Model Simulations of Resource Use Scenarios for Europe

Deliverable No. 5

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Abstract

This paper describes the introduction of biophysical constraints into a disaggregated dynamic New Keynesian (DYNK) model using the example of different resource use scenarios for Europe, derived from global UNEP scenarios. The DYNK model covers 59 industries and five income groups of households and has similar features to a DSGE model (e.g. QUEST). The model solution converges towards a long-run full employment equilibrium, but exhibits short-run institutional rigidities (imperfect credit and capital markets, wage bargaining). The DYNK model links physical energy and material flow data to production and consumption activities. Different sources of technical change are modelled at the disaggregate level: TFP, factor-bias and material efficiency in production and energy efficiency in private consumption. These components of technical change drive – together with relative prices – economic growth and resource use and therefore decoupling. A scenario of modest resource use reduction (per capita) is implemented by shifting the bias of technological change from labour/capital saving to energy/resource saving. As one example for a scenario of radical reduction of resource use per capita, the radical reduction of energy demand and GHG emissions is analysed. The results show the various interlinkages between different categories of material flows, which lead to co-benefits of policies. Further policy options are discussed (re-use and recycling of material in key industries, structural change in agriculture) and shall be analysed in a follow-up of this paper.

Key words:

Decoupling of resource use, technological and structural change, policy simulation

JEL codes:

Q32, Q55, C54

Introduction

Global, long-term economic growth is restricted by the availability of natural resources as well as planetary boundaries (Rockström, et al., 2009) which act as biophysical constraints. The surge in international raw material and energy prices between 2000 and 2007 can be seen as one potential indicator of the effectiveness of these boundaries. The European Commission (DG Energy) publishes energy and greenhouse gases (GHG) emission scenarios on a regular base as an input to formulating the roadmap for a low carbon economy (European Commission, 2011a). Within the WWWforEurope project, Fischer-Kowalski, et al. (2013) have analysed policy targets on resource use at the global and European levels, as well as UNEP global resource scenarios, in order to derive different European resource scenarios. These scenarios can be seen as the most recent scenario work on resources for the EU 27, which exhibit the additional advantage of being well integrated into the global scenario framework (UNEP). The linkage of this scenario work to the DYNK model used in the WWWforEurope project is based on common trends in both frameworks of analysis, driven by income growth and population density, and defined by common resource indicators, such as per capita DMC (domestic material consumption). Therefore, the resource scenarios which comprise different trend scenarios on the saturation of resource use in Europe as well as one 'radical transformation scenario' shall be modelled in a DYNK (Dynamic New Keynesian) model for the EU 27. In this paper, two exemplary simulations are provided and the full analysis of resource scenarios for the EU 27 will be provided in a follow-up of this paper. Additionally, policy implications for other economic and social targets (employment, income distribution), which are core issues of the WWWforEurope project, shall also be dealt with in the continuation of this paper. The definition of resources in the DYNK model is based on the standard categories of Material Flow Analysis (MFA), as contained in the Environmental Accounts of the WIOD database (http://www.wiod.org/new_site/database/eas.htm).

The DYNK model describes the inter-linkages between 59 industries as well as the consumption of five household income groups using 47 consumption categories. The model is closed by endogenizing parts of public expenditure in order to meet the mid-term stability programme for public finances in the EU 27.

Satellite systems of physical data of energy and resource use are fully integrated in the DYNK model. The link between monetary and physical data is established at the disaggregated level of single commodities (for monetary data) and energy and material flow categories (for physical data). The model explicitly deals with prices of energy categories and import prices of primary products. The price system of the DYNK model also incorporates consumption taxes (taxes less subsidies) and taxes on factors of production. These model features allow for the implementation of environmental tax policies as one instrument to reduce resource use per unit of output.

From Fischer-Kowalski, et al. (2013) the 'trend scenario', the 'best practice scenario' and the 'radical transformation scenario' are taken as inputs in the model simulations. The scenarios are described by certain values of material flow indicators that are achieved for Europe in the long run. The 'trend' scenario describes the continuation of past and current trends, the 'benchmark case' scenario is oriented along the lines of the experience of some high-income countries, and the 'radical transformation' scenario defines reductions of resource use in Europe that are required for a globally sustainable and egalitarian path of resource use. Some factors of these scenarios in terms of general and specific policy instruments that determine the results are implemented in the structure of the DYNK model. The simulations presented in this paper have exemplary character and serve as an empirical demonstration of the integration of biophysical constraints into the DYNK model. More detailed policy simulations with the model aiming at resource use reduction in Europe and accompanying policies for other economic and social targets will be analysed in a follow-up of this paper.

For the 'best practice scenario' this policy is made up by a shift of the technological bias in all material and energy intensive industries from labour and capital saving towards energy and material saving. For the 'radical transformation scenario' a menu of policy options is applied. The starting point is a radical reduction of CO_2 emissions energy use that is consistent with the 80% emission reduction target until 2050 from the EU Roadmap, brought about by carbon prices and technological change in power generation. This partial reduction of resource inputs also leads to a considerable decrease in other material flows, as the DYNK model describes the many inter-linkages between different material flow categories. In the follow-up of this paper, this general policy shall be complemented by specific policies like increasing the input of recycling material in industrial processes and in construction (which in turn reduces energy inputs) and reducing the material intensity in agriculture, driven by diet shifts.

The paper is organized as follows. The first section describes the different blocks of the model: household behaviour, firm behaviour and the production structure, the labour market, the government sector including model closure and the environmental features. The second part briefly describes data, calibration and core parameters of the model. In section 3 the inputs for and results of two exemplary simulations of resource scenarios are derived. Further policy options for future model simulations are also briefly discussed. Finally, section 4 presents summary and outlook of work.

1. The model

The DYNK model approach bears some similarities with DSGE (Dynamic Stochastic General Equilibrium) models like QUEST (Roeger, in't Veld 2002), as it explicitly describes an adjustment path towards a long-term equilibrium. This feature of dynamic adjustment towards equilibrium is most developed in the consumption block and in the macroeconomic closure via a fixed short- and long-term path for the public deficit. The term 'New Keynesian' refers to the existence of a long-run full employment equilibrium, which will not be reached in the short run, due to institutional rigidities. These rigidities include liquidity constraints for consumers (deviation from the permanent income hypothesis), wage bargaining (deviation from the competitive labour market) and an imperfect capital market. Depending on the magnitude of the distance to the long-run equilibrium, the reaction of macro-economic aggregates to policy shocks can differ substantially.

The DYNK model is an input-output model in the sense that it is demand driven, as everything in demand is produced. The price block in the DYNK model is equally elaborated, as in a CGE model, with user-specific prices and a proper account of margins, taxes less subsidies, and import shares that are different for each user. A large part of the DYNK model has similar specifications to a dual CGE model, such as that presented in Conrad, Schmidt (1998) or Lofgren et al. (2002). The dual model is based on price and cost functions instead of production functions and therefore these models are in a certain sense also 'demand driven', especially if constant returns to scale do not allow for price setting on the supply side. In the DYNK model, the treatment of demand is elaborated in greater detail. This captures consumption, investment and exports (i.e. the main categories of final demand), which are endogenous, explained by consumer behavior (demand system), import demand functions (differentiated by intermediate and final use) and producer behavior (K,L,E,M model with M split up into domestic and imported). Therefore, the aggregates of the column of IO coefficients (total intermediates, energy goods, value added components) are endogenous and explained in the K,L,E,M model, whereas in the IO price model they are taken as exogenous. The growth of total factor productivity (TFP) is the most important long-term supply side force in the DYNK model.

Physical satellite accounts data for energy and GHG emissions as well as for material flows are linked to the monetary flows of the IO structure of the model. For energy a two nest-function is applied, with the K,L,E,M aggregate as the first nest, where the demand for aggregate energy (E) is determined and the E aggregate as the second nest, where the demand for coal, oil, gas, renewables, and the electricity/heat bundle is determined. The monetary demand for these five fuels is split up into detailed physical energy data, from which GHG emissions are derived. Physical data for material flows are linked to the output of primary sectors (domestic extraction) and to monetary imports and exports (domestic consumption).

Therefore, the DYNK model is – due to its detailed modelling structure of consumption and production activities – well suited for the analysis of the driving forces of resource use in the European economy. One main shortcoming is that technical progress is only partly modelled on a detailed level or as induced or endogenous, so that policies can only indirectly be applied (by using some other partial analytical models) in order to influence technical progress in a resource saving direction. One promising alternative to adding these features to the DYNK model consists of linking the model to partial analytical models (for example of the energy system) with detailed modelling of technology.

Macroeconomic closure of the DYNK model mainly works by fixing the public sector balance. Savings in the economy (domestic plus external) are not fixed by a fixed current account balance, but are determined in the buffer stock model of consumption, taking into account the wealth position of households. The public sector takes into account mid-term fiscal stabilization targets (for public net lending and public debt as percentage of GDP). The public sector budget constraint is applied by endogenizing public consumption, given the target path of net lending as a percentage of GDP.

1.1 Household behaviour and private consumption

The consumption decision of households in the DYNK model is modelled along the lines of the 'buffer stock model' of consumption (Carroll, 1997), including the consumption of durables and nondurables (Luengo-Prado, 2006). Consumers maximize the present discounted value of expected utility from the consumption of nondurable commodity and from the service provided by the stocks of durable commodity. The budget constraint in this model – without adjustment costs for the durables stock – contains income, assets and durable stock. This latter aspect differentiates this model from the traditional dynamic optimization models of consumption. The derivation of disposable household income takes into account that profit income is a consequence of past savings decisions as well as all the interactions between households and the public sector (taxes and transfers). For policy analysis, unemployment benefit transfers are dealt with separately. The following taxes are charged on household income: social security contributions, which can be further decomposed into an employee's and an employer's tax rate and income taxes. The wage income of households is determined by total hours demanded by firms and wage bargaining between firms and unions over the employee's gross wage and hours worked.

Financial assets of households are built up by saving after durable purchasing has been financed. Part of the durable stock needs to be held as equity. The consideration of this collateralized constraint is operationalized in a down payment requirement parameter, which represents the fraction of durables purchases that a household is not allowed to finance.

Luengo-Prado (2006) has shown that, though the model has no analytical solution, it can be used to derive policy functions for nondurable and durable consumption and formulate both as functions of the difference between cash on hand (the household's total resources) and the equity that the consumer wants to hold in the next period. The long-run path of consumption growth in this model is, as in the original version of the 'buffer stock model' (Carroll, 1997), described by an equilibrium relationship between voluntary equity and permanent income. The equity that needs to be held to finance durables develops in line with durable demand. For durables the equilibrium is described by a maximum durable stock by households, so that when this level is achieved, nondurables are consumed or voluntary equity is built up. This property of durables demand is described by a non-linear consumption function for durables, similar to the function described in Luengo-Prado and Sørensen (2004) for nondurables. Therefore, with higher levels of durables per household, the marginal propensity of investment in durables with respect to cash on hand decreases.

The demand function for total nondurable consumption is modelled with a positive marginal propensity of nondurable consumption to 'cash on hand' and a negative marginal propensity of total nondurable consumption to the product of the down payment (in percentage of durables) and durable demand.

The energy demand of households comprises fuel for transport, electricity and heating. These demands are part of total nondurable consumption and are modelled in single equations, therefore assuming separability from non-energy, nondurable consumption. According to the literature on the rebound effect (e.g.: Khazzoom, 1989), the energy demand is modelled as (nominal) service demand and the service aspect is taken into account by dealing with service prices. The durable stock of households (vehicles, own houses, appliances) embodies the efficiency of converting an energy flow into a service level linked by the efficiency parameter of converting the corresponding fuel into a certain service. For a given conversion efficiency, a service price can be derived, which is a function of the energy price and the efficiency parameter. Any increase in efficiency leads to a decrease in the service price and therefore to an increase in service demand ('rebound effect').

The non-energy demand of nondurables is treated in a demand system. The one applied in this DYNK model is the Almost Ideal Demand System (AIDS), see: Deaton and Muellbauer, (1980). The AIDS model is represented by budget share equations for the i nondurable goods in each period.

The commodity classification $i = 1...n$ in this model comprises the n non-energy nondurables:

(i) food, beverages and tobacco, (ii) clothing and footwear, (iii) furniture and household equipment, (iv) health, (v) communication, (vi) recreation and accomodation, (vii) financial services, and (viii) other commodities and services.

In three stages, the household model determines the demand for different categories of durables, energy demand and different categories of nondurables. The total consumption vector of categories of consumption in National Accounts (according to the COICOP classification) is transformed into a consumption vector by commodities of the input-output core in the DYNK model in purchaser prices by applying the consumption bridge matrix. After this conversion, in a first step, taxes less subsidies are subtracted in order to arrive at consumption vectors net of taxes. Tax policies which imply taxation of commodities (also environmental consumption taxes) can be implemented at this stage.

1.2 Firm behaviour and production structure

The production side in the DYNK model is analysed within the cost and factor demand function framework, i.e. the dual model, in a Translog specification. The representative producers in each industry all face a unit cost function with constant returns to scale that determines the output price (unit cost) for given input prices. The input quantities follow from the factor demand functions once all prices are determined. The Translog specification chosen in the DYNK model comprises different components of technological change. Autonomous technical change can be found for all input factors (i.e. the factor biases) and also as the driver of TFP (total factor productivity), measured by a linear and a quadratic component.

Substitution in a K,L,E,M^m,M^d model

The Translog model is set up with inputs of capital (K), labor (L), energy (E), imported (M^m) and domestic non-energy materials (M^d), and their corresponding input prices $p_K, p_L, p_E,$ p_{Mm} and p_{Md}. One part of total imports, the imports of intermediate goods, therefore is determined in a direct substitution process against all other factors of production. That covers processes of international outsourcing and relocation of industries, due to a rise in domestic factor prices, e.g. for labour and energy. Applying Shepard's Lemma yields the cost share equations in the Translog case, which in turn are used to derive the quantities of factor demand for (K), (L), (E), (M^m) and (M^d). For this production system the input prices can be viewed as exogenous. One part of the input prices is determined at national or global factor markets, which applies to the prices of (K), (L), and (E). The price of labour is determined at the labour market via wage functions by industry (see below). The price of capital is formulated as a simple static user cost price index with the following components: (i) the price of investment by industry, (ii) the smoothed interest rate, and (iii) the fixed depreciation rate. The financial market and monetary policy are not described in detail in the DYNK model, therefore the interest rate is assumed as exogenous and is approximated by the smoothed benchmark interest rate. The depreciation rate by industry is fixed (see below for data sources) and the price of investment by industry is endogenously derived from the price system in the DYNK model. The price of energy carriers is assumed to be determined at world markets for energy and is therefore treated as exogenous. Each industry faces a unit cost function for the price (p_Q) of output Q, with constant returns to scale

$$\log p_Q = \alpha_0 + \sum_i \alpha_i \log(p_i) + \frac{1}{2}\sum_i \gamma_{ii}\left(\log(p_i)\right)^2 + \sum_{i,j}\gamma_{ij}\log(p_i)\log(p_j) + \alpha_t t + \frac{1}{2}\alpha_{tt}t^2 + \sum_i \rho_{ti} t \log(p_i) \quad (1)$$

, where p_Q is the output price (unit cost), p_i, p_j are the input prices for input quantities x_i, x_j, and t is the deterministic time trend. This specification comprises different components of technological change. Autonomous technical change can be found for all input factors (i.e. the factor biases, ρ_{ti}). Another source of autonomous technical change that only influences unit costs is TFP, measured by α_t, and α_{tt}.

The Translog model is set up with inputs of capital (K), labor (L), energy (E), imported (M^m) and domestic non-energy materials (M^d), and their corresponding input prices p_K, p_L, p_E, p_{Mm} and p_{Md}. As is well known, Shepard's Lemma yields the cost share equations in the Translog case, which in the case of five inputs can be written as:

$$\begin{aligned}
v_K &= \left[\alpha_K + \gamma_{KK}\log(p_K/p_{Md}) + \gamma_{KL}\log(p_L/p_{Md}) + \gamma_{KE}\log(p_E/p_{Md}) + \gamma_{KM}\log(p_{Mm}/p_{Md}) + \rho_{tK}t\right]\\
v_L &= \left[\alpha_L + \gamma_{LL}\log(p_L/p_{Md}) + \gamma_{KL}\log(p_K/p_{Md}) + \gamma_{LE}\log(p_E/p_{Md}) + \gamma_{LM}\log(p_{Mm}/p_{Md}) + \rho_{tL}t\right]\\
v_E &= \left[\alpha_E + \gamma_{EE}\log(p_E/p_{Md}) + \gamma_{KE}\log(p_K/p_{Md}) + \gamma_{LE}\log(p_L/p_{Md}) + \gamma_{EM}\log(p_{Mm}/p_{Md}) + \rho_{tE}t\right]\\
v_M &= \left[\alpha_M + \gamma_{MM}\log(p_{Mm}/p_{Md}) + \gamma_{KM}\log(p_K/p_{Md}) + \gamma_{LM}\log(p_L/p_{Md}) + \gamma_{EM}\log(p_E/p_{Md}) + \rho_{tM}t\right]
\end{aligned} \quad (2)$$

The homogeneity restriction for the price parameters $\sum_i \gamma_{ij}$ = 0, $\sum_j \gamma_{ij}$ = 0 has already been imposed in (2), so that the terms for the price of domestic intermediates p_{Md} have been omitted. The immediate reaction to price changes is given by the own and cross-price elasticities. These own and cross-price elasticities for changes in input quantity x_i are given as:

$$\varepsilon_{ii} = \frac{\partial \log x_i}{\partial \log p_i} = \frac{v_i^2 - v_i + \gamma_{ii}}{v_i} \tag{3}$$

$$\varepsilon_{ij} = \frac{\partial \log x_i}{\partial \log p_j} = \frac{v_i v_j + \gamma_{ij}}{v_i} \tag{4}$$

Here, the v_i represent the factor shares in equation (2), and the γ_{ij} the cross-price parameters.

The deterministic trend t captures the two different sources of autonomous technological change that together influence factor demand, i.e. TFP and factor bias. The rate of total technical change in time t for factor x_i is given by:

$$\frac{d \log x_i}{dt} = \rho_{ti} \left[\log p_i + \alpha_t + \alpha_{tt} t + \frac{p_{Q,t}}{v_i} \right] \tag{5}$$

This term in brackets is negative if the negative TFP term (α_t + $\alpha_{tt}t$) compensates for the other two variables. If this is the case, then a negative parameter for the bias of technical change (ρ_{ti}) leads to the result of a factor using rate of technical change. The TFP rate of technical change on output prices (i.e. on income at constant prices) is given as:

$$\frac{\partial \log p_Q}{\partial t} = \alpha_t + \alpha_{tt} t \tag{6}$$

For positive TFP growth, this term is negative and increasing or decreasing over time, depending on the second order parameter α_{tt}. The rate of technical change for factor x_i without accounting for TFP growth is given by the impact of the bias and equals $\rho_{ti} \left[\log p_i + \frac{p_{Q,t}}{v_i} \right]$. It therefore is factor saving, if the parameter for the bias of technical change (ρ_{ti}) is negative.

The factor shares v_i in (2) can be directly used to derive factor demand (in nominal terms), once the output at current prices $p_Q Q$ is given. For given input prices p_L, p_E, p_{Mm} and p_{Md} this can be transformed into factor demand in real terms (hours worked or employees for L and physical energy units for E). A special treatment is applied to the capital input. This is due to the inherent difference between the *ex post* rate of return to K that is implicit in treating operating surplus as the residual in total output and the *ex ante* rate of return to K used for the specification of the price of K (user cost). An equation links both prices and defines the adjustment of the *ex post* rate of return to K towards the *ex ante* rate of return to K which takes time. Once the *ex post* p_K is determined, the factor share for K in (2) can be used to determine K_{jt} by industry (j), which in turn determines investment by industry.

Intermediate input demand and factor prices

The factors E, M^m, and M^d are aggregates of the use matrix from the supply and use table system, which is the framework of this DYNK model. The domestic as well as the import matrix are converted into the 'use structure matrices' $\mathbf{S}_{\mathrm{NE}}^{\mathrm{m}}$ and $\mathbf{S}_{\mathrm{NE}}^{\mathrm{d}}$ through dividing by the column sum of total domestic (M^d) and imported non-energy intermediates (M^m), respectively. Intermediate inputs by commodity are determined by multiplying diagonal matrices of the factor shares in (2), $\hat{\mathbf{V}}_{\mathrm{D}}$ and $\hat{\mathbf{V}}_{\mathrm{M}}$ with the 'use structure matrices' and with the column vector of output in current prices. The full domestic commodity balance for non-energy commodities is given by adding the column vector of domestic consumption, capital formation by domestic goods, and other domestic final demand (exports $\mathbf{ex}^{\mathrm{d}}$, changes in stocks $\mathbf{st}^{\mathrm{d}}$ and public consumption $\mathbf{cg}^{\mathrm{d}}$). The (column vector) of the domestic output of commodities in current prices, $\mathbf{p}^{\mathrm{d}}\mathbf{q}^{\mathrm{d}}$, is transformed into the (column vector) of output in current prices, $\mathbf{p}_{\mathrm{Q}}\mathbf{q}$, by applying the market shares matrix, $\mathbf{C}$ (industries * commodities) with column sum equal to one:

$$\mathbf{p}^{\mathrm{d}}\mathbf{q}^{\mathrm{d}} = \left[\hat{\mathbf{V}}_{\mathrm{D}}\mathbf{S}_{\mathbf{NE}}^{\mathbf{d}}\right]\mathbf{p}_{\mathrm{Q}}\mathbf{q} + \mathbf{c}^{\mathrm{d}} + \mathbf{cf}^{\mathrm{d}} + \mathbf{ex}^{\mathrm{d}} + \mathbf{st}^{\mathrm{d}} + \mathbf{cg}^{\mathrm{d}} \tag{7}$$

$$\mathbf{p}_{\mathrm{Q}}\mathbf{q} = \mathbf{C}\left[\mathbf{p}^{\mathbf{d}}\mathbf{q}^{\mathrm{d}}\right] \tag{8}$$

The final demand categories in (7), i.e. $\mathbf{c}^{\mathrm{d}}$, $\mathbf{cf}^{\mathrm{d}}$, $\mathbf{ex}^{\mathrm{d}}$, $\mathbf{st}^{\mathrm{d}}$ and $\mathbf{cg}^{\mathrm{d}}$ are all in current prices.

The balance for non-energy imports is given by summing up over all imports. The intermediate imports are defined by the product of the factor share matrix $\hat{\mathbf{V}}_{\mathrm{M}}$ with the corresponding use structure matrix for imports plus imported final demand. The split of total final demand ($\mathbf{c}$, $\mathbf{cf}$, $\mathbf{ex}$, $\mathbf{st}$ and $\mathbf{cg}$) between domestic and imported products is in the existing version of the DYNK model done by fixed import shares. This shall be further developed by applying an Armington function in the case of $\mathbf{c}$ and $\mathbf{ex}$.

$$\mathbf{p}^{\mathrm{m}}\mathbf{q}^{\mathrm{m}} = \left[\hat{\mathbf{V}}_{\mathrm{M}}\mathbf{S}_{\mathbf{NE}}^{\mathbf{m}}\right]\mathbf{p}_{\mathrm{Q}}\mathbf{q} + \mathbf{c}^{\mathrm{m}} + \mathbf{cf}^{\mathrm{m}} + \mathbf{ex}^{\mathrm{m}} + \mathbf{st}^{\mathrm{m}} + \mathbf{cg}^{\mathrm{m}} \tag{9}$$

Equation (7) and (9) describe the commodity balance for non-energy commodities. The same can be applied to energy commodities by using the factor share matrix $\hat{\mathbf{V}}_{\mathrm{E}}$ and splitting up total energy supply ($\mathbf{p}^{\mathrm{E}}\mathbf{q}^{\mathrm{E}}$) into domestic and imported commodities with fixed import shares for final as well as intermediate demand in a second step. Total energy supply is given by intermediate energy demand and final energy demand which comprises household demand ($\mathbf{c}^{\mathrm{E}}$), determined in the consumption model, as well as exports and stock changes. As in the case of non-energy commodities, a use structure matrix for energy ($\mathbf{S}_{\mathrm{E}}$) can be derived from the use table.

$$\mathbf{p}^{\mathrm{E}}\mathbf{q}^{\mathrm{E}} = \left[\hat{\mathbf{V}}_{\mathrm{E}}\mathbf{S}_{\mathrm{E}}\right]\mathbf{p}_{\mathrm{Q}}\mathbf{q} + \mathbf{c}^{\mathrm{E}} + \mathbf{ex}^{\mathrm{E}} + \mathbf{st}^{\mathrm{E}} \tag{10}$$

Factor prices are exogenous for the derivation of factor demand, but are endogenous in the system of supply and demand. Some factor prices are directly linked to the output prices p_Q which are determined in the same system. All user prices are the weighted sum of the domestic price p^d and the import price, p^m. The import price of commodity i in country s is given as the weighted sum of the commodity prices of the k sending countries ($p^{d,k}$)

$$p_{i,s}^{m} = \sum_{k=1}^{s-1} w_{mk,s} p^{d,k} \tag{11}$$

This is derived from an inter-regional input-output system from the WIOD database (see next section). This gives one domestic price per user for each commodity (i.e. no price differentiation for domestic goods) and different import prices per user for each commodity, given by the different country source structure of imports of the same commodity by user. Once this user specific prices for intermediate goods are given, the 'use structure matrices' ($\mathbf{S}_{\mathrm{NE}}^{\mathrm{m}}$ and $\mathbf{S}_{\mathrm{NE}}^{\mathrm{d}}$) can be applied in order to derive the price vectos $\mathbf{p}_{\mathrm{Mm}}$ and $\mathbf{p}_{\mathrm{Md}}$:

$$\mathbf{p}_{\mathrm{Mm}} = \mathbf{p}^{\mathrm{m}}\mathbf{S}_{\mathrm{NE}}^{\mathrm{m}} \qquad \mathbf{p}_{\mathrm{Md}} = \mathbf{p}^{\mathrm{d}}\mathbf{S}_{\mathrm{NE}}^{\mathrm{d}} \tag{12}$$

The price of capital is based on the user cost of capital: $u_K = p_{CF}(r+\delta)$ with p_{CF} as the price of investment goods an industry is buying, r as the deflated benchmark interest rate and δ as the aggregate depreciation rate of the capital stock K. The investment goods price p_{CF} can be defined as a function of the domestic commodity prices and import prices, given the input structures for investment, derived from the capital formation matrix for domestic and imported investment demand. The capital formation matrix contains the structure of commodities for each unit of investment of an industry and is split up into a domestic and an imported part by applying the import share of each commodity in the investment (commodity) vector of the use table.

$$\mathbf{p}_{\mathrm{CF}} = \mathbf{p}^{\mathrm{m}}\mathbf{B}_{\mathrm{K}}^{\mathrm{m}} + \mathbf{p}^{\mathrm{d}}\mathbf{B}_{\mathrm{K}}^{\mathrm{d}} \tag{13}$$

It is important to note that by these input-output loops in the model, indirect effects or feedback effects of prices occur and factor demand reactions therefore differ from what the *ceteris paribus* price and substitution elasticities indicate. All aggregate user prices (for example the price of private consumption) can further be aggregated in order to derive the aggregate price index of the corresponding demand aggregate.

Physical input demand

Physical input demand in the DYNK model comprises energy inputs in physical units (TJ) by user and energy category as well as material flows in physical units (1,000 t) for domestic extraction, imports and exports by material flow category.

The aggregate E comprises four energy industries/commodities, and M^m, M^d the other 55 non-energy industries/commodities. In a second nest, the factor E is split up into aggregate fuels i (coal, oil, gas, renewable, electricity/heat) in a Translog model. The unit cost function of this model determines the bundle price of energy, p_E , and the cost shares of the five aggregate fuels:

$$\log p_E = \alpha_0 + \sum_i \alpha_{E,i} \log(p_{E,i}) + \frac{1}{2}\sum_i \gamma_{E,ii} \left(\log(p_{E,i})\right)^2 + \sum_{i,j} \gamma_{E,ij} \log(p_i)\log(p_j) + \sum_i \rho_{tE,i} t \log(p_{E,i}) \quad (14)$$

$$v_{E,i} = \left[\alpha_{E,i} + \sum_{i,j} \gamma_{E,ij} \log(p_{E,i}) + \rho_{tE,i} t\right] \quad ; i = \text{coal, oil, gas, renewable, electricity/heat} \quad (15)$$

In analogy to (3) and (4), own and cross price elasticities between different fuels can be derived. The own price elasticities are on average around –0.3 and these elasticities as well as the fuel bias of technical change, measured by $\rho_{tE,i}$, lead to significant long-run shifts in the fuel mix of energy demand.

This set of fuels i is directly linked to the use structure matrix of energy commodities ($\mathbf{S}_E$) as applied in equation (10). The energy prices $p_{E,i}$ used in the Translog model are based on prices per physical unit (TJ). The part of primary energy prices in $p_{E,i}$, i.e. the prices for coal, oil, gas, and biomass are directly derived from exogenous world market prices and in turn determine import prices ($\mathbf{p}^m$) and part of the domestic output price vector ($\mathbf{p}^d$) of the four energy commodities in the use matrix. The domestic price of the electricity and heat producing sector is determined by equation (1) of this sector and drives the electricity/heat price in $p_{E,i}$. Finally, the composite price of each energy commodity is the price $\mathbf{p}^E$ in equation (10).

The third nest of the factor E starts from the cost shares in each industry j, $v_{E,ij}$ for given energy prices $p_{E,i}$. The physical energy inputs are finally dealt with at the level of 17 energy categories e of the DYNK model (EQ_{eij}) applying fixed sub-shares s_{eij} by industry and energy category. The physical inputs are the link to GHG emissions by industry, applying a fixed emission factor $em_{GHG,e}$ per energy unit.

$$EQ_{eij} = s_{eij} \frac{v_{E,ij} E}{p_{E,i}} \quad ; \quad EM_{GHG,j} = em_{GHG,e} \left[s_{eij} \frac{v_{E,ij} E_j}{p_{E,i}} \right] \quad (16)$$

The emission factors at the detailed level of energy categories e are the link to introduce prices of GHG emissions in the DYNK model which are then aggregated to the level of fuel prices, $p_{E,i}$ and added to the price as a tax component.

For material flows a different treatment for domestic material extraction and for trade flows of materials needs to be applied, due to the statistical concepts and data structures. The vector of domestic extraction of material flows (with dimension 1xq), $\mathbf{dme}_q$ is linked to the vector of deflated gross output of the eight primary industries (agriculture, forestry, fishing, and the several mining industries) $\mathbf{q}$ by a diagonal matrix of material input coefficient, m_{qj} :

$$\mathbf{dme}_q = \left[\hat{\mathbf{M}}_q\right]\mathbf{q} \quad (17)$$

The external trade of the q material flows in physical units (the vectors $\mathbf{imm}$ and $\mathbf{exm}$) is derived from physical trade volumes linked to exports and imports in monetary units which are then aggregated to the q material flows by applying the bridge matrix $\mathbf{B}_M$:

$$\mathbf{imm}_q = \mathbf{B}_M \left[\left(\hat{\mathbf{M}}\mathbf{m}_q \right) \mathbf{p}^m \mathbf{q}^m \right] \quad ; \quad \mathbf{exm}_q = \mathbf{B}_M \left[\left(\hat{\mathbf{M}}\mathbf{x}_q \right) \mathbf{ex} \right] \tag{18}$$

The diagonal matrices $\hat{\mathbf{M}}\mathbf{m}_q$ and $\hat{\mathbf{M}}\mathbf{x}_q$ therefore can be mainly interpreted as prices as they link physical imports and exports to monetary trade data. The vector of domestic material consumption $\mathbf{dmc}_q$, used as the main indicator for resource use in the scenarios, is defined as:

$$\mathbf{dmc}_q = \mathbf{dme}_q - \mathbf{exm}_q + \mathbf{imm}_q \tag{19}$$

Material flows are reduced, if – for a given use structure matrix ($\mathbf{S}_{NE}^m$ and $\mathbf{S}_{NE}^d$) – factor demand for intermediates is reduced. As material flows q are linked to only one small part of the intermediate inputs column, some flexibility and substitution in the use structure matrix ($\mathbf{S}_{NE}^m$ and $\mathbf{S}_{NE}^d$) needed also to be taken into account for certain policy scenarios. In the current version of the DYNK model this flexibility and substitution only exists between energy and non-energy categories. As the q material flows also include mining of primary energy (coal, oil, gas), substitution between energy and non-energy inputs has an important impact on domestic material consumption. The other scenarios analysed in this paper act on domestic material consumption by exogenously introducing technological change in (i) the factor demand functions (2), (ii) certain columns of matrix $\mathbf{S}_{NE}^m$ and $\mathbf{S}_{NE}^d$, representing primary material intensive industries, and (iii) material input coefficients in $\hat{\mathbf{M}}_q$, $\hat{\mathbf{M}}\mathbf{m}_q$, and $\hat{\mathbf{M}}\mathbf{x}_q$.

1.3 Labour market

The market that has the most important repercussions in the case of policy simulations in the DYNK model is the labour market. In CGE modelling, different labour market approaches can be integrated (Boeters and Savard, 2013) and calibrated. In this exercise, the theoretical approaches need to be confronted with the results from empirical wage curve estimation, which can be seen as a robust empirical relationship (Card, 1995 and Blanchower and Oswald, 1994). The wage curves in the DYNK model are specified as the employee's gross wage rate per hour by industry. The labour price (index) of the Translog model is then defined by adding the employers' social security contribution to the gross wage rate. Combining the *meta-analysis* of Folmer (2009) on the empirical wage curve literature with a basic wage bargaining model from Boeters and Savard (2013) gives a base specification for the sectoral hourly wages. These functions describe the responsiveness of hourly wages to labour productivity at industry or aggregate level, consumer prices, hours worked per employee, and the rate of unemployment. The inclusion of the variable 'hours worked per employee' corresponds to a bargaining model in which firms and workers (or unions) bargain over wages and hours worked simultaneously (Busl and Seymen, 2013). The basic idea is that the gains in labour productivity can be used to simultaneously cut hours worked and increase wages. We specify the wage function in such a way that the hours can be determined in a first step, followed by the hourly wage rate. Bargaining over hours that leads to fewer hours worked per employee increases the hourly wage rate, so income per year does not fall in the proportional amount of working time reduction. The parameter estimated for labour productivity is conditional on this impact of working time on hourly wages.

An important aspect of the wage curve is the term that considers the unemployment elasticity of the wage rate. In the DYNK model this is specified in terms of the difference to the equilibrium rate, measured in this case as the minimum rate in the sample used for estimation. The estimation of the corresponding parameter yields the same result as the parameter of the unemployment rate elasticity in the traditional wage curve, because all the variance in the term stems from changes in the unemployment rate. The specification of the unemployment term as a gap to full employment yields a NAWRU characteristic: wage inflation increases with approximation to full employment.

Labour supply is given by age and gender-specific participation rates of age groups of the population at working age (16 to 65 years) and evolves over time according to demographic change (age group composition) and logistic trends of the participation rates. Therefore, labour supply does not react endogenously to policy shocks. Unemployed persons are the difference between labour supply and employment for given hours worked per person.

1.4 Government and model closure

The model closes with public sector balances, showing the main interactions between households, firms and the general government. As we put special emphasis on labour market policies, unemployment benefits are separated from the other social expenditure categories. Taxes from households and firms are endogenized via tax rates and the path of the deficit per GDP share according to the EU stability programmes is included as a restriction.

Wage income of households is taxed with social security contributions and wage income plus operating surplus accruing to households are taxed with income taxes. Additionally, households' gross profit income is also taxed. Taxes less subsidies are not only levied on private consumption, but also on the other final demand components in purchaser prices as well as on gross output. The expenditure side of government is made up of unemployment transfers and other transfers to households, public investment and public consumption. Additionally, the government pays interest on the stock of public debt. The change in this public debt is equal to negative government net lending.

In that specification, tax revenues and unemployment benefits are endogenous and can from a policy perspective be influenced by changing tax rates or the unemployment benefit replacement rate. The model is closed by further introducing a public budget constraint, specified via the stability programme for public finances of each EU member state that defines the future path of government net lending to GDP.

2. Data, estimation and calibration

The data for the estimation of consumption demand functions are mainly taken from EUROSTAT's National Accounts. That comprises the expenditure data as well as all income components and asset data, which are part of cash on hand. The categories of durable consumption in our model comprise investment in own houses and purchases of vehicles. Due to the specific treatment of housing in the consumption accounts of national accounting, investment in own houses is pooled together with other dwelling investment to derive total dwelling investment. In a first step, a capital stock of housing property was estimated for one year, by combining different data sources in order to calculate the time series of own houses for those 14 EU countries (Belgium, Czech Republic, Denmark, Germany, France, Italy, Cyprus, Lithuania, Austria, Poland, Portugal, Romania, Slovakia, Finland) where sectoral accounts (income, asset data) were available from 1995 to 2011. A more simple procedure could be applied to vehicles, as the expenditure data are available and no re-valuation of the existing stock needed to be taken into account.

The functions for the two durable demand categories and for total nondurables have been estimated with panel data econometrics for 14 EU countries (1995 to 2011), based on EUROSTAT and other sources. Non-linear relationships of durable consumption and 'cash on hand' have been identified from these estimations. Non-stationarity has not been considered by normalizing permanent income, as is usual in the calibrated versions of the buffer stock model, but by directly estimating an error correction mechanism (ECM) model. The model has been calibrated for the income quintiles in the EU 27, based on income data from EU SILC and wealth data from the HFCS survey.

The other more important property of the buffer stock model, however, is the reaction of consumption (growth) to lagged income growth (excess sensitivity) – an empirical phenomenon first found by Hall (1978) which challenges the permanent income hypothesis. This is usually tested by an OLS regression of consumption growth on lagged income growth, including a constant. Luengo-Prado (2006) presents excess sensitivity results from stylized US macroeconomic facts and confronts these results with results from her calibrated model. For the DYNK model presented in this paper, excess sensitivity has been tested at the level of income quintiles and based on the baseline run of the model for the EU 27 until 2050. Sensitivity analysis has been carried out for high and low liquidity constraints between the durable stock and household debt.

The energy expenditure of households is based on consumption expenditure data from EUROSTAT, the Energy Accounts from the WIOD database, as well as IEA Energy Prices. In order to calculate service prices, energy efficiency data had to be added. Energy efficiency for electricity is calculated as a weighted average of efficiency of electrical appliances from the ODYSSEE database. The durable stock of households (vehicles, houses, appliances) embodies the efficiency of converting an energy flow into a service level. Policy measures that increase the efficiency of the new durables purchased or speed up the renovation of the durable stock by premature scrapping therefore lead to less direct energy demand of households and rebound effects from higher service demand. The panel data set resulting from this data collection process comprises all EU 27 countries. The data for the estimation of the demand system for non-energy nondurables could all be taken directly from the consumption expenditure data from EUROSTAT.

All data for the production system are derived from the WIOD (World Input Output Database) dataset that contains World Input Output Tables (WIOT) in current and previous year's prices, Environmental Accounts (EA), and Socioeconomic Accounts (SEA). The latter are used to derive data for capital and labour, like the base year capital stock and depreciation rates as well as labour compensation by hour and by person. For energy and emissions, we use data from the EA of energy use by 25 energy carriers in physical units (TJ) and CO_2 emissions and combine the physical energy inputs with information on energy prices from the IEA to get a full system of energy quantities and prices. For resource use, we apply the EA data of domestic extraction by 12 MFA categories, comprising different categories of biomass, fossil fuels, and minerals for construction, metal and other industrial production. These data of domestic extraction are complemented by external trade data from EUROSTAT in volumes, which at the aggregate only slightly deviates from the aggregate MFA exports and imports, also published by EUROSTAT. By applying the bridge matrix for these trade data described above, we finally arrive at domestic material consumption.

The WIOT in current and previous year's prices have been used to derive quantities and prices for (M^m) and (M^d). All these data are available at the level of 35 industries in WIOD, which are defined by aggregating the 59 NACE industries of the EUROSTAT SUTs, which is also the classification of the DYNK model. The system of the unit cost function and the factor cost shares has been estimated with panel data econometrics for 27 EU countries with time series from 1995 to 2009. The systems have been estimated applying the Seemingly Unrelated Regression (SUR) estimator for balanced panels under cross section fixed effects for each of the 35 industries (345 observations). The estimation results yield parameter values for all price terms which together with the factor cost shares give the own and cross price elasticity according to the formulae for the Translog model. Table 1 to 4 contain the price elasticities for capital, labour, energy, and imported intermediates respectively. The own price elasticity of labour is on average about –0.5, with relatively high values in some manufacturing industries. The own price elasticity of energy is very heterogenous across industries and rather high in energy intensive industries. These elasticities have then in turn been used to calibrate the production system for the DYNK model base year (2005) for the EU 27. This implies inverting the elasticity formula and calculating the parameters applying the factor cost shares of the base year.

Table 5 shows the impact of autonomous technical change on factor demand from the factor bias (i.e. without TFP) in terms of the rate of technical change ($\frac{\partial \log x_i}{\partial t}$) that either decreases or increases factor input in an industry. In general, the factor bias is labour saving (in most industries) and also energy saving in a series of important industries. At the same time the factor bias is materials using, both for imported materials as well as for domestic materials (not shown in Table 5).

Wage data including hours worked are taken from WIOD Sectoral Accounts and are complemented by labour force data from EUROSTAT. The wage equations have been estimated for the full EU 27 panel, applying an error correction model, formulated as an ADL specification. Not all industries show a significant impact of hours worked on the hourly wage rate. In industries without this coefficient in the wage curve, a reduction of hours worked *ceteris paribus* leads to a proportional income loss of workers.

Table 1 **Price elasticity of *K* (EU 27, 1995 – 2009)**

K	*K*	*L*	*E*	M^m
Agriculture	2.88	0.94	0.34	0.71
Mining, quarrying	-0.70	0.31	0.15	0.12
Food, beverages	-0.62	-0.09	-0.06	0.20
Textiles	-0.89	0.43	0.01	0.39
Leather, footwear	-0.99	0.48	0.31	0.41
Wood and cork	-0.47	0.00	-0.09	-0.03
Pulp.paper	-0.96	-0.10	-0.05	0.22
Coke, refinery	0.00	0.00	0.00	0.00
Chemicals	-0.91	0.10	0.35	0.22
Rubber and plastics	-0.74	0.11	-0.04	0.11
Non-metallic minerals	-1.17	0.23	-0.06	0.06
Basic metals	-1.09	0.20	0.28	0.34
Machinery	-1.21	0.20	0.01	0.24
Electrical equipment	-0.62	0.15	-0.14	0.00
Transport equipment	-1.06	-0.12	-0.10	0.20
Other manufacturing	-1.29	1.06	-0.06	0.47
Electricity, gas, water	-1.08	0.17	0.57	0.08
Construction	-0.40	-0.14	-0.01	0.17
Sale of motor vehicles	-0.25	0.37	0.49	0.26
Wholesale trade	-0.64	-0.12	-0.03	0.20
Retail trade	-0.50	-0.63	0.20	0.50
Hotels, restaurants	-0.58	-0.21	0.03	0.24
Other inland transport	-0.79	0.09	-0.01	0.11
Other water transport	0.00	0.00	0.00	0.00
Other air transport	-1.24	-0.21	-0.01	0.50
Other transport activities	-0.93	0.04	-0.12	0.12
Post, telecommunications	-0.63	0.29	-0.08	-0.01
Financial intermediation	-0.93	0.21	-0.06	0.39
Real estate activities	-0.49	0.05	0.01	0.16
Other business activities	-0.68	-0.02	0.01	0.17
Public administration	-1.00	0.96	0.26	-0.09
Education	-0.91	0.66	0.12	0.02
Health	0.00	0.52	0.57	0.30
Social, personal services	-0.80	0.09	0.01	0.09

Source: Own calculations

Table 2 **Price elasticity of *L* (EU 27, 1995 – 2009)**

L	*K*	*L*	*E*	M^m
Agriculture	0.12	-0.49	0.10	0.18
Mining, quarrying	0.37	-0.33	0.01	0.04
Food, beverages	-0.07	-0.62	-0.12	0.33
Textiles	0.22	-0.72	0.09	0.08
Leather, footwear	0.25	-1.10	-0.42	0.13
Wood and cork	0.01	-0.65	0.06	0.26
Pulp.paper	-0.07	-0.58	0.02	0.36
Coke, refinery	0.00	0.00	0.00	0.00
Chemicals	0.14	-0.72	0.06	0.55
Rubber and plastics	0.08	-0.61	0.09	0.46
Non-metallic minerals	0.18	-0.50	0.10	0.22
Basic metals	0.11	-0.57	0.00	0.51
Machinery	0.09	-0.65	0.00	0.35
Electrical equipment	0.09	-0.60	-0.02	0.43
Transport equipment	-0.13	-0.71	0.04	0.75
Other manufacturing	-0.15	-0.63	-0.01	0.31
Electricity, gas, water	0.35	-0.54	0.50	-0.03
Construction	-0.06	-0.59	0.06	0.11
Sale of motor vehicles	0.25	-0.64	-0.32	0.21
Wholesale trade	-0.06	-0.54	0.11	0.12
Retail trade	-0.08	-0.38	0.09	0.11
Hotels, restaurants	-0.06	-0.36	0.02	0.07
Other inland transport	0.02	-0.46	0.12	0.13
Other water transport	0.00	0.00	0.00	0.00
Other air transport	-0.15	-0.49	0.04	0.12
Other transport activities	0.01	-0.90	-0.14	0.18
Post, telecommunications	0.40	-0.66	0.08	0.02
Financial intermediation	0.22	-0.66	-0.09	0.23
Real estate activities	0.17	-0.09	-0.41	-0.13
Other business activities	0.00	-0.37	0.10	0.10
Public administration	0.26	-0.71	-0.14	0.02
Education	0.08	-0.24	-0.02	0.02
Health	0.13	-0.42	-0.05	0.08
Social, personal services	0.07	-0.43	0.09	0.07

Source: Own calculations

Table 3 **Price elasticity of *E* (EU 27, 1995 – 2009)**

E	*K*	*L*	*E*	M^m
Agriculture	0.48	1.07	0.00	0.10
Mining, quarrying	0.77	-0.05	-0.18	0.01
Food, beverages	-0.43	-0.93	-0.25	0.11
Textiles	0.02	0.86	0.00	1.15
Leather, footwear	2.20	-6.21	-4.09	3.58
Wood and cork	-0.42	0.47	-0.26	0.44
Pulp.paper	-0.36	0.14	-0.32	-0.57
Coke, refinery	0.00	0.00	0.00	0.00
Chemicals	1.49	0.14	-0.97	-0.49
Rubber and plastics	-0.24	0.56	-0.63	-0.28
Non-metallic minerals	-0.26	0.37	-0.52	0.11
Basic metals	0.85	-0.05	-1.05	0.47
Machinery	0.04	-0.06	-0.32	1.19
Electrical equipment	-1.98	-0.36	-0.48	0.04
Transport equipment	-0.89	0.49	-0.27	-0.75
Other manufacturing	0.46	-0.18	-0.42	-0.48
Electricity, gas, water	0.53	0.24	-0.68	0.14
Construction	-0.09	1.01	-0.66	0.93
Sale of motor vehicles	5.06	-4.96	-0.43	-1.21
Wholesale trade	-0.42	1.92	0.00	0.32
Retail trade	1.06	1.69	0.00	-0.12
Hotels, restaurants	0.21	0.19	-0.31	0.20
Other inland transport	-0.11	0.58	-0.30	-0.18
Other water transport	0.00	0.00	0.00	0.00
Other air transport	-0.07	0.11	-0.32	0.36
Other transport activities	-1.66	-1.71	-1.91	-0.06
Post, telecommunications	-1.95	1.52	0.00	2.35
Financial intermediation	-1.84	-3.75	0.00	-5.00
Real estate activities	-3.31	-6.19	-0.47	-1.93
Other business activities	0.24	2.94	0.00	-0.09
Public administration	1.49	-3.61	-1.44	1.36
Education	1.21	-1.41	0.00	0.00
Health	2.77	-1.63	-0.10	-1.12
Social, personal services	0.04	1.22	-0.42	0.12

Source: Own calculations

Table 4 **Price elasticity of M^m (EU 27, 1995 – 2009)**

M^m	K	L	E	M^m
Agriculture	0.37	0.73	0.04	-1.03
Mining, quarrying	0.27	0.10	0.03	-0.56
Food, beverages	0.21	0.38	0.02	-0.67
Textiles	0.19	0.06	0.12	-1.07
Leather, footwear	1.53	-1.07	3.58	-1.72
Wood and cork	-0.03	0.33	0.07	-0.66
Pulp.paper	0.17	0.41	-0.07	-0.93
Coke, refinery	0.00	0.00	0.00	0.00
Chemicals	0.16	0.31	-0.05	-0.84
Rubber and plastics	0.05	0.35	-0.03	-0.92
Non-metallic minerals	0.04	0.29	0.04	-0.90
Basic metals	0.13	0.37	0.06	-0.30
Machinery	0.10	0.34	0.08	-1.65
Electrical equipment	-0.02	0.25	0.01	-0.73
Transport equipment	0.06	0.45	-0.03	-1.27
Other manufacturing	0.00	0.40	-0.04	-0.68
Electricity, gas, water	0.28	-0.09	0.52	-1.57
Construction	0.17	0.19	0.10	-0.59
Sale of motor vehicles	0.50	0.60	-0.23	-1.01
Wholesale trade	0.59	0.43	0.07	-0.96
Retail trade	0.95	0.70	-0.04	-1.44
Hotels, restaurants	0.54	0.29	0.07	-0.83
Other inland transport	0.23	0.54	-0.15	-0.88
Other water transport	0.00	0.00	0.00	0.00
Other air transport	0.44	0.12	0.12	-1.24
Other transport activities	0.22	0.38	-0.01	-0.93
Post, telecommunications	-0.04	0.02	0.37	-0.29
Financial intermediation	1.69	1.19	-0.71	0.00
Real estate activities	5.34	-0.20	-0.21	-1.98
Other business activities	0.47	0.39	-0.01	-0.98
Public administration	-0.16	0.03	0.46	-0.71
Education	0.02	0.29	0.00	-1.48
Health	0.36	0.40	-0.26	-1.27
Social, personal services	0.20	0.27	0.04	-0.84

Source: Own calculations

Table 5 **Rate of technical change (factor bias, EU 27, 1995 – 2009)**

t (factor bias)	K	L	E	M^m
Agriculture	-0.031	-0.003	-0.003	0.007
Mining, quarrying	0.035	-0.036	0.008	0.006
Food, beverages	0.007	0.000	0.002	0.010
Textiles	-0.005	-0.002	-0.002	0.000
Leather, footwear	-0.004	0.009	0.036	-0.001
Wood and cork	-0.003	-0.005	0.001	0.007
Pulp.paper	-0.002	-0.005	0.003	0.002
Coke, refinery	0.000	0.000	0.000	0.000
Chemicals	0.001	-0.007	0.001	0.005
Rubber and plastics	0.001	-0.012	-0.005	0.003
Non-metallic minerals	-0.001	-0.011	-0.005	0.001
Basic metals	-0.004	-0.012	-0.002	0.010
Machinery	0.005	-0.007	-0.010	0.001
Electrical equipment	-0.010	-0.009	-0.003	0.005
Transport equipment	0.008	-0.016	-0.010	0.005
Other manufacturing	0.003	-0.013	0.002	0.009
Electricity, gas, water	-0.005	-0.026	0.010	-0.008
Construction	0.005	-0.011	-0.002	0.004
Sale of motor vehicles	-0.001	-0.003	0.006	0.007
Wholesale trade	0.000	-0.007	-0.015	0.008
Retail trade	0.000	-0.004	-0.028	0.000
Hotels, restaurants	0.001	0.000	-0.008	0.003
Other inland transport	0.000	-0.014	0.009	0.017
Other water transport	0.000	0.000	0.000	0.000
Other air transport	0.000	-0.020	0.012	0.006
Other transport activities	0.004	0.009	0.055	0.020
Post, telecommunications	-0.003	-0.020	0.004	0.013
Financial intermediation	-0.001	-0.011	-0.004	-0.001
Real estate activities	-0.007	0.001	0.106	0.053
Other business activities	-0.006	-0.004	-0.023	0.008
Public administration	-0.007	0.003	0.040	0.001
Education	0.002	-0.002	0.000	0.000
Health	0.005	-0.006	0.004	0.008
Social, personal services	0.007	-0.011	-0.001	0.007

Source: Own calculations

3. Resource scenarios for the EU 27

In the following, the results of two exemplary simulations will be presented, which are based on the work carried out in Fischer-Kowalski, et al. (2013) and on the European Roadmap for resource efficiency, laid down in European Commission (2011b, 2011c). First, the DYNK model is run until 2050 to derive a 'baseline' scenario, which corresponds to the 'trend' scenario in Fischer-Kowalski, et al. (2013). As we are mainly interested in the simulation results, we do at this stage not compare the results of this 'baseline' scenario with the 'trend' scenario described in Fischer-Kowalski, et al. (2013). Fischer-Kowalski, et al. (2013) further describe a 'benchmark case' scenario, oriented along the lines of the experience of some high-income countries that converged to lower per capita material consumption than the European average, as well as a 'radical transformation' scenario with significant reductions of resource use in Europe that are required for a globally sustainable and egalitarian path of resource use. A mix of policies (CO_2 prices, support measures for recycling) and shifts in the direction of technological change are used to converge to the path defining the 'radical transformation' scenario. In the following, the contribution of these different policy instruments that attempt to overcome market failures linked to an excessive resource use shall be shown in two different scenarios. For a scenario with modest reduction of resource use – corresponding to the 'benchmark case' scenario in Fischer-Kowalski, et al. (2013) – the contribution of directed technical change is analyzed. For a scenario with radical reduction of resource use – corresponding to the 'radical transformation' scenario in Fischer-Kowalski, et al. (2013) – the impact of CO_2 prices is analysed.

In a first step, the DYNK model has been solved for a baseline scenario from the base year 2005 to 2050, taking into account recent data until 2012 and making assumptions for the period to 2050 about the development of exogenous variables. Import prices, especially for energy, a simple (autoregressive) forecast of exports, interest rates, house prices, as well as detailed population and labour force projections are the main exogenous variables in this model. An important constraint is the long-run value that is to be achieved on average for the household debt ratio. For a baseline scenario we use the assumption that the debt-to-durables ratio converges back to the pre-crisis level. Another constraint is the public deficit stability programme of all EU 27 member states, defined as a target path of government net lending as a percentage of GDP until 2018. This is guaranteed by endogenizing public consumption. Tax and transfer policies with respect to their distributional impact across the five income groups also remain constant for the baseline scenario. In general, the debt de-leveraging process of households and the government net lending constraint dampen the economy until 2018.

The average growth rate of GDP in constant prices between 2012 and 2050 is 1.4% p.a. in this baseline scenario. The growth rates of TFP by industry have been set as constant during the simulation period, i.e. without assuming acceleration of TFP growth by specific innovation activities. The factor bias of technical change has also been kept constant and had to be dampened in the case of energy, as well as at the K, L, E, M^m, M^d level of factor demand (as in the fuel submodel) in order to avoid negative values for shares of energy (e.g. in some service sectors) or for shares of some fuels (e.g. coal). Total energy demand by the production sector rises less than GDP, given the interaction of the factor bias of technical change and TFP growth. Emissions of greenhouse gases (GHG) rise slightly at the beginning and after that stay almost constant. This 'decarbonization' trend is driven by a fuel shift towards electricity given the underlying energy price developments and the fuel bias of technical change. The domestic material consumption (DMC) indicator stays almost constant at 16.5 t/capita. This result is completely in line with the trend scenario described in Fischer-Kowalski, et al. (2013).

3.1 The 'best practice' scenario

In Fischer-Kowalski, et al. (2013) this scenario is motivated by a convergence of all EU 27 countries towards the resource efficiency path of some large selected countries (UK, France and Germany). As Fischer-Kowalski, et al. (2013) point out, specific circumstances (de-industrialization, German reunion) led to a decrease of DMC per capita in the 1970 to 2000 period in these countries. These circumstances pushed structural and technical change into a more resource-saving direction. This scenario therefore cannot be described as a policy scenario, but rather as one with specific exogenous shocks.

The general philosophy of this scenario is implemented in the DYNK model by assuming a shift in the factor bias of technological change without any changes in TFP growth. One could think that this shift in technological change comes from a shift in R&D spending towards resource saving technologies and therefore represents a version of policy implemented directed technical change. One could further assume that this shift is the consequence of taxation of energy and resources. Such a policy scenario would have as a prerequisite that the factor bias of technical change is modelled as endogenous or induced. This is not the case in the current version of the DYNK model.

The starting point for the implementation of this shock is the rate of technical change of the factor bias, as laid down in Table 5 and in the parameter ρ in the factor share equations (equation (2)). Note that in the DYNK model the industry classification is more disaggregated than in Table 5, as the DYNK model builds upon the SUTs of the EU 27, which are in NACE two digit-industries. The implemented shock decreases the labour saving effect of the bias (i.e. ρ) in industries and service sectors (without the primary sectors) by 35% and shifts this bias towards the factors E, M^m, and M^d. In those industries in which the bias is not labour-saving but labour-consuming, a smaller shift of about 10% has been implemented, making technical progress slightly more labour-consuming.

The main economic impact of this shock is more employment creation, which in turn increases disposable household income and decreases unemployment. The ceiling of the unemployment rate built into the model is 4% and this is already reached in 2030 in this scenario. As the policy variable hours per employee have not changed, the demand for hours shows the same development as the demand for employees.

Due to the shift in the bias, energy demand and GHG emissions as well as DMC per capita rise less in this scenario than in the 'baseline' scenario. The shift in technical change is neutral in a first round, but then has second-order effects, especially on output prices and consumption. The output price effects are negative (compared to the 'baseline' scenario) until 2020 and then this impact turns positive. This price development also drives the development of exports. In general, the shift in technical change diverts demand from exports to consumption and thereby also creates feedback effects on energy demand and emissions from households (GHG emissions from households are 8.8% higher than in the 'trend' scenario in 2050). This is driven by the high impact of employment creation on real disposable income (+12.2% in 2050).

Until 2020 this demand shift, driven by the technological bias shift, has a positive net impact on GDP. In the long-run, the negative impact on price competitiveness depresses exports outside the EU 27 to a larger extent (compared to the 'baseline' scenario) and also consumption, especially of durables, is lowered. Therefore the long-run GDP impact compared to the 'baseline' scenario is slightly negative. GHG emissions from production are 9.5% below their value in the 'baseline' scenario, whereas GHG emissions from households increase.

Table 7 shows the impact of this scenario on income distribution in the household sector. In general, the positive real income effect is smaller for the group with the lowest income (1st quintile) than for the others. This is a main driver behind the negative impact on durable demand, as due to the non-linear function for durables, the marginal propensity of durable consumption is much higher for low income households. That follows directly from the implicit equilibrium position of durables per household. Energy consumption of households which contains both private and public transport (besides heating and electricity) rises compared to the 'baseline' scenario due to a high income elasticity of transport demand. The distributional impact of this policy therefore is negative and contributes to important rebound effects on energy demand and GHG emissions from the household sector.

The impact on gross output is negative for the whole period (Table 8) though GDP is increased compared to the 'baseline' scenario, as the throughput of energy and materials is reduced. Output of coal and crude oil is decreased significantly, as well as the production of ores and minerals. This contributes to an important reduction of DMC of minerals, not only of energy. Therefore, important inter-linkages of material flows are present in the DYNK model, leading to co-benefits. This is driven by the decrease in export demand of material intensive industries (other non-metallic mineral products, basic metals) as well as in domestic construction, which both decrease the output of the primary sectors. This in turn decreases transport demand and leads to an above average negative impact on the gross output of the land transport sector (–9.5% in 2050), which again reduces the demand for transport fuels. Private transport demand is stimulated by the income effects on households, which leads to an output increase in the air transport sector. The gross output of public services is stimulated, as the technological shift towards higher use of labour leads to an increase in tax revenues and makes the public budget constraint less binding.

The shift in the bias of technological change from labour saving to resource saving leads to high positive employment effects which are combined with negative or only small positive gross output effects. The result of this combination is an important decrease in labour productivity, which leads to an impact on price competitiveness of the EU 27 industry. In order to avoid these negative productivity impacts an optimal shift in the bias would decrease the labour saving technical change less and at the same time increase the resource and energy saving technical change, so that negative effects on price competitiveness can be avoided.

Table 6 **Aggregate effects in the 'best practice' scenario (difference to 'baseline scenario' in %)**

	2015	2020	2030	2050
GDP, constant prices	0.68	1.50	-1.05	-2.00
Private consumption, constant prices	0.18	0.34	-0.61	5.23
Capital formation, constant prices	0.00	-0.01	-0.05	-0.07
Exports, constant prices	0.15	-0.07	-3.81	-8.91
Employment (persons)	2.11	6.56	10.01	23.26
Employment (hours)	2.11	6.53	9.93	23.06
Unemployment (persons)	-12.18	-38.36	-61.00	-96.41
Unemployment rate (% points)	-1.80	-5.60	-8.60	-12.34
GHG emissions, households	-0.01	0.04	1.31	8.79
GHG emissions, production	-2.04	-5.60	-7.94	-9.46
GHG emissions, total	-1.60	-4.44	-6.21	-6.87
DMC/capita	0.03	-1.23	-4.50	-7.65
DMC, energy	0.13	-1.86	-6.81	-13.62
DMC, minerals	0.01	-1.69	-5.46	-8.51

Source: Own calculations

Table 7 **Income and consumption effects in the 'best practice' scenario (difference to 'baseline scenario' in %)**

	2015	2020	2030	2050
Durable consumption, constant prices	0.07	-0.36	-3.53	-4.23
Nondurable consumption, constant prices	0.00	0.01	0.01	0.11
Energy, constant prices	0.05	0.29	1.79	9.56
Real disposable income	2015	2020	2030	2050
Total	0.71	2.01	2.77	12.21
1st quintile	0.28	0.89	1.55	8.70
2nd quintile	0.77	2.24	3.34	12.39
3rd quintile	0.83	2.41	3.54	13.20
4th quintile	0.88	2.53	3.60	13.58
5th quintile	0.61	1.72	2.14	11.68

Source: Own calculations

Table 8 **Output effects of selected industries in the 'best practice' scenario (difference to 'baseline scenario' in %)**

	2015	2020	2030	2050
TOTAL	-0.30	-1.09	-3.70	-4.50
Coal and lignite; peat	-1.84	-4.97	-8.23	-12.93
Crude petroleum and natural gas; services incidental to oil and gas extraction excluding surveying	-1.66	-4.92	-10.29	-17.39
Metal ores	-1.13	-3.21	-5.49	-9.16
Other mining and quarrying products	-1.13	-3.21	-5.60	-8.43
Food products and beverages	-0.09	-0.18	-0.43	3.83
Tobacco products	0.40	1.23	1.37	7.38
Textiles	-0.67	-2.77	-8.52	-12.96
Wearing apparel; furs	-0.39	-1.97	-7.35	-10.88
Leather and leather products	0.02	-0.03	-1.91	-2.84
Wood and products of wood and cork (except furniture); articles of straw and plaiting materials	-0.97	-3.03	-6.61	-9.29
Pulp, paper and paper products	-0.66	-1.95	-4.22	-6.00
Printed matter and recorded media	-0.88	-2.76	-6.47	-9.97
Coke, refined petroleum products and nuclear fuels	-1.61	-4.61	-6.26	-4.72
Chemicals, chemical products and man-made fibres	-0.25	-0.90	-2.97	-4.28
Rubber and plastic products	-0.74	-2.06	-4.11	-5.61
Other non-metallic mineral products	-0.73	-2.13	-4.71	-10.64
Basic metals	-1.08	-2.92	-4.21	-3.29
Fabricated metal products, except machinery and equipment	-1.15	-3.35	-6.37	-7.76
Machinery and equipment n.e.c.	-0.65	-1.94	-5.45	-9.58
Office machinery and computers	-0.33	-0.77	-1.10	1.63
Electrical machinery and apparatus n.e.c.	-0.50	-1.17	-1.91	-0.06
Radio, television and communication equipment and apparatus	-0.04	-0.02	-0.30	2.82
Medical, precision and optical instruments, watches and clocks	0.19	0.68	0.46	3.14
Motor vehicles, trailers and semi-trailers	-0.39	-1.25	-4.78	-19.16
Other transport equipment	-0.02	-0.48	-4.78	-19.67
Furniture; other manufactured goods n.e.c.	-0.40	-1.50	-4.75	-7.13
Secondary raw materials	-0.84	-2.19	-2.98	-0.77
Electrical energy, gas, steam and hot water	-1.76	-4.86	-6.19	-3.70
Construction work	-0.41	-1.51	-5.11	-8.09
Wholesale trade and commission trade services, except of motor vehicles and motorcycles	-0.30	-0.92	-3.35	-5.00
Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods	-0.03	0.02	-0.85	2.41
Hotel and restaurant services	-0.20	-0.75	-1.91	3.34
Land transport; transport via pipeline services	-0.90	-2.71	-5.98	-9.49
Water transport services	0.02	-0.05	-2.04	-5.05
Air transport services	0.66	2.63	3.11	2.38
Supporting and auxiliary transport services; travel agency services	-0.59	-1.59	-3.39	-2.23
Research and development services	0.27	0.37	-2.94	-4.64
Other business services	-1.31	-4.01	-8.36	-12.54
Public administration and defence services; compulsory social security services	1.86	5.91	8.51	19.33
Education services	1.41	4.40	6.42	17.79
Health and social work services	1.60	4.96	6.98	18.95
Sewage and refuse disposal services, sanitation and similar services	0.11	0.62	0.51	0.54
Membership organisation services n.e.c.	0.41	2.08	5.46	14.99
Recreational, cultural and sporting services	0.25	1.33	3.49	10.52
Other services	0.06	0.35	0.14	5.38

Source: Own calculations

Table 9 **Employment effects of selected industries in the 'best practice' scenario (difference to 'baseline scenario' in %)**

	2015	2020	2030	2050
TOTAL	2.11	6.56	10.01	23.26
Coal and lignite; peat	-1.60	-4.03	-5.09	-2.47
Crude petroleum and natural gas; services incidental to oil and gas extraction excluding surveying	-2.01	-5.27	-7.37	-5.77
Metal ores	-1.09	-2.75	-2.33	2.70
Other mining and quarrying products	-1.46	-3.98	-6.45	-25.88
Food products and beverages	4.39	13.96	25.13	56.24
Tobacco products	6.04	19.37	35.58	79.96
Textiles	0.09	-1.96	-13.92	-26.05
Wearing apparel; furs	0.28	-1.26	-11.94	-22.33
Leather and leather products	3.79	11.10	15.24	24.85
Wood and products of wood and cork (except furniture); articles of straw and plaiting materials	0.31	0.56	-2.27	-0.45
Pulp, paper and paper products	3.12	10.21	18.97	63.67
Printed matter and recorded media	2.08	6.56	10.98	34.98
Coke, refined petroleum products and nuclear fuels	-0.02	-0.23	-1.64	-6.06
Chemicals, chemical products and man-made fibres	2.78	8.39	12.04	44.88
Rubber and plastic products	2.11	7.17	13.10	36.31
Other non-metallic mineral products	4.60	16.33	35.78	118.94
Basic metals	-0.65	-1.99	-5.51	-8.53
Fabricated metal products, except machinery and equipment	-0.67	-2.21	-6.68	-10.16
Machinery and equipment n.e.c.	2.80	8.86	14.15	53.75
Office machinery and computers	-0.76	-2.22	-3.26	-0.97
Electrical machinery and apparatus n.e.c.	2.25	7.46	15.30	39.06
Radio, television and communication equipment and apparatus	-0.46	-1.42	-2.11	1.05
Medical, precision and optical instruments, watches and clocks	-0.26	-0.94	-2.00	-1.05
Motor vehicles, trailers and semi-trailers	8.90	33.55	87.29	432.64
Other transport equipment	4.01	13.58	26.53	67.33
Furniture; other manufactured goods n.e.c.	3.50	11.07	19.03	60.26
Secondary raw materials	0.98	4.11	12.43	34.73
Electrical energy, gas, steam and hot water	2.02	5.71	12.35	32.17
Construction work	2.21	5.89	5.45	10.36
Wholesale trade and commission trade services, except of motor vehicles and motorcycles	2.01	6.44	10.20	26.55
Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods	1.21	4.15	7.75	22.19
Hotel and restaurant services	1.91	5.39	8.40	23.72
Land transport; transport via pipeline services	1.55	4.78	7.14	23.39
Water transport services	1.96	6.34	10.46	27.82
Air transport services	3.36	10.64	16.97	36.55
Supporting and auxiliary transport services; travel agency services	2.85	10.05	19.74	41.21
Research and development services	2.55	6.64	5.90	9.39
Other business services	0.54	1.20	-0.46	1.07
Public administration and defence services; compulsory social security services	3.44	11.71	21.34	48.78
Education services	2.34	7.33	11.74	27.80
Health and social work services	1.66	5.29	8.02	22.97
Sewage and refuse disposal services, sanitation and similar services	1.14	4.24	8.44	17.47
Membership organisation services n.e.c.	1.69	6.62	15.61	40.45
Recreational, cultural and sporting services	1.40	5.37	12.48	31.83
Other services	2.83	9.43	18.38	45.71

Source: Own calculations

3.2 The 'radical transformation' scenario

A series of measures and targets described by the European Commission (2011 b,c) defines the environment for this scenario in the work of Fischer-Kowalski, et al. (2013). As a first exercise we introduce a price for CO_2 (tax or auctioned permits), where the revenues are redistributed by lower employers' and employees' social security contributions. This first simulation experiment can be further complemented by other policy elements aiming at a reduction of material use. The price for CO_2 is taken from a scenario in the EU roadmap for radical GHG emission reduction (European Commission, 2011a) and starts with 25 €/t CO_2 in 2011 and linearly increases 250 €/t CO_2 (in 2005 €) in 2050.

As a result, GDP growth is dampened compared to the 'baseline' scenario, mainly due to the double price effects on products that contain energy, as well as those on energy products that are consumed. These price effects build up and in the long run counteract the price-decreasing impact of lower social security contributions and lower labour costs. Per capita energy and DMC decrease by the same amount in this scenario, but GHG emissions decrease even more. As in the EU Roadmap scenario for GHG emissions, the total impact on emissions consists of an energy efficiency effect, as well as a de-carbonization effect. GHG emissions decrease by almost 50% until 2050, and DMC by about 20%. The inter-linkages between the different categories of DMC can also be observed in this scenario, as the material flows of minerals for industry, for metal production and for construction all decrease by the same amount as the material flows of energy. A policy for GHG mitigation therefore has important spillovers for DMC reduction. The DMC per capita in this scenario decreases to 12 t/capita, which is what Fischer-Kowalski, et al. (2013) derive for the case of the 'best practice' scenario. The low reduction of households' GHG emissions compared to the 'baseline' scenario make it clear that the pricing of CO_2 needs to be complemented by other specific instruments and measures aiming at energy efficiency and de-carbonization in the household sector.

The economic impact of the CO_2 price with redistribution of revenues is different in the short and long run. Until 2030, employment increases though the GDP impact is negative and after that the impact on employment as well as GDP becomes more pronouncedly negative compared to the 'baseline' scenario. The combination of a pronounced negative impact on GDP in 2050 (–13%) with a negative employment impact of only 1% in 2050 reveals the important substitution effect in favour of labour, triggered by the huge reduction in social security contributions.

Table 11 shows that the impact of this scenario on income distribution is regressive as the real disposable income of the 1st and 2nd quintile are affected much more negatively than the 4th and 5th quintile. This is in line with energy taxation (via the price of CO_2) that hits low income households more, despite the reduction in social security contributions. Energy consumption and durable consumption are reduced significantly, therefore. The impact on durable consumption is due to the non-constant marginal propensity of durable consumption across household income groups. The distributional impact of this policy therefore is negative. Accompanying policies would be needed in order to avoid this regressive income distribution impact.

The larger negative impact on gross output than on GDP is – as in the 'best practice' scenario – driven by a reduction of the throughput of energy and materials. Output of the energy producing sectors as well as the production of ores and minerals decrease significantly. Again, this contributes to an important reduction of DMC of minerals, not only of energy and reveals the inter-linkages of material flows and the possible co-benefits of policies. Only very few industries increase their gross output compared to the 'baseline' scenario.

The employment effects are very heterogeneous across industries, depending on the labour intensity and social security share in wage costs of an industry.

Table 10 **Aggregate effects in the 'radical transformation' scenario (difference to 'baseline scenario' in %)**

	2015	2020	2030	2050
GDP, constant prices	0.13	-0.80	-4.56	-12.98
Private consumption, constant prices	-0.46	-2.09	-6.43	-13.12
Capital formation, constant prices	0.00	-0.01	-0.05	-0.13
Exports, constant prices	-0.17	-1.49	-6.07	-16.70
Employment (persons)	0.56	0.70	-0.02	-1.00
Employment (hours)	0.58	0.73	0.03	-0.95
Unemployment (persons)	-3.26	-4.11	0.10	5.11
Unemployment rate (% points)	-0.48	-0.60	0.01	0.84
GHG emissions, households	-2.68	-4.36	-6.80	-8.49
GHG emissions, production	-13.69	-24.05	-40.75	-57.64
GHG emissions, total	-11.32	-19.99	-34.40	-50.68
DMC/capita	0.00	-1.24	-5.81	-19.06
DMC, energy	0.00	-0.82	-4.93	-20.66
DMC, minerals	0.00	0.04	-2.43	-19.24

Source: Own calculations

Table 11 **Income and consumption effects in the 'radical transformation' scenario (difference to 'baseline scenario' in %)**

	2015	2020	2030	2050
Durable consumption, constant prices	0.16	-0.65	-3.41	-9.34
Nondurable consumption, constant prices	0.00	-0.01	-0.04	-0.08
Energy, constant prices	-2.03	-4.49	-9.80	-17.92
Real disposable income	2015	2020	2030	2050
Total	-0.25	-1.58	-5.32	-11.09
1st quintile	-1.51	-3.88	-9.42	-17.88
2nd quintile	-1.03	-3.10	-8.34	-16.44
3rd quintile	-0.64	-2.37	-6.98	-14.23
4th quintile	-0.24	-1.59	-5.49	-11.75
5th quintile	0.25	-0.64	-3.49	-7.79

Source: Own calculations

Table 12 **Output effects of selected industries in the 'radical transformation' scenario (difference to 'baseline scenario' in %)**

	2015	2020	2030	2050
TOTAL	-0.65	-2.18	-7.00	-16.38
Coal and lignite; peat	-1.22	-2.92	-9.38	-31.10
Crude petroleum and natural gas; services incidental to oil and gas extraction excluding surveying	-1.73	-4.22	-9.36	-19.57
Metal ores	-1.40	-2.31	-9.82	-24.26
Other mining and quarrying products	-2.15	-4.54	-12.17	-28.12
Food products and beverages	-0.24	-1.36	-4.59	-9.15
Tobacco products	0.23	-0.54	-3.18	-6.75
Textiles	-0.42	-1.47	-4.11	-9.42
Wearing apparel; furs	-0.02	-0.93	-3.40	-8.16
Leather and leather products	-0.05	-1.26	-5.46	-14.19
Wood and products of wood and cork (except furniture); articles of straw and plaiting materials	-0.14	-1.00	-4.15	-10.33
Pulp, paper and paper products	-0.79	-2.08	-5.93	-13.72
Printed matter and recorded media	-0.31	-1.21	-4.33	-11.19
Coke, refined petroleum products and nuclear fuels	-2.72	-7.97	-20.48	-41.86
Chemicals, chemical products and man-made fibres	-0.92	-2.66	-8.20	-18.92
Rubber and plastic products	-0.13	-0.70	-3.18	-8.66
Other non-metallic mineral products	-1.08	-2.58	-7.13	-17.06
Basic metals	-1.55	-3.09	-6.90	-11.84
Fabricated metal products, except machinery and equipment	-0.30	-0.97	-3.61	-8.07
Machinery and equipment n.e.c.	-0.04	-0.76	-3.73	-10.06
Office machinery and computers	-0.14	-0.25	-0.55	-0.37
Electrical machinery and apparatus n.e.c.	-0.12	-0.69	-3.48	-12.42
Radio, television and communication equipment and apparatus	0.15	0.24	0.28	0.33
Medical, precision and optical instruments, watches and clocks	0.02	0.02	-0.13	0.51
Motor vehicles, trailers and semi-trailers	0.06	-0.22	-2.07	-6.60
Other transport equipment	-0.20	-1.20	-4.92	-13.09
Furniture; other manufactured goods n.e.c.	-0.22	-1.27	-4.82	-11.80
Secondary raw materials	-0.89	-2.05	-5.71	-13.50
Electrical energy, gas, steam and hot water	-8.29	-16.41	-34.47	-61.71
Construction work	-0.19	-1.01	-3.89	-9.01
Wholesale trade and commission trade services, except of motor vehicles and motorcycles	0.07	-0.72	-3.98	-10.77
Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods	0.26	0.10	-0.95	-3.22
Hotel and restaurant services	-0.10	-1.01	-3.26	-3.95
Land transport; transport via pipeline services	-0.57	-3.69	-13.61	-30.09
Water transport services	-0.28	-2.38	-8.84	-20.45
Air transport services	-1.64	-9.71	-30.73	-56.44
Supporting and auxiliary transport services; travel agency services	0.04	-1.04	-5.72	-15.08
Research and development services	-0.04	-0.86	-3.92	-8.74
Other business services	-0.04	-0.69	-3.26	-7.59
Public administration and defence services; compulsory social security services	-1.47	-3.41	-8.92	-17.99
Education services	-0.88	-1.82	-4.29	-6.13
Health and social work services	-1.38	-3.20	-8.17	-16.15
Sewage and refuse disposal services, sanitation and similar services	0.06	0.03	-0.80	-3.32
Membership organisation services n.e.c.	0.60	1.46	3.07	5.67
Recreational, cultural and sporting services	-0.09	-0.35	-1.46	-2.49
Other services	-0.18	-0.76	-2.51	-4.92

Source: Own calculations

Table 13 **Employment effects of selected industries in the 'radical transformation' scenario (difference to 'baseline scenario' in %)**

	2015	2020	2030	2050
TOTAL	0.56	0.70	-0.02	-1.00
Coal and lignite; peat	1.24	3.37	9.27	17.68
Crude petroleum and natural gas; services incidental to oil and gas extraction excluding surveying	1.06	2.62	9.22	18.14
Metal ores	0.90	3.48	6.63	12.70
Other mining and quarrying products	-0.13	-0.05	-5.65	-90.14
Food products and beverages	0.58	0.34	-1.16	-2.79
Tobacco products	1.45	1.72	0.85	0.65
Textiles	0.94	1.58	4.52	13.35
Wearing apparel; furs	1.12	1.71	4.39	13.46
Leather and leather products	0.26	-1.32	-7.17	-16.52
Wood and products of wood and cork (except furniture); articles of straw and plaiting materials	0.96	0.95	-1.14	-7.19
Pulp, paper and paper products	0.39	0.16	-2.07	-11.21
Printed matter and recorded media	0.59	0.65	-0.30	-3.60
Coke, refined petroleum products and nuclear fuels	0.84	1.10	-0.44	-3.04
Chemicals, chemical products and man-made fibres	1.01	1.46	0.38	-5.86
Rubber and plastic products	1.14	1.73	1.06	-3.57
Other non-metallic mineral products	0.55	0.62	-1.46	-14.20
Basic metals	0.25	0.02	-2.59	-9.64
Fabricated metal products, except machinery and equipment	1.14	1.48	-0.18	-5.89
Machinery and equipment n.e.c.	0.98	1.03	-1.05	-9.48
Office machinery and computers	1.28	3.34	9.03	20.56
Electrical machinery and apparatus n.e.c.	1.06	2.16	4.36	7.60
Radio, television and communication equipment and apparatus	1.22	2.91	7.15	14.13
Medical, precision and optical instruments, watches and clocks	0.92	2.16	5.48	13.30
Motor vehicles, trailers and semi-trailers	1.08	1.43	-1.49	-19.69
Other transport equipment	0.96	1.31	0.80	-1.00
Furniture; other manufactured goods n.e.c.	0.44	0.03	-2.69	-11.22
Secondary raw materials	1.11	2.95	6.85	15.38
Electrical energy, gas, steam and hot water	-0.57	-0.39	-0.40	-1.46
Construction work	0.66	0.85	0.12	-1.77
Wholesale trade and commission trade services, except of motor vehicles and motorcycles	1.16	1.54	0.31	-3.73
Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods	1.35	2.66	5.33	10.53
Hotel and restaurant services	0.55	0.68	1.39	6.81
Land transport; transport via pipeline services	0.32	-1.25	-7.12	-17.54
Water transport services	0.86	0.03	-4.22	-15.20
Air transport services	0.28	-3.00	-11.73	-15.85
Supporting and auxiliary transport services; travel agency services	1.03	1.77	2.64	8.04
Research and development services	0.48	0.21	-1.92	-6.13
Other business services	0.54	0.41	-1.17	-4.41
Public administration and defence services; compulsory social security services	0.07	0.32	0.33	2.80
Education services	-0.20	-0.35	-1.05	-0.13
Health and social work services	-0.66	-1.58	-4.35	-8.17
Sewage and refuse disposal services, sanitation and similar services	1.04	2.41	5.23	9.74
Membership organisation services n.e.c.	1.64	4.01	9.73	22.18
Recreational, cultural and sporting services	0.80	1.82	4.03	9.98
Other services	0.66	1.48	3.57	11.42

Source: Own calculations

4. Summary and outlook

This paper describes the introduction of biophysical constraints into a disaggregated dynamic New Keynesian (DYNK) model using the example of two different policy scenarios of resource use in Europe. Important features of the DYNK model in this context are the level of detail (59 industries and five income groups of households), the explicit link of physical energy and material flow data to production and consumption activities and the modelling of different sources of technical change, especially relevant for decoupling of resource use from economic growth. The model links activities of different industries by input-output relationships and takes into account different sources of private consumption (income vs. wealth) across household income groups. The links between production and consumption need to be considered, if aggregate policy targets shall be pursued. Measures that reduce energy and resource use in the production sector might have income rebound effects in the household sector that counteract the attainment of the aggregate target. Policies using pricing instruments and price an externality at the same rate in production as in consumption also might have different impacts and therefore need to be accompanied by other measures in order to achieve aggregate policy targets.

Two exemplary simulation exercises, partially based on the work of Fischer-Kowalski, et al. (2013) on European resource scenarios show the role of directed technological change and of pricing instruments in reducing resource use to long-run globally sustainable levels. Measures that are *ex ante* neutral in terms of total productivity (directed technical change) and of macroeconomic impacts (revenue neutral emission tax) show important feedback effects and repercussions in the model context.

The policies analyzed here shall in a follow-up of this work be complemented by more general policies aiming at the reduction of resource use and material flows. The most important instruments are a general tax on resource inputs, diet shifts brought about by taxation shifts on different food products and an increase in the recycling in resource intensive productions. The regressive impact of the policies analyzed here also give an impulse to design and simulate accompanying policies that might be adequate to avoid these distributional impacts.

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Project Information

Welfare, Wealth and Work for Europe

A European research consortium is working on the analytical foundations for a socio-ecological transition

Abstract

Europe needs change. The financial crisis has exposed long-neglected deficiencies in the present growth path, most visibly in the areas of unemployment and public debt. At the same time, Europe has to cope with new challenges, ranging from globalisation and demographic shifts to new technologies and ecological challenges. Under the title of Welfare, Wealth and Work for Europe – WWWforEurope – a European research consortium is laying the analytical foundation for a new development strategy that will enable a socio-ecological transition to high levels of employment, social inclusion, gender equity and environmental sustainability. The four-year research project within the 7th Framework Programme funded by the European Commission was launched in April 2012. The consortium brings together researchers from 34 scientific institutions in 12 European countries and is coordinated by the Austrian Institute of Economic Research (WIFO). The project coordinator is Karl Aiginger, director of WIFO.

For details on WWWforEurope see: www.foreurope.eu

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