THE ECONOMIC COST OF A TRANSITION TO A LOW-CARBON ECONOMY: THE CASE OF BULGARIA AND ROMANIA

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In October 2014, the European Council adopted the 2030 climate and energy policy framework setting a 40-percent greenhouse gas (GHG) reduction target for 2030 compared to 1990 levels.[1] This target is set at the European Union (EU)

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level and is to be attained with the operation of the EU Emissions Trading System (ETS) market and by national-specific policies and measures for the non-ETS sectors. Yet, the exact method of implementation and burden sharing of the non-ETS target has not been decided upon.

The focus of this paper is threefold: (1) to calculate the abatement effort required by Bulgaria and Romania if the EU 40-percent target is to be achieved in the least costly way (i.e., a uniform carbon tax across all member states); (2) to quantify the macroeconomic adjustment of these two countries; and (3) to identify the cost-efficient abatement options in these two nations. The focus is on Bulgaria and Romania as they are both characterized—compared to the other EU member states—by high energy and GHG intensities. In 2013 Bulgaria and Romania were ranking at the first and fourth highest positions, respectively, among all EU member states in terms of energy intensities—610 kilograms of oil equivalent per 1,000 euros (koe/1000€) and 335 koe/1000€, respectively (figure 1A)—and GHG intensities of 1.3 kilograms of carbon dioxide equivalent per euro (kgCO_2eq/€) and 0.8 kgCO_2eq/€, respectively (figure 1B); the former presenting the highest intensity in the EU. At the same time, these nations are the economically weakest countries within the EU in terms of gross domestic product (GDP) per capita—Bulgaria at 5,341 euros and Romania at 6,745 euros in 2013. Hence, restructuring toward a low-carbon economy might be a challenge for both countries, which is an issue worth examining.

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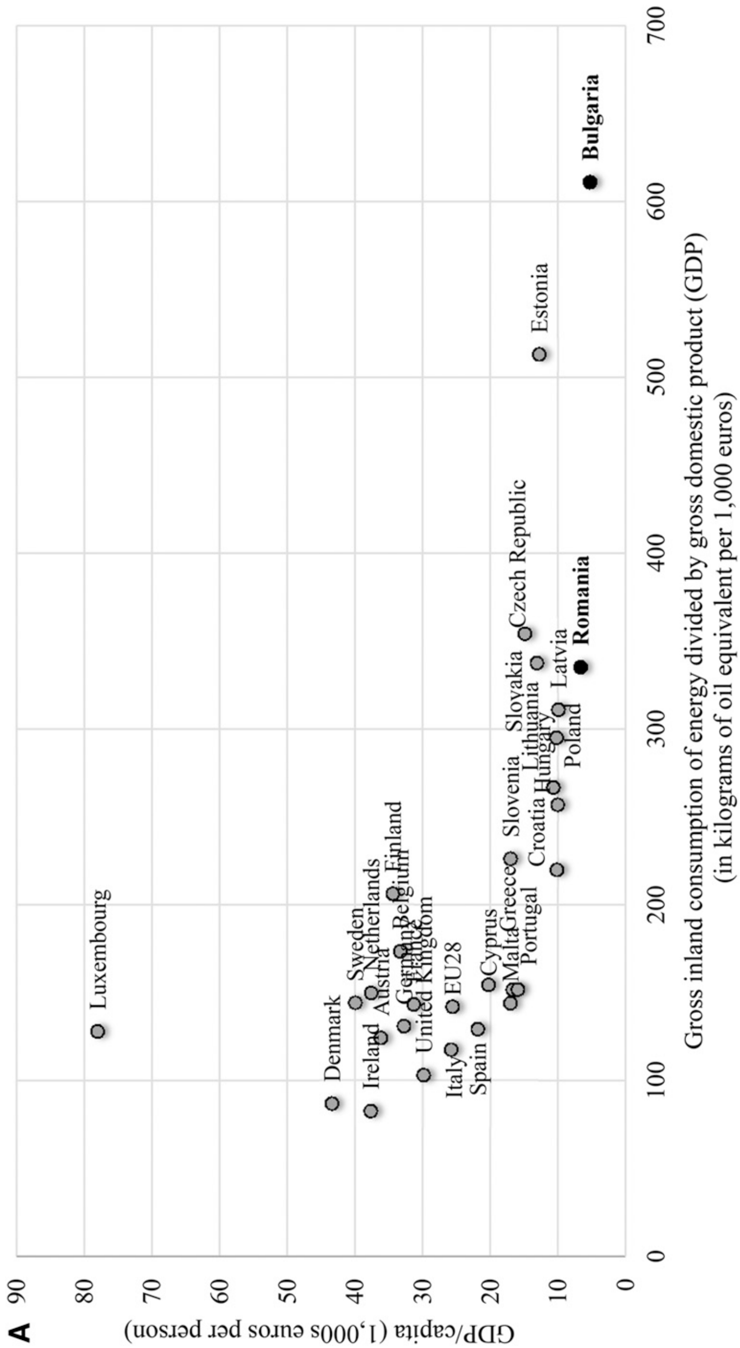
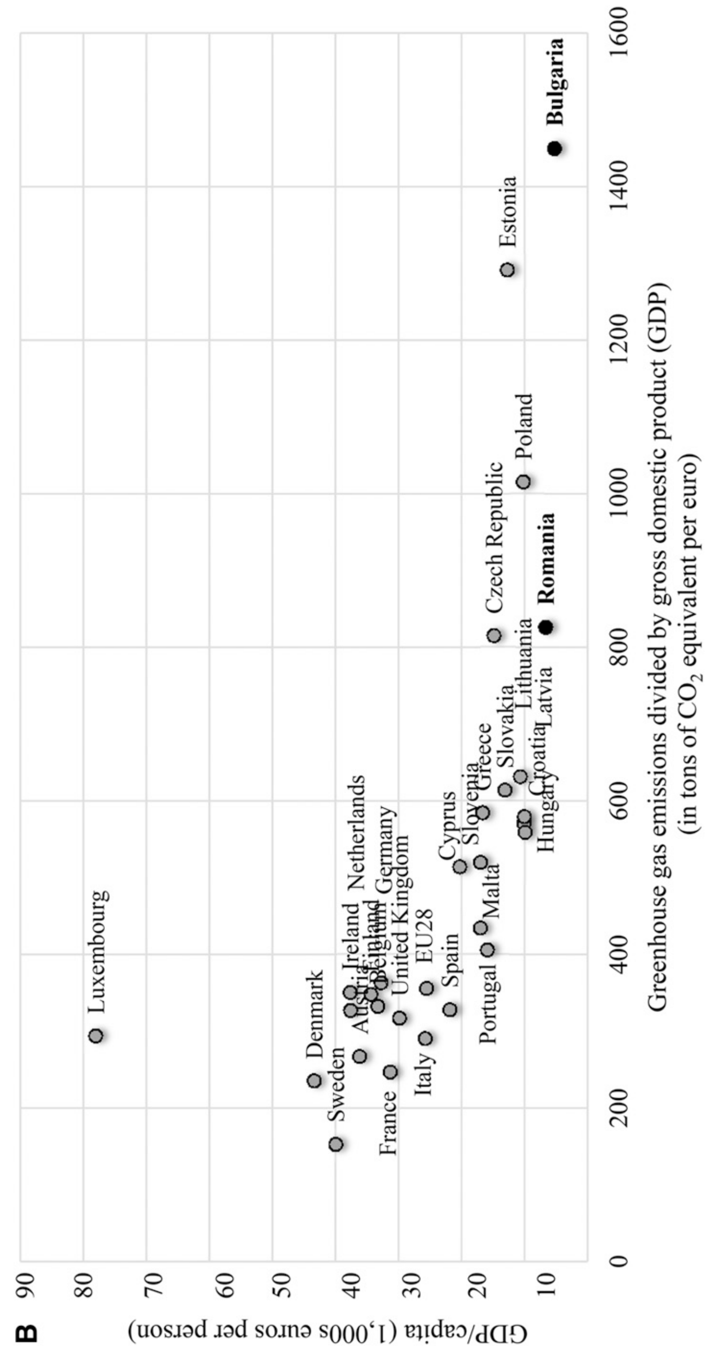
Figure 1A
ENERGY INTENSITY OF THE EU28 MEMBER STATES, 2013



Source: Authors' calculations based on EUROSTAT data.

Figure 1B
GREENHOUSE GAS (GHG) INTENSITY OF THE EU28 MEMBER STATES, 2013



Source: Authors' calculations based on EUROSTAT data.

In both Bulgaria and Romania, the period after the breakdown of the Soviet Union saw great economic losses coupled with significant reductions in GHG emissions due mostly to the restructuring of the old industrial structure.

Our analysis is based on the quantification of an EU-wide 40-percent target with a recursive dynamic computable general equilibrium (CGE) model named GEM-E3-NMS.[2] The model simultaneously represents all countries of the world aggregated to 46 countries/regions, where EU28 member states are individually identified. All countries are linked with endogenous trade transactions and the model provides simulation results up to 2030. The model has been used to quantify the following scenarios: (1) a reference scenario that already includes energy efficiency, renewables (RES) penetration, and GHG mitigation policies resulting in the EU reducing its GHG emissions by almost 30 percent in 2030 compared to their 1990 levels and (2) a GHG emission-reduction scenario where the EU reduces its emissions by 2030 by 40 percent as compared to the 1990 levels. Both scenarios have been quantified up to 2030 with a 5-year time step.

The rest of the paper is structured as follows. In the next portion we outline the economics of climate policy followed by the presentation of the GHG policies in Bulgaria and Romania alongside a survey of the literature regarding the abatement possibilities and costs for these countries under alternative GHG emission-reduction targets. Subsequently, the methodology of our analysis is given, after which the reference scenario is provided. The main results of the alternative 40-percent scenario are discussed in the sixth section, with the last portion of the article a summation of our conclusions.

Literature Review: Economics of Climate Change Policy

In the scholarly literature of the economics of climate change there is a long tradition of the usage of CGE models to evaluate the economic impact of alternative GHG mitigation policies both at regional and national levels (see J. Weyant, U. Springer, C. Böhringer and A. Löschel, C. Bohringer et al., and L. Paroussos et al.). [3] However, very few studies focus on the impact of alternative climate policies on national economies and in particular those of Bulgaria and Romania despite the fact that these two economies are characterized by high energy and carbon intensities, which makes them "vulnerable" to stringent GHG mitigation policies. In many studies, the effects of climate policies on these two economies are masked under the "EU28" or "others" large regional groupings.

In one of the few studies assessing the economic consequences of the implementation of climate mitigation measures in Romania, R. Loisel shows that environmental policies can generate positive economic outcomes in the long term.[4] Such policies (i.e., the implementation of a carbon dioxide permit market and introduction of a tax on carbon dioxide emissions) are examined using a CGE model. The author suggests that both policies can stimulate economic growth, although carbon tax revenues require being cycled back into the economy, for example, by reducing payroll taxes to companies. Under the permit market's simulation, real GDP slightly increases (0.08 percent). D. Diaconu et al. raise doubts of the economic effects of restructuring the power sector on industry competitiveness.[5] Regarding Bulgaria, Y. Spassov et al. shed some light on the design of incentive systems based on environmental considerations in the electricity sector and its impact on the economy.[6]

Several studies evaluating energy policies for an energy transition in Bulgaria and Romania widely acknowledge that renewable energy and/or energy efficiency will be the main drivers for this ongoing transition (S. Colesca and C. Ciocoiu, R. Stefanov et al., and L. Dragos et al.).[7] Analyses of energy efficiency measures have shown that their implementation can reduce significantly carbon dioxide (CO_2) emissions, particularly in the short and medium term, in some sectors with positive marginal abatement costs and, hence, such measures should be prioritized (V. Taseska et al. and C. Koroneos and E. Nanaki).[8] While renewable power generation seems to be taking off in both countries (in 2010 installed capacity in Bulgaria was 2.7 gigawatts (GW) and Romania with 6.4 GW), renewables also face major limitations with their potential only being fully realized in the long term. [9] This is mainly due to technological constraints, grid absorption capacity, and the level of investments needed (F. Cruetzig et al. and C. Ciubota-Rosie et al.).[10] A number of studies emphasize the co-benefits of energy efficiency measures and increases in renewables, particularly in terms of energy security; among them are R. Stefanov et al. and C. Mateescu et al.[11] For instance, C. Mateescu et al. point out the advantages of using biogas technologies to save 7,000 kg CO_2 per year with each 1kW of electricity produced by biogas plants.[12] F. Cruetzig et al. highlight how these transitions to low carbon can help stabilize national economies in the European South and other periphery countries and result in an increase of GDP between 0.5 and 1 percent.[13] Several studies argue that sustainable mitigation policies promoting and financing these measures should be designed and implemented in parallel, in a coherent manner (F. Cruetzig et al., S. Colesca and C. Ciocoiu, and C. Christov et al).[14] C. Koroneos and E. Nanaki, in a study focused on the Eastern Balkans, emphasize the importance of energy efficiency in sound energy policies helping economic recovery and the energy transition.[15]

The present study focuses on the economic implications of the EU GHG policies on Bulgaria and Romania and contributes to the current literature by providing a detailed economic assessment both at the macro and sectoral level of the EU climate policy of the two states.

Energy and Climate Policies in Bulgaria and Romania

EU Framework on Climate and Energy for 2030: Building on the "climate and energy package" for 2020[16] and aligned with the roadmap to 2050, the

European Council has adopted a new EU framework on climate and energy for 2030.[17] It seeks to ensure two major binding targets—the reduction of GHG by 40 percent below the 1990 level and renewable energy accounting for at least 27 percent across all member states—in addition to increasing energy efficiency by at least 27 percent, a new governance system, and a set of new indicators for a competitive and secure energy system.

While action on climate change and the EU's competitiveness is at the core of this initiative, some specific elements underscore this energy and climate policy. According to the European Commission,[18] the GHG reduction target of 40-percent emissions reduction will be met in a cost-effective manner where a 43-percent reduction from 2005 levels will be offered by the ETS sectors and a 30-percent reduction from 2005 levels will be made by the non-ETS sectors. After 2020, the EU ETS sectors' annual reduction will change from 1.74 percent to 2.2 percent.[19] Energy efficiency policies will be reviewed more exhaustively in the conclusion of the Energy Efficiency Directive, especially the proposed energy efficiency target of at least 27 percent.

Other related elements include a set of key indicators focusing on energy prices and costs as well as energy system sources and capacities to build a more competitive, affordable, and secure energy system. The report on energy prices and costs accompanies the 2030 Communication. A new governance system will be discussed between the EC and Member States in an iterative process to ensure investment certainty, coordination, and compliance over time. A legislative proposal has been developed to improve the robustness for a market stability reserve in the EU ETS starting in 2021.

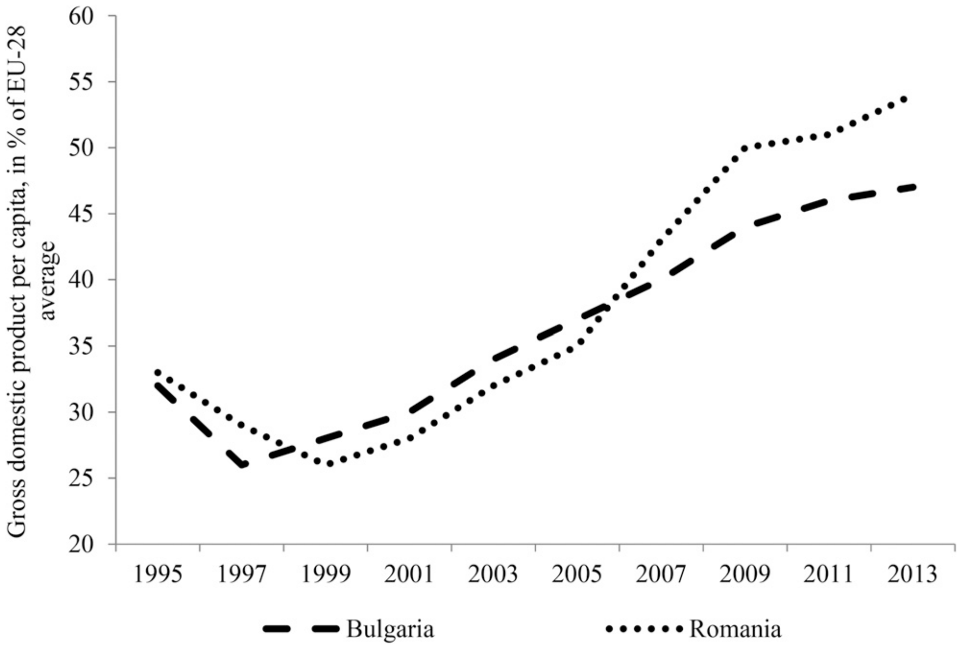
Energy and Climate Policies in Bulgaria and Romania – Current Status: For more than two decades after the collapse of their communist regimes, Bulgaria and Romania went through major economic restructuring and downturns (in 1996–1997 and again in 2009) that, *inter alia*, reshaped social and demographic conditions. Substantial changes in GDP per capita were evidenced during these two restructuring periods as can be seen in figure 2.

Both Bulgaria and Romania are characterized by high energy intensities. This is attributed to two factors, the first being the inefficient transformation, transmission, distribution, and use of energy. In 2014, the ratio of final to primary energy was 0.51 and 0.67 in Bulgaria and Romania, respectively, whereas the EU average was 0.64. The second issue is the production structure of their economies in which energy-intensive industries, such as mining and quarrying, manufacturing, steel production, chemicals, and power generation, represent a large share in total value added to the overall economy.

Energy efficiency in Bulgaria has been improving over the past decade (i.e., energy intensity was reduced by around 5 percent annually from 2001 to 2010 at 670 koe/1,000€); however, its energy intensity is still twice as high as the average of the new EU member states.[20]

Figure 2

GROSS DOMESTIC PRODUCT PER CAPITA IN BULGARIA AND ROMANIA, IN RELATION TO EU-28 AVERAGE, 1995–2013



In 2013, the GHG emissions intensity of the Bulgarian energy system was 1.3 $kgCO_2eq$/€ while the EU average was at 0.3 $kgCO_2eq$/€. In Romania, energy intensity also has decreased constantly throughout the past decade, except for a small increase in 2010. From 2001 to 2011, it was reduced from about 580 kgoe/ 1,000€ to around 400 kgoe/1,000€.

The GHG emissions intensity of the energy consumed was cut in half from 2000 to 2011. The main share of Romanian GHG emissions (123.3 $MtCO_2e$) came from the energy industries (29.7 percent), industrial processes (20.4 percent), and agriculture (15.4 percent).[21]

The Bulgarian and Romanian Energy Strategies: With the accession of Bulgaria and Romania to the EU, questions arose about how best to transition toward a low-carbon economy in order to reduce CO_2 emissions, protect the environment, and promote sustainable growth. Energy efficiency and renewable energy sources were identified as crucial drivers for the transition.[22]

The 2011 Bulgarian Energy Strategy formulated the main priorities to align with the EU 2020 energy and climate package and transition toward a low-carbon economy while seeking energy security supply coupled with targets for renewable energy sources (16 percent by 2020) and energy efficiency and development of a competitive energy market.[23] Regarding energy efficiency, following the 2012 EU Directive (2012/27/EU) Bulgaria set new targets in that same year to increase energy efficiency by 25 percent by 2020 and reduce energy intensity by 50 percent until 2020 compared to 2005 levels.

However, Bulgaria faces major challenges to move its energy strategy forward. Support mechanisms for renewable energy sources are being reconsidered and retroactive cuts have driven away investors and developers alike. Moreover, problems associated with the aged electricity grid, lack of information for investors, grid access denial by the owners, and no smart grids investment, all have contributed to the considerable slowdown in the transition to a low-carbon state.[24]

In the transportation sector, the 10-percent renewable energy source target by 2020 is seriously questioned by the industrial players, particularly considering recent unsuccessful attempts such as diesel and gasoline blending with 5.75-percent biodiesel in 2008 and with 2-percent bioethanol in 2011.[25]

In terms of energy efficiency, major difficulties have arisen from the outdated physical residential infrastructure. A quarter of the energy consumed in Bulgaria is used in the residential sector and most of the buildings are energy inefficient. Furthermore, residential heating is based predominately on electricity (28.6 percent) and wood (31.1 percent). Other obstacles include the dearth of data on housing stock and energy consumption, lack of energy and carbon footprint audits, and high levels of "energy-poor" individuals who cannot afford efficiency improvements.

In Romania, as in Bulgaria, the country developed a National Energy Strategy in 2007 for the period 2007–2020 focused on energy security and fostering competitive energy markets, as well as climate protection aspects outlined in terms of efficiency production targets for energy distribution, the development of cogeneration plants, and bolstering renewable energy sources. The strategy does not outline a set of concrete implementation measures but underlines the necessity to define measures for ensuring future sustainable development.[26] The national strategy was revised in 2011 to incorporate updated economic growth and energy consumption forecasts, new EU directives, and political decisions regarding the state-owned energy companies along with extending the strategy through 2035.[27] The 2020 EU climate-energy package fixes the share of renewable energy sources in Romania's gross final energy consumption at 24 percent and an energy efficiency increase by 19 percent in 2020.

The implementation of the strategy has encountered some difficulties and lacks accuracy. Proposed changes in the renewable legislation have raised political tensions between the Parliament (which intends to shorten the renewable energy source promotion durations by 2017) and the energy regulatory body—the ANRE. Renewable energy connection to the grid also has proven to be problematic in terms of transparency of the grid connection approval processes and predictability of the legal system.

On energy efficiency, slow progress has been made in recent years, particularly in the transportation sector and in appliance efficiency. While the economic recession in 2008 and 2009 can be partially to blame as it impacted Romanian energy efficiency policy by cutting public spending, other factors contributed to the slackening of energy efficiency advancement including a lack of information, absence of energy audits and energy management, minimal definitions for energy performance standards in residential and industrial sectors, negligible technology phase-outs, and scarce economic incentives.[28]

Methods

In this study we use the GEM-E3-NMS[29] model to quantify the economic and energy impacts in Romania and Bulgaria when the EU28 adopts a 40-percent GHG emission reduction target in 2030. The model is able to quantify the impact of the GHG emission reduction constraint to the GDP, production structure, and to the labor market. The GHG emission reduction constraint is imposed at the EU28 level and then the model calculates the least-cost allocation of the abatement effort among the EU member states.

The EU least-cost abatement effort requires that the ETS and non-ETS sectors across the EU have the same carbon value (i.e., the carbon price used to clear the permit markets is equal to the shadow carbon value that drives emission reductions in the non-ETS sectors). The EU legislation for the 20-20-20 package has set the rules for the allocation of carbon permits for the ETS sectors and the implementation of policies measures for the national non-ETS sectors. We do not make such a distinction in this study as we are primarily concerned with the economic implications from an "optimal" implementation of the 40-percent GHG emission reduction target; hence, we impose a uniform carbon tax in both the ETS and non-ETS sectors.

The public revenues generated from the carbon tax are recycled back into the economy (i.e., are not held by the government to reduce/increase its deficit/surplus) by reducing employers' social security contributions. This recycling option has been found[30] to be efficient both in terms of GDP and employment adjustment.

The internalization of this additional cost into the cost structures and choices of the economic agents is governed by their "optimizing behavior" (i.e., firms maximize profit, households maximize utility, etc.). The resulting equilibrium prices and quantities, incorporating both the primary and secondary effects of the policy intervention, lead to an endogenous least-cost allocation of the abatement effort.

The model includes different endogenous abatement options including energy efficiency, use of renewable energy sources, and fuel switching. A bottom-up approach has been adopted to represent the structure of the power generation system. The model includes the following power generation technologies: (1) coal fired, (2) oil fired, (3) gas fired, (4) nuclear, (5) biomass, (6) hydro, (7) wind, (8) solar, (9) carbon capture storage (CCS) coal, and (10) CCS gas. The power generation mix is calculated as the least-cost mix of the different power generation technologies given capacities and technology availability. Technologies compete with each other based on their relative prices and the substitution possibilities implied by the power generation production function used in the model (resource and capacity constraints are reflected by the substitution elasticities of the power generation production function).

In the model, unit production costs of power generation technologies are endogenously computed and are subject to the technology-specific production function and the country-specific labor, capital, and fuel costs. The calibration of the production function of each power generation technology is based on the TECHPOL[31] database.[32] Although TECHPOL provides universal cost structures of each electricity production technology in the model, we consider that these are differentiated across countries depending on national taxation on fossil fuel prices, capital costs, and wages. The universal production structure for each technology is presented in table 13 of appendix 2.

The capital costs of power generation technologies are formulated by an investment matrix that translates the investment demand of each power generation technology to specific demand for investment products. This matrix is based on a literature survey of the specific technologies.[33] The investment matrix used for the different power generation technologies is presented in table 14 of appendix 2.

Capital costs of new power generation technologies like wind, solar, and biomass decrease over time due to learning-by-doing[34] and learning-by-research effects (the latter are exogenously defined in the model). The learning capacities are calculated at the world scale. Table 15 of appendix 2 presents the learning rates used in the model.

The EU average unit production costs of representative power generation technologies for the year 2010 are presented in table 16 of the appendix 2.

Energy consumption is endogenous in the GEM-E3-NMS model. At sectoral level, energy consumption is derived from profit maximization under a nested CES (constant elasticity of substitution) specification. Energy enters the production function together with other production factors (capital, labor, material). Substitution of energy and the rest of the production factors is imperfect (energy is considered an essential input to the production process) and it is induced by changes in their relative price.

Residential energy consumption is derived from the utility maximization problem of households. Households allocate their income between different consumption categories and savings to maximize their utility subject to their budget constraint. Consumption is split between durable (i.e., houses, cars, electric appliances) and non-durable goods. For durable goods, stock accumulation depends on new purchases and scrapping. Use of durable goods requires the consumption of certain non-durable goods and services, including energy products. The latter are endogenously determined depending on the stock of durable goods and on relative energy prices.

Energy efficiency in the GEM-E3-NMS model is driven by: (1) an increase in the amount agents spend to improve energy intensity in response to regulations, for example, by mirroring energy-saving obligations or minimum performance of energy efficiency (endogenous mechanism based on cost-potential curves for energy efficiency by sector); (2) a change in energy prices that triggers the substitution of relatively less-expensive inputs for more expensive energy, along the frontiers of substitution possibility; and (3) improvement of energy-embodied technological progress (based on exogenous projections).

Expenditures in energy efficiency imply the accumulation of stock that is more energy efficient than the benchmark. Thus, specific rates of energy consumption (of equipment) and energy requirements are reduced, which contributes to savings of energy consumption following their installation. The higher upfront expenditures for energy efficiency imply funding requirements that need to be drawn from savings and from borrowing. The additional funds are not drawn from agents' funds, which are intended to accumulate productive capacity or basic capacity, but are drawn from the entire economy, eventually stressing capital supply in the economy. Thus, energy efficiency expenditures have no direct impact on the capital stock (productive capacity) of the economy. Spending on energy efficiency stimulates demand for sectors that produce the required good and services, such as construction, industrial materials, equipment, and certain market services. The modeling takes into account that the demand for and expenditure on energy decrease permanently in periods that follow energy efficiency expenditures. The amount of energy efficiency expenditures that is required to reach this pre-specified rate of reductions of energy intensity is then determined by energy efficiency cost curves. Expenditures can be further divided into demand for goods and services using technical coefficients.

Table 1 summarizes the indicative composition of energy efficiency expenditures by sector. These sectors then generate demand for the output of all other sectors through Leontief's input-output system, based on technical coefficients.

In the current version of GEM-E3-NMS, the endogenous mechanism of energy efficiency expenditures (the first option mentioned above) is used, which employs energy efficiency cost curves that describe the relationship between the energy

Table 1

SECTORS DELIVERING THE ENERGY EFFICIENCY PROJECTS

Sector	**Share in % of Total**
Ferrous metals	4
Non-ferrous metals	4
Chemical products	7
Non-metallic minerals	8
Electric goods	2
Construction	60
Market services	15

Source: Authors' assumptions.

efficiency expenditures and energy efficiency improvements relative to the benchmark. The efficiency cost curves exhibit decreasing (to scale) returns, assuming that the energy-saving potential is inter-temporally limited (differently by sector) and that higher energy saving entails an increase in marginal costs.

In the GEM-E3-NMS model, the creation of an un-sustained current account deficit is possible when no endogenous fiscal instrument is activated in order to prevent this imbalance. In the current simulations it has been assumed that the EU-wide interest rate would adjust so that the EU current account would remain unchanged as a percentage of GDP from the reference case. This ensures that the GHG mitigation effort is financed by EU28 internal resources without deteriorating the current account position of the region.

The GEM-E3-NMS model has been used to quantify the following scenarios: (1) the reference scenario that already includes energy efficiency, renewable energy source (RES) penetration, and GHG mitigation policies (i.e., in 2030 the EU reduces its GHG emissions by almost 30 percent compared to 1990) and (2) a GHG emission reduction scenario where the EU reduces its emissions by 2030 by 40 percent as compared to 1990 levels. Both scenarios have been quantified up to 2030 with a 5-year time step.

Results

The Reference Scenario: The reference scenario serves as the benchmark against which the alternative scenario (40-percent emissions reduction target) is evaluated. The reference projection is constructed by calibrating the macroeconomic part of the model on the Directorate General for Economic and Financial Affairs' Ageing report[35] that includes GDP and employment projections for all EU member states until 2060. The exogenous variables of the model that are used to perform the calibration of the reference scenario are the technical progress, labor force, and expectations on sectoral growth.

The reference scenario reflects, to a large extent, some of the main policy assumptions of the European Commission reference scenario, as specified in the EU Energy Roadmap 2050[36] and is consistent with the EU Climate and Energy Package by 2020 (see the European Commission's Commission Decision of 26 March 2013).[37] Beyond 2020, the reference scenario assumes a linear annual reduction of the EU ETS cap, no additional policies for energy efficiency, and RES penetration (but the measures implemented until 2020 will continue to deliver energy efficiency gains and RES facilitation after 2020 without specifying further targets beyond that date), limited electrification of the transport sector, and non-ETS GHG emissions to remain below the cap specified for 2020.

The key projections on the evolution of the main socio-economic variables (population and GDP) and GHG emissions at the world and EU28 level are presented in table 2. Note that for the EU28 member states, the evolution of such

Table 2
WORLD AND EU28 KEY REFERENCE PROJECTIONS, 2015–2030

2015–2030 (Annual % Change)	**Gross Domestic Product (GDP)**	**Greenhouse Gases (GHG)**	**Population**
World	3.04%	1.49%	0.86%
EU28	1.57%	–1.10%	0.15%

Source: GEM-E3-NMS.

variables is calibrated to the European Commission's Energy Trends to 2050. The carbon price used in the reference scenario is presented in table 3. In the reference scenario, Bulgaria and Romania are assumed to accelerate growth while reducing CO_2 emissions (figures 3A and 3B).

Bulgaria's and Romania's GDP are projected to grow on average by 1.7 percent and 1.8 percent, respectively, in the period 2010–2030 (see table 4 for the reference projections). The main driver is investments that grow at a higher rate than any other GDP component. Exports are assumed to grow somewhat faster than imports, hence, the trade balance position of each country improves in the long term. Population is assumed to decline and, as a consequence, the labor force of Bulgaria and Romania decreases, respectively, by 1 percent and 0.65 percent per annum in the 2010–2030 period. The increase in GDP, coupled with the decline in labor force over this period, implies an almost doubling of labor productivity by 2030.

In Bulgaria, services increase their share in total production from 36 percent in 2010 to 40 percent in 2030 (figure 4A). Even in the reference scenario all economic sectors become more energy efficient and the share of the energy sector in GDP decreases to less than 9 percent of GDP in 2030. Market services increase their share in GDP mainly at the expense of agriculture and consumer goods industries.

Production in Romania is diversified across many industrial sectors (figure 4B). Services, agriculture, and equipment goods represent a large part of the overall economic production. In the reference projection, it is assumed that the Romanian

Table 3
REFERENCE EU CARBON PRICE, 2010–2030
(in € 2005 per ton of carbon dioxide)

	2010	**2015**	**2020**	**2025**	**2030**
Carbon price	7	9	17	22	32

Source: GEM-E3-NMS.

Figure 3A
BULGARIA: REFERENCE GROWTH FOR GROSS DOMESTIC PRODUCT (GDP) AND GREENHOUSE GAS (GHG) EMISSIONS, 2005–2030
(2005 = 100)

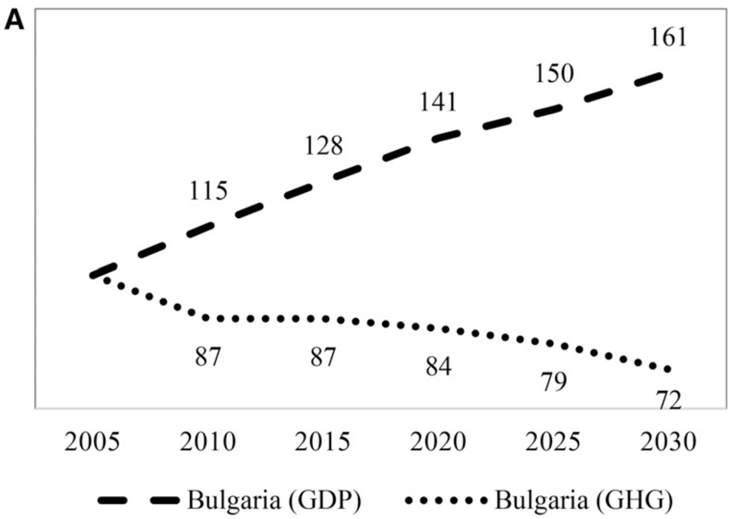


Figure 3B
ROMANIA: REFERENCE GROWTH FOR GROSS DOMESTIC PRODUCT (GDP) AND GREENHOUSE GAS (GHG) EMISSIONS, 2005–2030
(2005 = 100)

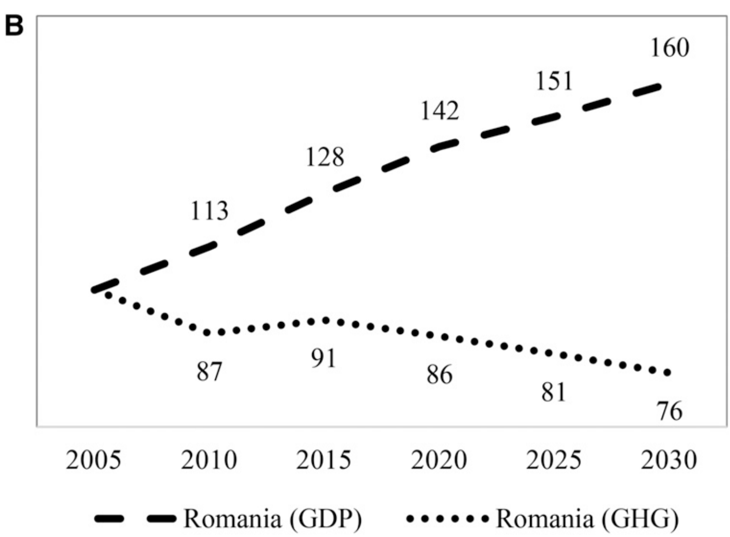


Table 4
BULGARIA AND ROMANIA: REFERENCE PROJECTIONS FOR MAIN MACROECONOMIC AGGREGATES, 2010–2030

	In Billion €		Annual % Change	
Bulgaria	**2010**	**2010–2020**	**2020–2030**	**2010–2030**
Gross domestic product (GDP)	36.1	2.1%	1.3%	1.71%
Investment	6.6	2.5%	1.6%	2.05%
Public consumption	7.2	1.6%	0.7%	1.15%
Private consumption	22.8	2.0%	1.3%	1.70%
	2010	**2010–2020**	**2020–2030**	**2010–2030**
Trade balance as % of GDP	–1.6%	–0.9%	–0.6%	
Population (millions of persons)	7.6	–0.6%	–0.7%	–0.67%
Labor force (millions of persons)	3.4	–1.1%	–1.0%	–1.05%
	In Billion €		**Annual % Change**	
Romania	**2010**	**2010–2020**	**2020–2030**	**2010–2030**
Gross domestic product (GDP)	104.2	2.3%	1.2%	1.78%
Investment	21.8	2.5%	1.4%	1.96%
Public consumption	10.6	1.7%	0.2%	0.97%
Private consumption	77.7	2.2%	1.2%	1.68%
	2010	**2010–2020**	**2020–2030**	**2010–2030**
Trade balance as % of GDP	–5.7%	–4.3%	–3.4%	
Population (millions of persons)	21.4	–0.2%	–0.4%	–0.29%
Labor force (millions of persons)	9.9	–0.4%	–0.9%	–0.65%

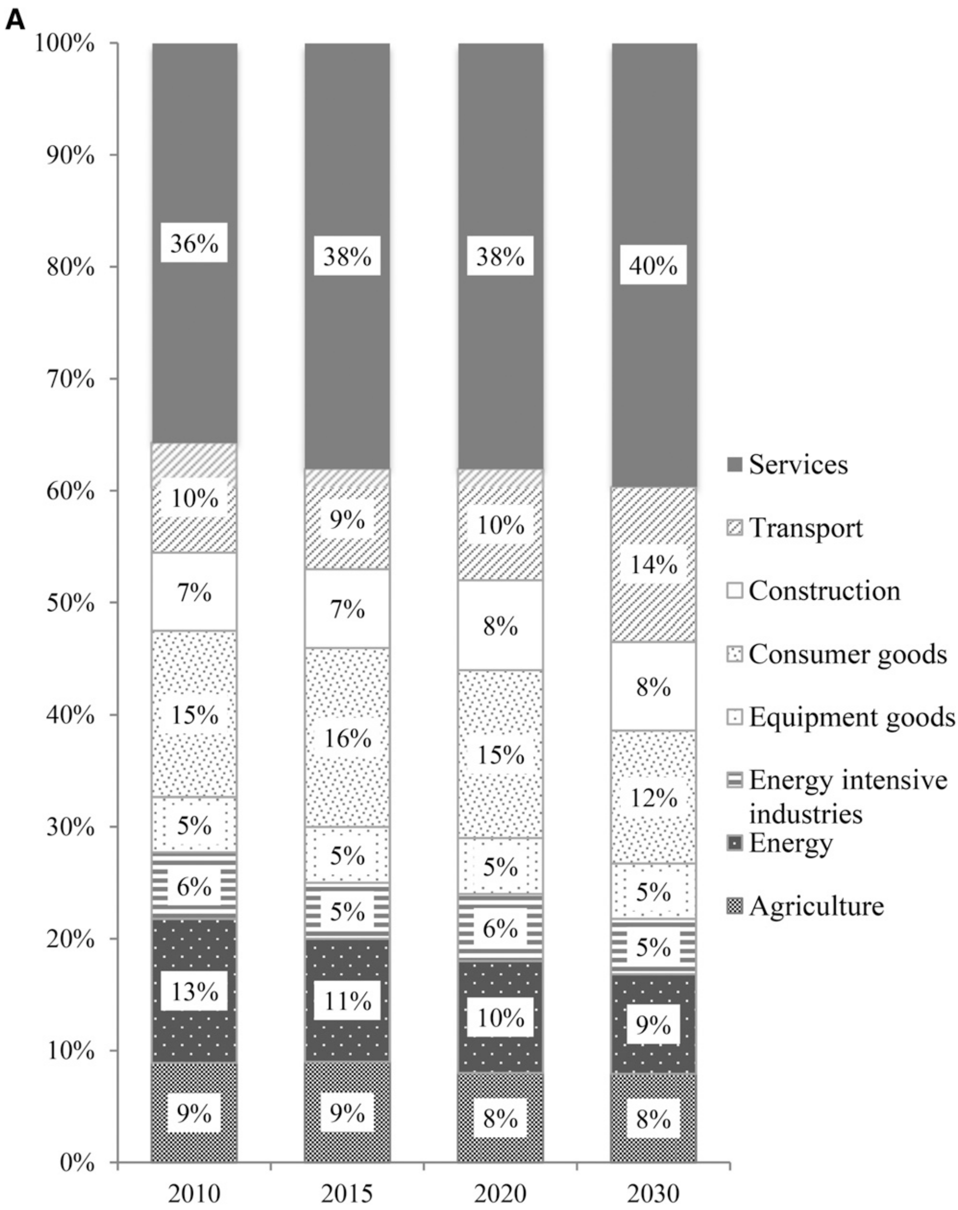
Source: GEM-E3-NMS.

economy will become more services oriented. Thus, the share of services in total production is projected to increase from 26 percent in 2010 to 30 percent in 2030, while the share of the agriculture and energy sectors will decline by 2030.

In Bulgaria the share of coal-fired technologies decreases from 47 percent in 2010 to 39 percent in 2030, as low- and zero-carbon power generation technologies penetrate into its power generation mix, mainly natural gas and wind (figure 5A). In Romania the structure of electricity production is projected to change significantly by 2030 (figure 5B). The share of coal-based power generation declines markedly from 32 percent in 2010 to 16 percent in 2030 where gas and RES jointly account for 62 percent of total electricity production. At the same time, the contribution of nuclear is projected to remain relatively stable in the 2010–2030 period. Biomass and CCS technologies do not enter the reference power generation mix by 2030 in either country.

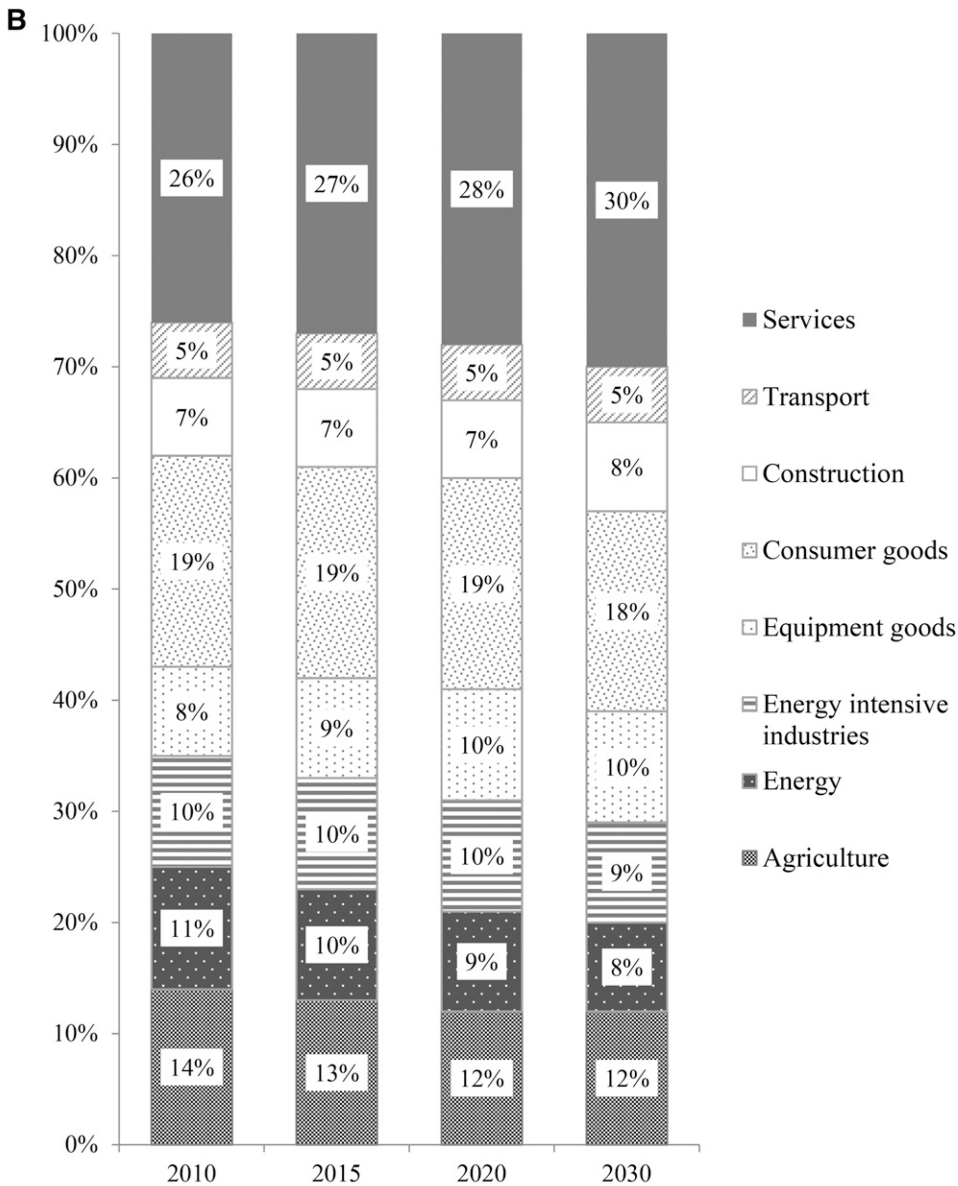
In Bulgaria energy efficiency improvement grows at an annual 1.6 percent rate over the 2010–2030 period (table 5). The improvement is stronger in the short term

Figure 4A
BULGARIA: SECTORAL SHARES IN TOTAL PRODUCTION, 2010–2030



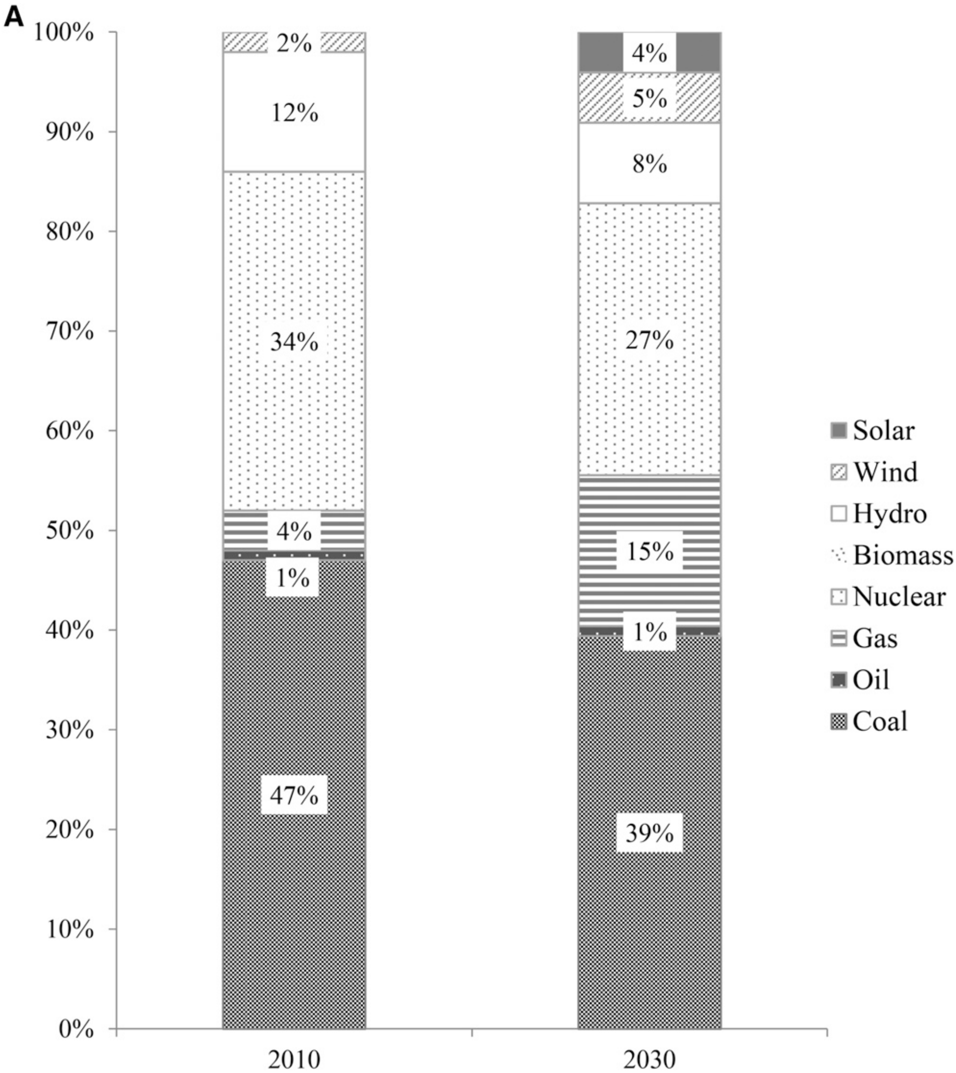
Source: GEM-E3-NMS.

Figure 4B
ROMANIA: SECTORAL SHARES IN TOTAL PRODUCTION, 2010–2030



Source: GEM-E3-NMS.

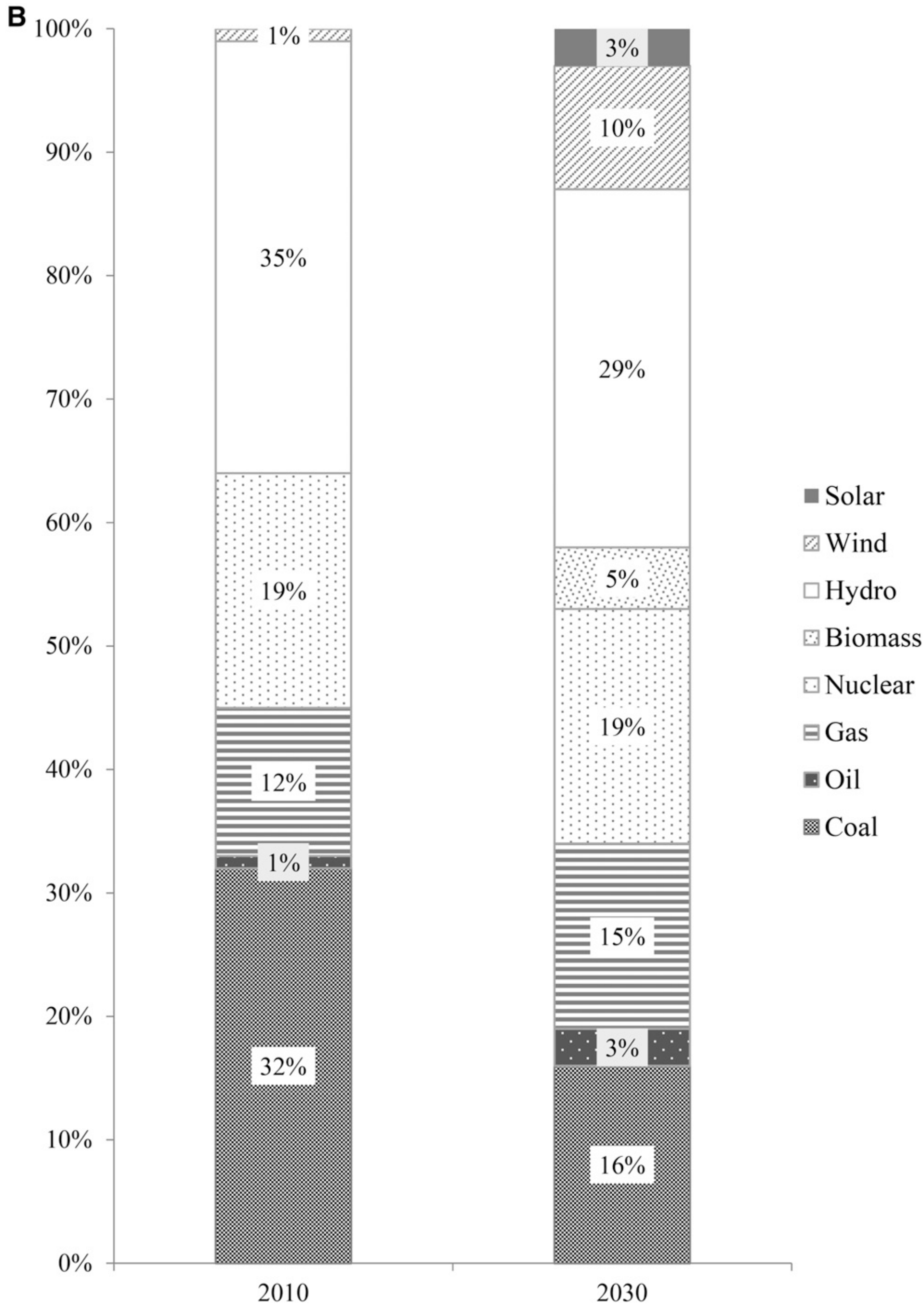
Figure 5A
BULGARIA: POWER GENERATION MIX IN THE REFERENCE SCENARIO, 2010–2030



Source:GEM-E3-NMS.

Figure 5B

ROMANIA: POWER GENERATION MIX IN THE REFERENCE SCENARIO, 2010–2030



Source: GEM-E3-NMS.

Table 5
ANNUAL ENERGY EFFICIENCY IMPROVEMENT, 2010–2030

	2010–2020	2020–2030	2010–2030
Bulgaria	1.75%	1.56%	1.65%
Romania	1.60%	1.30%	1.40%

Source: Authors' assumption.

(up to 2020). In 2020, under reference assumptions, energy intensity is projected to be close to 230 tons of oil equivalent/€(2010) and carbon intensity to 500 tons of CO_2/€(2010).

In the reference scenario, GHG emissions in Bulgaria decrease over the 2015–2030 period. In 2030, GHG emissions are projected to be 28 percent below their 2005 level and 59 percent below their 1990 level (table 6). GHG emissions in Romania decrease over the 2015–2030 period. In 2030 GHG emissions are projected to be lower by 24 percent from 2005 levels and by 58 percent from 1990 levels (table 6).

The 40-Percent Reduction GHG Scenario: The 40-percent GHG emission reduction target is driven by the imposition of a higher-than-reference carbon tax (see table 7). The revenues collected from this carbon tax amount to 0.2 percent of Bulgarian GDP and 0.3 percent of Romanian GDP, respectively, in 2030.

The EU28 target is allocated in a cost optimal way between Bulgaria and Romania. Hence, the abatement effort is a reduction from 2005 emissions of 44.5 percent and 38 percent by 2030 in Bulgaria and Romania, respectively, (see table 8). Even in this case, both countries still have high levels of energy and carbon intensities.

Table 6
BULGARIA AND ROMANIA: REFERENCE GREENHOUSE GAS (GHG) EMISSIONS, 1990–2030
(1990= 100)

1990 = 100	1990	2005	2010	2015	2020	2025	2030
Bulgaria	100	57	50	50	48	45	41
Romania	100	55	48	50	47	45	42

Source: GEM-E3-NMS.

Table 7
CARBON TAX IN 2005 EUROS PER TON OF CARBON DIOXIDE, 2020–2030

	2020	2025	2030
Carbon tax	21	33	58

Source: GEM-E3-NMS.

Compared to the reference case, the net investment[38] required to obtain the GHG emission reduction is presented in table 9. The cumulative amount sums up to 2.4 billion euros in Bulgaria and to 2.7 billion euros in Romania.

The decarbonization of the Romanian and Bulgarian energy systems includes the substitution of imported energy fuels with equipment and services part of which is domestically produced. The increased demand for domestically produced goods exerts an upward pressure in the capital market as additional financing is required. Given that the model assumes full employment of capital, the return on capital also increases, and, hence, the overall production costs. The annual GDP growth rate of Bulgaria and Romania over the period 2015–2030 is found to be at 1.44 percent and 1.45 percent, respectively, slightly below the levels obtained in the reference scenario, 1.53 percent and 1.50 percent, respectively, (table 10).

The unemployment rate in both countries remains virtually unchanged compared to the reference scenario, despite the fall in GDP, as the carbon tax revenues recycling scheme lowers labor costs, thereby favoring employment.

At a sectorial level, the energy and energy-intensive industries present the highest production reductions relative to the reference scenario. Sectors contributing to the decarbonization process, such as construction, equipment, goods, and a small part of agriculture (biofuels), are moderately affected or even see their production increase compared to the reference scenario (table 11).

Reducing GHG emissions requires the adoption of different abatement options at different scales. The abatement options considered are (1) fuel substitution,

Table 8
EMISSION REDUCTIONS IN BULGARIA AND ROMANIA, 1990–2030

	2015	2020	2025	2030		
	% Change from Reference Scenario				1990–2030	2005–2030
Romania	–1.7%	–2.2%	–6.6%	–18.1%	–66%	–38.0%
Bulgaria	–1.8%	–2.8%	–11.3%	–22.7%	–68%	–44.5%

Source: GEM-E3-NMS.

Table 9
ADDITIONAL TO REFERENCE EXPENDITURE IN THE EU 40-PERCENT REDUCTION SCENARIO, 2020–2030

	Investment Expenditure (% of gross domestic product–GDP)			Annual Investment Expenditure (in millon euros)		
	2020	**2025**	**2030**	**2020**	**2025**	**2030**
Bulgaria	0.11	0.37	1.13	43	153	501
Romania	0.06	0.09	0.33	85	136	532

Source: GEM-E3-NMS.

(2) deployment of low-carbon energy sources such as RES, CCS, and nuclear, and (3) energy efficiency.

Our results show that in the short term, where the power generation sector and the potential for structural changes in the transport fleet are limited, the majority of the emission reductions can be achieved through the implementation of energy efficiency measures. This is particularly the case in Romania, where energy efficiency measures are considered the most prominent option, delivering almost 70 percent of the emission reductions in 2020.

Emission reductions in the power sector are driven by a reduction of electricity production and a change in the power mix. As can be seen in table 12, power generation in Bulgaria and Romania is reduced as compared to the reference scenario by 2 percent and 0.4 percent, respectively. This is the net effect on power generation of the increased energy efficiency, the impact of the carbon tax, and the increase of generation costs induced by the penetration of RES in the system. The share of electricity based on RES increases in both countries (by 6 percent in Bulgaria and 3 percent in Romania—excluding hydro energy). Nuclear for Romania and CCS for Bulgaria are the most prominent low-carbon options; other low-carbon power generation options were found to be costlier.

Table 10
GROSS DOMESTIC PRODUCT (GDP) IMPACT IN ROMANIA AND BULGARIA, 2005–2030

	2020	2030	2005–2030 40% Scenario	2005–2030 Reference
	% Change from Reference Scenario		Average Annual Growth Rate	
Romania	–0.13%	–0.70%	1.45%	1.50%
Bulgaria	–0.28%	–1.33%	1.44%	1.53%

Source: GEM-E3-NMS.

Table 11
BULGARIA AND ROMANIA: SECTORAL PRODUCTION, 2015–2030

% Change from Reference	Bulgaria 2020	Bulgaria 2030	Bulgaria 2015–2030	Romania 2020	Romania 2030	Romania 2015–2030
Agriculture	–0.4	–1.9	–0.8	0.0	0.3	0.2
Energy	–0.9	–4.9	–2.3	–0.7	–4.3	–1.8
Energy-intensive industries	–1.7	–10.3	–4.4	–0.8	–5.3	–2.2
Equipment goods	–0.4	–1.3	–0.4	0.2	1.8	0.6
Construction	0.7	0.4	0.6	–0.1	–0.9	–0.3
Transport	–0.3	–2.3	–1.0	–0.3	–2.9	–1.1
Services	–0.1	–0.2	–0.1	–0.1	–0.5	0.0

Source: GEM-E3-NMS.

Summary and Conclusions

The transition to a low-carbon economy brings about higher expenditures by firms, the public sector, and households, to implement fuel switching, investment in building retrofitting, or in industrial processing toward less energy consumption per unit of output. In addition, it promotes the purchase of more expensive equipment, appliances, or vehicles that are more energy efficient compared with existing cheaper varieties. The main macroeconomic effects of these actions are summarized below.

(a) Keynesian multiplier effect: additional energy efficiency expenditure, relative to the reference scenario, implies higher demand for goods and equipment that are used to implement energy efficiency improvement and lower demand for

Table 12
BULGARIA AND ROMANIA: POWER GENERATION MIX CHANGES, 2010–2030[a]

Power Mix	Bulgaria Reference 2010	Bulgaria Reference 2030	Bulgaria 40% Scenario 2030	Romania Reference 2010	Romania Reference 2030	Romania 40% Scenario 2030
Fossil-based	52%	55%	48%	45%	34%	22%
% of which is CCS	0%	0%	10%	0%	0%	1%
Nuclear	34%	27%	28%	19%	19%	27%
RES (no hydro)	2%	10%	16%	1%	18%	21%
Hydro	12%	8%	9%	35%	29%	29%

[a] CCS = carbon capture storage; RES = renewable energy sources.
Source: GEM-E3-NMS.

energy commodities. This shift implies higher demand for domestically produced goods and services and lower imports of energy.

(b) Crowding-out effects due to primary production factors: incremental activity generated by the transition to the low-carbon economy requires more finance and labor than the reference case. Depending on how tight conditions are in the capital and labor markets, upward pressure on capital and labor prices may result, which implies greater scarcity of primary production factors as used in other sectors of the economy.

(c) Competitiveness effects: The relative competitiveness of the domestic economy is weakened as a result of eventual pressures in primary production factor markets.

The model results show that if the allocation of the abatement effort across member states were to be based on cost-efficient criteria, the optimal contribution of Bulgaria and Romania would be a reduction of their GHG emissions by 44.5 percent and 38 percent, respectively, as compared to 2005 levels (68 percent and 66 percent compared to 1990). This translates to 18 percent and 22 percent lower to reference emissions for Romania and Bulgaria, respectively.

In order for both countries to reduce their GHG emissions, important structural changes in the energy sector as well as in the industrial sector are required. The transition of Romania and Bulgaria to a low-carbon economy costs 0.3 percent and 0.6 percent of their GDP, respectively, over the 2015–2030 period. This translates to a slight decrease in the annual rate of their economic growth (by 0.09 and 0.05 percentage points over the period 2015–2030 for Bulgaria and Romania, respectively).

In the short term, where the cost of certain renewable technologies is still high, energy efficiency is considered to be the most cost-efficient abatement option for both countries, whereas significant fuel switching is required by 2030. Improving energy efficiency is largely dependent on equipment and services that are mainly domestically produced (e.g., construction sector), thereby supporting domestic activity. However, increasing the penetration of renewables can be very costly as Bulgaria and Romania are importers of equipment and (at least in the short term) the costs of certain technologies are still high. Therefore, a significant increase of renewables penetration would deteriorate the current account of both countries. In the long term, wind, biomass, nuclear, and CCS all contribute to emissions reductions, while the contribution of photovoltaics and additional hydro capacities are negligible.

The successful implementation of energy efficiency measures in the short term largely depends on the existence of sophisticated and versatile financing instruments that will allow middle- to low-income households to bear the burden of high upfront costs. The model used lacks the detailed representation of such financing instruments.

Capital scarcity imposes additional stress on capital costs and increases production costs throughout the economy. Our analysis does not take into account potential financial inflows related to EU climate and energy policy. Such flows would have the potential to impact the adjustment process of these two countries, as the stress on the capital markets would be moderated or even compensated. However, it is clear that the magnitude of restructuring in these two economies requires that financing frameworks and schemes have to be in place and adequate regulatory schemes and support have to be established.

Appendix 1

GEM-E3-NMS SHORT DESCRIPTION

The GEM-E3-NMS[39] is a multi-regional, multi-sectoral, recursive dynamic computable general equilibrium (CGE) model that incorporates all economic agents, an environmental module that includes permit GHG emissions trading markets, endogenous bilateral trade flows, discrete representation of power-producing technologies, and an imperfect labor market that allows involuntary unemployment. The model's input-output tables are computed using the GTAP dataset.[40]

Firms' Behavior: Domestic production is defined by branch with each branch producing a single product that is different from any other product in the economy. Production functions in the GEM-E3-NMS are of the constant elasticity of substitution (CES) type and exhibit a nested separability scheme, involving capital (K), labor (L), energy (E), and materials (M). Firms operate in a perfect competition environment and maximize their profits subject to their production function. The solution of the firms' optimization problem consists of the optimal demands for each production factor. The derived demand and the unit cost functions determine the firms' demand for production factors and its product supply.

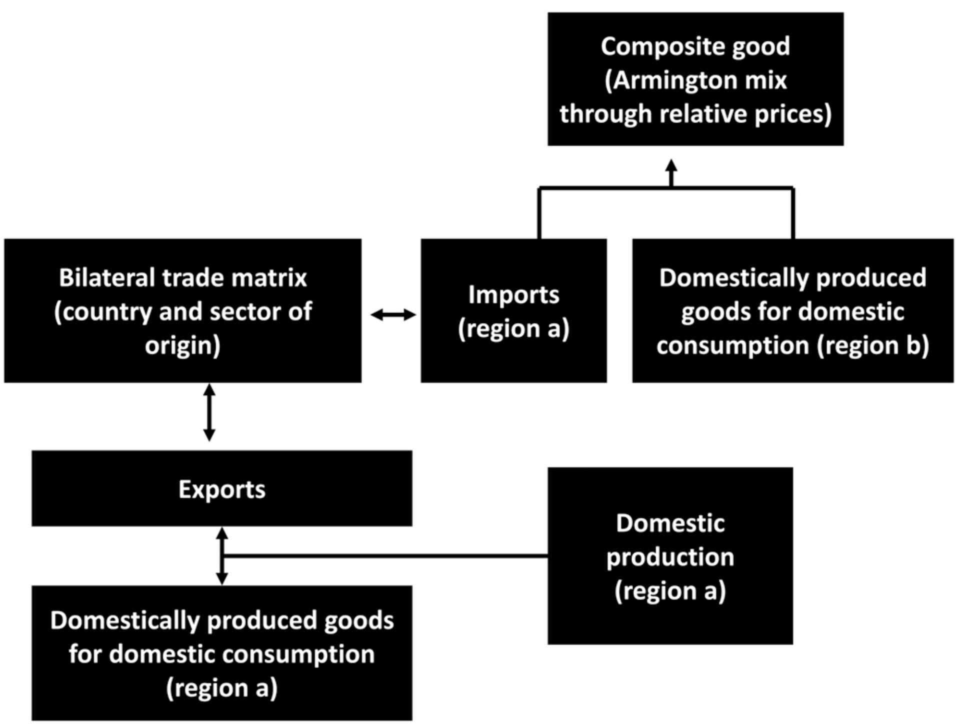
Household: In the model there is one representative household by region. Household behavior is derived through a two-stage utility optimization problem. The consumer utility function is a linear expenditure system (LES). In the first stage, households decide on the allocation of their income (M) between consumption of goods and leisure. In the second stage, the consumer should allocate consumption over the different consumption goods. In GEM-E3-NMS the consumption purposes are distinguished between durable and non-durable goods. The consumption of durable goods requires the use of linked non-durable goods in constant ratios.

Labor Market: A labor supply curve with an approximate 0.1 supply elasticity is included in order to represent involuntary (equilibrium) unemployment.

Investment: The demand for capital for the next year, which fixes the investment demand of firms, is determined through optimizing decisions on factor inputs for the next year within the framework described. The comparison of the available stock of capital in the current year with the desired one determines the volume of investment decided by the firms. Since capital is fixed within each period, the investment decision of the firms affects their production frontier only in the next period. The investment demand of each branch is transformed into a demand by product through fixed technical coefficients derived from an investment matrix by product and ownership. This, together with the government investments that are exogenous in the model, constitutes the total demand for investment goods.

Discrete Representation of Power-Producing Technologies: The input-output tables represent the electricity sector as an aggregate of two activities: (1) power generation and (2) electricity transmission and distribution. In the GEM-E3-NMS model, the electricity sector is split into different activities according to data from energy balances and company-related economic data about generation, transmission, and distribution activities by country. It is assumed that power technologies produce electricity using a constant elasticity of substitution (CES) production function. The data are extracted from Eurostat, International Energy Agency (IEA), and U.S. Department of Energy statistics.

Figure 6
TRADE FLOWS IN THE GEM-E3-NMS MODEL



Trade: The Armington assumption is adopted according to which demand for final or intermediate products is allocated between domestic and imported products. In this specification, branches and sectors use a composite commodity that combines domestically produced and imported goods, which are considered imperfect substitutes. Demand for imports is allocated across imported goods by country of origin. Bilateral trade flows are treated endogenously. The optimal demand for domestic and imported goods is obtained by employing the Shephard's lemma. Import demand is allocated across region of origin using a CES functional form. The model ensures that the balance of trade matrix in value and the global Walras law are verified in all cases.

Appendix 2

Table 13
POWER TECHNOLOGY COSTS BREAKDOWN

% Shares	Coal	Oil	Gas	Nuclear	Biomass	Hydro	Wind	Solar
Agriculture					66.4			
Coal	32.3							
Oil		70.6						
Gas			78.5					
Capital	50.6	22.3	15.5	79.6	27.2	80.3	84.4	95.2
Labor	17.1	7.2	6.0	20.4	6.4	19.7	15.6	4.8

Source: Authors' calculation based on TECHPOL data.

Table 14
POWER TECHNOLOGIES INVESTMENT MATRIX

% Shares	Coal	Oil	Gas	Nuclear	Biomass	Hydro	Wind	Solar
Metals	0.0	1.1	0.0	2.4	0.0	1.4	11.0	0.0
Chemical products	0.0	0.0	0.0	0.0	1.3	0.0	6.3	0.0
Electric goods	13.5	5.5	18.7	4.8	13.8	4.7	6.5	6.8
Other equipment goods	31.1	17.7	19.9	10.7	0.0	13.1	39.9	19.9
Construction	40.7	60.6	45.9	69.5	68.0	64.5	28.6	50.4
Market services	14.5	14.8	15.4	12.8	17.0	16.1	7.7	22.9
Total	100	100	100	100	100	100	100	100

Source: GEM-E3-NMS (adjusted from S. Krohn, P. E. Morthorst, and S. Awerbuch, *The Economics of Wind Energy* (Brussels: European Wind Energy Association, 2009) and Jobs and Economic Development Impact (JEDI) Models available at http://www.nrel.gov/analysis/jedi/about_jedi.html).

Table 15
LEARNING RATES OF NEW POWER-PRODUCING TECHNOLOGIES

Power Producing Technologies	**Price (euro per kilowatt hour)**	**Learning Rate**	**Floor Cost (euro per kilowatt-hour)**
Biomass	0.10	0.15	0.064
Wind	0.08	0.12	0.056
Photovoltaics	0.20	0.18 – 0.20	0.072
Carbon capture storage (CCS)	0.09	0.10 – 0.13	0.056

Source: U.S. Energy Information Administration (EIA), *Annual Energy Outlook 2012* (Washington, D.C.: EIA, 2012) and T. Jasmab, "Technical Change Theory and Learning Curves: Patterns of Progress in Electricity Generation," *The Energy Journal*, vol. 28, no. 3 (2007), pp. 51–71.

Table 16
BASE YEAR UNIT PRODUCTION COSTS (RELATIVE TO A REPRESENTATIVE COAL-FIRED POWER GENERATION PLANT)

	2010		**2010**
Coal-fired	1.0	Hydro electric	0.7
Oil-fired	2.4	Wind	1.5
Gas-fired	1.2	Solar	3.0
Nuclear	0.7	Carbon capture storage coal	1.7
Biomass	2.6	Carbon capture storage gas	1.6

Source: GEM-E3-NMS.

NOTES

[1]European Commission, *Impact Assessment Accompanying the Communication. A Policy Framework for Climate and Energy in the Period from 2020 up to 2030* (Brussels: European Commission, 2014).

[2]The model has been built on the blueprint of the GEM-E3 model.

[3]J. P. Weyant, "Economic Models: How They Work & Why Their Results Differ," in *Climate Change - Science, Strategies, & Solutions*, ed. Eileen Claussen (Leiden: Brill, 2001); U. Springer, "The Market for GHG Permits under the Kyoto Protocol: A Survey of Model Studies," *Energy Economics*, vol. 25, no. 5 (2003), pp. 527–51; C. Böhringer and A. Löschel, "Computable General Equilibrium Models for Sustainability Impact Assessment: Status Quo and Prospects," *Ecological Economics*, vol. 60, no. 1 (2006), pp. 49–64; C. Böhringer, E. J. Balistreri, and T. F. Rutherford, "The Role of Border Carbon Adjustment in Unilateral Climate Policy: Overview of an Energy Modeling Forum Study (EMF 29)," *Energy Economics*, vol. 34, Supplement 2 (2012), S97–S110; and L. Paroussos, P. Fragkos, P. Capros, and K. Fragkiadakis, "Assessment of Carbon Leakage through the Industry Channel: The EU Perspective," *Technological Forecasting and Social Change*, vol. 90, issue A (2014), pp. 204–19.

[4]R. Loisel, "Environmental Climate Instruments in Romania: A Comparative Approach Using Dynamic CGE Modeling," *Energy Policy*, vol. 37, no. 6 (2009), pp. 2190–204.

[5]D. Diaconu, G. Oprescu, and R. Pittman, "The Restructuring of Romanian Power Sector at the Crossroads: Competitive Markets or Neo-Colbertism?" *Romanian Journal of European Affairs*, vol. 7, no. 4 (2007), pp. 57–67.

[6]Y. Spassov, A. Krustev, and V. Nikolovska, "Lowest-Cost Abatement in Light of the EU ETS and Renewable Feed-in Tariffs in the Electricity Sector in Bulgaria," *Journal of Energy & Natural Resources Law*, vol. 29, no 2 (2011), p. 281.

[7]S. Colesca and C. Ciocoiu, "An Overview of the Romanian Renewable Energy Sector," *Renewable and Sustainable Energy Reviews*, vol. 24, issue C (2013), pp. 149–58; R. Stefanov, D. Hristov, V. Nikolova, N. Tagarov, and D. Mantcheva, "Green Energy Governance in Bulgaria at a Crossroads," *Center for the Study of Democracy Reports*, vol. 24 (2011), pp. 1–97; and L. Dragos, N. Scarlat, and C. Flureau, "Trends in the Evolution of CO_2 Emissions in Romania and Perspectives for Diminishing their Environment Impact," *Energy Conversion Management*, vol. 38 (1997), pp. 679–84.

[8]V. Taseska, N. Markovska, A. Causevski, T. Bosevski, and J. Pop-Jordanov, "Greenhouse Gases (GHG) Emissions Reduction in a Power System Predominantly Based on Lignite," *Energy*, vol. 36, no. 4 (2011), pp. 2266–270, and C. J. Koroneos and E. A. Nanaki, "Electric Energy Sustainability in the Eastern Balkans," *Energy Policy*, vol. 35, no. 7 (2007), pp. 3826–842.

[9]Renewable Energy Policy Network for the 21st Century (REN21), *Renewables Interactive Map: Country Profile for Bulgaria* (Paris: REN21, 2014) and *Renewables Interactive Map: Country Profile for Romania* (Paris: REN21, 2014).

[10]F. Creutzig, J. Goldschmidt, P. Lehmann, E. Schmid, F. von Blücher, C. Breyer, B. Fernandez, M. Jakob, B. Knopf, S. Lohrey, T. Susca, and K. Wiegandt, "Catching Two European Birds with One Renewable Stone: Mitigating Climate Change and Eurozone Crisis by an Energy Transition,"

Renewable and Sustainable Energy Reviews, vol. 38 (October 2014), pp. 1015–28, and C. Ciubota-Rosie, M. Gavrilescu, and M. Macoveanu, “Biomass - An Important Renewable Source of Energy in Romania,” *Environmental Engineering and Management Journal*, vol. 7, no. 5 (2008), pp. 559–68.

[11]R. Stefanov, T. Galev, M. Tsanov, M. Vladimirov, and N. Gantcheva, *Energy Sector Governance and Energy (In)security in Bulgaria* (Sofia, Bulgaria: Center for the Study of Democracy (CSD), 2014), and C. Mateescu, V. Baran, and V. Oros, “Opportunities and Barriers for Development of Biogas Technologies in Romania,” *Environmental Engineering and Management Journal*, vol. 7, no. 5 (2008), pp. 603–7.

[12]C. Mateescu et al., op. cit.

[13]F. Creutzig et al., op. cit.

[14]F. Cruetzig et al., op. cit.; S. Colesca and C. Ciocoiu, op. cit.; C. Christov, K. Simeonova, S. Todorova, and V. Krastev, “Assessment of Mitigation Options for the Energy System in Bulgaria,” *Applied Energy*, vol. 56, no. 3 (1997), pp. 299–308; and C. Christov, “Alternative Energy Balances for Bulgaria to Mitigate Climate Change,” *Environmental Management*, vol. 20, no. 1 (1996), pp. S27–S30.

[15]C. J. Koroneos and E. A. Nanaki, op cit.

[16]European Union, “Directive 2009/28/EC of the European Parliament and of the Council of 25 October 2012 on Energy Efficiency, Amending Directives 2009/125/EC and 2010/30/EU and Repealing Directives 2004/8/EC and 2006/32/EC,” in *Official Journal of the European Union L315* (Brussels: European Union, 2012), “Decision No. 406/2009/EC of the European Parliament and the Council of 23 April 2009 on the Efforts of Member States to Reduce their Greenhouse Gas Emissions to Meet the Community’s Greenhouse Gas Emission Reduction Commitment up to 2020,” in *Official Journal of the European Union L140* (Brussels: European Union, 2009), pp. 136–48, and “Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the Promotion of the Use of Energy from Renewable Sources and Amending and Subsequently Repealing Directives 2001/77/EC and 2003/30/EC,” in *Official Journal of the European Union L140* (Brussels: European Union, 2009), pp. 136–48.

[17]European Commission, “2030 Climate and Energy Goals for a Competitive, Secure and Low-Carbon EU Economy,” European Commission Press Release Database, IP/14/54, 2014.

[18]General Secretariat of the European Council, *Conclusions of the European Council: 23 and 24 October 2014* (Brussels: European Council, October 24, 2014).

[19]The European Commission’s Directorate-General Climate Action description of the ETS System: The EU ETS works on the “cap and trade” principle. The overall volume of greenhouse gases that can be emitted each year by the power plants, factories and other companies covered by the system is subject to a cap set at an EU level. Within this Europe-wide cap, companies receive or buy emission allowances that they can trade if they wish. From 2013 onwards, the cap on emissions from power stations and other fixed installations is reduced by 1.74% every year. This means that in 2020, greenhouse gas emissions from these sectors will be 21% lower than in 2005.

[20]We consider as new EU member states those that joined the EU after the 5th enlargement of 2004: Malta, Cyprus, Estonia, Latvia, Lithuania, Poland, Czech Republic, Slovakia, Slovenia, Hungary, Bulgaria, Romania, and Croatia.

[21]Eurostat, "Statistical Data," 2013, available at http://ec.europa.eu/eurostat/.

[22]B. Parthan, M. Osterkorn, M. Kenney. S. J. Hoskyns, M. Bazilian, and P. Monga, "Lessons for Low-Carbon Energy Transition: Experience from the Renewable Energy and Energy Efficiency Partnership," *Energy for Sustainable Devel*opment, vol. 14, no. 2 (2010), pp. 83–93.

[23]Republic of Bulgaria, *Energy Strategy of the Republic of Bulgaria till 2020 for Reliable, Efficient and Cleaner Energy* (Sofia: Republic of Bulgaria, 2010), p. 4.

[24]European Commission, "A Policy Framework for Climate and Energy in the Period from 2020 to 2030," in *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions* (Brussels: European Commission, 2014).

[25]R. Stefanov et al., op. cit.

[26]A. Popescu, *Overview of the Mitigation/Adaptation Policy Instruments in Romania* (Bucharest: Institute for Studies and Power Engineering (ISPE), 2011).

[27]P. Lificiu, "The Energy Sector in Romania. Present and Future," presentation by the Romanian Energy Regulatory Authority, April 27, 2012, available at http://www.econet-romania.com/files/documents/27April12/Vortrag%20ANRE.pdf.

[28]Energy Efficiency Watch Organization, *Energy Efficiency in Europe. Assessment of Energy Efficiency Action Plans and Policies in EU Member States: Country Report—Romania* (Brussels: Energy Efficiency Watch, 2013).

[29]GEM-E3-NMS is a recursive dynamic general equilibrium model that covers the whole world aggregated to 46 countries/regions (28 of which are the EU member states). All countries are linked through endogenous bilateral trade flows. The model represents a closed economic system (at the global level) in the sense that endowments/resources do not change. A more detailed description of the model is given in appendix 1.

[30]A detailed analysis on the impact on alternative recycling options has been performed within the MODELS EC funded project, available at http://www.ecmodels.eu/index_files/Page660.htm .

[31]Techpol is a proprietary database of the LEPii, a research institute that works closely with Enerdata. This database provides a view of new and existing technological characteristics and associated reference costs. For more information, see, http://www.enerdata.net/enerdatauk/energy-advisory/market-research/energy-technologies.php.

[32]Techpol database developed within the CASCADE MINTS Project (2004-2006). Case Study Comparisons and Development of Energy Models for INTEGRATED Technology Systems. Policy Oriented Research (ssp)-Integrating and Strengthening the European Research Area. SSP6-CT-2003-502445, available at www.e3mlab.ntua.gr/e3mlab/reports/Final_Report_Cascade_Mints.pdf.

[33]S. Krohn, P. E. Morthorst, and S. Awerbuch, *The Economics of Wind Energy* (Brussels: European Wind Energy Association, 2009).

[34]A world index of cumulative production of clean energy technologies is used.

[35]European Commission, Directorate General for Economic and Financial Affairs (DG-ECFIN), *The 2013 Ageing Report Economic and Budgetary Projections for the 28 EU Member States (2013-2060) Technical Report* (Brussels: European Commission, 2012).

[36]European Commission, Directive 2012/27/EC of the European Parliament and of the Council of 25 October 2012 on Energy Efficiency, Amending Directives 2009/125/EC and 2010/30/EU and Repealing Directives 2004/8/EC and 2006/32/EC, Official Reporting Targets to the European Commission from Member States.

[37]European Commission, "Commission Decision of 26 March 2013 on Determining Member States' Annual Emission Allocations for the Period from 2013 to 2020 Pursuant to Decision No 406/2009/EC of the European Parliament and of the Council," *Official Journal of the European Union L90* (2013), pp. 106–10.

[38]An important mechanism in general equilibrium models that determines the overall adjustment of the economic system is the crowding out effect (financing constraints). Due to the capital resource constraint in CGE models, increased investment in a given sector or for a given purpose can be achieved only by a reallocation of investment. The reallocation of investment towards decarbonization of the energy system implies that less capital is available for investment that is not part of the decarbonization process. Moving toward a low-carbon economy implies substitution of imported fuels with equipment that is capital-intensive. Building the new capital attracts investment from other activities while at the same time puts upward pressure in the capital market (given that capital resources are fully employed already in the reference case).

[39]The first version of the GEM-E3 model has been developed as a multinational collaboration project, partly funded by the Commission of the European Communities, DG Research, 5th Framework programme, and by national authorities.

[40]The Global Trade Analysis Project, Purdue University, available at https://www.gtap.agecon.purdue.edu/databases/v7/.