Circular economy and energy: a computable general equilibrium approach

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Very very preliminary, do not cite or quote

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Abstract

We develop a stylized applied model which focuses on the interactions between the economy and materials. In this CGE model, we follow the circulation of material at every possible stage: extraction, use in production, final consumption, waste generation, waste treatment by landfill or recycling and substitution between primary and secondary material. We pay attention on ensuring mass conservation, so that the model is consistent both from an economic and physical perspective. As primary production of durable materials (mineral) requires much more energy than secondary production, we also introduce non durable materials (fossil), to study the material energy nexus. The integrated tool provides results on economic, material efficiency and waste management variables. We study various policy instruments aiming at reducing landfill in France.

Keywords: CGE model, natural durable and non durable resources, circular economy, endogenous recycling rate, resource exhaustion, waste generation externality, mass conservation, material energy nexus.

JEL Classification: C68, D62, Q01, Q32, Q40, Q58.

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1 Introduction

Applied economic/environment applied models represent key tools to form policy recommendations and to calibrate the corresponding instruments such as taxes or quotas. While the energy thematic is widely studied, the role played by physical materials within the economy is rarely studied in macroeconomic models. Physical materials are nonetheless essential to the economy, as no production could occur without any physical content. Simple neoclassical growth models are based on the shortcut than materials are very abundant and consequently do not represent a major topic. However, decreasing grade of virgin ore and increasing population call this statement into question. Beside, material production is energy intensive, linking the material thematic to the energy one.

To get a full picture of the material/economy interaction in a macroeconomic model, a powerful approach is to think in terms of circular economy. It means that all material flows have to be considered, those before but also after the first final use. Otherwise, in partial equilibrium model, some mechanisms may be lost. Circular economy has already been studied in the literature, often part by part. One the one hand, some works focus on material efficiency. On the other hand, some other works focus on waste treatment.

Existing literature on macroeconomic models which focus on material circulation at every stage is not very numerous. Some pioneering works exist though. Among theoretical macroeconomic models, we can cite De Beir, Fodha and Magris (2010), in which the recycling rate is fixed exogenously by the public authority. Among CGE approaches, we can cite EMEC (Sjöström and Östblom, 2009), which is based on a detail CGE for Sweden and in which waste generation is linear in input factors, including labor and capital. AIM Material (Toshihiko, 2005) is also an advanced work, in which the waste treatment is computed after the economic equilibrium, at each date.

The challenge here is to build a stylized applied model, in which materials flows are fully integrated in the economic equilibrium. In particular, we wanted an endogenous recycling rate, determined by economic forces. Besides, we wanted to keep mass conservation, so that the model is realistic in terms of physics, even for large scale shocks. This implies to be careful at some specific stage, as waste generation or waste treatment. One difficulty lies in the fact that CES production functions do not preserve volume: the output (in volume) is not equal to the sum of inputs (in volume) when the equilibrium changes, except for limit cases.

The guideline for our work is to keep the model as simple as possible, under the constraint that we fully integrate every stage of material interactions with the economy. As a result, we detailed material specific sectors, leaving the rest on an aggregate level.

We distinguish durable from non durable resources, as only the first ones are recyclable. If a non durable resource is exhaustible, only one story allows long term growth, the Hartwick (1977) story: as exhaustion occurs, less and less material is incorporated in the good, though a substitution mechanism. Material efficiency is improved. If a durable resource is exhaustible, two polar stories may apply: the Hartwick story (improved material efficiency) or the circular economy story (recycling takes place). We try to integrate these two mechanisms in our model.

In part 2, we describe the model. Part 3 gives insights about the calibration. Results regarding instruments aiming at reducing landfill are presented in part 4.

2 The model

The guideline we had in mind while building the model was to keep the tool as small as possible, under the constraint that we could study the impact of instruments related to waste treatment and material efficiency. The final goal was to be able to quantify the economic and physical impacts of various instruments like taxes or norms, in order to formulate figures-based policy recommendations. While energy in CGE models is widely studied, modelling the circular economy topic (material flows before and after final use of goods) is much more challenging. We also included energy, as there is a natural interaction between the circular economy and the energy topic, as producing secondary material (from scraps) is highly energy-saving compared to producing primary material (from virgin ores).

The model is multi-country, as shocks on resources prices may impact a given country directly (a natural resource, used as an input by the country, is more expensive) but also indirectly (the demand addressed to this country changes due to the fact that the natural resource is also more expensive in other countries).

2.1 Structure overview

The approach we adopted here is to model specific sectors related to material flows and to consider the rest of the economy as an aggregate sector. The two reasons to keep the rest of the economy on an aggregate level were first to keep the model tractable, secondly to be able to calibrate it (data on material flows are mainly available on an aggregate level). We hence distinguish the waste treatment sector, the extractive sector (both for mineral and fossil material), the electricity sector and finally the rest of the economy.

Region, mineral material, fossil material sets are respectively $\mathcal{R}$, $\mathcal{M}$ and $\mathcal{F}$.

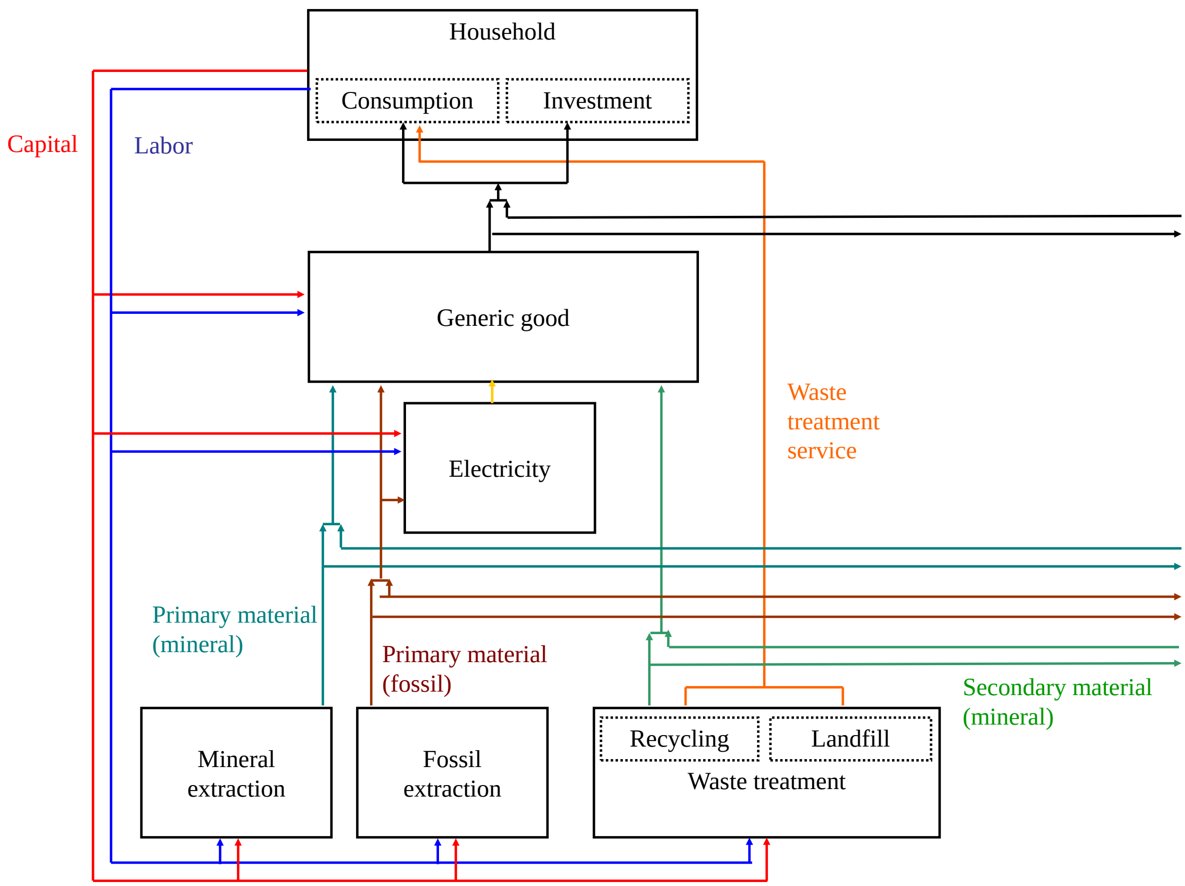


Figure 1: Model structure.

2.2 Households

The saving rate is exogenous, as in the Solow model. Two goods are consumed: the generic good and the waste treatment service. The quantity of waste treatment service consumed is exactly equal to the material content of the generic good consumed.

Waste generation is hence given by the following equation:

$$W_{r,t} = \frac{C_{r,t}}{C_{r,t} + I_{r,t}} \sum_{r_1 \in \mathcal{R}} \sum_{r_2 \in \mathcal{R}} \left(M^P_{r_1,r_2,t} + M^S_{r_1,r_2,t} \right) \frac{Y_{r,r_1,t}}{Y_{r_1,t}}$$

It implied that there is an externality of firms on households: the volume of physical materials in final goods is decided by firms, but households pay for the waste treatment of this volume.

2.3 Firms

2.3.1 Waste treatment service

The waste treatment service sector is a core part, as it links before-production and after-production material flows.

We had three goals while modeling this sector:

- Keep material balance (as a consequence of mass conservation, recycling rate cannot exceed 1);
- Having an endogenous recycling rate;
- Having plausible economic properties (like homogeneity of degree 1).

The production function is the following, with F a CES function and G a CET function.

$$G(V^{recycling}_{m,r,t}, V^{landfill}_{m,r,t}) = F(K^{waste}_{m,r,t}, A_{r,t} L^{waste}_{m,r,t}) \qquad m \in \mathcal{M}$$

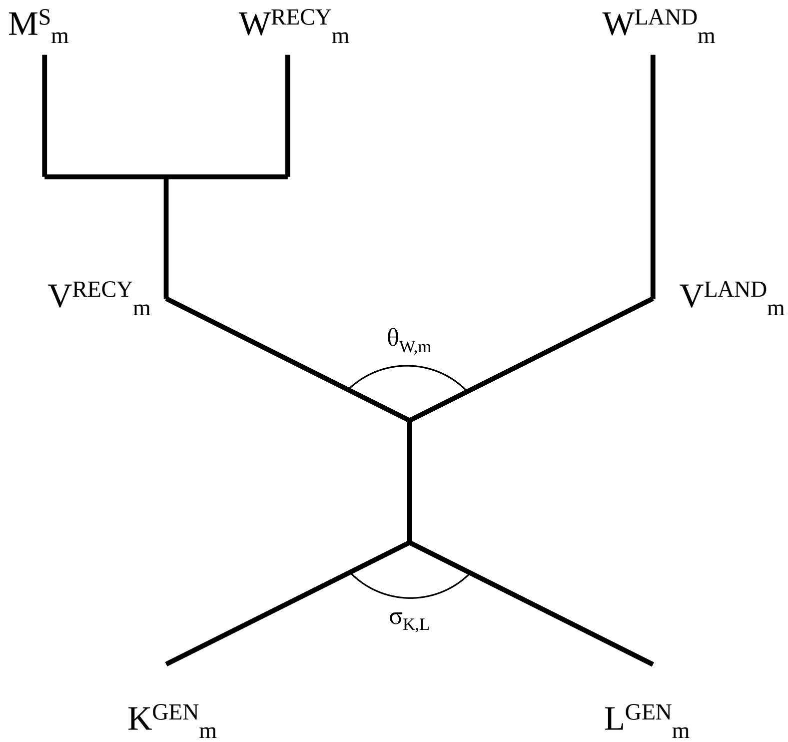


Figure 2: Waste treatment sector.

2.3.2 Mineral and fossil extraction

The production function is the following.

$$M^P_{mf,r,t} = \phi\left(\sum_{\tau<t} M^P_{mf,r,\tau}\right) F(K^{extraction}_{mf,r,t}, A_{r,t} L^{extraction}_{mf,r,t}) \qquad mf \in \mathcal{M} \cup \mathcal{F}$$

Under the least cost principle, we have $\phi' \leq 0$.

2.3.3 Electricity

The nested CES function is in line with the literature.

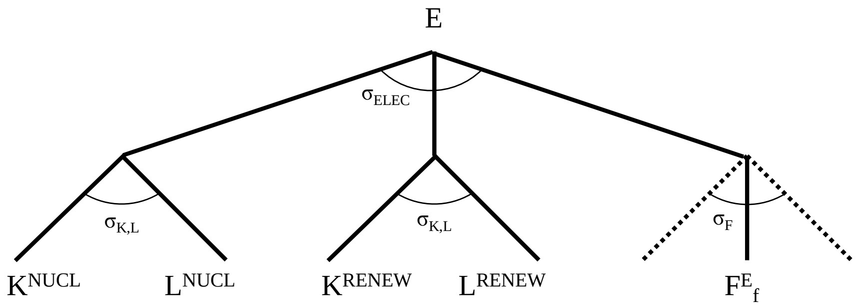


Figure 3: Electricity sector.

2.3.4 Generic

The tradeoff between primary and secondary material is on the right part of the figure, with specific energy mix for primary and for secondary material production.

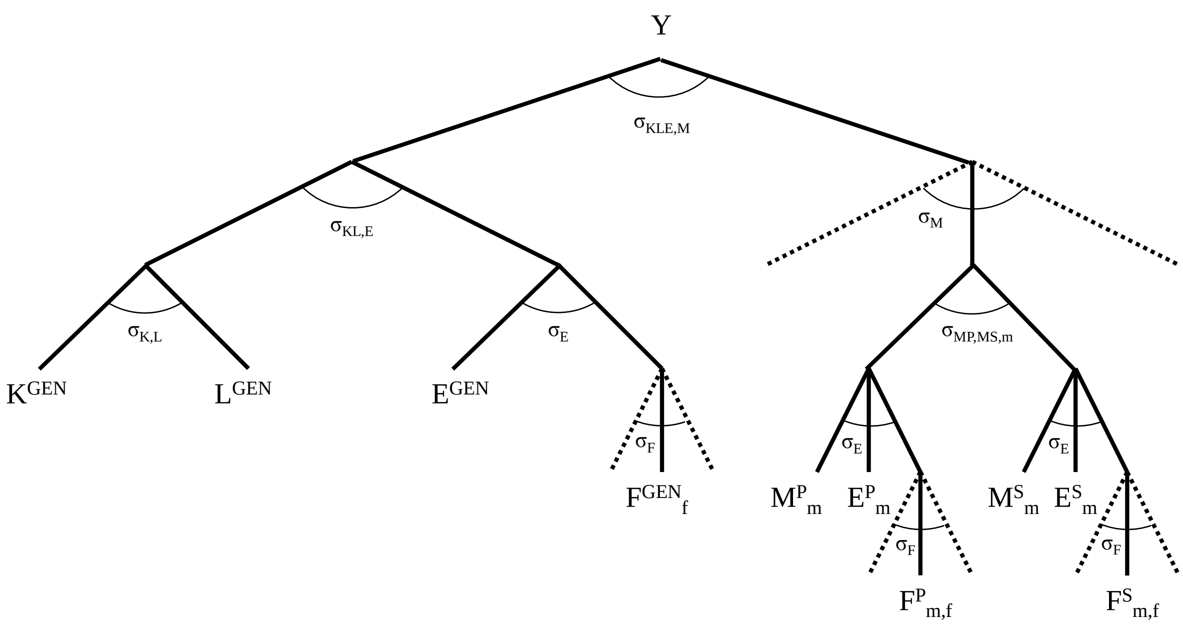
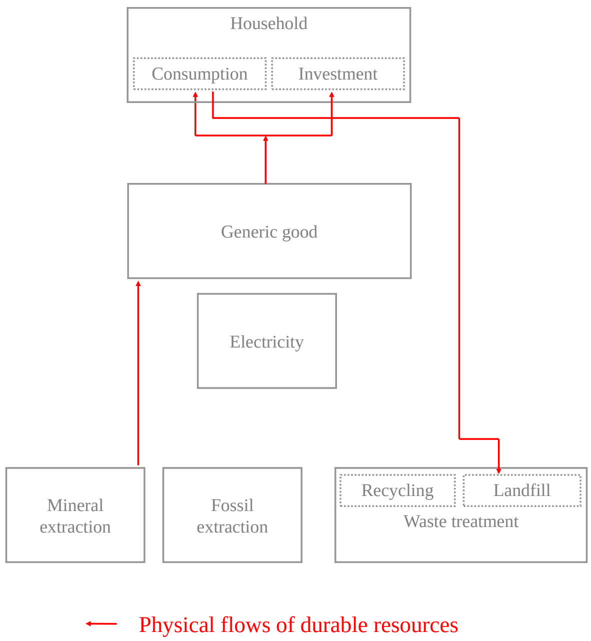
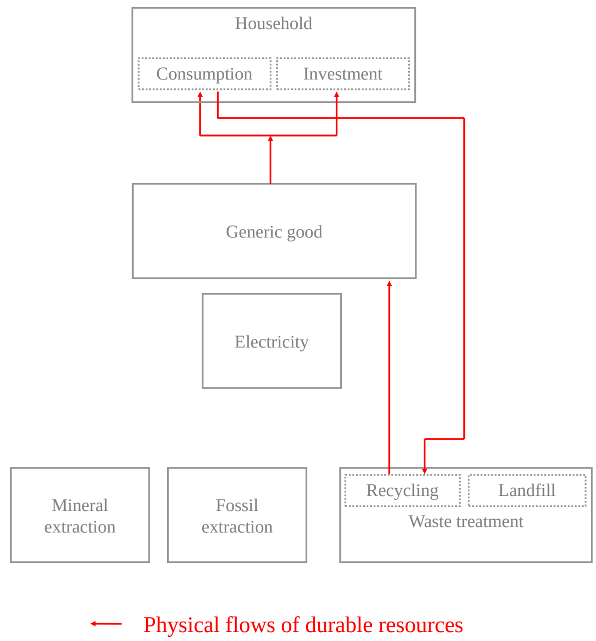


Figure 4: Generic sector.



(a) Full linear economy



(b) Full circular economy

Figure 5: Full linear versus full circular economy

2.4 Full linear versus full circular economy

We consider two polar cases for illustrative purpose: a full circular economy and a full circular economy. Material (mineral) flows are in red.

3 Calibration

We consider 2 regions, France and the rest of the world. Two mineral materials are considered: steel and aluminium. These two metals are not anecdotical: they represent together about 50% of the value added of the recycling sector in France. We also consider 3 fossil materials: oil, coal and gaz. The base year is 2010. The Model is running on GAMS.
French economic data come from the French office for statistics (INSEE) while economic data for the rest of the world come from IMF. Mineral materials flows for steel and aluminium come from steel and aluminium associations at the French and the world level. Energy flows come from French office for environmental statistics

(SOES) while their worldwide counterparts come from the World Energy Outlook 2012.

Elasticities of substitution and transformation are listed below.

Structural parameter	Value
$\sigma_{KLE,M}$	0.5
$\sigma_{KL,E}$	0.5
$\sigma_{K,L}$	1
σ_E	0.5
σ_F	0.9
σ_{ELEC}	0.5
σ_M	0.1
$\sigma_{PM,SM,m}$	3 (steel), 2 (aluminium)
$\theta_{W,m}$	0.5
$\sigma_{Armington}$	3 (generic good), 6 (materials)

Table 1: Structural parameters.

While estimations of structural parameters related to usual economic and energy nests are relatively numerous in the literature, estimations of structural parameters related to materials are quite rare. The elasticities of substitution between primary and secondary mineral materials $\sigma_{PM,SM,m}$ are found in Mannaerts (2004). Regarding the elasticity of transformation between waste treatment by recycling and waste treatment by landfill $\theta_{W,m}$, the meta-analysis by Choe C. and I. Fraser (1998) shows that the price elasticity of landfill clusters around 0.2 in the literature, which implies an elasticity of transformation of 0.5 in the model.

4 Impact of economic instruments aiming at reducing landfill in France

Quantifying the environmental externality due to landfill is not possible due to the lack of data. We hence consider a target, the quantity of waste sent to landfill, and we compare the impact on different instruments in France.

We consider 3 instruments :

- Tax on primary material and lump-sum transfer to the household.
- Tax on landfill (known in France as ”TGAP déchets”) and lump-sum transfer to the household.
- Norm on the recycling rate, which is modelled by a tax on landfill and a subsidy for recycling.

In the reference scenario, there is no tax. In the alternative scenarios, there are taxes in France only. We study changes in the static equilibrium.

The four main results are the following:

- Taxing landfill allows to reach the target of a 50% decrease of landfill, and at a relatively low real GDP loss (a 0.06% loss).
- Taxing primary material is not the good instrument to reduce waste generation, as substitution with secondary material and foreign semi-finite and finite goods occurs. The maximum feasible reduction of waste generation with this instrument is about 7%.
- When taxing landfill, the agent receiving the subsidy (the household in the first case, the recycling sector in the second case) does not matter.
- Taxing landfill so that the quantity of waste going to landfill is reduced by 50% induces a 0.2% decrease of energy consumption in France. This is mainly due to the use of secondary materials, whose supply curve is stimulated by the landfill tax, and which are more energy-saving than primary materials.

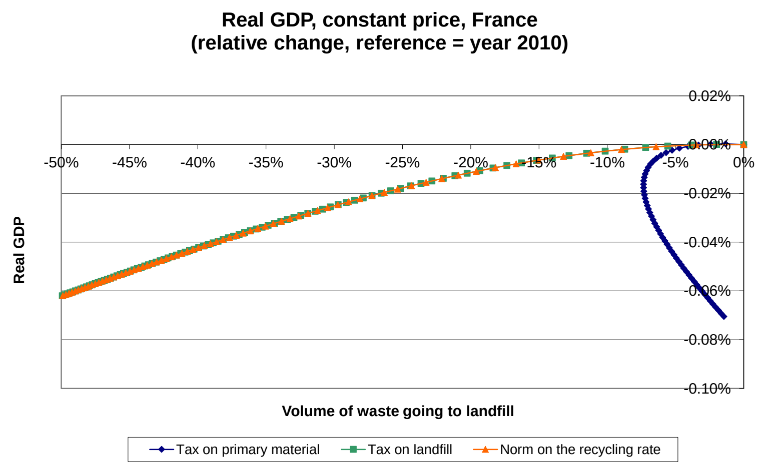


Figure 6: GDP, relative change to the reference scenario.

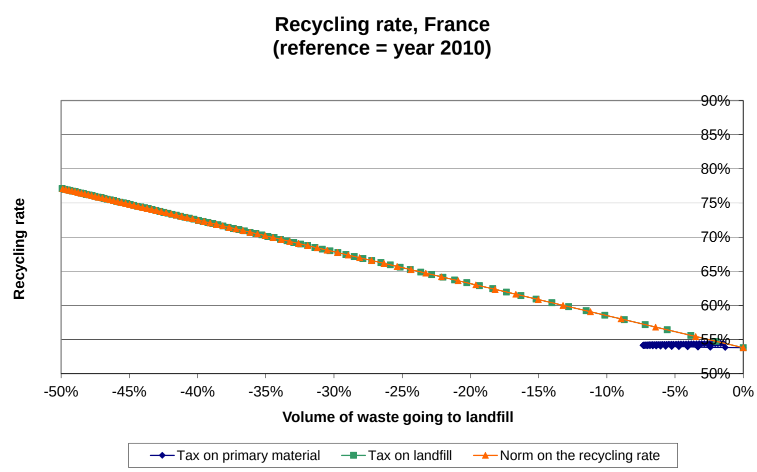


Figure 7: Recycling rate.

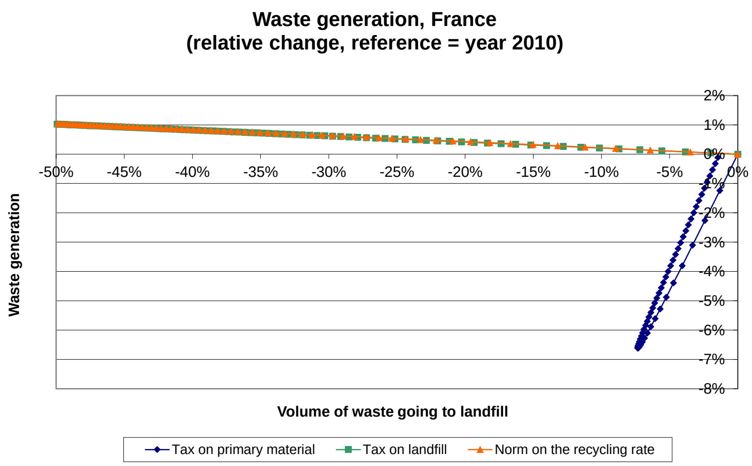


Figure 8: Waste generation, relative change to the reference scenario.

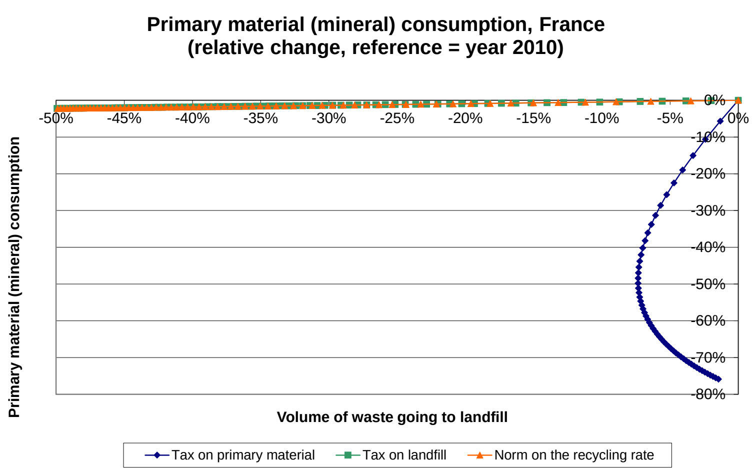


Figure 9: Primary material consumption, relative change to the reference scenario.

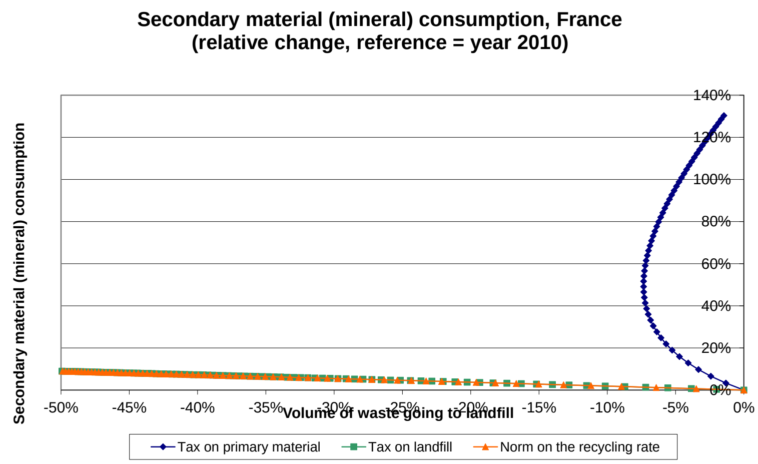


Figure 10: Secondary material consumption, relative change to the reference scenario.

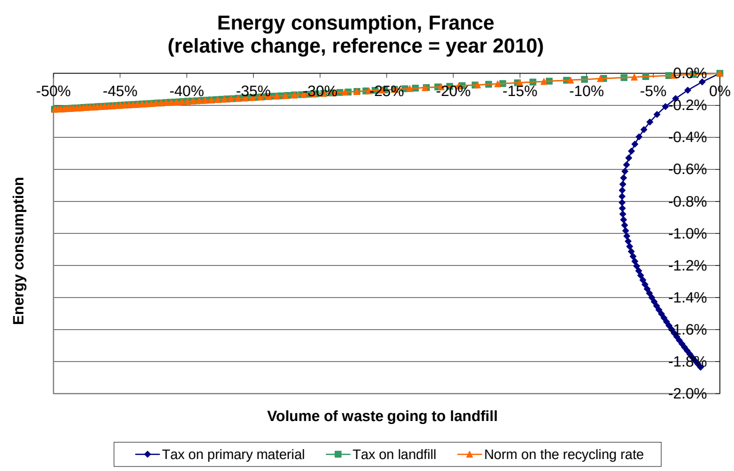


Figure 11: Energy consumption, relative change to the reference scenario.

5 Sensitivity analysis

[To be completed]

6 Conclusion

[To be completed]

Annex A: Variable list

[To be completed]

Annex B: CES and CET production functions

[To be completed]

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