# Fostering a low carbon economy with carbon pricing revenues: growth and employment impacts of directed technological change

Christian Lutz[1,*], Ulrike Lehr[1], Kirsten S. Wiebe[1,2]

[1] *Gesellschaft für Wirtschaftliche Strukturforschung mbH, Osnabrück, Germany*

[2] *UNU-MERIT, Maastricht, The Netherlands*

* *Corresponding author. Tel: +4954140933120, Fax: +4954140933110, E-mail: lutz@gws-os.com*

## Abstract

Large-scale economic models for analyzing climate change mitigation policies still lack a common concept of adequately addressing technological change, which is one major driver for differences in results. Price instruments fall into the category of policy measures that induce technical change. However, in these models revenues from environmental tax reform (ETR) or energy and emission taxes and auctioning in emission trading systems have mainly been used for reduction in other taxes and labour costs. The paper at hand analysis two sets of scenarios: one in which the revenues are recycled as known from previous studies and one focussing on the inclusion of directed technological change in such a multi-sector, multi-country model. The scenario analysis is conducted using the global energy-environment-economy model GINFORS, which includes input-output tables for the major economies. GINFORS has been applied to analyze impacts of an EU carbon price via ETS and ETR to reach the EU climate target in 2020. In the second set of scenarios, a small part of the additional revenues are earmarked for low carbon technologies. Simulations look into different specifications of such directed technological change: additional investment in renewable energy sources (RES), additional RES exports and the inclusion of different input structures of the RES industries. Compared to the usual recycling of ETR/ETS revenues, the proposed trigger for eco-innovations has not only positive employment, but also positive GDP impacts. The paper includes an outlook on future research needs such as the explicit modelling of learning curves for certain technologies.

## Keywords

Economy-energy-environment model, price instruments, low carbon technologies

## JEL classification

C54 - Quantitative Policy Modeling, O30 - Technological change, Q43 - Energy and the Macroeconomy

## 1. Introduction

The importance of innovations for social change, international competition, structural change and economic growth has been thoroughly analysed in the past decade. However, how and why innovation comes about and what triggers it or slows it down is still an open question. There is evidence, that knowledge is the most important input in the process of innovation; the importance of knowledge in certain innovative industries has been empirically shown (Dosi 1988, Hullmann 2001). Sparks of innovation emerge through the interplay of different forms of heterogeneous knowledge: their confrontation, combination, fusion, transformation. Different schools of thought describe the accumulation and the distribution of knowledge within the firm, in the economic sector and in innovation system differently.

From an individualistic perspective the analysis focuses on the entrepreneur, who decides about access to knowledge in the firm (Hauschildt 2004). Evolutionary economics takes a more comprehensive approach and sees the firm as knowledge storage and as part of a wider organizational system (Fagerberg et al. 2005). Additionally, the different knowledge generating processes at the level of the firm like learning by searching, learning by doing or learning by interacting and their respective impact on innovation processes are taken into consideration (Malerba 1992). With regard to renewable energies there are however just a few studies which analyse the influence of these different learning mechanisms (see e. g. Miketa and Schrattenholzer 2004) as most analyses are based on the well-known single learning curve approach. An overview on the incorporation of technical change into large-scale energy-environment models with a focus on learning curves can be found in Kahouli-Brahmi (2008). A second widely-used approach in this field is the modelling of energy-related technical change in optimal growth models such as Boucekkine et al. (2011).

The limited knowledge on the drivers of innovations is even more prominent when it comes to studying eco-innovations. The OECD (2009) publication on eco-innovation states that "Government policy initiatives and programmes that promote eco-innovation are diverse and include both supply-side and demand-side measures. As most countries recognize the need for a more collaborative approach to innovation, many initiatives involve creating networks, platforms or partnerships that engage different industry and non-industry stakeholders. Demand-side measures are receiving increasing attention, as governments acknowledge that insufficiently developed markets are often the key constraint for eco-innovation. (…) A more comprehensive understanding of the interaction between supply and demand for eco-innovation will be a pre-requisite for creating successful eco-innovation policies."

The literature body is larger when it comes to single technologies. Among eco-innovations, much research has been done on technologies for the use of renewable energy sources, since European energy markets currently undergo significant changes from centralized monopolistic markets to a more competitive environment with a lot of different participants and the challenges from climate change and environmental issues have to be met. Apart from environmental goals, the support policies aim at economic development and technological change. The German feed-in tariff, for instance, has already triggered the rapid development in the German wind industry and in the photovoltaic industry. But it is widely agreed that still a lot of innovation is needed for technologies to provide clean electricity at affordable cost at a large scale for the future.

Success factors in these innovation systems hinge on a wide array of determinants. They differ depending on the innovation phase, the technology and the actors, institutions and participants in the innovation system. For instance, the technological system for solar cells exhibits some very interesting characteristics (Roloff et al. 2008): Firstly, the technology as such has been known for more than 100 years by now (Green 2000). However, the technological development was dominated by 'science-based experimentation' until the 1990s. Solar cells were first used for extraterrestrial applications during the so called 'Space Age' (1958 to 1973). Later on they were also used for consumer electronic products as well as for off-grid power systems (1974 until mid-1990s). Nevertheless public policy measures still had a strong focus on the support of R&D activities. Until Japan and Germany started their first demand-oriented programs during the 1990s the role of photovoltaics (PV) with regard to the supply of energy thus remained quite limited. These initiatives and successive programmes and regulative changes eventually led towards a significant growth of the PV-industry and therefore to an expansion of the whole technological system (Jacobsson et al. 2002). As the technology evolved, the motifs of actors changed and new actors have been attracted to the field.

Other case studies show similar effects, for instance on wind energy supported by tax breaks in Texas (Langniss 2003), introduction of wind energy in Denmark supported by R&D support (Buen 2006) and demand oriented instruments as the most important instrument, or the German example with successful diffusion of innovative production technologies due to demand support mechanisms and low interest rates on credits for wind mills.

The Japanese and the German experience with solar modules seem to support the hypothesis that R&D support, followed by demand side mechanisms and a strong regulatory framework promote innovations. The guaranteed market created by demand side instruments helps diffusion of innovative products *and* the invention by innovative firms as well. R&D support and tax breaks, however, have proved to be successful as well, as long as the system is transparent and continuous.

However, these studies focused on success or failure case studies of specific eco-innovations such as wind mills or solar panels. To get a complete picture, Lehr et al. (2010) screened studies on the relation between environmental regulation and price-based policy instruments. They conclude that "the studies reviewed suggest that environmental regulation in general, and price-based policy instruments such as environmental taxes and investment subsidies in particular, can (in theory) and do (in practice) have a positive impact on both innovation and diffusion of environmental technologies. However, the supporting empirical and case study evidence is not universal and the effectiveness of these instruments would appear to vary across different sectors and different types of innovation."

All of this suggests that caution should be exercised in drawing general, definitive conclusions about the impacts of price-based policy instruments such as environmental taxes and investment subsidies on innovation – particularly relative to other policy instruments. While it would appear that they can be effective in stimulating both innovation and diffusion in many cases – at least in terms of the rate of technological change, there may be situations in which other policy instruments may be more appropriate. In general, the stringency and point of incidence of an environmental policy intervention may be more important than the choice of a particular policy instrument in determining the rate and direction of eco-innovation.

In macro models the treatment of technological change is still a major source of cost differences of climate change mitigation (IIASA 2009), despite various research efforts in the last years. Most models compared in a OECD/IEA (2009) study set technological progress exogenously by assumption. In a literature review on eco-innovation and economic instruments Lehr et al. (2010) conclude that quantification of eco-innovation is still difficult, despite evidence on the positive impact of higher energy prices. Johnstone and Hasic (2009, p. 161) examined the effects of public policies on innovation in the area of renewable energies in a cross-section of OECD countries over the period 1978-2003, finding that the empirical results indicate a strong influence of policies on innovation in renewable energy technologies. Schwark (2010) compares two CGE models with regard to the modelling of technical change (endogenous/exogenous) and the resulting effects on the impacts of carbon taxes on different industries. The main finding is that endogenizing technical change using 'gains from specialization' reveals dynamic growth patterns that cannot be reproduced in a model with exogenous technical change. Overviews on modelling technical change in growth theoretic models as well as large-scale econometric models can be found in Löschel (2002) and for models developed more recently in Kahouli-Brahmi (2008).

Most recent efforts to endogenize technological change in economic models of climate change mitigation often abstract from specific technologies. Acemoglu et al. (2012) look at environmentally directed technological change in a simple one-good-two-sector growth model with environmental constraints. According to their analysis substitutability of clean and dirty inputs is very important to avoid growth losses. Optimal environmental policy includes carbon taxes and research subsidies. One major conclusion (on p.28 in the forthcoming version) is that "it would be useful to develop a multi-country model with endogenous technology and environmental constraints," to discuss global policy coordination and to deploy the link between environmental and trade policy.

Popp et al. (2010) differentiate between direct price-induced, R&D-induced and learning-induced technological change to be included in aggregate energy-environment models. Interesting areas for further research include modelling of policy instruments that are closer to the real world policy mix, progress on learning curve and directed R&D modelling

In macro models revenues from environmental tax reform or energy and emission taxes and auctioning in emission trading systems have been mainly used for reduction in other taxes or labour costs. This has often been related to the debate about a double dividend of environmental taxes (Patuelli et al. 2005). Australia's new carbon tax will be basically refunded via cuts in other taxes. R&D support, focussing on the environmental problem discussed, or support for the diffusion of (best) available technologies are other options. In Germany, all EU-ETS auctioning revenues are collected in the energy and climate fund, which is fully earmarked for energy efficiency and climate mitigation or adaptation measures.

The modelling exercise actually looks into scenarios designed to explicitly support low carbon technologies such as renewable energy sources (RES) technologies. Simulations build on the Anglo-German Foundation (AGF) petrE (Resource Productivity and Environmental Tax Reform in Europe) project (Ekins and Speck 2011). In one of the scenarios 10% of the ETS/ETR revenues are earmarked to support investment in renewable energy and energy efficiency to enhance innovation. In further scenarios additional EU exports due to RES investment in other parts of the world and changes in the EU industry structure due to a shift towards RES in the electricity sector are explicitly modelled. With the current enormous increase in RES installation in China and the international response to the nuclear disaster in Japan, these assumptions seem to be more realistic than the quite pessimistic international perspective about RES technology deployment in the underlying baseline development. The latest IEA (2011) world energy outlook calls for enormous efforts to foster renewable energy sources and to increase energy efficiency improvements.

The paper is structured as follows. In section 2 the model GINFORS is briefly described. Implemented scenarios are presented in section 3. Modelling results are discussed in section 4. Some conclusions and further research needs close the paper with section 5.

## 2. The GINFORS model

The simulation instrument – the global model GINFORS (Global INterindustry FORecasting System) – describes the economic development, energy demand, $CO_2$ emissions and resource inputs for 50 countries, 2 regions, 41 product groups, 12 energy carriers and 9 resources. The regions are "OPEC" and "Rest of the World". The explicitly modelled region "OPEC" and the 50 countries cover about 95% of world GDP and 95% of global $CO_2$ emissions. The aggregated region "Rest of the World" is needed for the closure of the system. The model is documented in Lutz et al. (2010). Current applications of the model can be found in Barker et al. (2011a), Giljum et al. (2008), Lutz and Meyer (2009a, 2009b, 2010) and Lutz (2010). The related German model PANTA RHEI has been applied to endogenize technological change in a few industry sectors as iron and steel and paper (Lutz et al. 2005 and 2007) and to evaluate the German energy concept (Lindenberger et al. 2010).

GINFORS is in many respects close to neoclassical CGE models, but shows some major differences. One is the representation of prices, which are determined due to the mark-up hypothesis by unit costs and not specified as long run competitive prices. But this does not mean that the model is demand side driven, as the use of input-output models might suggest. Even though demand determines production, all demand variables depend on relative prices that are given by unit costs of the firms using the mark-up hypothesis, which is typical for oligopolistic markets. Firms are setting the prices depending on their costs and on the prices of competing imports. Demand is reacting to price signals and thus determining production. Hence, the modeling in GINFORS includes both demand and supply elements.

Allowance prices and carbon tax rates are endogenous to the model. To avoid long solving procedures, the prices are changed in an iterative process manually until the GHG reduction target is reached. Allowance prices increase the shadow prices of energy carriers and reduce energy demand according to the specific price elasticities. Different allocation methods therefore have no direct influence on energy demand and the emission levels in the model. But increasing profits of private companies in the case of grandfathering deliver macroeconomic impacts other than government spending financed by auctioning revenues.

All behavioural parameters of the model are estimated econometrically, and different specifications of the functions are tested against each other, which gives the model an empirical validation. An additional confirmation of the model structure as a whole is given by the convergence property of the solution which has to be fulfilled on a yearly basis. The econometric estimations build on times series from OECD, IMF and IEA from 1980 to 2006. However, for a number of variables the data were only available for a shorter time period. The modelling philosophy of GINFORS is close to that of INFORUM type modelling (Almon 1991) and to that of the model E3ME from Cambridge Econometrics. Common properties and minor differences between E3ME and GINFORS are discussed in Barker et al (2011b).

As GINFORS is an input-output model it includes the structure of the economies in the technical coefficient matrices. Innovation and technological change at the industry level is represented by changes in these coefficients. In the current GINFORS version technological progress is implicitly modelled. The technology is depicted in a two-stage approach. In the first stage capital, labour, energy and material are factors of a limitational technology, but the input coefficients are not constant. The sectoral factor demand functions for labour, capital, energy and material of the first stage depend on the relation of the factor price and the sector price, which is interpreted as the effect of cost push driven technological progress. Additionally time trends reflect autonomous progress. In the second stage the energy input is divided into the demand for the different energy carriers assuming price dependent substitution. The input of wind, solar, biomass and geothermal is assumed to be mainly policy driven and set exogenously according to national allocation plans for EU countries or global scenarios such as IEA (2010) or Krewitt et al. (2008). Using global learning or logistic curves the technological change in the renewable energy sector and the diffusion of technology around the world can be endogenously modelled in GINFORS: By considering global installed capacity of the different renewable energy technologies cost reductions can be endogenously modelled. For most countries these cost reductions are exogenous, but through changing relative prices for the different energy technologies the countries' energy mix changes. This in turn influences global installed capacity.

## 3. Scenarios

Environmental tax reforms (ETR) fall into the category of policy measures that induce technical change. To investigate the impacts of an ETR for Europe six separate scenarios have been designed in the petrE project to understand a variety of tax reform options (Barker et al. 2011a). The scenario analysis allows for an understanding of different revenue recycling methods and various scales of ETR in order to meet different greenhouse gas emissions targets. The scenarios include:

- BH: Baseline (reference case),
- Scenario S1H: ETR designed to meet unilateral EU 2020 GHG target with revenue recycling,
- Scenario S2H: ETR designed to meet unilateral EU 2020 GHG target with revenue recycling, 10% of revenues are spent on eco-innovation measures,

In the baseline scenario coal and gas prices develop in line with the increases to the oil price. In this scenario energy prices are close to the assumptions in the current IEA World Energy Outlook (2011).

Each of the ETR scenarios has the same key taxation components:

- a carbon tax rate is introduced to all non EU ETS sectors equal to the carbon price in the EU ETS that delivers an overall 20% reduction in greenhouse gas emissions by 2020, in the international cooperation scenario this is extended to 30%,
- aviation is included in the EU ETS at the end of Phase 2,
- power generation sector EU ETS permits are 100% auctioned in Phase 3 of the EU ETS,
- all other EU ETS permits are 50% auctioned in 2013 increasing to 100% in 2020,
- material taxes are introduced at 5% of total price in 2010 increasing to 15% by 2020.

In scenario S1H environmental tax revenues are recycled through reductions in income tax rates and social security contributions in each of the member states, such that there is no direct change in tax revenues. In scenario S2H 10% of the environmental tax and ETS revenues are recycled through spending on eco-innovation measures, the remaining 90% is recycled through the same measures as in the other scenarios. In GINFORS the share of renewable sources in electricity production is increased by additional investment, which is induced by part of the ETR revenues. Another part of the revenues goes to household energy efficiency spending. Investment needed for a certain increase in renewable energy supply (RES) or efficiency improvement is based on German and Austrian experience (Lehr et al. 2008 and 2009, Stocker et al. 2011, Lutz and Meyer 2008). This assumption is quite conservative as parameters for other countries can be assumed to be more positive. They can make use of available technologies without corresponding R&D spending.

In scenario S1H the 20% GHG target translates into a 15% reduction of energy-related carbon emissions against 1990 as other emissions such as methane and nitrous oxide have already been reduced above average. The target is reached by a tightened EU ETS cap and the introduction of a carbon tax on the non-ETS sector. The tax rate applied is equal to the carbon price in the EU ETS that will deliver 20% reduction in GHG by 2020.

ETR tax will be allotted to energy outputs, i.e. the final use of energy, and will be based on the carbon content of each fuel. Carbon prices are assumed to be fully passed on to consumers. All carbon taxes will be in addition to any existing unilateral carbon and energy taxes. The carbon reductions in the different EU Member States (MS) will be those that the same carbon tax increase across the EU produces.

All of the revenues, including EU ETS auctioning revenues, carbon tax revenues and material tax revenues will be recycled. The environmental tax paid by industry will be offset by a reduction in employers' social security contributions, which will in turn reduce the cost of labour. Recycling will be additional to the existing ETRs in some member states. Revenues raised from households will be recycled through standard rate income tax reductions. Traditional energy tax revenues will be lower compared to the respective baseline, as the tax base (energy consumption) is reduced. So revenue-neutrality does not mean budget-neutrality of an ETR.

Earlier analyses (Boira-Segarra 2004, Kammen et al. 2004, Moreno and López 2007, Lehr et al. 2008, ISI et al. 2009) studied the impacts of large shares of RES in the energy mix for different countries. The overall question in these studies has been the impact of increasing RES shares on the economy, especially on the labour market. For the scope of our work here it is interesting to note that macroeconomic impacts of higher RES shares mainly depend on

(1) additional investment in RES (minus lower investment in conventional, i.e. fossil and nuclear power) obviously even more so if a country has the respective industry,
(2) additional (net) exports due to better international competitiveness for RES (first mover advantage),
(3) lower fossil fuel needs,
(4) the cost differences between RES and conventional energy and
(5) the shift from capital- and energy-intensive industries to labour- and technology-intensive industries.

All these channels are driven by international energy prices, carbon prices, the policy framework and the RES technology development itself. Innovation enters the process at various stages: Firstly, innovation drives the currently positive additional costs of RES technologies down and into the negative realms, depending on the respective fossil fuel scenario. Secondly, innovative products increase the competitive advantage of products on the international markets. Though a fair share of the RES technology production in Europe is traded in Europe, innovation will still provide an edge on current and emerging international markets. The EmployRES study (ISI et al. 2009) finds for Europe that currently strong investment impulses - based on installations in Europe and exports to the rest of the world - dominate the economic impact of RES policies and therefore lead to positive overall effects. The results in the study suggest that this positive balance can only be kept up in the future, if the competitive position of European manufacturers of RES technology is even improved: The authors strongly recommend “policies which promote technological innovation in RES and lead to a continued and rapid reduction of their costs”.

(1) and (2) will have substantial impacts in the short and medium-term, whereas (3) adds up and will show positive stock impacts mainly in the long-term. (4) strongly depend on the global development. (5) may have significant effects on employment.

Impacts of additional investment (1) have already been analysed in scenario S2H of the petrE project. To focus on the impacts of innovation directed towards low carbon technologies two additional scenarios have been designed, that build on scenario S2H of the petrE project:

- S2HE: ETR with revenue recycling designed to meet the unilateral EU 2020 GHG target, 10% of revenues are spent on eco-innovation measures, trade shares of EU-27 economies with the rest of the world in machinery and electrical machinery increase by .1% due to the deployment of the fast growing RES markets. This assumption is based on the strong EU policy effort to increase the share on renewable energy in final energy consumption to 20% by 2020 (ISI et al. 2009) and the possibility of very strong world market development of the RES until 2020 (Krewitt et al. 2008), which offers additional export opportunities for European RES industries.
- S2HI: ETR with revenue recycling designed to meet the unilateral EU 2020 GHG target (high oil price), 10% of revenues are spent on eco-innovation measures, input structures of the utility sector are changed according to the input structure of the German RES industry (Lehr et al. 2008).

S2HE looks at the possible role of international trade (2), S2HI analyses changing in the input structure of the utility sector, i.e. from conventional electricity production to renewables (5). In the petrE project (as in GHK et al. 2007) only the energy inputs of the utility sector had been adapted to changes in the energy input mix.

Both scenarios focus on RES and efficiency technologies. As mentioned above, an ETR will trigger a variety of innovations as such. Therefore the results can be thought of as conservative in the sense that innovations e.g. on automotive energy consumption, industrial efficiency, community efforts etc. are not included explicitly.

## 4. Overview of modelling results

The main results of the simulations are highlighted in Table 1. In the baseline scenario BH, EU-27 carbon emissions will be 7.2% below 1990 level in 2020. EU-15 has committed in the Kyoto protocol to reduce its GHG emissions 8% below 1990 levels in the period 2008-2012. As emissions in the new member states are substantially below their 1990 levels today, EU-27 will keep its emissions more or less constant over the coming decade. As in the PRIMES baseline an ETS price of 18 Euro/t in 2008 prices is assumed in 2020 (DG TREN 2008).

In scenario S1H the ETS price and carbon tax rate has to be increased to 68 Euro2008/t of $CO_2$ to reach the 20% GHG reduction target, which is equal to a 15% reduction of $CO_2$ emissions against 1990 as other greenhouse gases have already been reduced above average.[1] Compared to the baseline, $CO_2$ emissions are 8.4 % lower in 2020 which means an additional 1% p.a. reduction in the period 2012 to 2020. GDP will be about 0.6% lower compared to the baseline in 2020. This means that annual average growth rates will be less than 0.1% below their baseline development. This is especially low compared to the current financial and economic crisis, with a GDP deviation against the baseline of around 6% in 2009, which may further increase due to the debt crisis until 2020..

As the recycling mechanism reduces labour costs and the tax burden is shifted from labour-intensive to carbon- and material-intensive sectors employment will be 0.36% (or more than 800.000 jobs) higher than in the baseline. The ETR is not fully budget-neutral for the EU economies that can slightly increase their net savings. If this extra saving is spent, negative GDP impacts will be further reduced.

**Table 1: Main results in the different scenarios**

| Scenario | Target in 2020 | $CO_2$ price | GDP | | Employment | $CO_2$ reduction | |
|---|---|---|---|---|---|---|---|
| | | Euro2008/t | pc against baseline | | pc against baseline | pc against 1990 | pc against baseline |
| | in year | 2020 | 2015 | 2020 | 2020 | 2020 | 2020 |
| BH | | 18 | | | | -7.2 | 0.0 |
| S1H | 20% GHG | 68 | -0.22 | -0.57 | 0.36 | -15.1 | -8.4 |
| S2H | 20% GHG | 61 | -0.13 | -0.30 | 0.41 | -15.2 | -8.5 |
| S2HE | 20% GHG | 61 | -0.09 | -0.04 | 0.51 | -15.1 | -8.4 |
| S2HI | 20% GHG | 61 | -0.06 | -0.24 | 0.45 | -15.2 | -8.4 |

If part of the revenues is used for investment in low carbon technologies, the carbon price in scenario S2H can even be lower (61 Euro2008/t in 2020) and the GDP loss halved against scenario S1H to only 0.3%, as the investment in renewable energies is assumed to be additional. Employment impacts will be more positive than in scenario S1H. The 10% investment in low carbon technologies will amount to more than 20 Bill. Euro in 2020. In comparison, the energy scenarios for the German energy concept expect additional annual green investment in German of around 15 Bill. Euro.

If we assume additional EU exports of RES technologies in scenario S2HE, GDP could be almost the same as in the baseline in 2020. Employment will be 0.51% (or more than 1 mill. jobs) higher than in the baseline. A shift in the input structure of the utility sector towards machinery and electrical machinery, that reflects the different nature of RES in relation to conventional electricity generation, has also smaller additional positive impacts on GDP and employment compared to scenario S2H.

[1] Note that economic development does nor take the economic crisis into account. Therefore reported carbon prices are much higher than current EUA prices and futures.

The following figures show impacts of the different scenarios in comparison to the baseline BH. According to Figure 2 GDP is slightly lower. The comparison of scenario S1H with the other 3 scenarios shows that additional RES investment (S2H), additional RES exports (S2HE) and the inclusion of different input structures of the RES industries (S2HI) have per se positive GDP impacts. Both results are in line with model-based analysis in the EMPLOY-RES study (ISI et al. 2009).

In contrast to GDP, employment increases in all scenarios (Figure 3). Due to the scenario design the structure of the EU economies is shifted from energy-intensive to labour-intensive sectors. The magnitude of the employment gain is influenced by the carbon price and the tax shift, the underlying energy prices and the production loss. The largest part of the employment increase stems from the ETR (scenario S2), whereas a shift in industry structures (S2HI) and additional RES exports (S2HE) are both positive for the labour market but less important. As ETR is directly targeting labour costs, it is better suited to create additional jobs than positive effects of eco-innovation on the industry structure or export markets.

Part of the modeled technical change becomes apparent when comparing the energy productivity in the different scenarios. Figure 4 displays the deviation of energy productivity in percent from the baseline, showing that by 2020 it is about 6% to 7% higher in the EU 2020 GHG target scenarios. Energy productivity here is measured as GDP (in billion USD2005) divided by total primary energy supply (in Mtoe) and increases in the baseline from 6.5 in 2010 to 7.9 in 2020 for the EU-27. The increase in the different scenarios is higher so that the value is between 8.4 and 8.5 in 2020. Note however, that the additional efficiency increase in the new scenarios S2HI and S2HE is small, partly due to the targeted $CO_2$ cap. The difference between the scenarios is rather visible in the economic indicators. Energy efficiency improvements should additionally be modelled and analysed for each country at the sectoral level in order to better identify the effect of technical change on energy usage.

**Figure 1: GDP of EU-27 in Bill. US-Dollars (PPPs) in prices of 2005 in different scenarios**

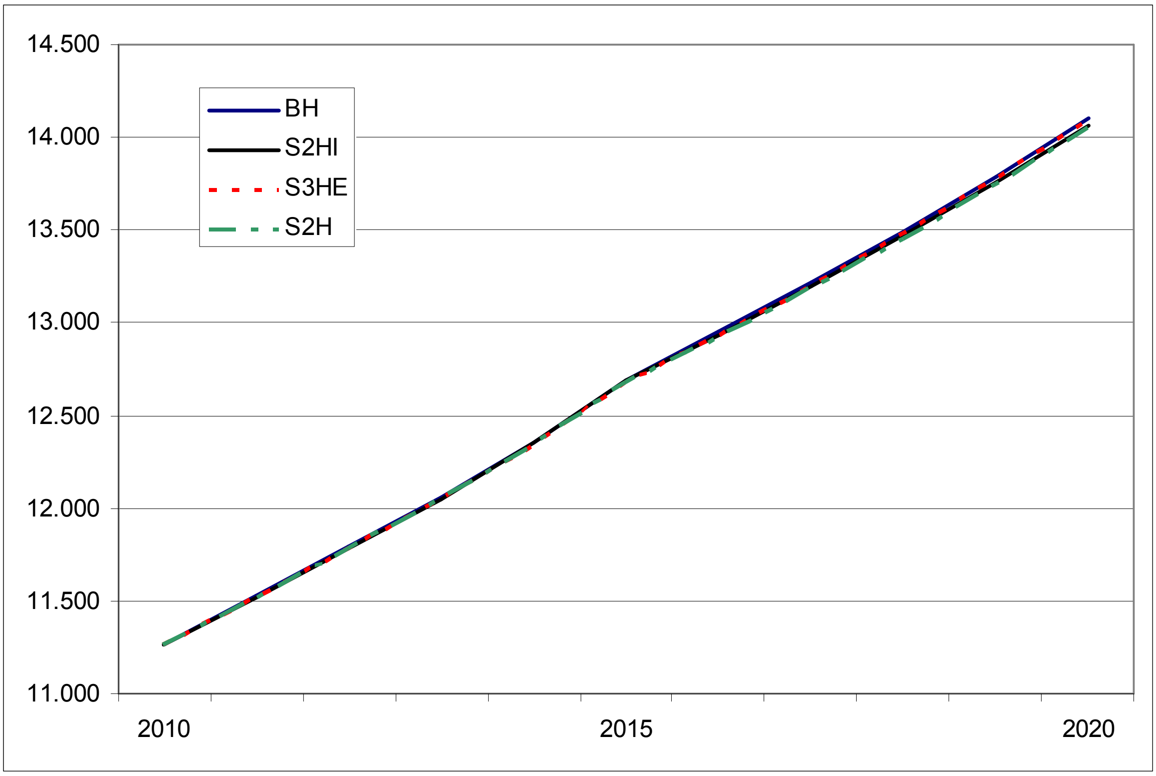



**Figure 2: GDP of EU-27 in Bill. US-Dollars (PPPs) in prices of 2005 in different scenarios - percentage deviations against the baseline BH**

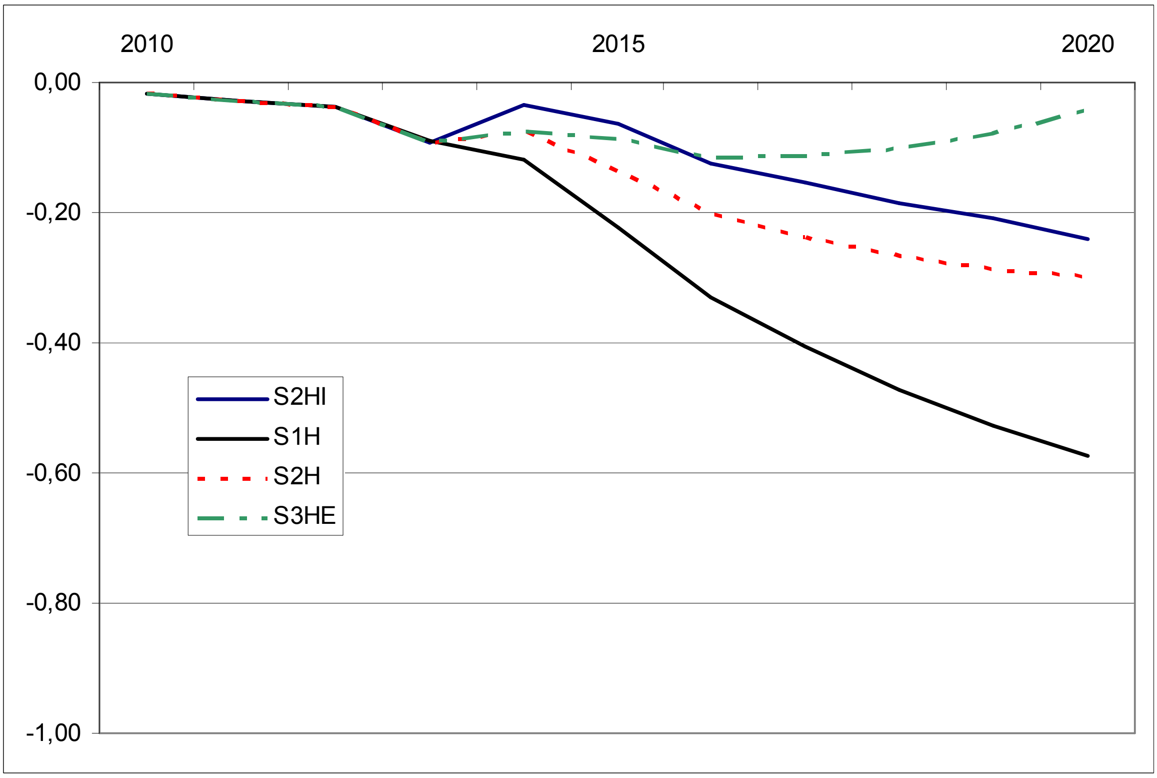


**Figure 3: Employment in EU-27 in 1000 in different scenarios - percentage deviations against the baseline**

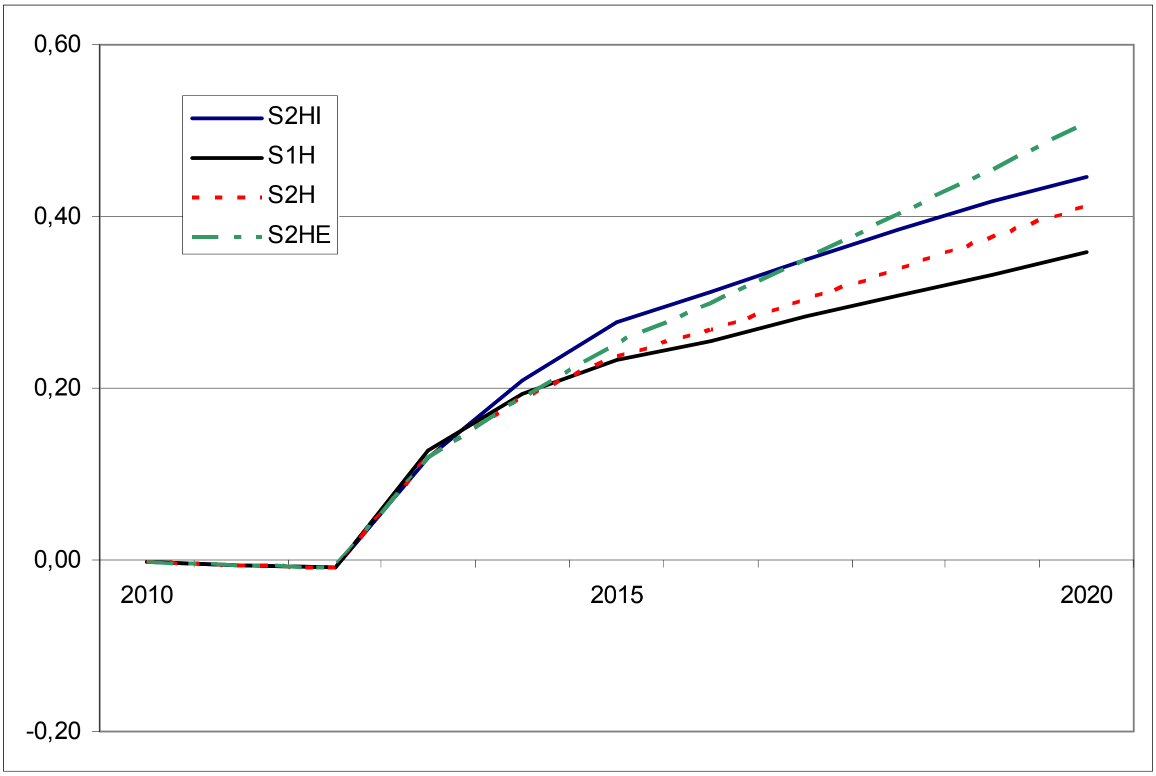
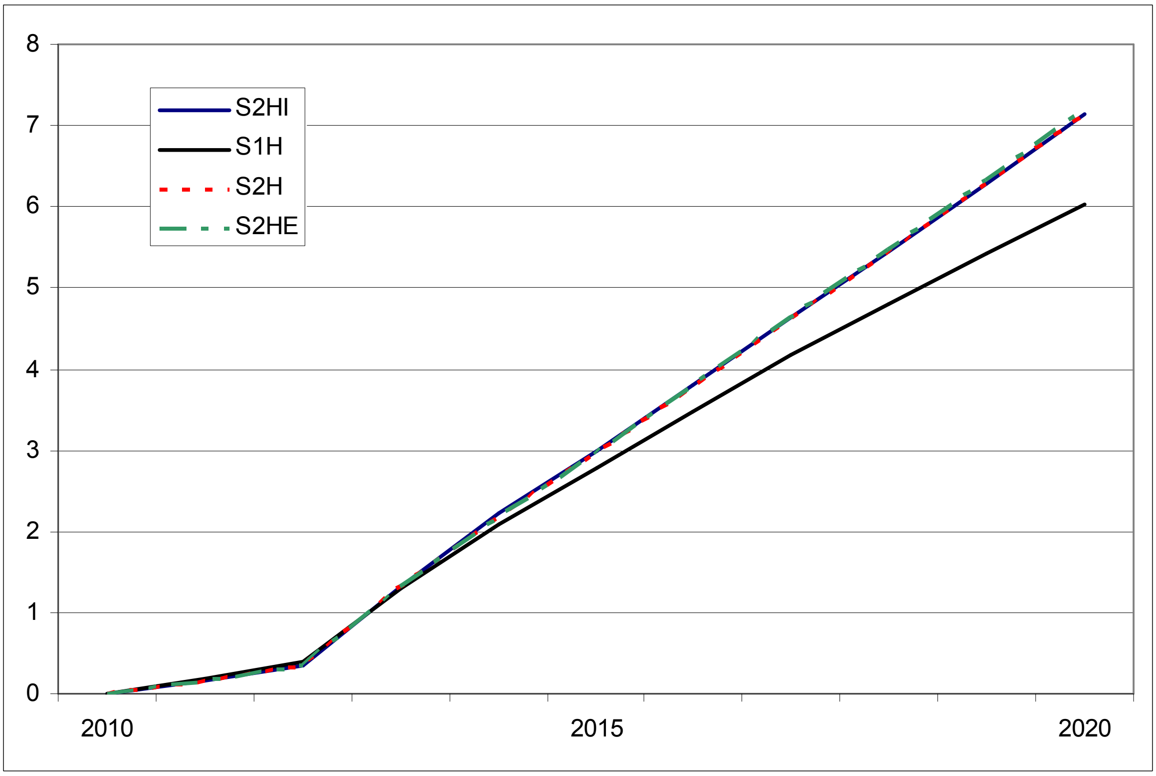



**Figure 4: Energy productivity in EU-27 in different scenarios - percentage deviations against the baseline**



Additional exports in scenarios S2HE mainly create new jobs in machinery and in related business services as the German example shows in Table 2. A shift in the input structure of the utility sector leads to a shift in the industry structure and creates a few jobs in the service sector (Table 3).

**Table 2: Employment impacts of scenario S2HE in Germany – deviations from scenario S2H in 2020**

| **Employment in 2020** | Deviation from S2H | Deviation from S2H |
|---|---|---|
| | in % | absolute |
| Agriculture, forestry | -0,1 | -0,2 |
| Industry | 0,3 | 19,4 |
| Non-metallic minerals | 0,2 | 0,5 |
| Iron and steel | 0,4 | 0,5 |
| Machinery and equipment | 1,3 | 13,0 |
| Electrical machinery | 2,4 | 11,7 |
| Construction | 0,1 | 1,8 |
| Trade and transport | 0,0 | 2,6 |
| Business services | 0,7 | 30,8 |
| Other services | 0,1 | 10,7 |
| Total | 0,2 | 63,4 |

**Table 3: Employment impacts of scenario S2HI in Germany – deviations from scenario S2H in 2020**

| **Employment in 2020** | Deviation from S2H | Deviation from S2H |
|---|---|---|
| | in % | absolute |
| Agriculture, forestry | -0,1 | -0,2 |
| Industry | 0,0 | 0,0 |
| Non-metallic minerals | 2,5 | 6,5 |
| Iron and steel | -2,7 | -3,6 |
| Machinery and equipment | 0,8 | 7,8 |
| Electrical machinery | 0,4 | 1,9 |
| Construction | 0,0 | -0,4 |
| Trade and transport | 0,0 | 0,7 |
| Business services | 0,2 | 11,5 |
| Other services | 0,0 | 5,6 |
| Total | 0,0 | 16,7 |

## 5. Conclusions and outlook

The GINFORS model has been applied to assess economic and environmental impacts of ETS and ETR to reach the EU GHG targets in the EU in 2020. Results show positive employment effects and only small negative impacts on GDP. Economic impacts depend on the level of international energy prices, the recycling mechanism, country specifics such as carbon and energy intensity and structure of energy consumption.

Although there is large evidence, that low carbon technologies are positively driven by higher energy-prices, quantification is difficult. In two simulations possible impacts of a shift in the industry structure towards renewable energy in the electricity sector and an overall increase of EU exports due to higher global demand for renewable energy are modelled. The main results can be summarized as follows:

An ETR, shifting taxes from labour to energy and resources will create additional jobs and trigger eco-innovation. Impacts of eco-innovation in the form of additional EU exports or shifts in industry structures will slightly increase GDP and create a smaller number of additional jobs. These findings correspond to results from the EmployRES study. As ETR is directly targeting labour costs, it will create additional jobs in the short and medium term. The impacts of eco-innovation in the form of cost reduction and new technologies will play a larger role in the longer term.

ETR together with auctioning of ETS allowances can be a major source of revenues for EU countries in the future. But at least the share of revenues from carbon pricing will be limited. Part of the revenues will have to be earmarked for adaptation and mitigation measures in developing countries.

Results should be carefully related to the EU policy debate. In the model simulations the single carbon price is the only instrument to reach the EU 2020 GHG targets except the 10% of revenues spent for low carbon technologies. Renewable energy and efficiency policies will also contribute to carbon reduction and have to be taken into account, when comparing the results (especially the high carbon prices) to other studies. Both reduce the potential revenues from fossil energy carriers and carbon emissions. There are different renewable energy and efficiency policies that could further improve the economic impacts of reaching the climate and energy targets. The results clearly indicate to intensify the discussion on market-based instruments, but eventually a policy mix will be needed to reach the EU GHG targets.

In the current GINFORS version technological progress is implicitly modelled. Future research will focus on the possible inclusion of technological change, which might be twofold. First, for the following RE technologies global capacity and electricity production can be explicitly modelled: Wind onshore and offshore, geothermal, solar thermal (CSP), and photovoltaic. Reported learning curves can be included in the model for these technologies. Every doubling of global capacity will reduce the costs by the learning rate. From a national policy point of view, this can be seen as an exogenous cost reduction with the exception of PV. About 50% of global PV installations have been made in Germany in 2010, expected to fall to 1/3 in 2011. Costs have been halved during the last 10 years.

Second, Germany and Europe are also a RE technology driver or setter. This is currently obvious for PV, with halve of global installations driven by the German feed-in-tariff in 2010, but has also been the case for international CSP development and probably wind power. The role of the German feed-in-tariff will become even more important, if the “export” of the German RE regulation into many countries is taken into account. About 45 countries have today adopted feed-in-tariffs. The diffusion of the national (German) regulation itself is a major driver for global installations, which brings down technology costs via global learning curves, and increases, by the way, German RE technology exports. This loop indicates that the policy mix of a frontrunner country can influence global technology development and create additional first-mover advantages.

In another step, the supplemented model might be used for impact assessment and sensitivity analyses. GINFORS offers possibilities of a global simulation model, which includes a quite detailed country model for important EU economies. Once enlarged and improved as described above, it is an ideal instrument for impact assessment, i.e. for answering “if-then” questions. Different scenario results can be compared to a reference scenario concerning EU and global welfare (GDP, employment) and other model results such as trade, energy use or emissions.

## References


Acemoglu, D., Aghion, H., Bursztyn, L & Hemous, D. (2012): The environment and directed technical change. The American Economic review, forthcoming.

Almon, C. (1991): The INFORUM Approach to Interindustry Modeling. In: Economic Systems Research, Vol. 3, pp. 1-7.

Barker, T., Lutz, C., Meyer, B., Pollitt, H. & Speck, S. (2011a): Modelling an ETR for Europe. In: Ekins, P. & Speck, S. [ed.]: Environmental Tax Reform (ETR) - A Policy for Green Growth, Oxford University Press, New York, pp. 204-235.

Barker, T., Lutz, C., Meyer, B. & Pollitt, H. (2011b): Models for Projecting the Impacts of ETR. In: Ekins, P. & Speck, S. [ed.]: Environmental Tax Reform (ETR) - A Policy for Green Growth, Oxford University Press, New York, pp. 175-203.

Boira-Segarra, I. (Mott McDonald) et. al (2004): Renewable Supply Chain Gap Analysis. Study on behalf of the Department of Trade and Industry.

Boucekkine, R., Hritonenko, N., Yatsenko, Y. (2011): Sustainable growth under pollution quotas: optimal R&D, investment and replacement policies, Working Papers halshs-00632887, HAL.

Buen, J. (2006): Danish and Norwegian wind industry: The relationship between policy instruments, innovation and diffusion. Energy Policy, Vol. 34 (18), pp. 3887-3897.

DG TREN (2008): European Energy and Transport. Trends to 2030 - update 2007, Luxembourg.

Dosi, G. (1988): Sources, Procedures, and Microeconomic Effects of Innovation. In: Journal of Economic Literature, Vol. 26, pp. 1120-1171.

Ekins, P. & Speck, S. (2011): Environmental Tax Reform (ETR): Resolving the conflict between economic growth and the environment. Oxford University Press.

Fagerberg, J., Mowery, D. C. & Nelson, R. R. (eds.) (2005): The Oxford Handbook of Innovation. Oxford University Press, Oxford.

GHK, Cambridge Econometrics & IEEP (2007): Links between the environment, economy and jobs’, Final Report submitted to DG Environment, European Commission, November 2007.

Giljum, S., Behrens, A., Hinterberger, F., Lutz, C. & Meyer, B. (2008): Modelling scenarios towards a sustainable use of natural resources in Europe. Environmental Science and Policy, Vol. 11, pp. 204-216.

Green, M. A. (2000): Photovoltaics: technology overview. Energy Policy, Vol. 28 (14), pp. 989-998.

Hauschildt, J. (2004): Innovationsmanagement. Vahlen, München.

Hullmann, A. (2001): Internationaler Wissenstransfer und technischer Wandel (Dissertation). Physica-Verlag, Heidelberg.

IIASA (2009): GHG mitigation potentials in Annex I countries. Comparison of model estimates for 2020. Interim report 09-034. Laxenburg, Austria.

International Energy Agency [IEA] (2010): World Energy Outlook 2010, Paris.

International Energy Agency [IEA] (2011): World Energy Outlook 2011, Paris.

ISI (Fraunhofer ISI), ECOFYS, Energy Economics Group, Rütter + Partner, SEURECO & LEI [ISI et al.] (2009): The economic impact of renewable energy policy on economic growth and employment in the European Union. Brussels.

Jacobsson, S., Andersson, B. A., & Bångens, L. (2002): Transforming the energy system - the evolution of the German technological system for solar cells. SPRU (Science and Technology Policy Research), University of Sussex: *Electronic Working Paper Series*, No. 84. Online: http://www.sussex.ac.uk/Units/spru/publications/imprint/sewps/sewp84/sewp84.pdf (accessed: 05-14-2007).

Johnstone, N., Hascic, I. & Popp, D. (2010): “Renewable energy policies and technological innovation: evidence based on patent counts”, Environmental & Resource Economics, 45, 133-155.

Kahouli-Brahmi, S. (2008). Technological learning in energy-environment-economy modelling: A survey. Energy Policy, 36, 138–162.

Kammen, D. M., Kapidia, K. & Fripp, M. (2004): Putting Renewables to Work: How Many Jobs Can the Clean Energy Industry Generate? University of California, Berkeley.

Krewitt, W., Teske, S., Pregger, T., Naegler, T., Simon, S., Graus, W., Blomen, E. et al., 2008. “Energy (R)evolution – a Sustainable World Energy Outlook.” Study commissioned by Greenpeace Int. and the European Renewable Energy Council (EREC), Stuttgart, Utrecht, 2nd edition 2008.

Langniss, O. (2003): Governance Structures for Promoting Renewable Energy Sources. Dissertation. Lund, Stuttgart

Lehr, U., Nitsch, J., Kratzat, M., Lutz, C. & Edler, D. (2008): Renewable Energy and Employment in Germany. Energy Policy, 36, 108-117.

Lehr, U., Wolter, M.I. & Großmann, A. (2009): Economic Impacts of RES Obligations in Austria – an Application of the Macro-Econometric Model e3.at. GWS Discussion Paper 2009/1, Osnabrück.

Lehr, U., Lutz, C. & Salmons, R. (2010): Literature review on eco-innovation and ETR Modelling of ETR impacts with GINFORS. GWS Discussion Paper 10/2, Osnabrück.

Lindenberger, D., Lutz, C. & Schlesinger, M. (2010): Szenarien für ein Energiekonzept der Bundesregierung. Energiewirtschaftliche Tagesfragen, 60(11), 32-35.

Löschel, A. (2002). Technological change in economic models of environmental policy: A survey. Ecological Economics, 43, 105–126.

Lutz, C. & Meyer, B. (2008): Beschäftigungseffekte des Klimaschutzes in Deutschland. Untersuchungen zu gesamtwirtschaftlichen Auswirkungen ausgewählter Maßnahmen des Energie- und Klimapakets. Forschungsbericht 205 46 434, Dessau-Roßlau.

Lutz, C. & Meyer, B. (2009a): Environmental and Economic Effects of Post-Kyoto Carbon Regimes. Results of Simulations with the Global Model GINFORS. Energy Policy, Vol. 37, pp. 1758-1766.

Lutz, C. & Meyer, B. (2009b): Economic impacts of higher oil and gas prices. The role of international trade for Germany. Energy Economics, 31, 882-887.

Lutz, C. & Meyer, B. (2010): Environmental Tax Reform in the European Union: Impact on $CO_2$ Emissions and the Economy. Zeitschrift für Energiewirtschaft, 34, 1-10. DOI: 10.1007/s12398-010-0009-x

Lutz, C., Meyer, B., Nathani, C. & Schleich, J. (2005): Endogenous technological change and emissions: The case of the German steel industry. Energy Policy, 33 (9), 1143-1154.

Lutz, C., Meyer, B., Nathani, C. & Schleich, J. (2007): Endogenous innovation, economy and environment: impacts of a technology based modelling approach for energy-intensive industries in Germany. Energy Studies Review, 15(1), 2-18.

Lutz, C., Meyer, B. & Wolter, M.I. (2010): The Global Multisector/Multicountry 3E-Model GINFORS. A Description of the Model and a Baseline Forecast for Global Energy Demand and $CO_2$-Emissions. International Journal of Global Environmental Issues, 10(1-2), 25-45.

Lutz, C. (2010): How to increase global resource productivity? Findings from modelling in the petrE project. International Economics and Economic Policy, 7, 343-356. DOI: 10.1007/s10368-010-0160-1

Malerba, F. (1992): Learning by firms and incremental technical change. The Economic Journal, Vol. 102 (413), 845-859.

Miketa, A. & Schrattenholzer, L. (2004): Experiments with a methodology to model the role of R&D expenditures in energy technology learning processes; first results. Energy Policy, Vol. 32 (15), 1679-1692.

Moreno, B. & López, A. J. (2007): The effect of renewable energy on employment. The case of Asturias (Spain). Renewable and Sustainable Energy Rewiews (2007), doi: 10.1016/j.rser.2006.10.011.

OECD (2009): Sustainable Manufacturing and Eco-innovation: Towards a Green Economy. OECD Policy Brief, June 2009.

OECD, IEA (2009): National and sectoral GHG mitigation potential: A comparison across models, Paris. COM/ENV/EPOC/IEA/SLT(2009)7

Patuelli, R., Nijkamp, P. & Pels, E. (2005): Environmental Tax Reform and the double dividend: A Meta-analytical Performance Assessment, Ecological Economics, 55, 564-583.

Popp, D.; Newell, R.G.; Jaffe, A.B. (2010): Energy, the Environment, and Technological Change. In: Hall, B.H.; Rosenberg, N. (Ed.): Handbook of the Economics of Innovation. Amsterdam: Elsevier B.V., 873-937.

Roloff, N., Lehr, U., Krewitt, W., Fuchs, G., Wassermann, S., Weimer-Jehle, W. & Schmidt, B. (2008): Success determinants for technological innovations in the energy sector - the case of photovoltaics. In: Möst, D., Fichtner, W., Ragwitz, M. & Veit, D. (eds.): New methods for energy market modelling. Proceedings of the First European Workshop on Energy Market Modelling using Agent-Based Computational Economics. Universitätsverlag Karlsruhe.

Schwark, F. (2010): Economics of endogenous technical change in CGE models -The role of gains from specialization. ETH Economics Working Paper Series, Working Paper 10/130, June 2010.

Stocker, A., Großmann, A., Madlener, R. & Wolter, M.I. (2011): Sustainable energy development in Austria until 2020: Insights from applying the integrated model "e3.at". Energy Policy (2011), doi: 10.1016/j.enpol.2011.07.2009