Changing energy efficiency technology adoption in households

D 6.2 Scientific working paper on macroeconomic effects of energy efficiency policy

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1 Summary

Accelerating the adoption of energy efficiency technologies in households within the EU28 inevitably affects the overall economy. This working paper presents the results of the macroeconomic analysis within the CHEETAH project.

Estimating the macroeconomic effects of energy efficiency policy requires a detailed understanding of how the policy measures act on the micro level. The methodological approach applied in this analysis creates a coupling between the detailed bottom-up energy demand models Invert/EE-Lab (for buildings) and FORECAST (for appliances) with the macroeconomic system dynamics model ASTRA-EC. The coupling approach combines technology-based engineering knowledge in the relevant energy-using sectors with a macroeconomic perspective by taking advantage of the detailed data on technologies in the energy demand models, and of the dynamic input-output structure in the macroeconomic model.

The macroeconomic effects of the energy efficiency policy scenarios are analysed using a three-step methodology. In the first step, the investments and energy cost reductions induced in the scenarios are calculated using a detailed bottom up modelling approach. In a second step, the investments and savings are allocated to the affected economic sectors. In a third step, the macroeconomic impacts are calculated using the dynamic input-output based macroeconomic model ASTRA-EC.

The overall effect on GDP and employment on the European level is relatively small in both scenarios. Over the entire simulation period, average EU 28 GDP is 0.03% above the current-policies scenario in the individual policy instrument scenario (S1), and 0.05% above the current-policies scenario in the policy-package scenario (S2). The effects on employment are smaller with an increase of 0.01 % in both scenarios. In absolute terms, these changes equate to 5 billion € of additional EU 28 GDP per year in the S1 scenario and 8 billion € additional yearly GDP in the S2 scenario. The yearly changes in European employment are approximately 19.000 additional jobs in FTE in both scenarios.

On a sectoral level, it can be observed that manufacturing generally benefits from the investments in appliances and building technologies. The biggest accrue to the electronics sector. In contrast, the energy and minerals sectors (which also include fossil fuels) experience a small decline in value added and employment relative to the baseline scenario. The macroeconomic effects are also negative in some service sectors, due to the negative impulse on final consumption in the case of higher investment costs than energy savings.

The distribution of the macroeconomic effects are relatively uniform among different socioeconomic groups. Using disposable income as an indicator of different impacts per quintile, it can be shown that all quintiles experience a small relative increase in disposable income. This indicates that the efficiency measures portrayed in the modelling do not appear to have negative redistributive effects.

Taken together, the macroeconomic impacts of the scenarios show characteristics of an investment process, which one the one hand strengthens manufacturing industries but comes at the cost of temporarily reduced aggregate consumption. At the same time, the fiscal position of households is strengthened through energy savings that extend beyond the investment period.

The macroeconomic analysis has some caveats, including the types of impulses considered, the modelling time horizon and the assumptions regarding the crowding out of investments. Therefore, the results should be interpreted as a constituting a lower boundary of possible macroeconomic effects. In line with the literature, it can however be concluded that investments in energy efficiency are likely to have at least moderate positive macroeconomic impacts for the EU.

2 Introduction

Energy efficiency is one of the main pillars of European climate and energy policy (European Commission 2010, 2011c, 2011d, 2011b, 2011a). Improving energy efficiency can also deliver a range of economic and social benefits to Europe (OECD/IEA 2012). Next to individual-level and sectoral benefits, such as increases in household incomes and the competitiveness of companies, energy efficiency may have desirable effects on GDP, employment, trade balances, and the security of energy supply.

In this working paper, the macroeconomic effects of energy efficiency measures in households in the EU-28 will be analysed. It is part of the project CHEETAH (*Changing Energy Efficiency Technology Adoption in Households*). The CHEETAH project has the objectives of providing evidence-based input to energy efficiency policy-making by investigating the role of household decision-making on three levels:

1. On the micro level, the project provides empirical evidence of household energy-efficiency technology choices and responses to policy employing large-sample household surveys in eight EU member states and micro-econometric analyses based on stated preferences discrete choice experiments.
2. On the meso level, the project explores the impact of policies affecting household energy efficiency decision-making in the residential sector in Europe up to 2030. The project uses inputs from the micro-level analysis in order to improve the representation of investment decisions in energy demand modelling tools.
3. On the macro level, CHEETAH explores the long-term macroeconomic impacts of changes in micro-economic decision-making and of energy efficiency policy on employment, GDP and exports in the EU up to 2030.

Accelerating the adoption of energy efficiency technologies and services inevitably affects the whole economy through the following main effects (Walz and Schleich 2009; IEA 2014). On the one hand, macroeconomic effects result from increased investments in energy efficiency technologies and services. On the other hand, energy cost reductions arising from the reduction of energy demand lead to negative effects of the related sectors. If the energy costs savings surmount investments, additional demand effects are likely, and vice versa. These effects induce further macroeconomic effects, and also contribute to a change in the structural composition of the economy. Additionally, the reduction of energy demand lowers the dependence on imported fossil fuels, which has a positive impact on national trade balances. Changes in the structural composition of the economy also contribute to changing imports, and also lead to effects on the average labour intensity of the economy. The effects are described in Table 1.

Table 1: Effects resulting from investments and energy cost reductions for consumers of energy efficiency technologies

Effects resulting from investments	Energy efficiency investments increase demand in sectors providing energy efficiency technologies and services, leading to increased production and employment in these sectors and the sectors related to them. Furthermore, it enhances the chances of domestic producers to increase their technology exports.
Effects resulting from energy cost reductions	Energy savings reduce spending on energy, leading to reduced production and employment in these sectors, and the sectors related to them.
Effects resulting from cost differentials	The differences between investment increases and energy cost reductions may affect disposable income and thus consumption in economic sectors not related to energy efficiency.

Effects resulting from production changes	Changes in production of investment and consumption goods lead to changes in income, which induce further multiplier effects, and lead to changes in the structural composition of the economy.
Effects resulting from changes in the structural composition	The economic sectors differ with regard to import shares and labour intensity. Thus, structural sectorial change leads to changes in overall import and labour intensity of an economy.

The paper is structured as follows. In Chapter 3, an overview of the literature on macroeconomic effects of energy efficiency is provided. Chapter 4 presents the methodological approach used for modelling the macroeconomic effects of energy efficiency improvements. Chapter 5 summarizes the macroeconomic impulses generated from the energy demand projections of the energy demand models Invert/EE-Lab and FORECAST. The results of the macroeconomic analysis are presented in chapter 6, which closes with a discussion and interpretation of the results. A short conclusion is provided in Chapter 7.

3 Literature review

Energy efficiency has been widely studied on the micro level, whereas only a small number of studies have analysed the macroeconomic impacts of energy efficiency. The IEA (2014) provides a good overview of the multiple levels on which energy efficiency can have an impact. On the macro level, Integrated Assessment Models (IAMs) are often used to capture the multiple macroeconomic mechanisms unfolding in the wake of energy efficiency measures. Pollitt et al. (2016), using the macro-econometric E3ME model, expect overall positive impacts on GDP and employment in Europe, whereas a considerable negative impact is expected on extractive industries, specifically in EU Member States which heavily rely on these industries. In a global study on measures to close the 2020 emissions gap, Barker et al. (2015) find positive impacts of energy efficiency on GDP. Turner (2009), using a Computable General Equilibrium (CGE) model, finds positive GDP and employment effects of energy efficiency in the UK. Also concentrating on the UK economy and using the MDM-E3 model, Barker et al. (2007) find a positive development for GDP and employment until 2010 under energy efficiency policies.

A number of other reports do not base their studies on complex models but use other quantitative or qualitative methods for the evaluation of the macroeconomic impacts of energy efficiency. Mirasgedis et al. (2014) evaluate the impact of energy efficiency policies on the Greek building and construction sector and find evidence for significant employment benefits. However, they base these findings on the results of a relatively simple Input-Output Model. Furthermore, even though they account for positive benefits of energy cost savings reallocated to other consumer goods after the initial investment phase, they do not tackle the impacts that might happen during the investment phase if energy cost reductions are not high enough to compensate for investment expenditures. Saunders (2013) focuses on the fuel/GDP ratio by using a top-down theoretical macroeconomic model of a neoclassical growth variety to arrive at the qualitative conclusion that the increase in GDP due to a reduction in fuel consumption is most likely small. Croucher (2012) studies the impact of energy efficiency standards for the Southwestern States of America by using a qualitative method and discussing how these may be incorrectly estimated or even completely ignored within the literature. He finds evidence that the economic effects of energy efficiency are over-estimated. Energy efficiency standards tend to create jobs in relatively low-paid sectors (e.g. retail and service sector) which comes at the cost of a reduction of employment in higher paid job sectors (e.g. the utility sector). A review by the OECD/IEA (2012) comes to the conclusion that regarding the creation of jobs with a short lead time, energy efficiency has significant potential. Net improvement in this case can be traced back to energy efficiency programs through direct job creation and indirectly through consumer surplus spending. A reduced unemployment rate can additionally be beneficial for the national budget.

Previous meta-analysis of growth and employment effects of energy policies have shown that various factors are important when interpreting the results (see Walz and Schleich 2009). Among the most important ones are the level of no-regret-potentials, which drive down net costs for the economy, the assumptions about capital markets and macroeconomic situations, which influence the level of crowding out effects of investments, and the composition of the analysed economy, especially whether or not investment goods and energy are produced domestically or imported. Furthermore, the role of policy instruments plays an important role, especially if the energy policy is accompanied by a green tax reform, which lowers labour costs alongside reduced energy consumption, and allows for a substitution towards higher labour input. Finally, modelling characteristics play a role, e.g. the difference in results of CGE models compared to Keynesian econometric models.

4 Methodological approach

This section describes the methodological approach that is applied in the CHEETAH project for transferring the results from the energy demand modelling (WP 5) to the macroeconomic model ASTRA-EC, which is then used for the macroeconomic impact assessment (WP 6).

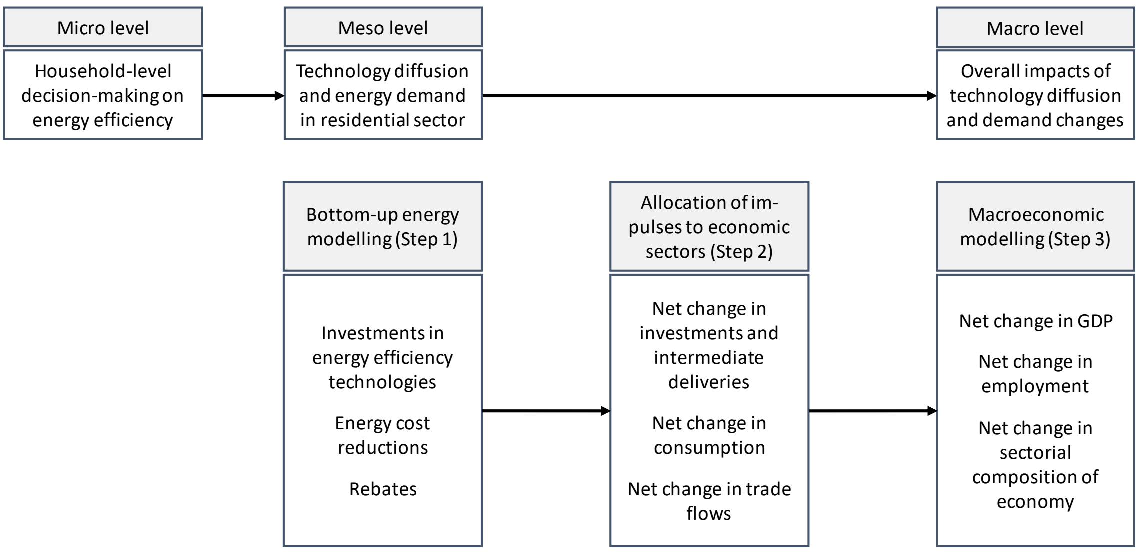

Figure 1: CHEETAH modelling approach

Estimating the macroeconomic effects of energy efficiency policy requires a detailed understanding of how the policy measures act on the micro level. For example, policy measures that address investments in thermal insulation have an effect (among others) on the construction sector, whereas product policy measures have an impact on the sectors that produce such products. It is therefore necessary to evaluate the projected energy savings at a technologically detailed level. The methodological approach applied in the CHEETAH project creates a coupling between the detailed bottom-up energy demand models Invert/EE-Lab (for buildings) and FORECAST (for appliances) with the macroeconomic simulation model ASTRA-EC. The coupling approach combines technology-based engineering knowledge in the relevant energy-using sectors with a macroeconomic perspective by taking advantage of the detailed data on technologies in the energy demand models, and of the dynamic input-output structure in the macroeconomic model.

The approach therefore addresses one of the shortcomings of macroeconomic modelling, which generally represents sector details, but does not support technology details (IEA 2014).

The macroeconomic effects of the energy efficiency policy scenarios generated in WP 5 of the CHEETAH project are analysed using a three-step methodology (see Figure 1). In the first step, the investments and energy cost reductions induced in the scenarios are calculated using a detailed bottom up modelling approach. In a second step, the investments and savings are allocated to the affected economic sectors. In a third step, the macroeconomic impacts are calculated using the dynamic simulation model ASTRA-EC. The methodological approaches that are applied in each of the three steps are outlined in the following subsections.

4.1 Bottom-up energy demand and investment projections (step 1)

The data on energy demand and investments are based on the scenarios presented in D 5.1 of the CHEETAH project, where energy demand projections are provided using bottom-up simulation models that capture the diffusion of energy efficiency technologies. The energy demand modelling platform FORECAST is used for projecting the investments in and energy demand of efficient residential appliances (see D 5.3). The modelling platform Invert/EE-Lab is used for projecting the energy demand of buildings and investments into energy efficiency technologies (see D 5.2).

The energy demand models include a detailed technology database and use a logit approach for modelling decision-making including observed barriers and heterogeneous expectations among decision makers (households or companies). The modelling approaches for the two policy scenarios include a mix of policy measures to support an accelerated diffusion of energy efficiency technologies, including minimum efficiency requirements and standardization, taxes, rebates and a range of information-based measures. Both approaches are enriched with information from an agent-based model developed within the CHEETAH project, which uses the results from a household survey in a select number of countries (developed within WP 4) in order to more accurately model household policy adoption under policy scenarios (see D 3.2).

4.2 Allocation of investments and savings to economic sectors (Step 2)

In order to transfer the outputs of the bottom-up modelling (WP 5) to the macroeconomic model ASTRA-EC (WP 6), the changes in investments, consumption, energy demand and rebates are allocated to the economic sector classification of the Input-Output tables used in ASTRA-EC. In the bottom up models, investments and energy savings are calculated considering individual energy efficiency measures and are not necessarily in the same sectoral classification as the economic sectors in the Input-Output tables. For each energy efficiency measure, it is therefore necessary to allocate the results from step 1 to the economic sectors of the Input-Output tables. Furthermore, it is necessary to determine the sectoral splits of the changes in the consumption bundle. The following sections outline how the results are transformed for residential appliances and residential buildings.

4.2.1 Residential appliances

For residential appliances, the macroeconomic effects are driven by the (individual) investments in energy efficient appliances undertaken by consumers (whose investments are treated as consumption in national accounting, except for investments in the building infrastructure – see the following section) and the energy cost reduction for consumers. Both the investments and the energy cost reductions are included in the consumption vector, where the investments lead to increased consumption in sectors producing energy efficient residential appliances (electronics and electrical equipment). The energy cost reduction leads to decreased consumption in the electricity-providing sector (see Table 2). The consumption changes are not simply additive; assuming a fixed consumption budget, a compensating impulse equivalent to all bottom-up consumption changes is introduced and allocated to sectors according to historic shares. There, the level of aggregate consumption remains unchanged, though its composition does change. This distinction is important since we do not assume that bottom-up policies change the marginal propensity to consume.

4.2.2 Residential Buildings

For buildings, deriving the inputs for the macroeconomic modelling is more complex due to the variety of efficiency technologies. The energy efficiency technologies can be split up into three broad categories: building envelope (i.e. thermal retrofits), smart thermostats and heating, ventilation and air conditioning (HVAC) technologies. The HVAC technologies are further split up into the following types:

1. Fossil
2. Biomass
3. Heat pumps
4. District Heating
5. Electric Heating
6. Solar Thermal

The energy efficiency investments of private home owners enter the input-output module of the macroeconomic model through the investment vector, where the elements corresponding to the sectors producing the efficiency technologies and providing services related to the installation of these technologies increase. As stated in the previous section, private households' expenditures are entirely contained in the consumption vector with the exception of investments in the building infrastructure, which are portrayed by the investment vector. The resulting energy savings, on the other hand, are portrayed by a decrease in the element of the consumption vector corresponding to the energy sector. The investments in thermal retrofits, smart thermostats and efficient HVAC technologies are typically financed through varying combinations of rebates, credits, and private capital. In the case of rebates received by private households, government expenditures are modelled to rise. Credit financing increases the consumption vector element corresponding to the financial sector (see Table 2). The reduced savings level and the increased value of the buildings are not considered in the model. Similar to the appliance case, the level aggregate consumption is assumed to remain unaffected by the efficiency policies; only the structure of consumption changes.

Energy efficiency investments of private landlords are also represented by increasing the investment vector elements corresponding to the sectors producing the efficiency technologies and credit services. The energy cost reduction of the tenant is represented by decreasing the element of the consumption vector corresponding to the energy sector. The financing of private landlords' investments is portrayed in the same way as that of private home owners. Similar to the case of residential appliances, the investments in smart thermostats and HVAC technologies and corresponding energy savings do not lead to a change in aggregate final demand but merely a shift between consumption purposes.

Commercial landlords for residential buildings: even though a fraction of the residential buildings are owned by companies, housing associations or housing cooperatives (in Germany, about 35 % of all rented properties), this distinction is not made in the CHEETAH project due to a lack of data. Energy efficiency investments of the housing industry and residential building cooperatives would also be represented by increasing the element of the investment vector that corresponds to the sectors producing efficiency technologies as well as related services. The energy savings of the tenant (private household) would be represented by decreasing the value of the consumption vector element corresponding to the energy sector, analogous to tenants of private landlords. Also analogous to private landlords, the energy efficiency investments are typically financed through varying combinations of rebates, credits, and retained earnings. The difference between private and commercial landlords therefore only lies in a slightly differing portrayal of investments and rebates, which is assumed not to have a large influence on the aggregated macroeconomic effects.

Table 2: Macroeconomic impulses from energy efficiency measures

Drivers for macroeconomic effects	Representation in macroeconomic model	Relevant sectors	Effects
Investments in building technologies	Investment vector	Minerals, chemicals, metal products, industrial machines, electronics, plastics, construction, other market services	Increase
Investments in energy efficient appliances	Consumption vector	Electronics, electrical equipment	Increase
Energy savings	Consumption vector	Energy	Decrease
Financing	Consumption vector	Banking and insurance	Increase

4.3 Macroeconomic modelling (Step 3)

The macroeconomic simulation model ASTRA-EC is at the core of the macroeconomic analysis in WP 6 of CHEETAH. ASTRA-EC is a System Dynamics model and emphasizes dynamic interactions, the integration of differences in short- and long-run effects and an explicit modelling of supply-side restrictions. At its core is an input-output module model portraying 25 economic sectors (see Appendix for a list of the sectors).

Figure 2 provides a schematic illustration of the modelling logic of ASTRA-EC and shows how the main policy impacts derived from the energy demand models (WP 5) flow into the macroeconomic modelling in WP 6. As outlined in the previous section, the energy efficiency measures covered in the energy demand models lead to changes in investments (e.g. investments in energy efficiency technologies) and consumption (e.g. reduced energy demand). As indicated in Figure 2, these bottom-up impulses are integrated in ASTRA-EC mainly by changing the investment demand and consumption vectors. Consumption (together with investment, government expenditures and exports) forms the second quadrant of input-output tables, which is equivalent to final demand. The latter represents the demand side of the economy. It is complemented by the supply side, which is fed by capital, labour and technological progress, representing the production potential of the economy. Gross Domestic Product (GDP) is derived by balancing both the supply and the demand sides of the economy. GDP growth initiates further growth in consumption, triggering investments to meet this new consumption demand. These feedback effects between GDP, income, consumption, investments and again GDP are a key feature of ASTRA-EC and allow for the modelling of induced effects of the implementation of energy efficiency measures. Taking into account these induced effects is particularly important when modelling the long-term macroeconomic effects of energy efficiency policies. A more detailed description of ASTRA-EC can be found in the Appendix.

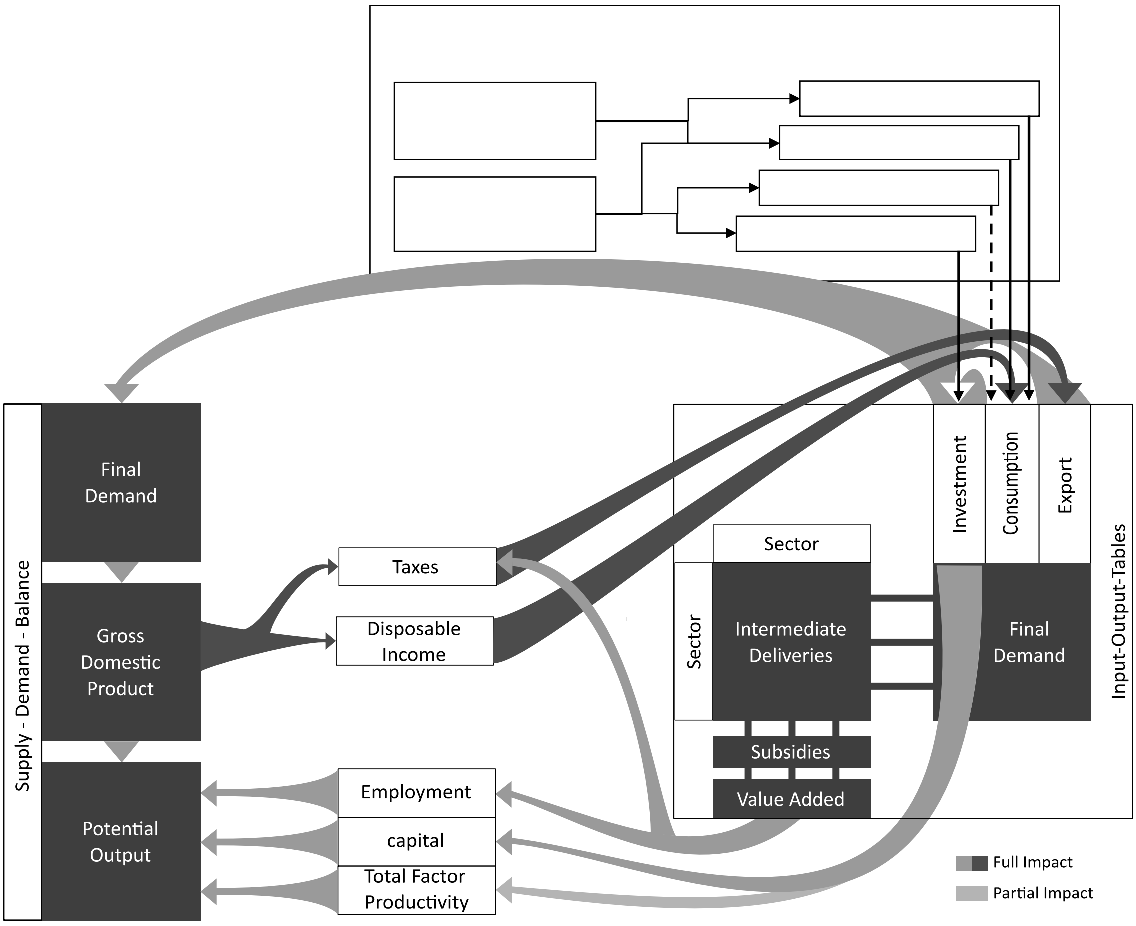

Figure 2: Macro-economic modelling logic in ASTRA-EC, own illustration

The impulses derived from the bottom-up energy demand models are implemented in ASTRA-EC in the following manner (cf. Figure 2):

- Consumption changes due to investments in appliances are implemented as relative changes to the baseline scenario in the consumption vector without changing overall consumption. This affects the elements of the consumption vector corresponding to the sectors producing energy efficient appliances.
- Investment changes due to investments in efficient heating technologies for buildings are implemented as relative changes to the baseline scenario in the investment vector without changing the overall level of final demand. The changes in the investment vector apply to sectors that produce energy efficient building technologies.
- In private households, energy is regarded as a consumption good and a reduction of energy demand is applied as a reduction in the consumption vector. The only affected sector is the energy sector.
- Rebates are applied to the government sector and thus change government consumption and the government budget. The positive consumption impulse counteracts the consumption normalisation outlined in Section 4.2 by re-increasing overall consumption at the level of the rebates. However, higher government expenditures may induce a crowding out effect due to government borrowing or increase in revenues.

These impulses not only directly affect the sectors producing appliances and efficiency technologies for buildings but also indirectly affect other sectors through the interconnectedness of the economy. The reduction in energy demand also indirectly leads to reductions in energy imports. In addition, the changes in consumption induce further macroeconomic effects, including a change in aggregate value added (GDP), leading to subsequent changes in the overall investment volume, employment and productivity. Therefore, the production potential of the economy may change as a result of the energy efficiency measures.

5 Macroeconomic impulses

This section summarizes the output from the energy demand models, which serves as input to the macroeconomic modelling. The energy demand models deliver investment impulses for each country and technology. These investment impulses are then broken down into sectoral impulses per country based on detailed sector mappings for each technology covered (see Figure 3). The energy demand impulses are allocated to the energy sector and the rebates to the government sector (see Section 4.3).

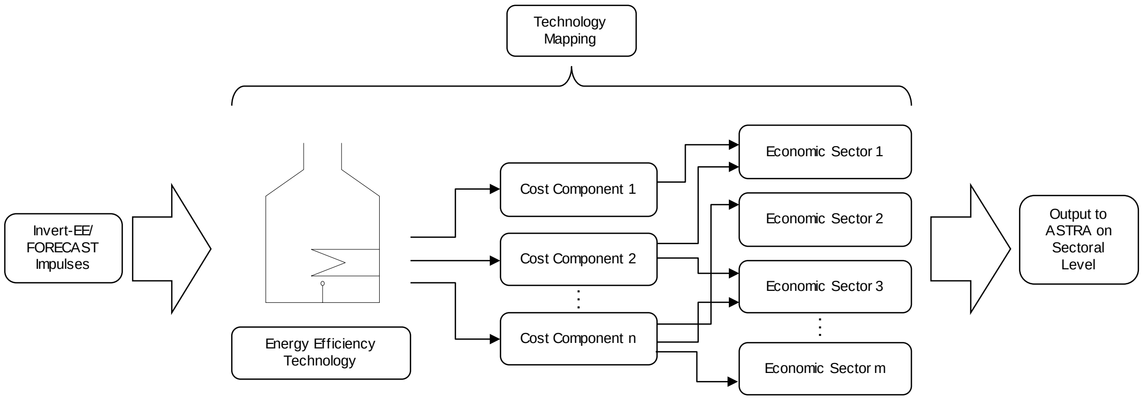

Figure 3: Illustration of the impulse conversion for the macroeconomic modelling, own illustration

The country-level impulses for appliances and building technologies are summarized in Sections 5.1 and 5.2, respectively. All impulses are presented as differences between a baseline case, which has also been defined as part of the scenarios in D 5.1 and the two considered policy scenarios:

1. Individual policy instrument scenario (S1)
2. Policy-package scenario (S2)

5.1 Appliances

This section presents the output from the energy demand model FORECAST for appliance and lighting technologies, e.g. refrigerators, washing machines, lighting and televisions. The following table shows the differences of impulses between the individual policy instrument scenario (S1) or the policy-package scenario (S2) and the current-policy scenario, respectively, for the three variables investments, energy expenditures and rebates. In FORECAST, the policy scenarios are modelled to start after 2020. Therefore, in contrast to the building impulses, appliance impulses are only shown for the base years 2025 and 2030.

Table 3: Overview of differences in investments, energy expenditures and rebates related to appliances between individual policy instrument scenario (S1) and current-policy scenario, and between policy-package scenario (S2) and current-policy scenario [Mio. EUR]

	2025		2030	
Variable/scenario	**S1**	**S2**	**S1**	**S2**
Investments	5992.6	7062.1	6933.2	8852.0
Energy expenditures	-1590.8	-1691.7	-3504.0	-3692.1
Rebates	0.0	1327.3	0.0	1822.5

5.2 Buildings

This section presents the output from the energy demand model Invert/EE-Lab for efficient building technologies: building envelope (i.e. thermal retrofits), smart thermostats and heating, ventilation and air conditioning (HVAC) technologies. The data exchange focuses on differences in costs and spending on energy carriers and investments into heating systems as well as thermal renovation measures. Please also see the summary report of WP 5 for details on energy demand developments in the building sector for building technologies. The following table shows the differences of impulses between the individual policy instrument scenario (S1) or the policy-package scenario (S2) and the current-policy scenario, respectively, for the three variables investments, energy expenditures and rebates.

Table 4: Overview of differences in investments, energy expenditures and rebates related to building technologies between individual policy instrument scenario (S1) and current-policy scenario, and between policy-package scenario (S2) and current-policy scenario [Mio. EUR]

	2020		2025		2030	
Variable/scenario	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**
Investments	-440.8	3231.3	7648.4	6869.7	10718.1	12072.1
Energy expenditures	-301.6	-711.2	-8953.8	-10808.9	-12244.6	-17596.2
Rebates	-246.7	-189.5	4053.1	4555.5	4680.2	5189.3

6 Macroeconomic effects

6.1 Overview of results

The investment, energy expenditure and rebate impulses serve as inputs for the macroeconomic model ASTRA-EC, which is used for the assessment of macroeconomic effects. As described above, these impulses represent the difference between the individual policy instrument scenario (S1) or the policy-package scenario (S2) and the current-policy scenario, which is also referred to as the business-as-usual (BAU) scenario. The simulation of macroeconomic effects is conducted for the period from 2012 to 2030. All monetary indicators are portrayed in real terms in 2005 €. Thus, the unit "€" henceforth refers to 2005 €. The model calculations are performed on a yearly basis. However, due to the small size of the results at the beginning of the simulation period, the results are only shown for the target year 2030.

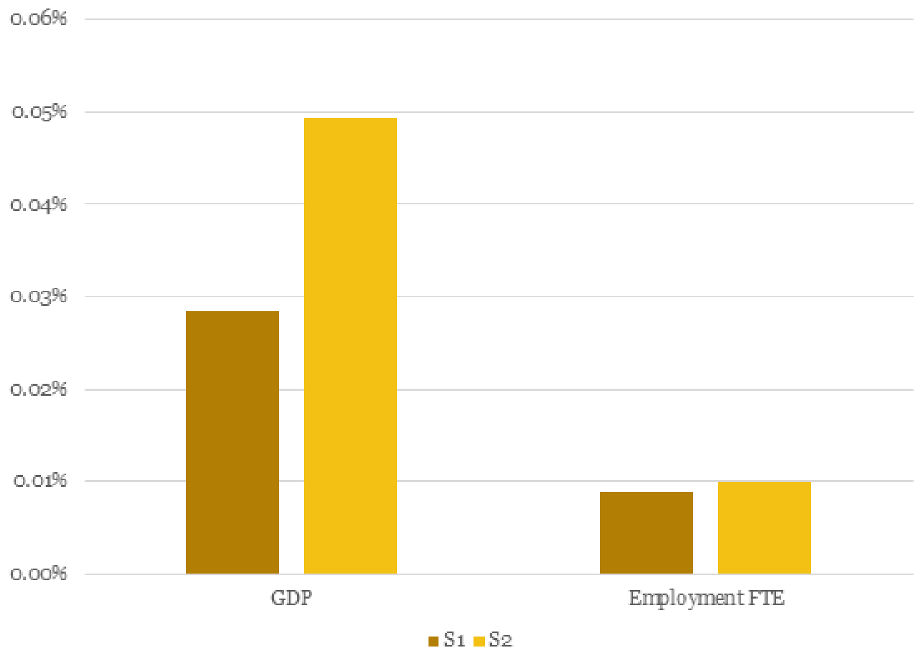

Figure 4: Relative yearly GDP and employment change (in full time equivalents, FTE) for EU 28 in 2030 for the individual policy instrument scenario (S1) and the policy-package scenario (S2)

The investment impulses have a positive effect on the sectors which provide investment goods in the form of appliances, efficiency technologies and insulation for buildings. The energy demand reduction has a negative effect on the energy sector. Depending on the relationship between the investment impulse and the energy expenditure impulse, a different reaction is supposed for final consumption. If the energy savings are higher than the investment impulse, the saved money is assumed to be spent on other goods, and aggregate consumption thus increases accordingly. If the investments in one country are higher than the associated energy savings, it is assumed that aggregate consumption has to be reduced accordingly. This consumption reduction is alleviated by rebates, which however increase government expenditures, which have to be alimented by the private sector. Thus, from a macroeconomic real goods perspective, the spending on energy efficient technologies has an investment character: in the year of the investment, there might be a crowding out of other elements of final demand, if the achieved reduction of energy consumption is not strong enough. However, in the following years, the energy efficiency technologies also lead to energy demand reductions, which enable to spend more on consumption. In our S1 and S2 scenarios, there are flows of investment between 2012 and 2030. The effects of the investments taking place in the latter years also have a payback in the form of reduced energy consumption which takes place after 2030. Thus, it has to be kept in mind that the modelling time frame does not cover all of the positive effects of the impulses.

Figure 4 illustrates that the overall effect on GDP and employment on the European level is relatively small in both scenarios. Over the entire simulation period, average EU 28 GDP is 0.03% above the current-policies scenario in the individual policy instrument scenario (S1), and 0.05% above the current-policies scenario in the policy-package scenario (S2). The effects on employment in full time equivalents (FTE) are even smaller: The results point towards an increase of 0.01 % in both scenarios. In absolute terms, these changes equate to 5 billion € of additional EU 28 GDP per year in the S1 scenario and 8 billion € additional yearly GDP in the S2 scenario.

The yearly changes in European employment are approximately 19.000 additional jobs in FTE in both scenarios.

6.2 Sectoral effects

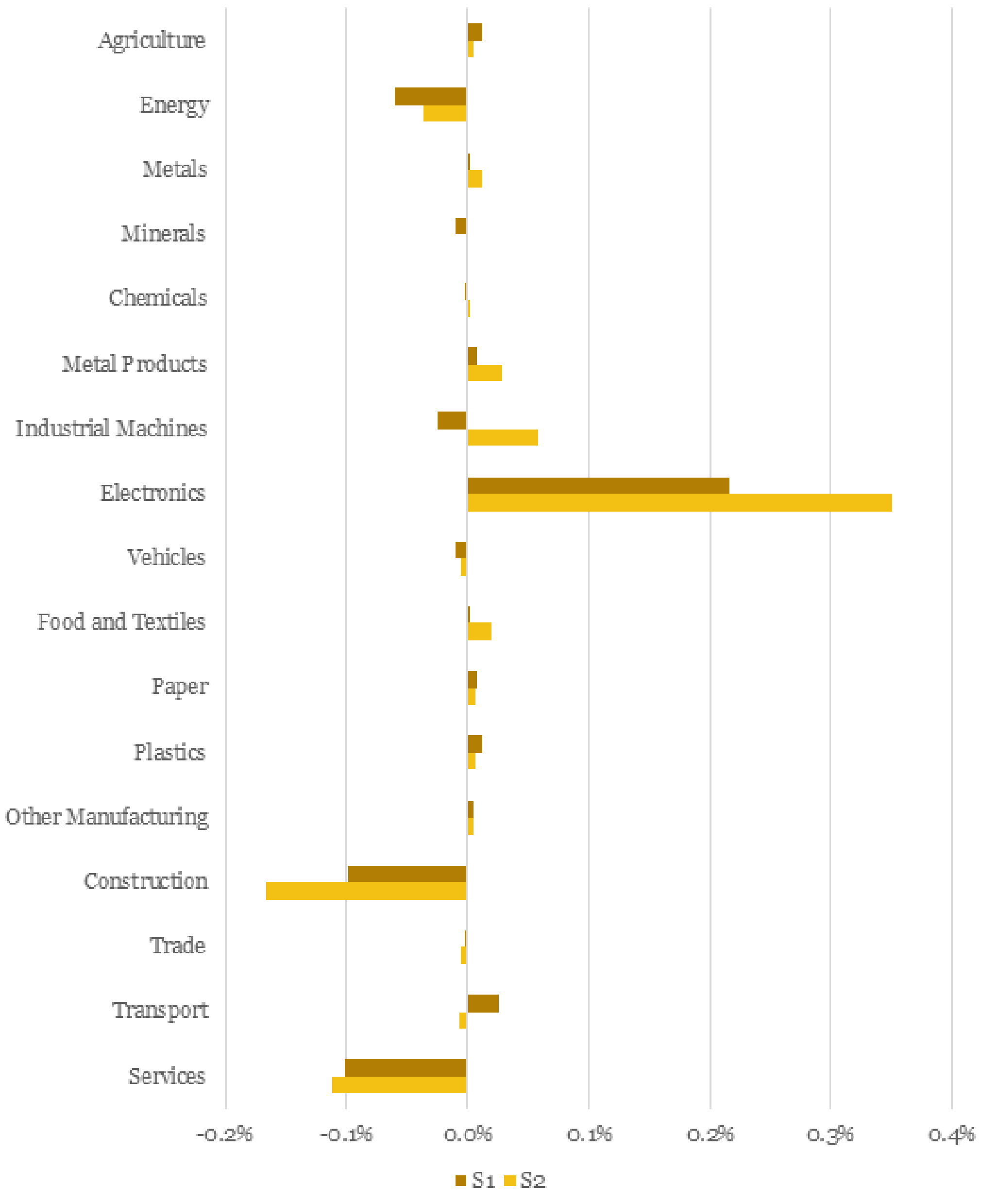

Figure 5: Relative sectoral FTE employment changes in the EU 28 for the S1 and the S2 scenario in 2030

The difference between the GDP and employment effects is mainly due to shifts between economic sectors with different labour productivities. The S1 and S2 scenarios represent a strategy in which energy is substituted for by capital (investment into energy efficient technologies), which temporarily have to be financed on the macroeconomic level by foregone consumption. As consumption is more strongly linked to service sectors than investment, the service sectors decline in importance. In general, the more manufacturing based sectors linked to the production of appliances and building technologies are more labour productive than service sectors. Thus, we see a trend that the employment results are somewhat less positive than the effects on GDP.

On a sectoral level, the results reflect the structure of the impulses. Figure 5 exemplarily illustrates the EU 28 change in employment per sector for both scenarios. The manufacturing sectors generally benefit from the investments in appliances and building technologies. The biggest gain in FTE employment relative to the baseline scenario is in the electronics sector with over 0.3 %. In contrast, the energy and minerals sectors (which also include fossil fuels) experience a small decline in employment relative to the baseline scenario. The employment effects are also negative in some service sectors, due to the negative impulse on final consumption in the case of higher investment costs than energy savings. Even though the construction sector benefits from a small fraction of the investment expenditures from thermal retrofits, the negative consumption impulse is also responsible for an overall negative effect in this sector. These negative effects are, however, comparatively small. The structure of changes to sectoral value added is similar to that of employment.

6.3 Distributive effects

In order to assess the macroeconomic effects with respect to their distribution among different socioeconomic groups, the effects on the disposable incomes per quintile are portrayed in Figure 6. All quintiles experience a small relative increase in disposable income of about the same magnitude (~0.04%) in both scenarios. Only quintile 2 (in both scenarios) and quintile 3 (in the policy-package scenario) display slightly higher gains in disposable income than the other quintiles. This indicates that the efficiency measures portrayed in the modelling do not appear to have negative redistributive effects.

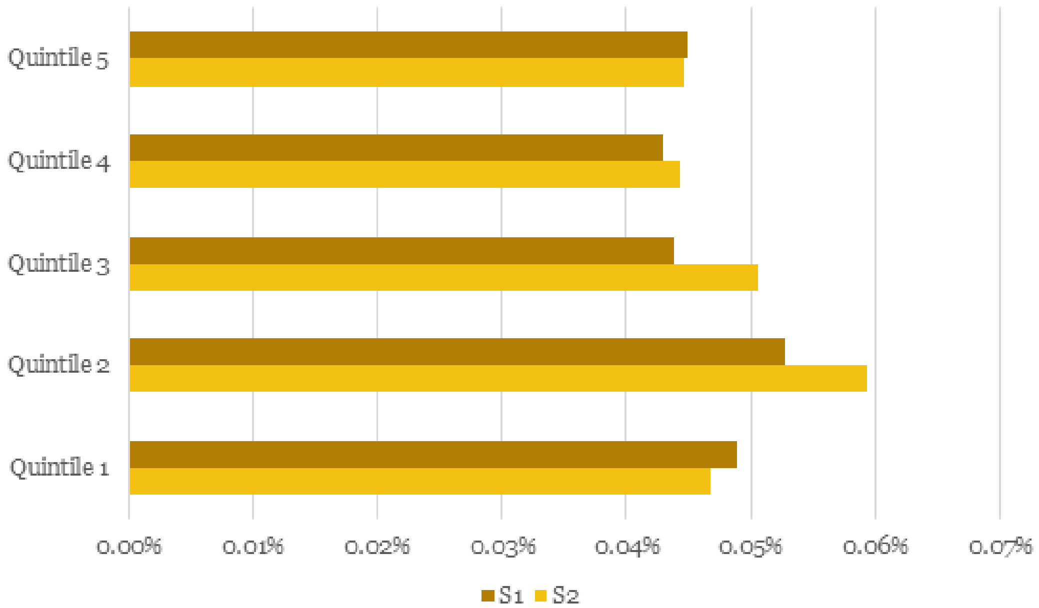

Figure 6: Relative changes to disposable incomes per quintile in the EU 28 for the S1 and the S2 scenario in 2030

The relatively equal distribution of the change in disposable incomes can be explained by two contrasting developments. On the one hand, the mostly indiscriminate allocation of rebates (in S1) and the higher propensity to invest in energy efficiency point towards more positive effects for higher quintiles. On the other hand, the structural shifts between economic sectors from the investment and compensatory consumption impulses (more manufacturing and less services) point towards more positive effects for lower quintiles. A more positive effect for the lower quintiles can be observed in S2, where appliance rebates only apply to low-income households. This increases the positive income effect especially for quintiles 2 and 3 relative to S1, as can be seen in Figure 6.

6.4 Discussion of results

It is difficult to quantitatively compare these results to the literature because the considered scenarios differ or may not be readily comparable since not all information is present. However, a rough comparison with the results of the other studies quoted in the introduction reveals some overall similarities but also some structural differences. Similar to these studies, we see positive economic impacts, which are partially driven by import substitution of energy carriers. However, the results in this study are considerably smaller than those in the literature. Differences are observable with regard to the sectoral composition. In the present analysis we see that some services are among the sectors losing employment. Due to the higher labour intensity of services, it is therefore not surprising to see that in our results – in contrast to some other studies – the employment impacts are less strong than the GDP impacts. Our assumption that crowding out effects are (temporarily) taking place contributes substantially to these differences.

There are various caveats which have to be taken into account in interpreting these results. First, the positive effects of energy costs reductions cannot fully be accounted for within the modelling time horizon, because they still accrue to households after the investments have been undertaken. Second, the results depend on the results of the energy demand modelling, and especially on the order of magnitude of investments in relation to energy cost reductions. Third, the results are influenced by our assumption that crowding out is taking place. This is a rather cautious, neoclassical assumption. If a Keynesian situation is assumed, in which underutilized capacity and idle capital can accommodate additional investments, the assumption of a crowding out of consumption by investment does not hold anymore. Under such assumptions, the additional investments lead to increases of final demand, which leads via multiplier effects to a higher increase in employment and GDP than in the present model results. Taken together, this means that the results should be interpreted as a constituting a lower boundary of possible macroeconomic effects.

7 Conclusions

The macroeconomic effects of the two analysed policy scenarios are very small compared to the overall economy of the EU 28. The small magnitude of effects is expectable since the sums of the impulses on the country level rarely surpass 0.5% of GDP. However, it could be shown that the investment in energy efficiency technologies and the associated energy savings can have moderate positive overall effects, reduce the reliance on energy imports and point towards structural shifts of the economy that does not have regressive effects.

Taken together, the macroeconomic impacts of the scenarios show characteristics of an investment process, which one the one hand strengthens manufacturing industries but comes at the cost of temporarily reduced aggregate consumption. At the same time, the fiscal position of households is strengthened through energy savings that extend beyond the investment period. In sum, it can be concluded that investments in energy efficiency will have at least moderate positive macroeconomic impacts for the EU.

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List of abbreviations

GDP	Gross Domestic Product
FTE	Full Time Equivalent
HVAC	Heating, Ventilation and Air Conditioning
ICT	Information and Communication Technologies
IO	Input-Output
NUTS	Nomenclature of Territorial Units for Statistics
NACE	European sector classification: Nomenclature generale des Activites Economiques dans les Communautes Europeennes
NACE-CLIO	Is the branch of NACE 1970 used for the compilation of input-output tables

Appendix A Description of the ASTRA-EC model

1.1 The modelling approach

The ASTRA-EC-EC model is based on System Dynamics methodology. System Dynamics does not focus on the analysis of specific fields like economy or transport, but is a general methodology that can be applied to any kind of system meeting some basic conditions. In brief, a System Dynamics model consists of a set of hypotheses on the relationship between causes and resulting effects. Hypotheses may be based on theory or only informed by theory, but empirical inputs from statistics, surveys or other observations may also be used.

Relationships are represented by equations that are written and solved by mathematical simulation. In other words, a System Dynamic model does not have a specific set of unknown parameters or variables whose value is estimated as a solution of the model. Instead, most of the model variables change dynamically over time as an effect of the interaction of positive or negative feedback loops. This can be considered as the most important characteristics of any complex systems. System Dynamics models consist of three main types of variables: level, flow and auxiliary variables. The state of a variable is mainly calculated within level variables changed over time by inflows and outflows that are driven by auxiliary variables. Mathematically, level variables are solved with differential equations. Since the solution of a system with a set of level variables is too complex, an approximation is applied by solving only the related difference equations. Nevertheless, the mathematical calculations in a large scale System Dynamics model like ASTRA-EC-EC are challenging and demanding on the computational equipment.

As opposed to computed general equilibrium models, reaching a steady state or equilibrium in each stage of the simulation is not foreseen in System Dynamics models. Dedicated software allows the development of System Dynamics models concentrating on the causal relationships by means of intuitive graphical interfaces.

The ASTRA-EC-EC model is therefore focused on the investigation of functional cause-and-effect relationships between the systems represented (transport, economy, environment) and connected through several feedback loops. The model is developed using Vensim® software.

1.2 Overview of the model structure

The model covers the time period from 1995 until 2050. Results in terms of main indicators are available on a yearly basis via a user interface. Geographically, ASTRA-EC-EC covers all EU28 member states plus Norway and Switzerland.

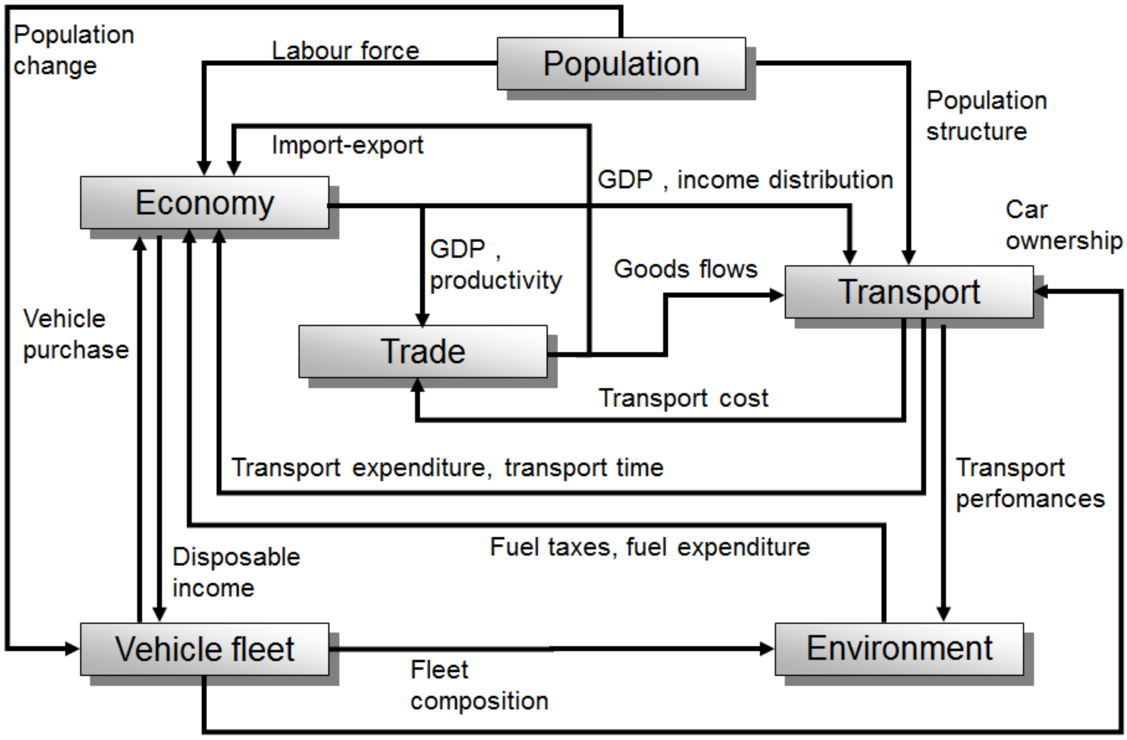
ASTRA-EC-EC consists of different modules, each related to one specific aspect, such as the economy, the transport demand, the vehicle fleet. The main modules cover the following aspects:

- Population and social structure (household types and income groups).
- Economy (including input-output tables, government, employment and investment).
- Foreign trade.
- Transport (including demand estimation, modal split, transport cost and infrastructure networks)
- Vehicle fleet (road).
- Environment (including pollutant emissions, CO_2 emissions, fuel consumption).

A key feature of ASTRA-EC-EC as an integrated assessment model is that the modules are linked together. Changes in one system are thus transmitted to other systems and can feed back to the original source of variation. For instance, changes in the economic system immediately feed into changes of the transport behaviour and alter origins, destinations and volumes of European transport flows. In turn, via some micro-macro bridges (see below), the changes in the transport system feed back into the economic system e.g. adapting the consumption behaviour of households or the sectoral interchange of intermediate goods and services.

Since all modules are part of the same dynamic structure, the whole model is simulated simultaneously. The most appealing consequence is that there is no need of iterations to align the results of the various modules. All parts of the model are always consistent to each other throughout the whole simulation.

An overview on the modules and their main linkages is presented in Figure 7.



Source: TRT - Fraunhofer-ISI

Figure 7: Overview of the linkages between the modules in ASTRA-EC

1.3 Geographical scope and zoning system

Different levels of spatial categorizations are applied in parallel in ASTRA-EC-EC:

- The first categorization is based on the country level spatial differentiation, applied in all the modules of the model;
- The second categorization is founded on the NUTS I zones level, which is applied in the transport module to represent national trips;
- The third categorization is built on the NUTS II zones level, applied in the transport modules (for trips generation) as well as for population;

Further differentiation within NUTS II zones is provided in some modules like e.g. the transport module. Finally, for intercontinental trade and transport demand an aggregated zoning system is applied to non-European areas, including the following world regions: Arab-African Oil Exporters, Asian Oil Exporters, Brazil, China, East Asia, India, Japan, Latin America, North America, Oceania, Russia, South-Africa, South-Asia, Turkey, Rest-of-the-World.

At the European level, each country is treated separately in the model, resulting in a total of 30 states. The specific application of spatial categories in the modules of ASTRA-EC-EC is shown in the following table.

Table 0-5: Summary of spatial categorizations used in different modules of ASTRA-EC

Spatial category	**Population**	**Macro-economic**	**Trade**	**Transport**	**Vehicle fleet**	**Environment**
Country	X	X	X	X	X	X
NUTS I	X			X		
NUTS II	X			X		
Urban context				X		
World regions			X	X		

Source: TRT / Fraunhofer-ISI

As highlighted in the table above, the transport module includes the most detailed level of spatial categorization, while in the other modules (except the population module) the variables are mainly defined at country level.

It would be desirable that the same level of spatial detail is available also for the other modules, but this is not feasible within a System Dynamics model calculating each variable for every time step from 1995 to 2050. When NUTS I and NUTS II level is used to describe transport demand, the size of the model becomes already quite big. Using the same detail throughout the model would lead to unsustainable computational problems due to the overall model size.

Therefore, the implementation of more detailed spatial categorizations only in the transport module results from a balanced judgment of factors: model requirements, soft- and hardware capabilities, and data availability. Outside the transport module, the NUTS level is used only for selected socio-economic indicators.

1.4 Sectoral differentiation

Sectoral disaggregation in ASTRA-EC-EC is based on the concept of *NACE-CLIO* sectoral coding system where NACE stands for the general industrial classification of economic activities within the European communities and CLIO for Classification and nomenclature of input-output. Both are used Eurostat statistics, though the CLIO system is especially designed to generate harmonised input-output tables for the EU25 countries since each country used its own national system e.g. in Germany with 59 sectors or in the United Kingdom with 102 sectors.

Table 0-6: Differentiation into 25 economic sectors in ASTRA-EC

Nr.	IOSector	TradeSector
1	Agriculture	T Agriculture
2	Energy	T Energy
3	Metals	T Metals
4	Minerals	T Minerals
5	Chemicals	T Chemicals
6	Metal Products	T Metal Products
7	Industrial Machines	T Industrial Machines
8	Computers	T Computers
9	Electronics	T Electronics
10	Vehicles	T Vehicles
11	Food	T Food
12	Textiles	T Textiles
13	Paper	T Paper
14	Plastics	T Plastics
15	Other Manufacturing	T Other Manufacturing
16	Construction	not included
17	Trade	T Other Services
18	Catering	T Other Services
19	Transport Inland	T Transport Services
20	Transport Air Maritime	T Transport Services
21	Transport Auxiliary	T Transport Services
22	Communication	T Other Services
23	Banking	T Other Services
24	Other Market Services	T Other Services
25	Non Market Services	T Other Services

Source: Fraunhofer-ISI

The NACE system corresponds to international classifications like *ISIC* (International Standard Industrial Classification), such that also data following these categorisations could be used, and is available as NACE with 17, 25 or 44 sectors. Three main reasons suggest using the NACE-CLIO version with 25 sectors (see following table): firstly, in ASTRA-EC-EC the use of harmonised input-output tables for the EU27+2 countries is of significant importance to reflect the economic interactions that are induced in all sectors of the national economies by influences of policies in those sectors that are directly related to transport demand. Eurostat provides such tables for most of the EU27 countries plus Norway and Switzerland for 1995. Values for 1995 are required as the sectoral interweavement is initiated by data. Input output tables of upcoming years are endogenously calculated based on changing final use. They are not calibrated against input output tables of following years. Secondly, the split into 25 sectors offers five sectors that are directly related to transport demand changes and that would be affected by transport policies. These sectors are sector 2 Refined petroleum products and Electric power, gas, etc. influenced by private expenditures for fuel; sector 10 Transport Equipment affected by private car purchase and investments in any other kind of vehicles; sector 16 Building and Construction driven among others by investments in transport facilities (e.g. container terminals or stations) and transport networks; sector 19 Inland Transport Services influenced by expenditures for bus, rail, road freight transport and inland waterway transport; sector 20 Maritime and Air Transport Services affected by ocean ship transport and air transport. Thirdly, among the 25 sectors are already 9 service sectors which enable the model to take account of the ever increasing importance of services for the European economies. A conversion table from the NACE Revision 2 classification of economic sectors (65 sectors) to the NACE-CLIO version called IOSector (25 sectors) is provided below.

Table 0-7: Conversion factors from NACE Rev. 2 CPA 65 classification to ASTRA-EC NACE-CLIO 25 classification

NACE Rev.2	**Sector Name**	**IOSector**	**Conversion**
A_01	Products of agriculture, hunting and related services	Agriculture	1
A_02	Products of forestry, logging and related services	Agriculture	1
A_03	Fish and other fishing products; aquaculture products; support services to fishing	Agriculture	1
B	Mining and quarrying	Metals	0.43
B	Mining and quarrying	Minerals	0.21
B	Mining and quarrying	Energy	0.36
C_10-12	Food products. beverages and tobacco products	Food	0.9
C_10-12	Food products. beverages and tobacco products	Other Manufacturing	0.1
C_13-15	Textiles. wearing apparel and leather products	Textiles	1
C_16	Wood and of products of wood and cork. except furniture; articles of straw and plaiting materials	Other Manufacturing	1
C_17	Paper and paper products	Paper	1
C_18	Printing and recording services	Paper	0.5
C_18	Printing and recording services	Other Manufacturing	0.5
C_19	Coke and refined petroleum products	Energy	1
C_20	Chemicals and chemical products	Chemicals	1
C_21	Basic pharmaceutical products and pharmaceutical preparations	Chemicals	1
C_22	Rubber and plastics products	Plastics	1
C_23	Other non-metallic mineral products	Minerals	1
C_24	Basic metals	Metals	1
C_25	Fabricated metal products. except machinery and equipment	Metal_ Products	1
C_26	Computer. electronic and optical products	Computers	1
C_27	Electrical equipment	Electronics	1
C_28	Machinery and equipment n.e.c.	Industrial Machines	1

C_29	Motor vehicles, trailers and semi-trailers	Vehicles	1
C_30	Other transport equipment	Vehicles	1
C_31-32	Furniture; other manufactured goods	Other_ Manufacturing	1
C_33	Repair and installation services of machinery and equipment	Trade	1
D	Electricity, gas, steam and air-conditioning	Energy	1
E_36-37	Natural water; water treatment and supply services	Energy	1
E_38-39	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services	Non Market Services	1
F	Constructions and construction works	Construction	1
G_45	Wholesale and retail trade and repair services of motor vehicles and motorcycles	Trade	1
G_46	Wholesale trade services, except of motor vehicles and motorcycles	Trade	1
G_47	Retail trade services, except of motor vehicles and motorcycles	Trade	1
H_49	Land transport services and transport services via pipelines	Transport Inland	1
H_50	Water transport services	Transport Air Maritime	1
H_51	Air transport services	Transport Air Maritime	1
H_52	Warehousing and support services for transportation	Transport Auxiliary	1
H_53	Postal and courier services	Communication	1
I	Accommodation and food services	Catering	1
J_58	Publishing services	Other Market Services	1
J_59	Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	Other Market Services	1
J_60	Telecommunications services	Other Market Services	1
J_62-63	Computer programming, consultancy and related services; information services	Other Market Services	1
K_64	Financial services, except insurance and pension funding	Banking	1
K_65	Insurance, reinsurance and pension funding services, except compulsory social security	Banking	1
K_66	Services auxiliary to financial services and insurance services	Banking	1
L	Real estate services	Other Market Services	1
L_68	Of which: imputed rents of owner-occupied dwellings	Other Market Services	1

M_69-70	Legal and accounting services; services of head offices; management consulting services	Other Market Services	1
M_71	Architectural and engineering services; technical testing and analysis services	Other Market Services	1
M_72	Scientific research and development services	Other Market Services	1
M_73	Advertising and market research services	Other Market Services	1
M_74-75	Other professional, scientific and technical services; veterinary services	Other Market Services	1
N_77	Rental and leasing services	Other Market Services	1
N_78	Employment services	Other Market Services	1
N_79	Travel agency, tour operator and other reservation services and related services	Catering	1
N_80-82	Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	Other Market Services	1
O	Public administration and defence services; compulsory social security services	Non Market Services	1
P	Education services	Non Market Services	0.8
P	Education services	Other Market Services	0.2
Q_86-87	Human health services	Non Market Services	0.8
Q_86-87	Human health services	Other Market Services	0.2
Q_88	Social work services	Non Market Services	1
R_90-91	Creative. arts and entertainment services; library, archive, museum and other cultural services; gambling and betting services	Non Market Services	0.1
R_90-91	Creative arts and entertainment services; library, archive, museum and other cultural services; gambling and betting services	Other Market Services	0.9
R_92-93	Sporting services and amusement and recreation services	Other Market Services	1
S_94	Services furnished by membership organisations	Non Market Services	1
S_95	Repair services of computers and personal and household goods	Other Market Services	1
S_96	Other personal services	Other Market Services	1
T	Services of households as employers; undifferentiated goods and services produced by households for own use	Other Market Services	1
U	Services provided by extraterritorial organisations and bodies	Other Market Services	1

Source: Fraunhofer-ISI