

Waste management and circular economy in a CGE framework

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Abstract

By 2050 the world is expected to generate about 3.4 billion tons of waste. A large part of this waste stream could be reused or recycled, however without an active effort to do so, most of this waste will end up dumped or in landfills or incinerators. The reuse, recycling and use of waste to substitute for virgin chemicals, energy and animal feed materials can contribute to more sustainable, efficient and integrated bio-based economy. In this paper we focus on developing the methodology to include a waste management system in a CGE modelling framework and on building a database to operationalize the new waste module within the global CGE model - MAGNET. It includes introducing municipal solid waste generated by households and various options of dealing with waste by including new waste treatment sectors like landfills, waste to energy, recycling and composting sectors. We distinguished 5 types of waste materials: food, garden, glass, paper and other waste. Depending on the waste material, waste will be treated. Recycled glass and paper, compost and biomass are generated and used as a substitute for virgin materials in the relevant sectors. In the developed system there is now a direct link between waste and bio-economic sectors in the model, thus making possible the feasibility studies for analysing circular economy.

Keywords: CGE modelling; circular economy

Introduction

In the EU between 118 and 138 million tonnes of bio-waste are produced every year, of which about 88 million tonnes are municipal waste. It is projected to increase on average by 10% by 2020. The reuse, recycling and use of bio-waste for materials, chemicals, energy and animal feed can contribute to more sustainable, efficient and integrated bio-based economy. Finding a sustainable way of dealing with especially municipal solid waste is a challenge. According to the Waste Framework Directive (2008/98/EC) a sound waste management system must following the so-called "waste hierarchy" (art 4(1)): Prevention, Preparing for re-use, Recycling, Other recovery, Disposal. The technological options available to manage organic-waste are: anaerobic digestion; composting; waste to energy and landfilling. All of these options can lead to the production of energy and/or added value products.

The implementation of waste in CGE models is not yet a default option. Concerning the inclusion of residues from agriculture and forest, first steps have been recently published (Van Meijl et al. 2016; Philippidis et al., 2016). In Rutten et al. (2013), food waste reduction by consumers is incorporated via a taste shifter, assuming that households who reduce their food waste need to consume less food to maintain the same utility level as before. However to analyse the use of municipal solid waste within the bio-economy and to explore the possibilities of a truly circular system further steps are needed.

Waste disposal within the GTAP database is included within the service sector OSG. Because waste collection is included as a service sector no link between consumption of goods and waste production/treatment is possible. To introduce this link, waste generation has been added as a margin commodity similar to how GTAP treats transport costs. The

idea of waste as a margin commodity means that an extra price and quantity wedge is added between households and suppliers. So the price a consumer pays for a good includes both the market price plus the price of collecting waste by the municipality. The main advantage of this method is that it provides the link between consumption and waste collection with an easy method which is already available. Peterson (2006) gives a detailed description of how to introduce domestic trade margins within GTAP. We follow his method in this paper.

This method also allows the implementation of both flat fee pricing and pricing by amount of waste generated depending on the policy a region implements. In many countries waste collection is still priced with a flat fee. A flat fee means that the fee households pay for waste collection is not related to the actual amount of waste produced. Therefore the marginal price of waste collection for households is equal to zero. The impact of such a policy can be recreated by implementing a subsidy on the price of the margin commodity such that the cost of waste collection are again zero.

In this paper we focussed on developing the methodology to include a waste management system in a CGE modelling framework and on building a database to run the new waste module within the global CGE model MAGNET. It includes introducing municipal solid waste generated by households and various options of dealing with waste by including new waste treatment sectors like landfills, waste to energy, recycling and composting sectors. Recycled materials like glass, paper, compost and biomass are generated and used as a substitute for virgin materials in the relevant sectors. In the developed system there is now a direct link between waste and bio-economic sectors in the model, thus making studies analysing circular economy feasible.

Materials and method

Introduction

The Modular Applied GeNeral Equilibrium Tool (MAGNET) is a recursive dynamic, multi-regional, multi-commodity CGE model, covering the entire global economy (Woltjer *et al.*, 2013). It is built upon the GTAP model (Hertel, 1997) and is the successor to the LEITAP model, which was used in the MEV I study and in many other policy analyses (see e.g. Banse *et al.*, 2008; van Meijl *et al.*, 2006; Nowicki *et al.*, 2009, Woltjer, 2011). MAGNET is one of the nine global models selected in the OECD\AgMIP model inter-comparison project on the long term future of agriculture (including bioenergy developments; see Nelson *et al.*, 2013; Von Lampe *et al.*, 2014, and Robinson *et al.*, 2014).

The MAGNET model, in comparison to GTAP, uses a more general multilevel sector-specific nested CES (constant elasticity of substitution) production function, allowing for substitution between primary production factors (land, labour, capital and natural resources) and intermediate production factors, and for substitution between different intermediate input components (e.g. energy sources and animal feed components). MAGNET includes an improved treatment of agricultural sectors (e.g. various imperfectly substitutable types of land, the land use allocation structure, a land supply function, and substitution between various animal feed components; Meijl *et al.* 2006, Eickhout *et al.* 2009), agricultural policy (e.g. production quotas and different land-related payments; Nowicki *et al.*, 2009) and biofuel policy (capital-energy substitution, fossil fuels-biofuels substitution; Banse *et al.*, 2008). On the consumption side, a dynamic CDE expenditure function is implemented which allows for changes in income elasticities when purchasing power parity (PPP) corrected real GDP per capita changes. Segmentation and imperfect mobility between agriculture and non-agriculture labour and capital are introduced in the modelling of factors markets.

Waste in MAGNET

In this paper we focus on the introduction of waste generation by households and the subsequent collection and disposal of waste. This needs a waste production mechanism by households and several new waste collection and waste treatment sectors.

Waste as a margin commodity

Municipal solid waste is linked to consumption of products. To introduce such a link, waste is treated as a domestic margin commodity. The main advantage of this method is that it provides the link between consumption and waste collection with an easy method already tested by Peterson (2006) within GTAP.

The GTAP structure for private consumption the private household allocates income between different composite commodities based on a CDE function. Each composite commodity is a CES function of domestically produced or imported goods.

The structure after introducing the waste margins changes to a more complex one. Along with demand for consumption (as in standard GTAP consumption structure), the private households now also demand different waste collection services to collect the types of waste generated in the process of consumption. The demand for the commodity for consumption and associated waste collection service to collect the waste from this commodities consumption are bundled as a composite demand.

Households demand waste collection services depending on their consumption composition. They can generate 5 types of waste materials: food waste, garden waste, glass waste, paper waste or other waste. Depending on the waste material generated, there are different options for collection and treatment of the waste.

Waste collection and treatment

Apart from the generation of waste, the model needs to be adjusted to collect and treat the waste generated. Figure 1 gives the schematic implementation of waste generation and treatment in MAGNET.

Three types of waste collection services exists: collection of rest waste or "grey waste" and collection of organic or "green" waste and collection of paper and glass.

Grey waste is sent to final disposal: landfills and incinerators.

Food and garden waste can be collected as green waste and sent to a composting sector to produce biomass to be used in the newly created bio fertilizer sector or in the second generation bio economy sectors: bioenergy, 2nd generation biofuels or bio chemicals. This biomass can substitute for the already existing residuals and pellets.

Finally paper and glass can be collected by paper and glass collection services and sent to a recycling services. Recycled paper and glass is used in the paper and glass industry as a substitute for virgin materials.

Not all food, garden glass and paper waste is collected separately. Any waste type collected as rest waste are only sent to the final disposal treatment options.

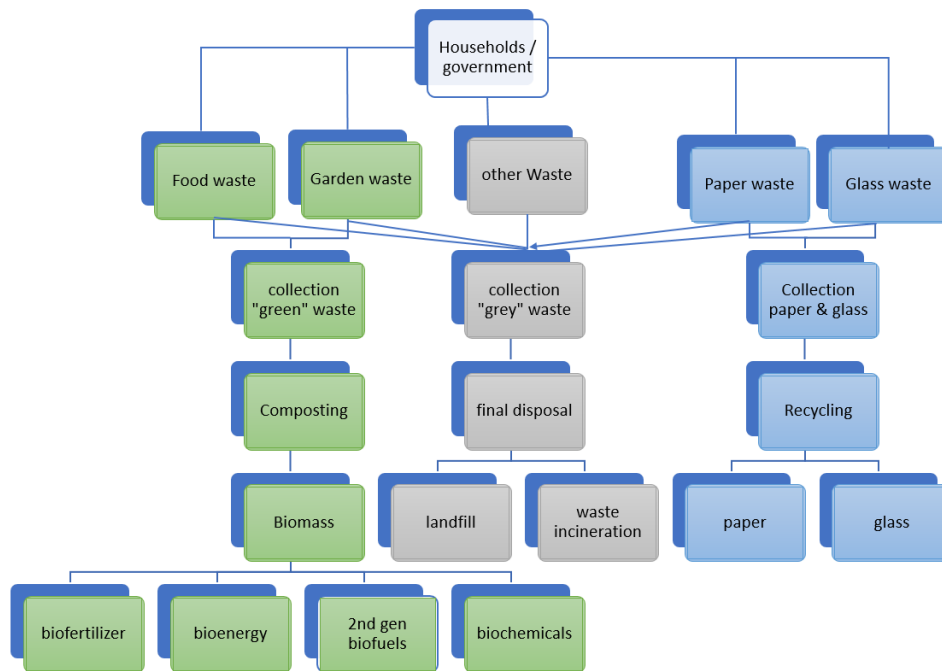


Figure 1 Structure for waste collection and management services in MAGNET

Data

Introduction

This section describes the extensive amount of data (on waste generation, waste collection and waste treatment and emissions related to waste treatment) that needed to be collected to operationalize the approach described in previous sections.

Total Waste generation and total waste generated by type

For all 141 countries in the GTAP database, data are collected or compiled on the production and treatment of Municipal Solid Waste (MSW). Data are taken from the World Bank report 'What a Waste 2' (Kaza et al, 2018), plus data from various other sources (RDC-Environment and Pira International 2003, Stenmarck et al, 2020).

The World Bank publishes data for the year 2016. As the GTAP database is based on the base year 2014, the data is rescaled to 2014. This gives us the MSW produced per region for 2014. Data about the composition of MSW (organic, glass, paper, metal, other) are also published by the World Bank on continental scale.

As World Bank reports food and garden waste as one category we used data from the World Bank and from the EU project Fusions (Stenmarck et al, 2020) to determine the share of food waste in the total amount of green waste collected. This data is available for limited number of regions - the World Bank data on food and garden waste data is available for 24 regions and the Fusions project data is available for 11 European countries. Figure 2 gives an overview of the countries for which data is available to determine the food waste share indicator. The food waste share in this limited sample varies between 30% to 98%. For all regions with missing data, a world average food share of 58% is assumed.



Figure 2 Food waste share

Source: Constructed from World Bank and Stenmarck et al, 2020

Assigning Waste material generation by commodity

Total waste generation is based on private consumption. This means that *ceteris paribus* if larger quantities of commodities are consumed, the more waste will be generated. The amount of waste differs also depending on the materials used to make the commodity.

A complete database with material flows is however not readily available. To link waste generation to consumption, we therefore assume that intermediate demand of materials within the production process is a good approximation for how much waste is generated during the consumption of that product. If for example more paper was used in the production of a commodity then more paper waste would be generated as a result of consuming this commodity. Based on GTAP database shares for paper, glass, food and garden waste coming from different commodities can be calculated.

As and when data about material flows through the system (starting from virgin materials up to materials ending in the waste stream) is available, this approximation can be replaced. Figure 3 shows the type of waste materials generated by consumption of certain product categories based on expenditure shares of virgin materials in their production.

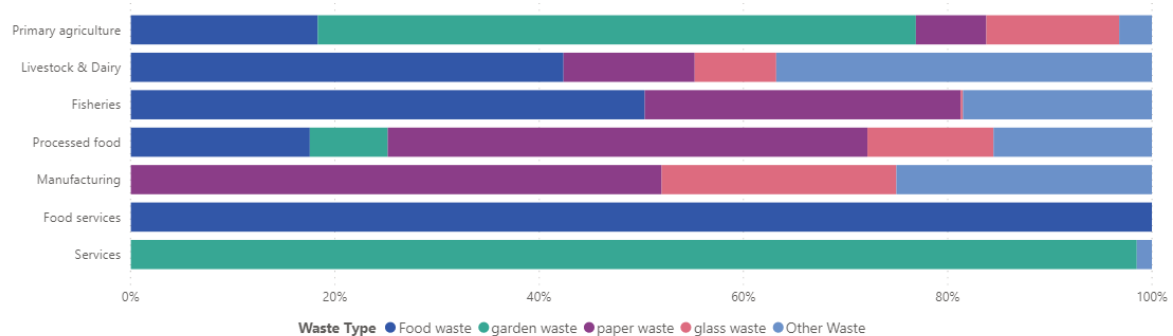


Figure 3 Waste materials by consumption category (in %)

Source constructed based on expenditure data GTAP and World Bank data

Waste Collection data

Not all waste generated is collected. On average worldwide about 75% of the waste generated is collected. The collection rate does differ a lot across regions (see Figure 4). In this report waste not collected is left out of the equation. Only waste collected is included in the data. This does underestimate the solid waste management problem in regions with low collection rates.

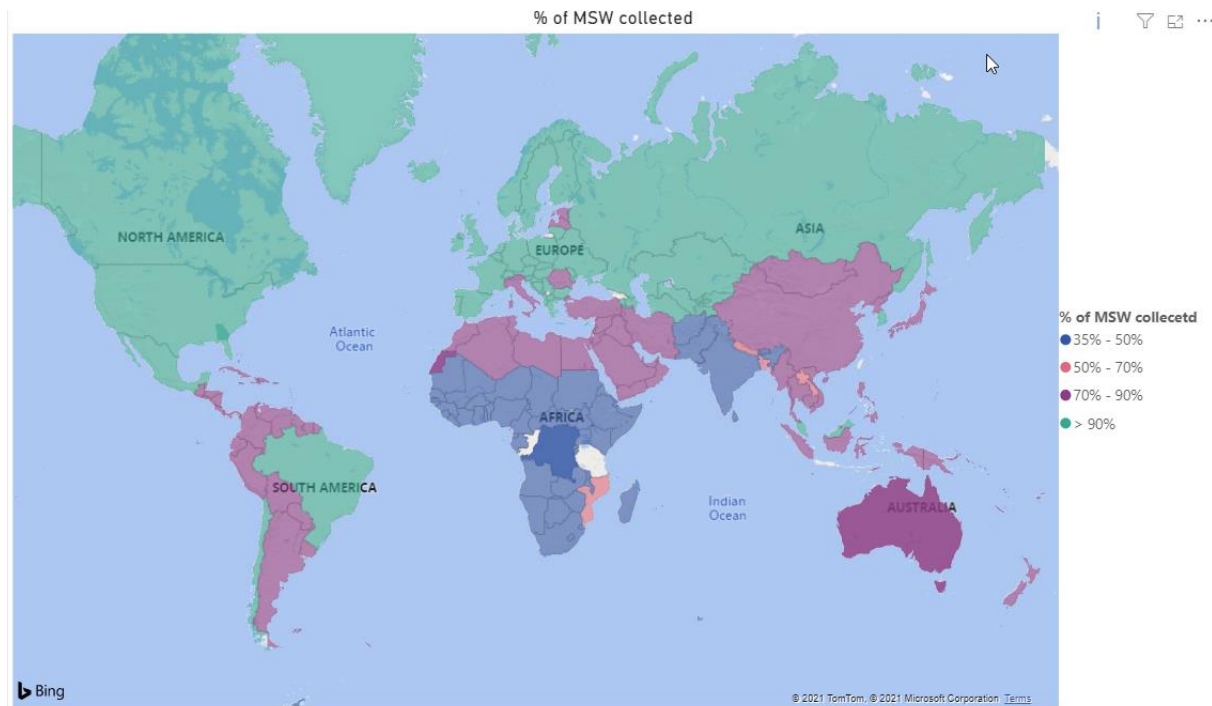


Figure 4 Waste collection rates for MSW (in %)

In most cases, waste materials are only recycled or reused if the waste materials are separately collected. While some trials are done with separating waste after collection, in most cases, separation and cleaning of waste materials is too expensive and non-separated waste is not reused, recycled or composted. Therefore type of collection influences the treatment of the waste stream. In the model it is assumed that only waste materials that are collected separately can be recycled or composted. Based on average recycling rates from the tons of waste collected as green waste or paper and glass, waste treatment can be determined.

Figure 5 below shows the total waste collection per waste type for the world and gives some insight in how much of the waste materials is collected separately to be composted or recycled and how much waste is still collected as rest waste meant for final disposal.

On average worldwide only a small percentage of waste is collected as green waste (30%) or paper (50%) and glass waste (40%). These percentages do differ a lot between countries.

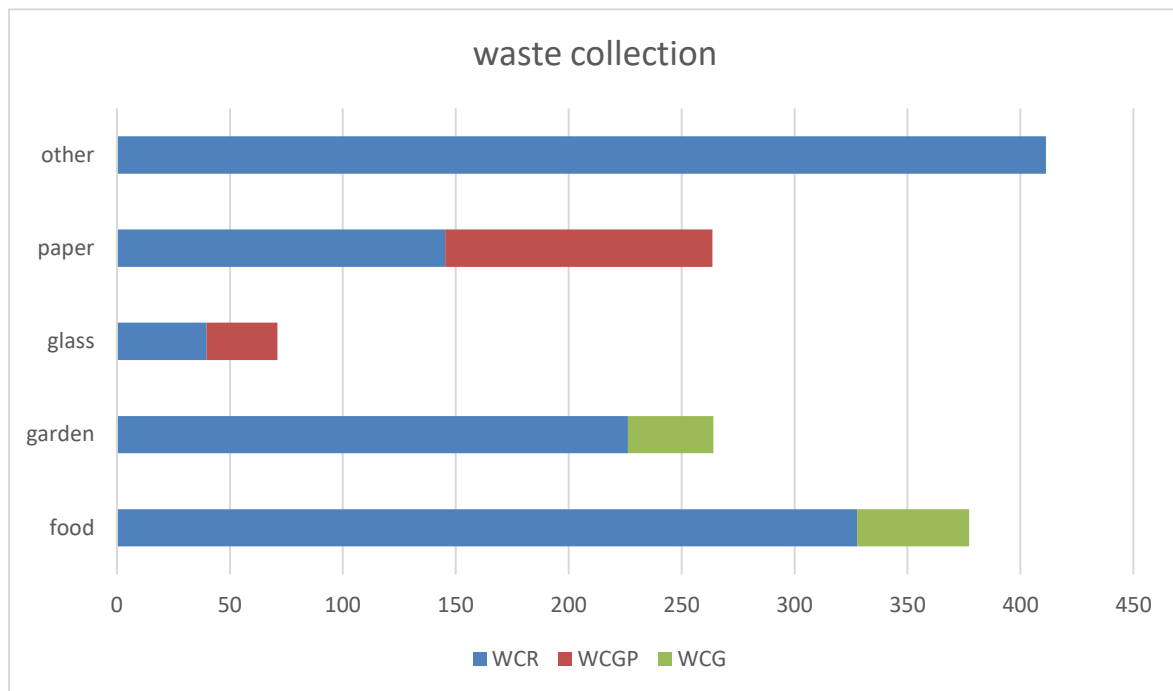


Figure 5 Collection of different types of waste worldwide (Mton)

Source constructed from World Bank

Waste Treatment data

The world Bank published data per country about the tons of waste treated. Treatment methods reported were: dumping and landfill; incineration; recycling and composting. The World Bank also publishes average waste treatment prices per category (landfill, incineration, recycling, composting) for 4 types of countries based on average income (low income, lower mid income, higher mid income and high income) of countries. These data are combined with average cost structures published by RDC-Environment and Pira International (2003) to calculate the economic value of waste treatment options around the world.

The type of waste treatment differs around the world (Figure 6). European countries and Asian countries (within ROW) mostly focus on incineration as final treatment. North America and African countries focus more on landfilling as final disposal option. The initial share of composting and recycling also differences a lot between regions.

Note that the figures below are based on actual collected data, home recycling or composting are not included in these numbers.

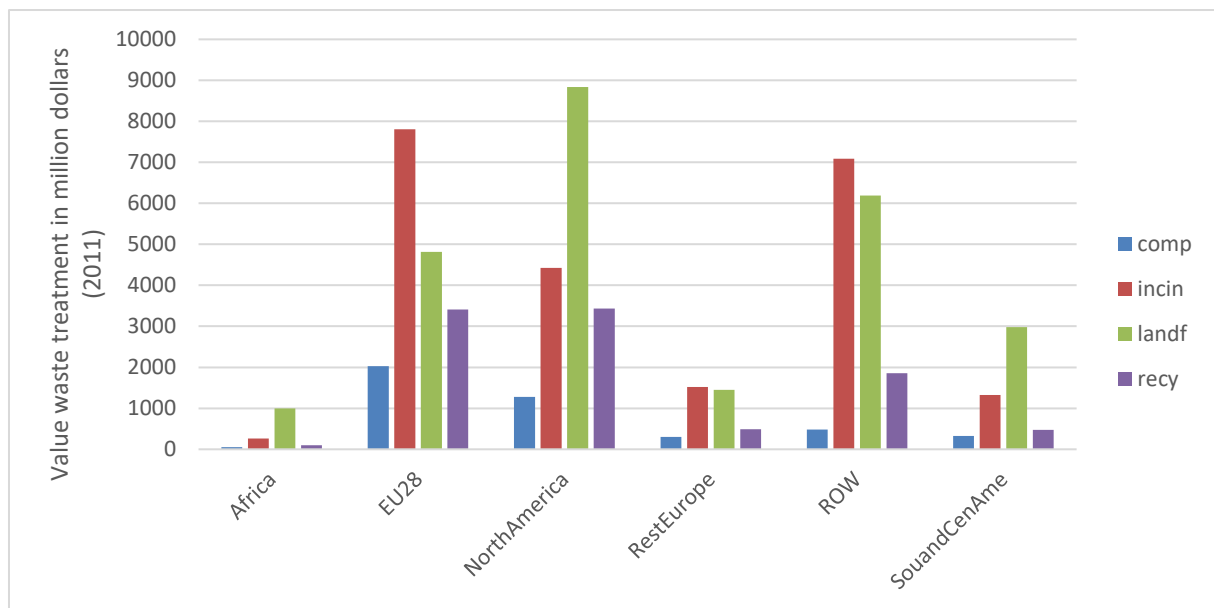


Figure 6 Value waste treatment in various regions in million dollars, 2011.

Source: constructed from (RDC-Environment and Pira International 2003), Hoornweg and Bhada-Tata 2012, Eurostat (EUROSTAT 2017)

Emission Data

The IPCC publishes total emissions of waste landfilled, incinerated and composted. These emissions include municipal solid waste, construction and industrial waste. For waste incinerated and composted it is assumed that the emissions per ton of waste from IPCC are representative for municipal waste. However for landfilled waste, this assumption does not hold. In several European countries hardly any municipal waste is landfilled and therefore the waste emission factors by ton of waste get too high. Therefore for landfilling, we used the IPCC data for the USA to calculate the emissions per tonne of waste landfilled and applied these factors to the rest of the world. (Figure 7).

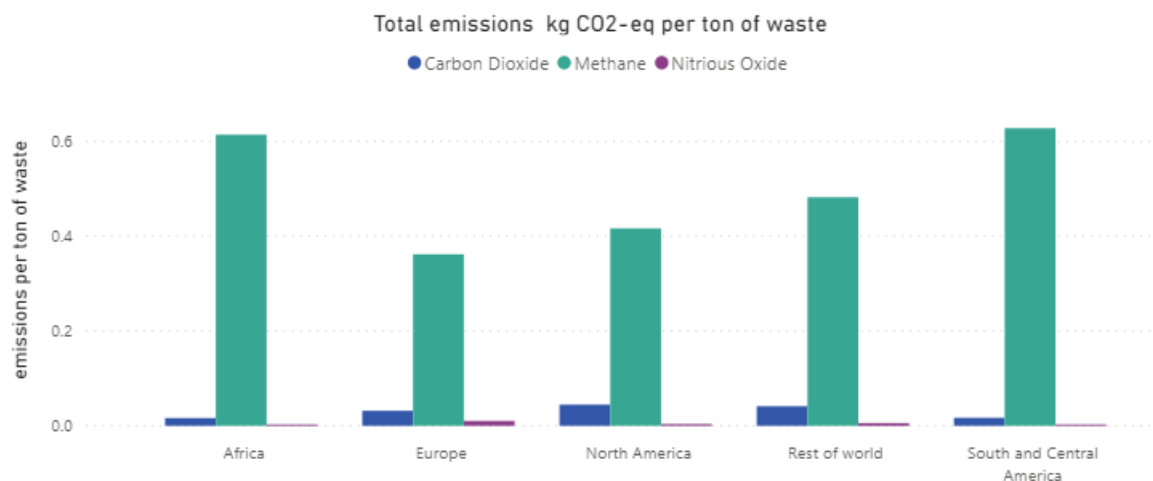


Figure 7 CO2 eq emissions per ton

Baseline

Based on the relation between GDP per capita and waste generation published by the World Bank, MAGNET can simulate the amount of waste generated by region in any given year. We have run an SSP2 scenario to establish a baseline.

In this paragraph we will discuss the main results of the baseline. **Error! Reference source not found.** gives an overview of the expected growth in both GDP and population. These macro assumption can be expected to have a significant impact on the development of the waste generation and collection in the period 2014-2050.

The biggest nominal GDP growth is expected in Asia and Africa. Population growth is expected to be highest in Africa and Oceania. In Europe the population growth is expected to be slight or even negative in the case of eastern Europe. GDP growth will be moderate to average for most European countries.

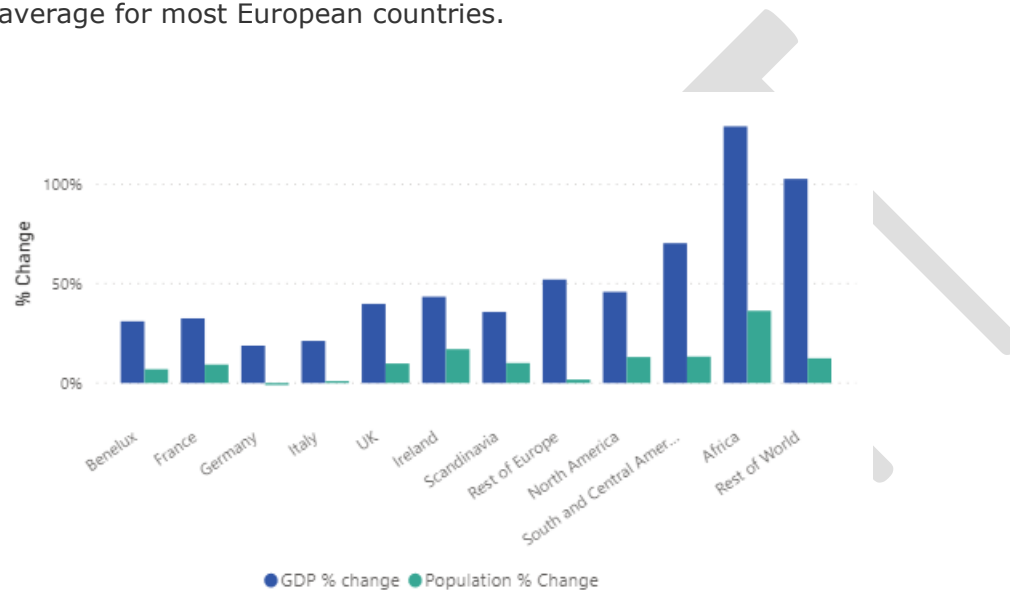


Figure 8 GDP and population development over 2014-2050

Source: Magnet results

Based on the relation between GDP per capita and waste generation calculated by the World Bank the model can predict the amount of waste generated by region. Total waste collected and the % growth is shown in Figure 9. In all regions waste generation and collection will grow. In Africa the grow in waste generated and collected is the highest. The growth does slowdown in later years in most regions but total waste will continue to increase.

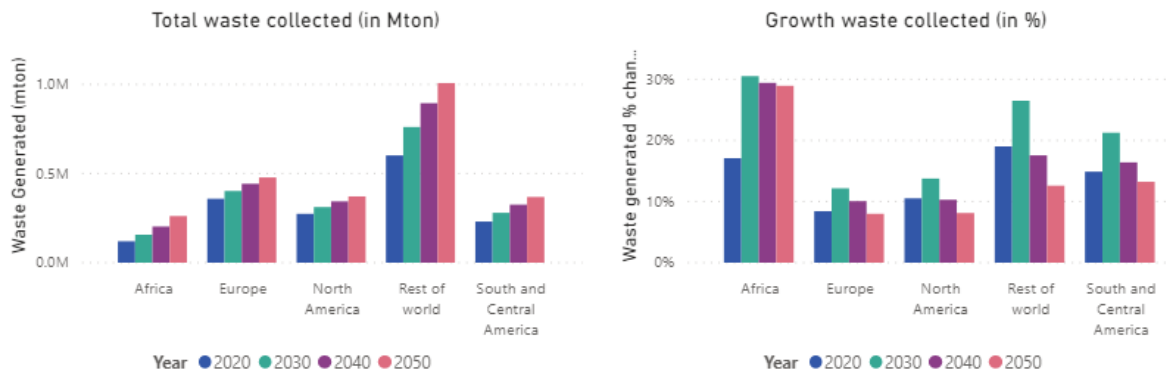


Figure 9 Waste collection (in Mton and % change)

Source: Magnet results

Zooming in on Europe, Figure 10 shows the waste stream in Europe in 2050. It shows the type of waste generation by households – traced to consumption of types of goods and services; amount of each type of waste as collected by the three collection services; and its final treatment. It also shows the contribution of waste collection and treatment choices on greenhouse gas emissions in Europe.

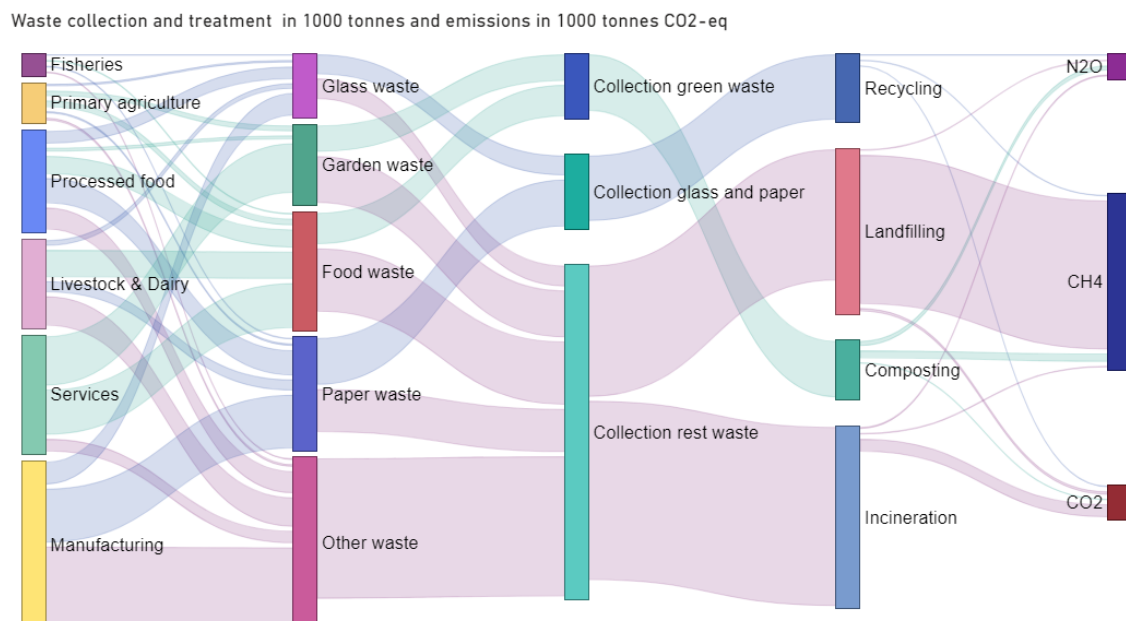


Figure 10 Waste material flows (Europe, in 2050)

Source: Magnet results

About 12% of the total waste stream is composted and 14% is recycled. The remainder of the waste stream is collected as rest/grey waste. Only about half of the food, garden, glass and paper waste is expected to be collected for composting or recycling. Better waste management policies are needed to promote waste separation as both recycling and composting contribute to a circular economy and reduce the amount of greenhouse gas emissions associated with waste disposal. About 40% of the rest waste will go to the

landfilling sector in 2050 if current waste management trends continue. As landfills are the biggest contributor to greenhouse gas emissions this is the least desirable option.

Figure 11 shows the waste collection across regions within Europe. Some regions, like Germany, separate more waste than others. However, waste collection as rest waste remains the most popular option in all regions in Europe. Without waste management policies, this is not expected to change. Rest waste collection will stay to be the most important type of collection within Europe. Paper and glass waste will increase relatively fast in the period 2014-2050. Collection of green waste is expected to grow the least of the three collection types.



Figure 11 waste collection within Europe in the period 2014 and 2050

Source: Magnet results

Figure 12 shows how waste is treated in European countries. Overall we see that incineration of waste is the most used waste treatment option. Composting is still the least used waste treatment option in Europe. Worldwide landfilling is still the most used waste treatment option. Treatment of waste differs across countries in Europe – Benelux, Germany and Scandinavia fare better in eliminating landfilling while in the other regions landfilling is not expected to disappear by 2050.

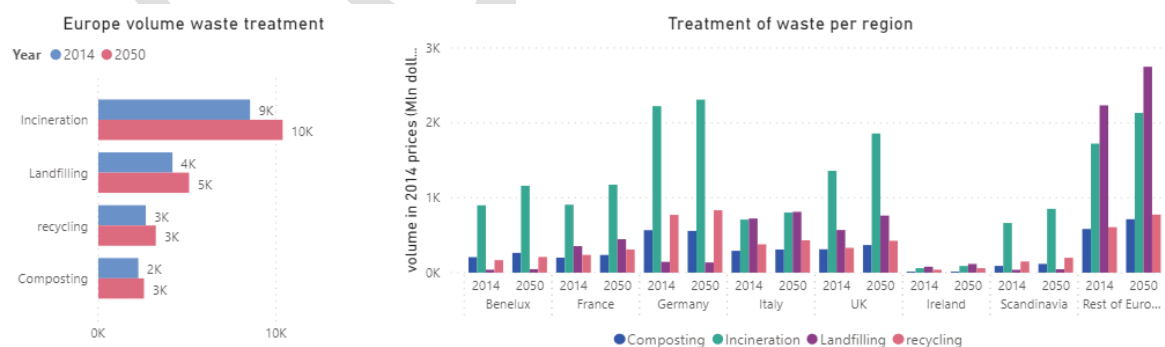


Figure 12 waste treatment in Europe

Source: Magnet results

Collection of waste determines how the waste can be treated like mentioned before. Not all waste materials are collected in such a way that they can be recycled or composted.

Figure 13 shows how much of the food and garden waste is collected as green waste and how much of the glass and paper waste is collected for recycling. Many countries collect about 60% of the glass and paper waste for recycling. These percentages are not expected to increase in the future without waste management policies. The amount of food and garden waste collected separately differs quite a bit between countries. Some countries like the Benelux and the UK already collect about 80% of food and garden waste separately for composting. Other regions like Ireland and the rest of Europe only collect about 25%-30% of the food and garden waste separately.

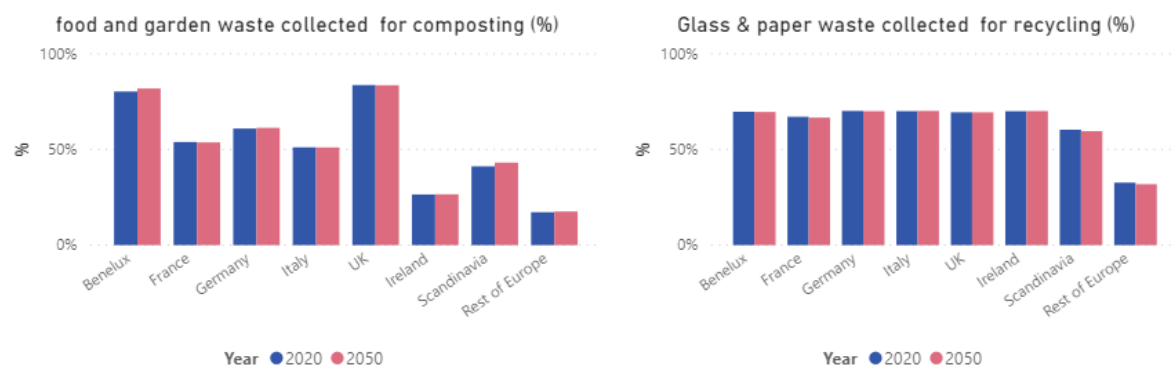


Figure 13 share of waste collected separately (%)

Source: Magnet results

In the base year most of the compost produced by the composting sector is used as biofertilizer. In 2014 95% of the compost is used by the crop sectors as Figure 14 shows. In 2050 the demand for energy will increase quite a lot. The price paid for energy increases and this means that the demand for bio electricity will increase. The increase in bio electricity production will lead to a bigger demand for biomass, part of this biomass can be supplied by the composting sector. This means that less compost will be available for the crop sectors as fertilizer.

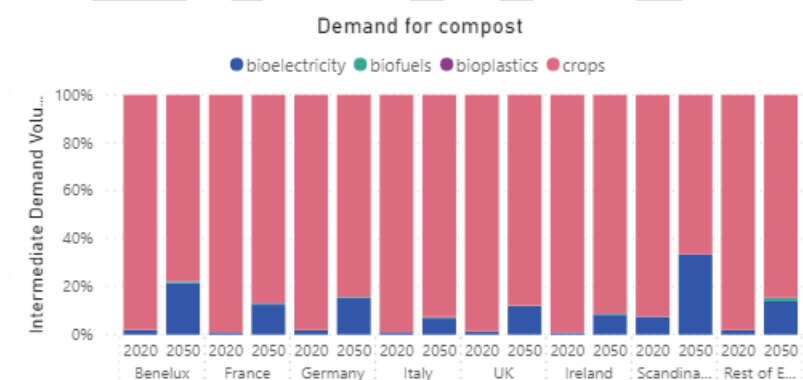


Figure 14 Demand for compost by different sectors (%)

Source: Magnet results

Although the demand share of compost for biofertilizer and bio-electricity changes, this does not automatically mean that the total amount of compost used in the crops sectors declines. Since more green waste will be produced in future years the overall share of biofertilizer use in the crop sectors increases (figure 15). This means that some fossil

fertilizers are expected to be replaced with bio fertilizer even without any policies stimulating this behavior. The share of biomass use in the bio energy sector is expected to increase quite a bit in 2050 compared to 2014.

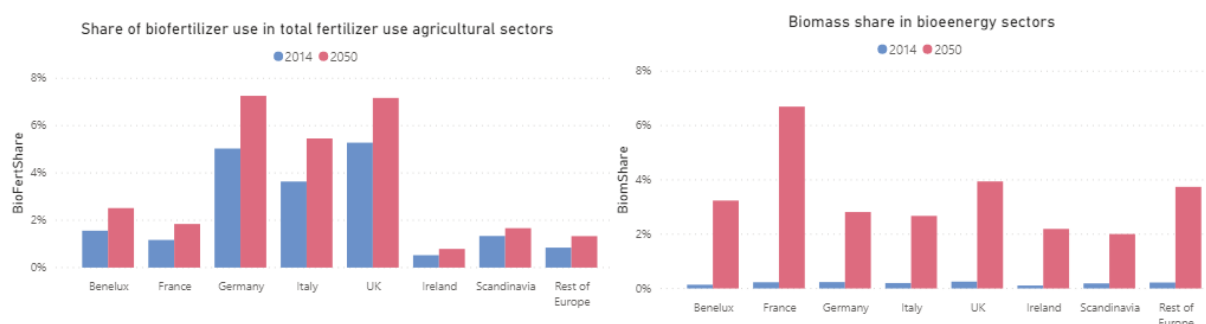


Figure 15 demand for biofertilizers and biomass
Source: Magnet results

Conclusions

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