-739. https://doi.org/10.1016/j.futures.2005.12.002

Eurostat (2020). Waste Statistics. https://ec.europa.eu/eurostat/statistics-explained/index.php/Waste_statistics#Waste_treatment

European Commission (2016). Guidance on municipal waste data collection.

European Commission (2021). Waste and recycling. https://ec.europa.eu/environment/topics/waste-and-recycling_en

European Environment Agency (2013). European Union CO2 emissions: different accounting perspectives EEA Technical report No 20/2013. doi:10.2800/10691

European Union (2015). Closing the loop - An EU action plan for the Circular Economy. European Commission, Brussels.

Eurostat (2018). Economy-wide material flow accounts handbook. 2018 edition.

Hatfield-Dodds, S., Schandl, H., Newth, D., Obersteiner, M., Cai, Y., Baynes, T., . . . Havlik, P. (2017). Assessing global resource use and greenhouse emissions to 2050, with ambitious resource efficiency and climate mitigation policies. Journal of Cleaner Production, 144, 403-414. https://doi.org/10.1016/j.jclepro.2016.12.170

Honkatukia, J. (2009). VATTAGE – A dynamic, applied general equilibrium model of the Finnish economy. Research Reports 150, Government Institute for Economic Research.

Honkatukia, J. (2019). FINAGE/REFINAGE General Equilibrium Models of the Finnish Economy. In Honkatukia et al. (2019): ALTA - Regional economic database for Finland. Prime Minister's Office Publications 41/2019.

McCarthy, A., R. Dellink and R. Bibas (2018). The Macroeconomics of the Circular Economy Transition: A Critical Review of Modelling Approaches, OECD Environment Working Papers, No. 130, OECD Publishing, Paris. http://dx.doi.org/10.1787/af983f9a-en

Official Statistics of Finland (OSF) (2020). Waste statistics [e-publication]. ISSN=2323-5314. Helsinki: Statistics Finland [referred: 16.4.2021].

Schandl, H., Lu, Y., Che, N., Newth, D., West, J., Frank, S., . . . Hatfield-Dodds, S. (2020). Shared socio-economic pathways and their implications for global materials use. Resources, Conservation and Recycling, 160, 104866. doi:https://doi.org/10.1016/j.resconrec.2020.104866

Seppälä, J., Mäenpää, I., Koskela, S., Mattila, T., Nissinen, A., Katajajuuri, J.-M., Härmä, T., Korhonen, M.-R., Saarinen, M., Virtanen, Y., 2011. An assessment of greenhouse gas emissions and material flows caused by the Finnish economy using the ENVIMAT model. Journal of Cleaner Production 19, 1833–1841. https://doi.org/10.1016/j.jclepro.2011.04.021