Waste management and circular economy: Building a CGE framework

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Abstract

Reuse, recycling and use of bio waste may contribute to a more sustainable bio economy. To analyse the impact of reuse and recycling can have on the bio economy and the economy as a whole, municipal solid waste generation needs to be included in a CGE framework. 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.

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 of waste and disposal of waste. This will mean that equations need to be added to produce the waste by households and several new waste collection and waste treatment sectors need to be added to the model to deal with the waste.

Waste as a margin commodity

Municipal solid waste is produced by households and should be linked to consumption of products. To introduce such a link, we treated waste as a domestic margin commodity. To include waste production by households as a margin commodity we will need to make quite some changes to the household demand equations. 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. GTAP has been working on introducing domestic margin commodities, this is a method which we can follow. Peterson (2006) gives a detailed description of how to introduce domestic trade margins within GTAP.

The normal GTAP preference structure for consumption by the private households is shown in Figure 1 in the white cells. The private household allocates income between different composite commodities based on a CDE function. The value of private household purchases of the composite commodity i at agent prices is equal to the price of the composite commodity PP(i,r) times the amount of the composite commodity QP(i,r) purchased.

Each composite commodity is a CES function of domestically produced or imported goods. Prices of domestic and imported goods are shown in agent prices or market prices. The difference between for example import agent prices (ppma) and import market prices (pim) is the taxation on consumer goods.

The preference structure after introducing the waste margins differs from the standard preference function. The layers added to the system to include the domestic waste margins are shown in figure 1 in the green cells. Instead of just two price levels, three price levels are introduced: market prices, composite prices (market price plus costs of waste collection) and agent prices. In addition there are two types of quantities: a basic and a delivered quantity, where the latter is an aggregate of the basic quantity and a waste collection margin.

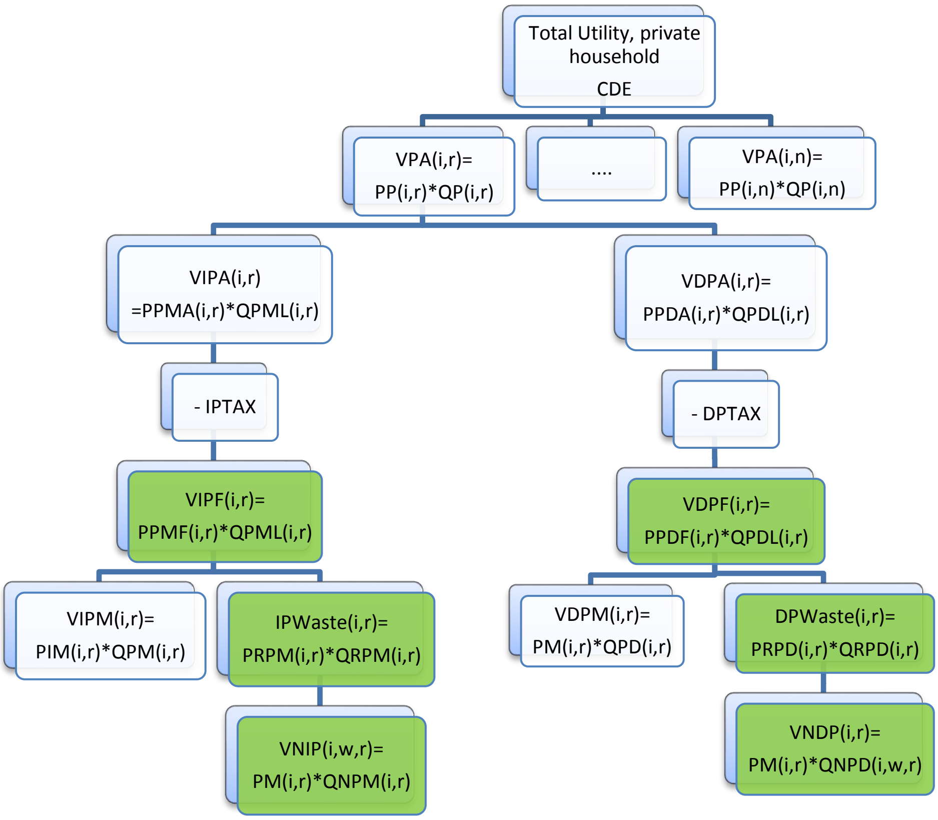

Figure 1 Preference structure for consumption by the private households with waste margins

If we start from the lower left side of figure 1: First the value of waste collection services is calculated as the market price of waste collection (pm) multiplied by the quantity of the individual waste collection service *w* incorporated in demand for import commodity *i* (QNPM). This can be aggregated to the total value of expenditure on waste collection services for the composite imported commodity *i* purchased by households (IPWaste). The aggregated waste collection margin can now be added to value of expenditure on the *imported* commodity purchased by *private* households at *market* prices (VIPM) to value of the delivered product (VIPF). Then any tax or subsidy can be added to calculate value of imported consumption at agent prices.

Waste collection and treatment

Apart from the generation of waste, the model needs to be adjusted to collect and treat the waste. Figure 2 gives the schematic implementation of waste generation and treatment in MAGNET. The production of waste starts with the households and the government. These households will demand waste collection services depending om consumption patterns. 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. It will depend on the product consumed whether collection of green waste is possible. This will be linked to any sector that produces a food product. Grey waste will be send to final disposal. Final disposal services will be delivered by 2 different sectors: landfills and incinerators. Green waste will be send to a composting sector. The composting sector will produce biomass which can either be used in the newly created bio fertilizer sector or in the bio economy sectors: bioenergy, 2nd generation biofuels or bio chemicals. This biomass will then be a substitute for the already existing residuals and pellets. Not all green waste collected will be suitable for composting. Part of the waste will be send to final disposal.

Finally paper and glass will be collected and send to a recycling services. Recycled paper and glass will be used in the paper and glass industry as a substitute for virgin materials. As with organic waste, not all paper and glass collected will be suitable for recycling and this will be send to final disposal sites.

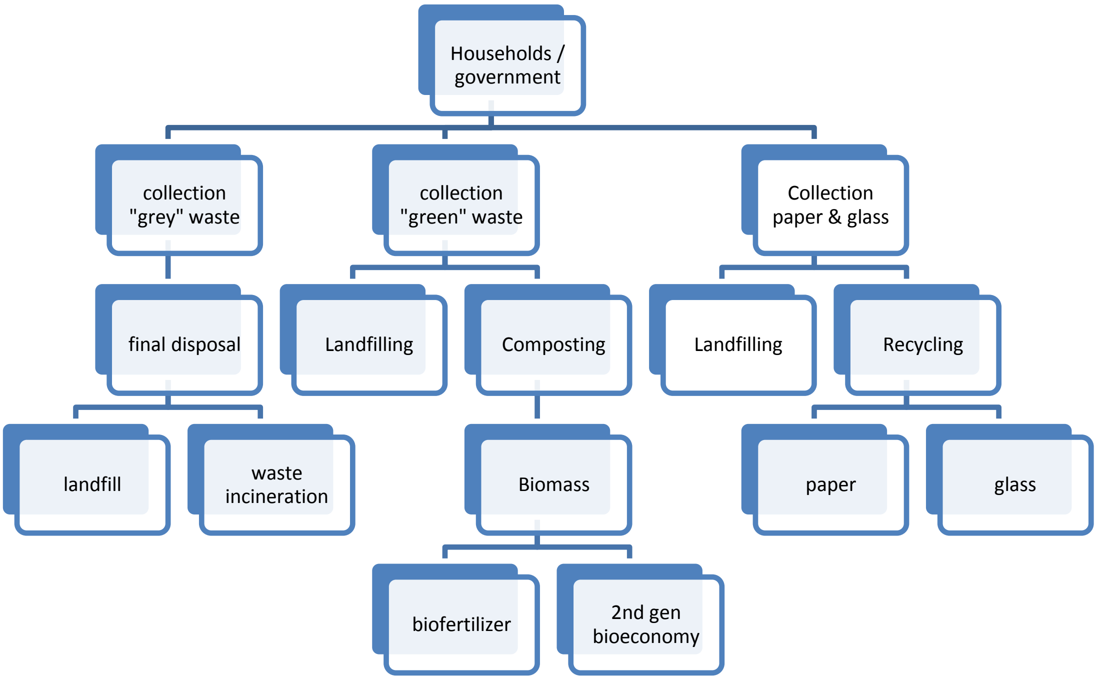

Figure 2 Demand structure for waste collection and management services in MAGNET

Data

For all 141 countries in the GTAP 9 database, data are collected or compiled on the production and treatment of Municipal Solid Waste (MSW). Most of the data for EU countries comes from Eurostat (EUROSTAT 2017) and most of the data on non-EU countries are taken from the World Bank report 'What a Waste - A Global Review of Solid Waste Management' (Hoornweg and Bhada-Tata 2012), plus data from various other sources (RDC-Environment and Pira International 2003). Municipal solid waste, as defined in the World Bank report, encompasses residential, industrial, commercial, institutional, municipal, and construction and demolition (C&D) waste. Municipal solid waste as defined by Eurostat consists of waste collected by or on behalf of municipal authorities and disposed of through waste management systems and consists mainly of waste generated by households, although it also includes similar waste from sources such as shops, offices and public institutions.
The World Bank data set and the Eurostat database are not completely compatible. The World Bank definition of municipal solid waste is broader then the Eurostat definition. Data using the Eurostat definition of MSW is however not available for non EU regions. While it would be more consistent to use the World Bank data which is available for the entire world, the Eurostat data is however preferred for the European countries. The definition of MSW is preferable and the data about treatment of waste is more detailed. Since waste is a non-traded commodity, we consider the inconsistencies of the two datasets acceptable and use the best available data for EU regions.

The database includes information about the production, collection and treatment of municipal solid waste. Only the share of municipal solid waste that is produced by the share of the population that lives in urban areas is considered, except for the EU. Of this share only the fraction that is collected is included.

Data about the composition of MSW (organic, glass, paper, metal, other) and about the treatment of MSW are used to calculate how much of the MSW is recycled, composted, converted into energy or otherwise processed (which includes landfilling, dumping and other not specified treatment).

In total five new sectors are added to MAGNET:

1. **Collection**. This sector collects MSW and delivers the MSW to the four MSW treatment options. The costs of collection and treatment are paid by the consumers. Data about the cost structure of MSW collection are taken from (RDC-Environment and Pira International 2003).
2. **Recycling**. Country and region specific figures about the share of MSW that is recycled and about the rate of recycling of paper, glass and metal are used to calculate the amount and costs of recycling of MSW. The cost structure of recycling and data about the revenues from recycled products are based on literature (RDC-Environment and Pira International 2003).
3. **Composting**. Country and region specific figures about the share of MSW that is composted are used to calculate the amount and costs of composting. A minimum share of 2.5% of the MSW is assumed to be composted, which allows to increase the share of organic MSW that is composted. Data about the cost structure of recycling and data about the revenues from recycled products are based on literature (RDC-Environment and Pira International 2003).
4. **Incineration and Waste To Energy (WTE).** This sector converts MSW to energy (electricity and heat). A minimum of 5% of the MSW that is collected is assumed to be converted into energy. Data about the cost structure of WTE is taken from (RDC-Environment and Pira International 2003).
5. **Dumping and landfilling.** The remaining MSW is landfilled or dumped or treated otherwise. Information about the cost structure of dumping and landfilling is based on data about the costs of landfilling in the EU (Tsilemou and Panagiotakopoulos 2006).

Table1 Aggregated input data for the EU28, rest of the world and the world as included in MAGNET

Collection in MT	**Organic**	**Recycling**	**Grey**	**Total MSW**
	Mt	Mt	Mt	Mt
EU28	35	65	147	247
Rest of the world	51	130	794	975
World	86	195	941	1,222
Collection in Million dollars	Composting	Recycling	Grey	Total
	MUS$	MUS$	MUS$	MUS$
EU28	3,131	2,898	12,183	18,212
Rest of the world	3,957	5,489	53,418	62,864
World	7,089	8,386	65,601	81,076
Price collection in dollar per ton waste	Organic	Recycling	Grey	
	$/t	$/t	$/t	
EU28	89	44	83	
Rest of the world	78	42	67	
World	82	43	70	

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

Data about the costs of MSW treatment are used from the World Bank report referred to above to calculate the turnover of the various waste treatment options (see figure 3). As is clear from figure 3, the treatment of waste differs a lot between regions. 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.

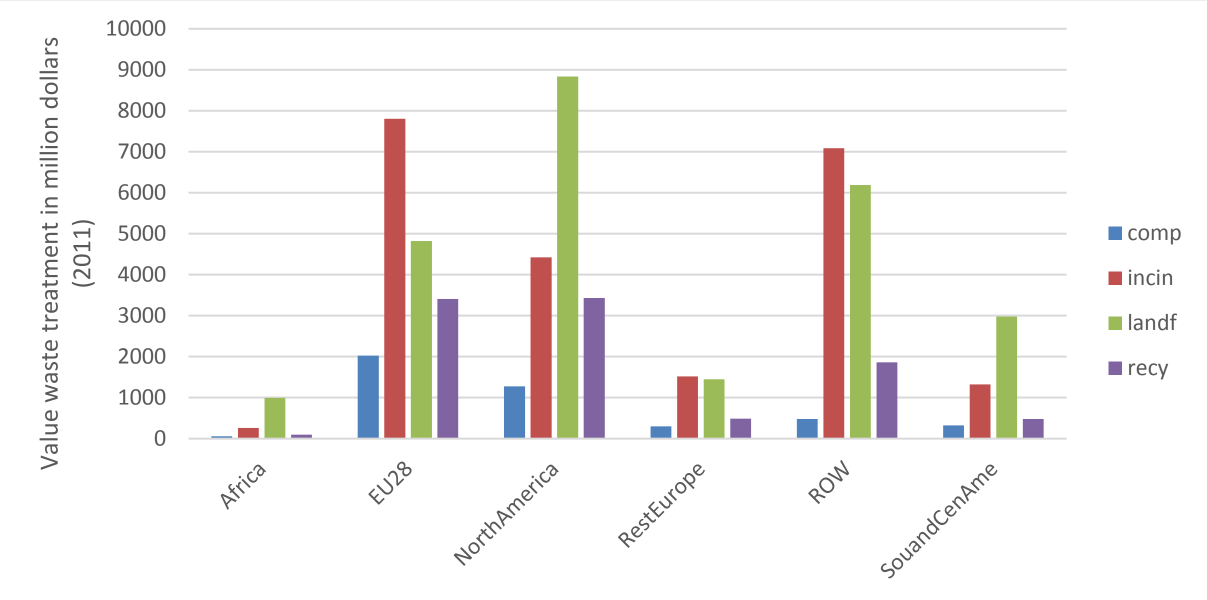

Figure 3. Value waste treatment in various regions in million dollars, 2011.
Source: constructed from (RDC-Environment and Pira International 2003), Hoornweg and Bhada-Tata 2012, Eurostat (EUROSTAT 2017)

Table 2 shows the cost structures corresponding to the three waste collection activities. The cost structure for waste collection services shown below is a world average. Namely the cost structure of waste treatment for each of the collection services depends on the region. As figure 3 showed, some regions will use far more landfilling to dispose grey waste and some regions, especially EU countries, use more incineration services. This will impact the cost structure. In the database a cost structure is implemented for each of the 141 regions.

The cost structure of waste collection services expenditure on waste treatment services is constructed. We know from Eurostat (EUROSTAT 2017) and the World Bank report (Hoornweg and Bhada-Tata 2012) how much MSW waste is collected and how this waste is treated. Hoornweg and Bhada-Tata (2012) 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 countries). Following Figure 2 above, we employ the assumption that WCR solely relies on incineration and landfilling services, WCG only uses composting services and WCGP exclusively employs recycling services. Following this structure we can calculate the total costs structure of waste treatment and add it to the cost structure of the different waste collection services.

Table 2 Cost-structure of waste collection services

	WCR	WCG	WCGP
capital	15.7%	16.6%	12.5%

labour	37.2%	39.1%	29.5%
P_c	1.9%	2.0%	1.5%
ome	2.2%	2.3%	1.7%
osg	0.2%	0.2%	0.2%
isr	1.1%	1.2%	0.9%
otp	0.0%	0.0%	0.0%
landf	21.8%	0.0%	0.0%
other	0.0%	0.0%	0.0%
comp	0.0%	38.6%	0.0%
recy	0.0%	0.0%	53.8%
incin	19.9%	0.0%	0.0%

Table 3 shows the cost structure for the waste treatment services. Data about the cost structure of MSW collection are taken from (RDC-Environment and Pira International 2003).

Table 3 Cost-structure of waste treatment services

	comp	recy	incin	landf
capital	54.0%	39.0%	61.0%	72.0%
labour	14.0%	14.0%	14.0%	10.0%
otp	3.0%	25.0%	0.0%	0.0%
landf	5.0%	5.0%	0.0%	0.0%
other	24.0%	17.0%	25.0%	18.0%

Baseline

This section describes the results of the baseline. In the simplified baseline we assume growth in GDP and population according to the SSP2 scenario. The growth in GDP and population will lead to an increase in consumption and therefor an increase in the production of waste. This is shown in Figure 4. Waste in all regions increase between 10% (EU) and 75% (Africa). Mostly the collection of rest waste (WCR) and paper and glass (WCGP) increases. Without the introduction of any waste policies the collection of green waste will stay at 2015 level for most regions.

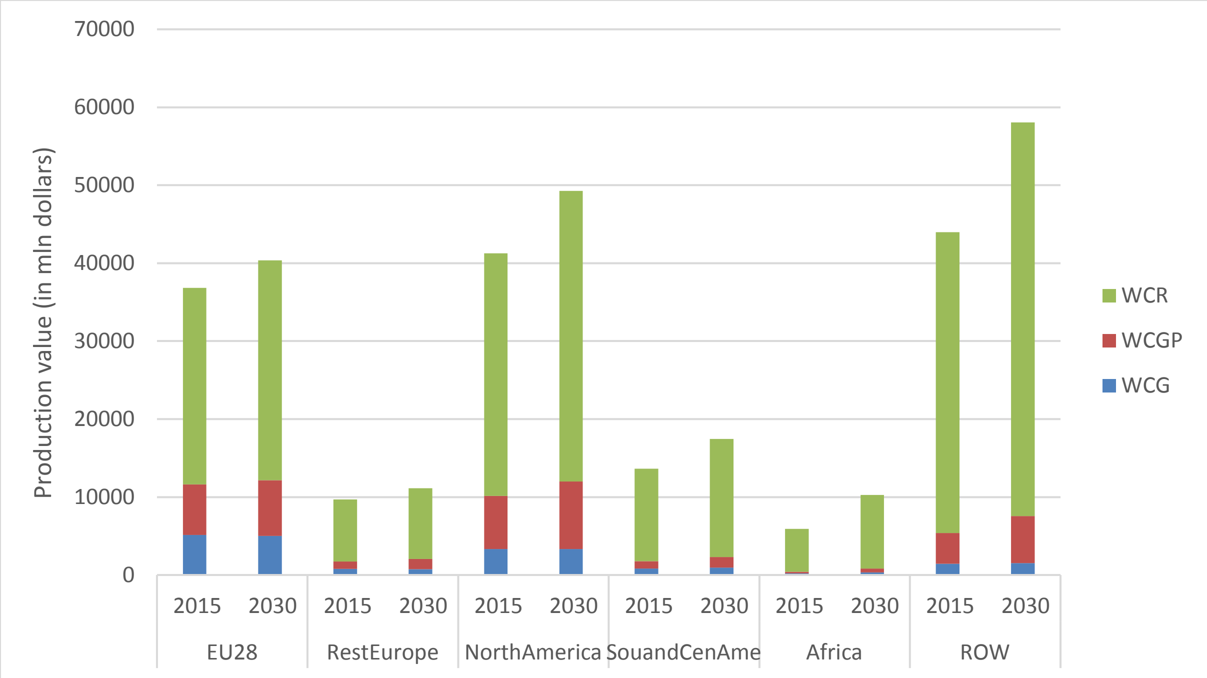

Figure 4 Value of waste collection 2015 and 2030 in million dollars

More waste collected leads to more waste disposal which is shown in Figure 5. Final disposal such as incineration and landfilling grows faster then sustainable treatment like recycling or composting in most regions.

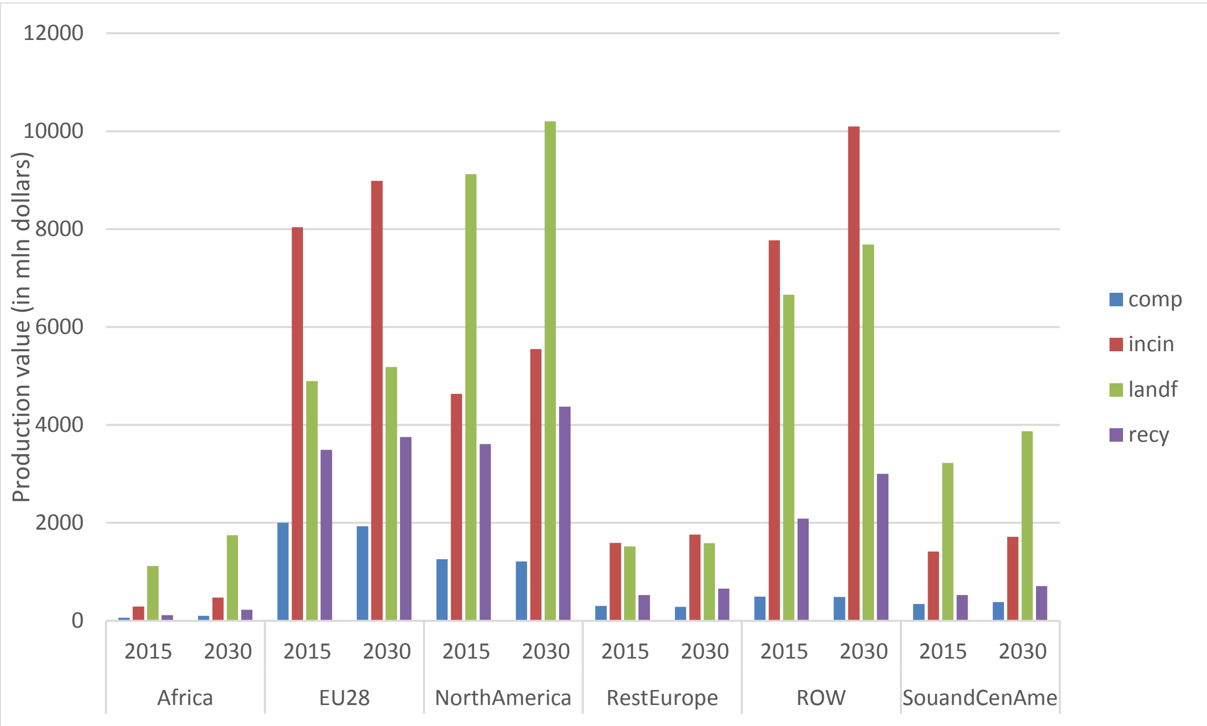

Figure 5 Value of waste disposal in 2015 and 2030 in million dollars

Composting stays constant in all regions which means that no more compost will become available for agricultural sectors as organic fertilizer or as feedstock for the second generation biofuel sectors. Therefore the share of biofertilizer use will decline in all regions as figure 6 shows.

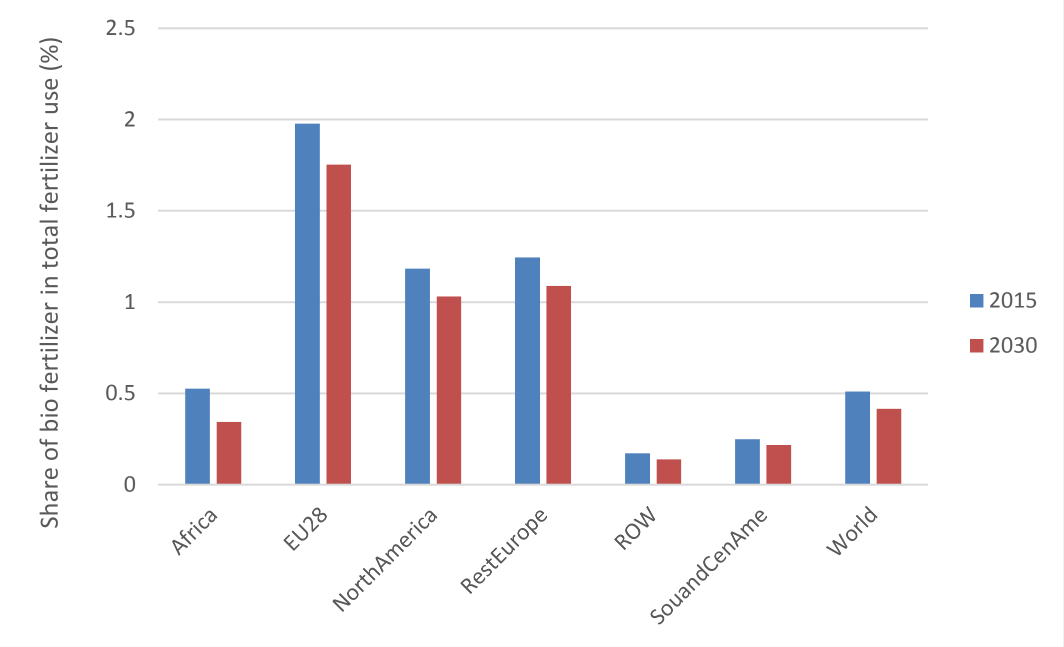

Figure 6 Share of biofertilizer use in total fertilizer use in 2015 and 2030 (in percentages)

Recycling increase in most regions. As recycled materials become cheaper, the demand for recycled materials increases. Figure 7 shows the share of recycled materials used in the paper sector. In most regions, the use of recycled paper increases faster then the use of virgin materials used in the paper sector. Thus the sector becomes more sustainable.

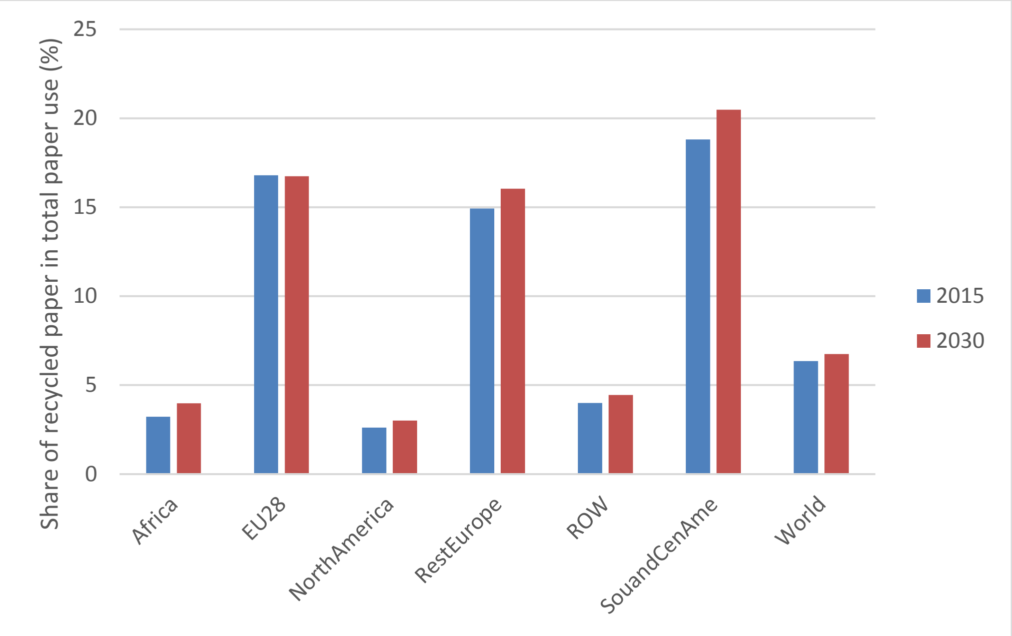

Figure 7 Share of recycled materials used in the paper sector in 2015 and 2030 (in percentages).

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