Chapter 4
Towards a low emissions economy*

4.1 Emissions reduction targets at the global, European and national level

4.1.1 The international and the European framework on climate change

At the 2009 United Nations Climate Change Conference, commonly known as the Copenhagen Summit, held in December 2009, the need to ensure that the temperature rise, relative to the pre-industrial era, does not exceed 2ºC was widely recognised. Such a target can only be achieved if the concentrations of greenhouse gases (GHGs) in the atmosphere are stabilised at 450 ppm.[1] This means that emissions worldwide must be drastically reduced by 2050 to about 50% of their corresponding levels of 1990.

The various countries and regions of the world cannot be held equally responsible for curbing greenhouse gas emissions. Given that emissions from developing economies (China, India, etc.) are likely to increase substantially, the analysis using global energy models —Prometheus (NTUA-E3MLab), POLES (IPTS) and WEO (IEA)— showed that emissions from the OECD countries must be reduced by 80%, relative to 1990 levels, by 2050. In order for this target to be achieved, developing countries will, on their part, have to reduce their emission levels by 25%, relative to 1990, by 2050, a target roughly corresponding to an 80% reduction of their emissions by 2050 given their current growth trends.

The target, therefore, for the European Union is to reduce its greenhouse gas emissions by 80% by 2050, relative to 1990 levels. As an intermediate target, GHG emissions would have to be reduced by 40% by 2030, once again relative to 1990 levels. Both reduction targets must be achieved within Europe. Using the PRIMES energy model (E3MLab), the European Commission in 2010 adopted the so-called "Effort Sharing Decision" which aims to distribute the emission reduction effort fairly among the Member States. Under this distribution, the national target for Greece is for emissions to have been reduced by 70-75% by 2050, relative to 1990.

Given that the energy sector accounts for roughly 80% of all greenhouse gas emissions, and that the drastic reduction of emissions (such as methane) in certain sectors (e.g. agriculture) is

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1 Parts per million.

particularly difficult, meeting the emissions reduction target in the energy sector alone would be sufficient to enable the EU to achieve its overall target, i.e. -80% by 2050 and -40% by 2030.

Therefore, as the emphasis of the challenge of reducing GHG emissions is placed on the energy sector, important changes will be required both on the energy consumption and the energy generation sides.

4.1.2 Global hydrocarbon market trends

In order to formulate assumptions about the future prices of hydrocarbons on the international energy market, an analysis was conducted of the dynamic evolution of global energy supply and demand, using the Prometheus model (NTUA-E3MLab).

The effort to drastically reduce carbon emissions will have repercussions on the international prices of hydrocarbons. These repercussions were therefore also taken into account in the modelling process.

Based on an analysis of the world's oil reserves, along with the trend in global demand, it can easily be concluded that there is likely to be a lot of tension in the oil market in the medium term, if today's trends continue. The decline in oil reserves and the prospect of oil depletion over the next 30-40 years are distinct possibilities. Without an intensive exploitation of unconventional oil reserves, the global oil market will not be able to find its equilibrium in the long term, unless global oil prices increase considerably. Meanwhile, dependence on geopolitically sensitive regions is expected to be high. This reinforces the prospects of a significant and continued rise in oil prices in the medium and the long term.

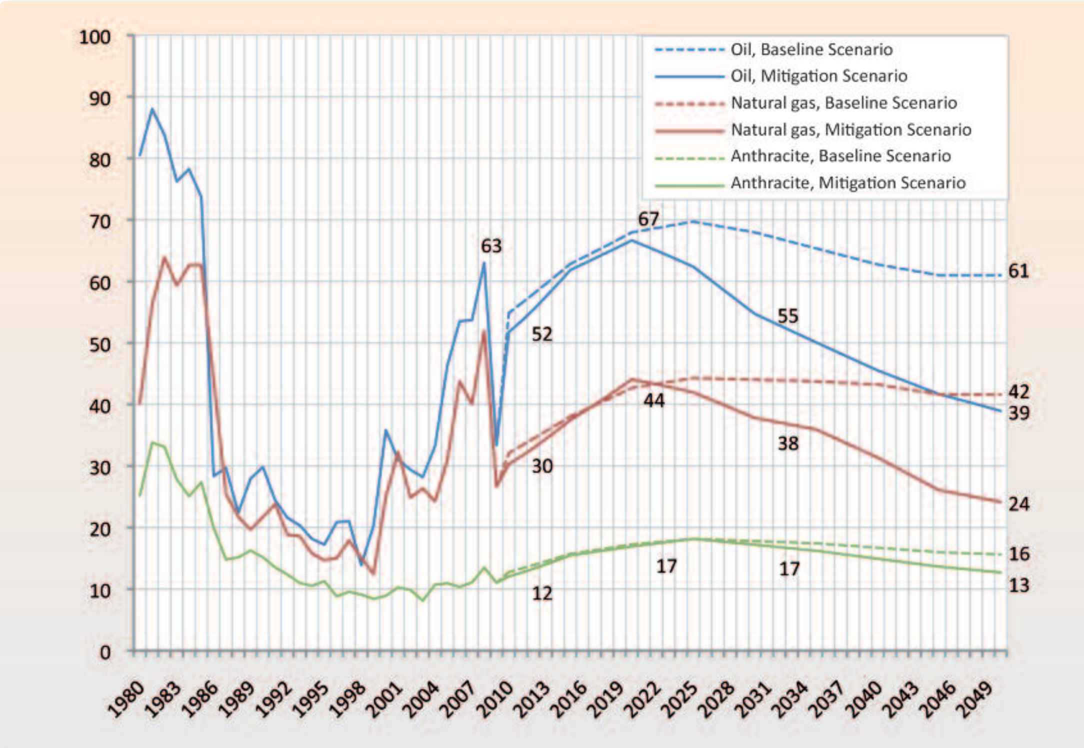
All of these considerations point to the need to achieve oil independence as a major priority of energy strategy. What is more, the pursuit of such a target could be combined with the effort to drastically reduce carbon emissions from the energy sector. By systematically reducing emissions, we can reduce the global demand for oil, thereby easing market pressures and causing global oil prices to drop.

The outlook regarding the world's natural gas reserves seems more favourable, since the production capacity will most likely decline much later than in the case of oil. The prospects of exploiting unconventional natural gas sources, both in the US and elsewhere, substantially improve the outlook for natural gas adequacy and explain why natural gas prices stabilise over the long term.

Nevertheless, in spite of pressure from the market for liquefied natural gas (LNG), the prices of which become particularly competitive in the short term, though not in the long term, the prices of natural gas, according to the analysis, remain linked to those of oil. Consequently, the increases in medium- and long-term oil prices anticipated under current growth trends would lead to a similar increase in natural gas prices.

Europe has been shown to be geopolitically vulnerable in terms of its natural gas supply, due to an insufficient diversification of import sources and delivery routes, combined with a sharp

Figure 4.1 **Projected international hydrocarbon prices (€ per barrel of oil equivalent, 2008 prices)**



Source: PROMETHEUS.

drop in its own reserves. Securing natural gas supply security will remain a top priority of energy strategy, especially in the move to a low-emissions energy system: the demand for natural gas, with its comparatively lower rate of carbon dioxide emissions, is projected to grow.

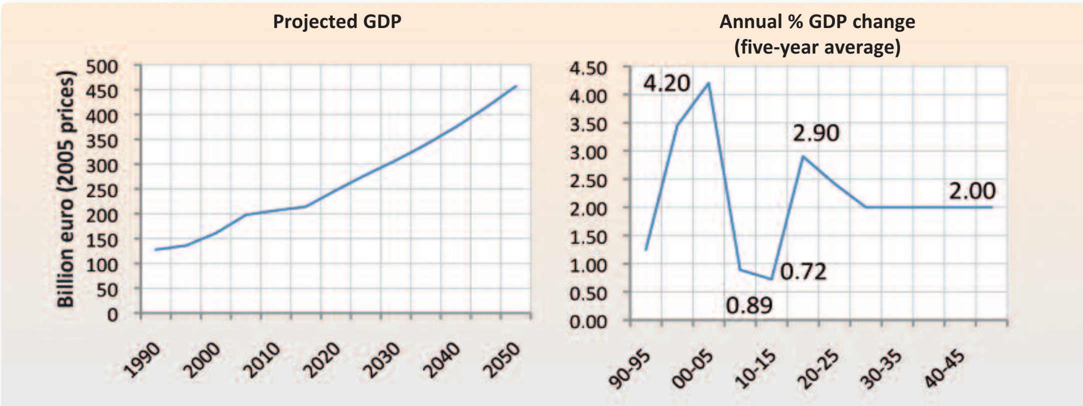
The outlook for the global coal market seems to be one of sufficient global supply, with a fairly low risk of price increases. However, the pursuit of a drastic emissions reduction target would leave no room for coal as a major energy source or as an answer to such issues as supply security and competitive energy costs.

The global price assumptions made for hydrocarbons in the Baseline Scenario and in the Mitigation Scenario (drastic emissions reduction at the global level) are presented in Figure 4.1. As can be seen, the global effort to reduce emissions has a definite depressive effect on the global hydrocarbons markets, causing substantial drops in prices over the long term, relative to the Baseline Scenario.

4.1.3 The future course of the Greek economy

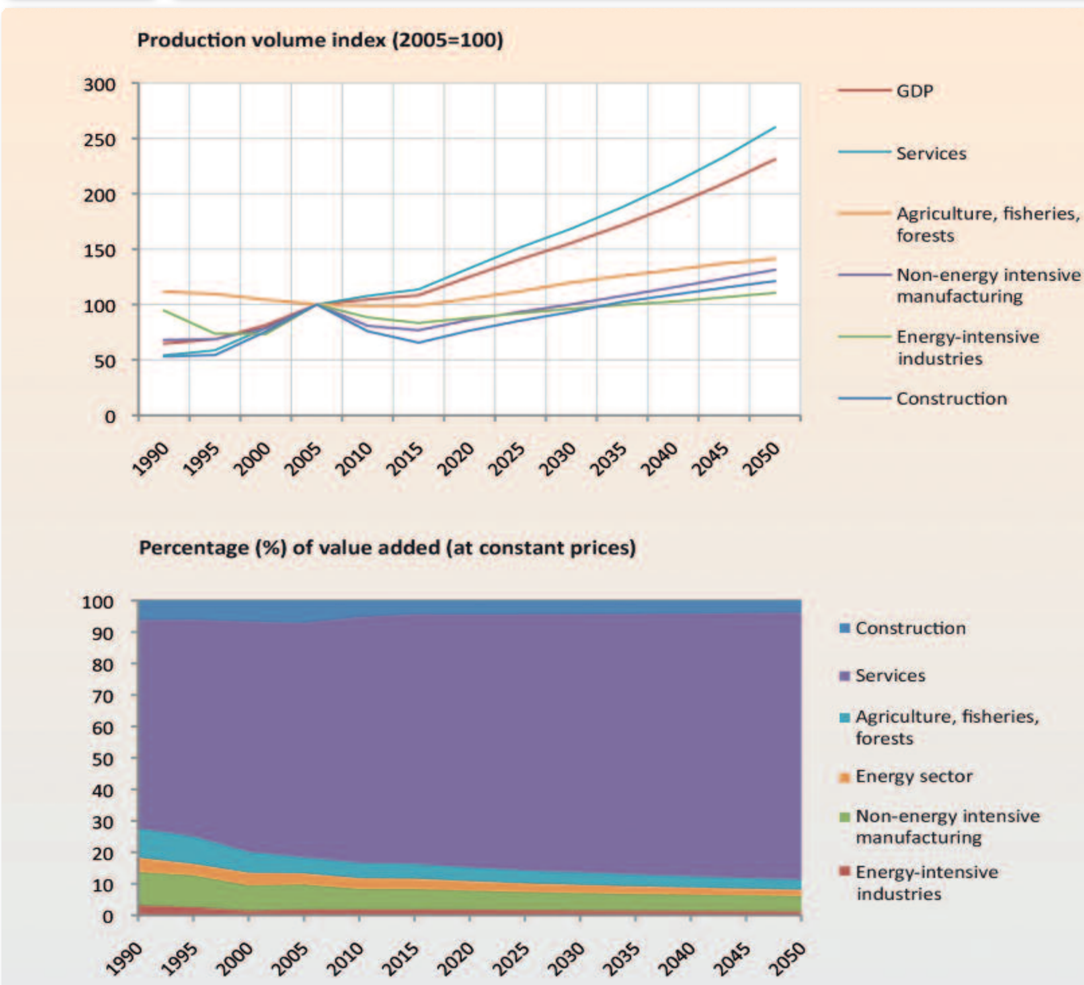
The present analysis involved making quantitative projections about the outlook for the Greek economy, both as a whole (GDP) and per sector of economic activity, using the general equilibrium model GEM-E3 (NTUA-E3MLab).

Figure 4.2 Projected GDP growth



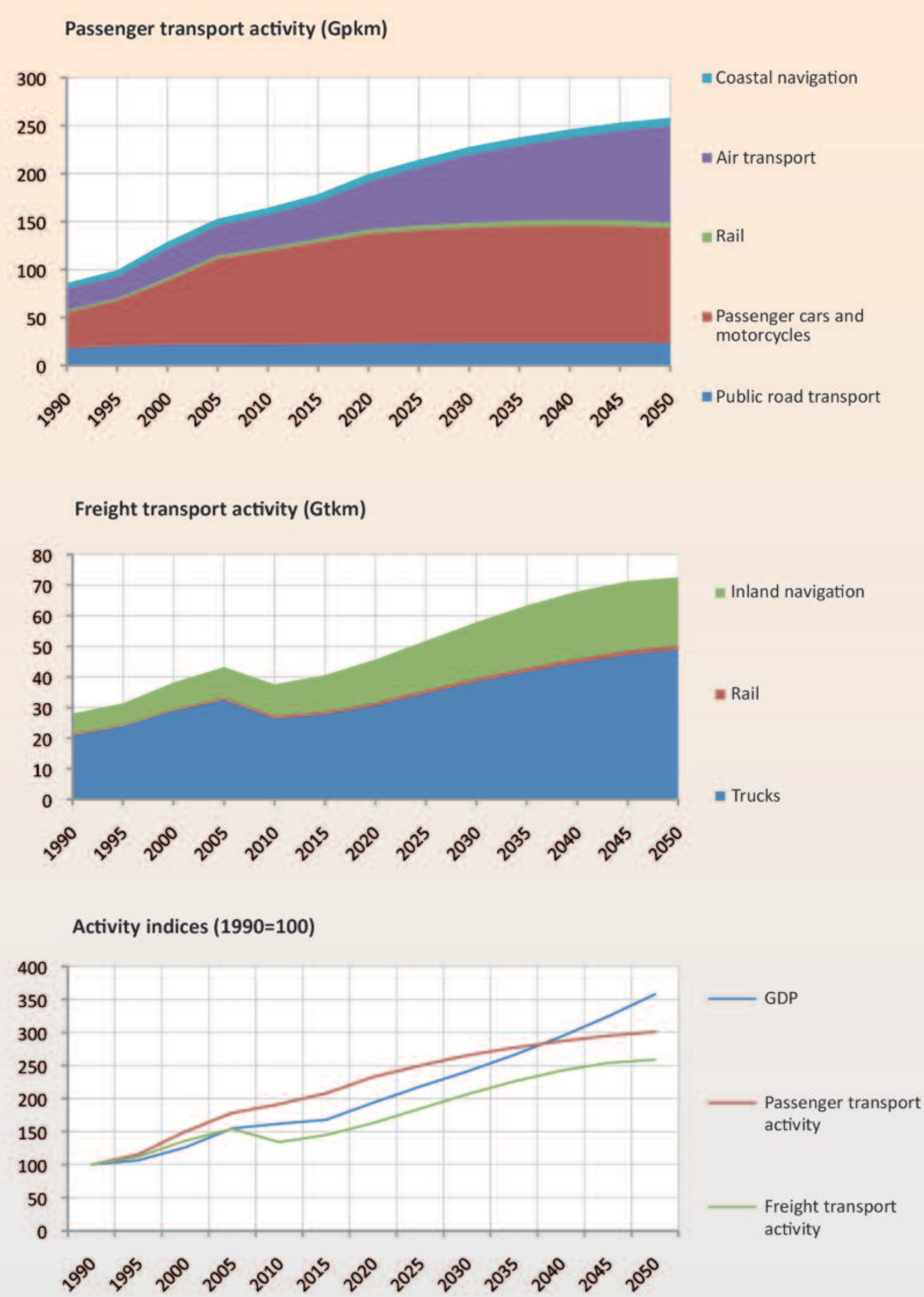
Source: GEM-E3.

Figure 4.3 Projected GDP by sector



Source: GEM-E3.

Figure 4.4 **Projection of transport activity**



Source: PRIMES.

The main aspects of these projections (Figures 4.2 and 4.3) can be summarised as follows:

• The economic recession of 2009-2011 has been incorporated in the projections.

• A period of limited growth lasts until end-2013, followed by a protracted period of recovery beginning in 2014 and continuing until the end of the projection horizon.

• Growth in the long term stabilises at 2% per year, after a small slowdown during the period 2020-2030.

• Population growth continues at first, halting in 2030. Thereafter, the population gradually declines.

• Highly energy-intensive industries remain present in Greece.

• Growth is mainly driven by services and low energy-intensive manufacturing.

The projections of transport sector activity (Figure 4.4), made using the mathematical model PRIMES, were based on the assumption of a gradual decoupling of transport activity from GDP and private consumption. It is assumed, in other words, that there will be gradual saturation in transport activity, as compared with economic activity, a trend already observed in other EU countries.

4.1.4 The European framework for energy

The European Union has already adopted a binding set of measures and targets for 2020, which include:

• the EU Emission Trading Scheme (EU ETS) covering emissions from installations such as power generation, large industries and, starting in 2012, the airline industry;

• targets for each Member State regarding the reduction of emissions in sectors outside the EU ETS; and

• targets for each Member State regarding the increase in the overall share of energy from renewable energy sources (RES).

In the same context, the European Union has adopted binding legislation on the energy efficiency of electrical appliances, buildings and houses, as well as on the carbon emissions from transportation.

The targets for 2020 are rather moderate, compared with the effort needed from the EU (and Greece) to avoid a temperature rise of more than 2ºC. The drastic reduction of emissions in the longer term (2050) would obviously require reinforcement of the initial targets and, by extension, of the policy for 2020.

Another major priority for European policy is the completion of the single energy market in Europe, for both electricity and natural gas, which would have indisputable benefits: better management of the EU's energy dependence on third countries, better quality of services and better prices as a result of enhanced competition, better resource management as a result of inter-regional cooperation (e.g. better incorporation of RES via joint load balancing).

The EU "Climate and Energy" package

In January 2008 the European Commission proposed binding legislation to implement the 20-20-20 targets. This 'climate and energy package' was agreed by the European Parliament and Council in December 2008 and became law in June 2009.

The core of the package comprises four pieces of complementary legislation:

1. A revision and strengthening of the Emissions Trading System (ETS), including: a) a single EU-wide cap on emission allowances, to apply as of 2013 and to be reduced annually (by 1.74%), thereby reducing the number of allowances available to businesses to 21% below the 2005 level in 2020; b) the free allocation of allowances will be progressively replaced by auctioning; c) the EU ETS will be expanded to include aviation as from 1 January 2012; and d) beyond 2020, the total number of allowances will continue to be reduced by 1.74% each year.

2. Binding national emissions limitation targets for 2020, which reflect each Member State's relative wealth.

3. Binding national targets for renewable energy, which collectively will lift the average renewable share across the EU to 20% by 2020.

4. A legal framework to promote the development and safe use of carbon capture and storage (CCS). The EU therefore plans to set up a network of 12 CCS demonstration plants by 2015, with the aim of commercial update of CCS by around 2020.

4.1.5 Evaluation of the current situation in Greece

Compared with other EU countries, Greece's energy sector is considered to be both less efficient and high emission generating. The transportation sector, both urban and long-distance, is particularly problematic, due to a long list of problems, such as inadequacy of the rail transit system, excessive use of air transport, the low levels of public transport usage, the inefficient expansion of road merchandise delivery, etc.

The only real progress in the energy supply sector achieved so far has been the introduction of natural gas, both for direct use and for power generation. Even so, the introduction of natural gas for direct use has advanced at a slow pace and thus remains limited.

The modernisation of power generation technology has been limited to gas-fired combined-cycle power plants, while outdated, polluting and inefficient plants (solid fuel-fired and oil-fired) remain in operation.

The Greek energy market is also faced with a series of other problems that need to be addressed, such as overdue island interconnection projects, slow development of RES, incomplete competition in the energy market and limited inter-regional cooperation.

If the current trends are allowed to continue, Greece will miss its targets and commitments by a widening margin in all sectors. The negative implications will be considerable, e.g. sizable increases in electricity prices to cover the emissions costs set by the EU ETS.

The Greek government recently submitted to the European Union a binding and rather ambitious programme for the development of RES by 2020. In the present analysis, the implementation of this programme was taken as part of the national effort to overhaul the energy system in line with a drastic reduction in carbon emissions.

4.1.6 The challenges for Greek energy policy

The challenges that Greece's energy policy must meet, both under the mandatory targets set by the EU and as part of its energy sector overhauling effort, are in summary the following:

- a continued and increasingly drastic reduction of carbon emissions from the energy sector, in a move towards an economy of particularly low emissions by 2050,
- a gradual shift away from oil dependence,
- enhancement of the security of the natural gas supply,
- a wide-scale development of renewable energy sources as clean and domestic energy sources,
- a reliable and adequate supply —to all consumers— of energy and energy services,
- achieving the most competitive energy prices and costs possible, and
- reducing access inequality to energy services.

4.2 Policy for emissions reduction per sector

In order to meet the obligations arising from its ratification of the Kyoto protocol and from respective commitments to the EU, Greece drew up a "National Action Programme"[2] for the abatement of GHG emissions over the period 2000-2010. This programme included measures to reduce emissions from the residential and tertiary sector, electricity generation, transport, agriculture, industry and industrial processes.

The need for further drastic emissions reduction by 2050 in the fight against climate change makes the reinforcement and expansion of these measures imperative.

The residential and tertiary sector

There is considerable room for energy saving in this dual sector, considering the old age of many buildings, the low level of RES penetration achieved so far, the low efficiency of energy-hungry appliances, and the irrationality of energy consumption patterns.

The policy for GHG reduction is mainly targeted at saving energy by improving the sector's energy consumption efficiency. This is an indirect way of reducing the emissions from power generation. The main lines of action which the GHG reduction policy has adopted are the following:

2 http://www.ypeka.gr/Default.aspx?tabid=431&language=el-GR

- Measures to improve the external envelope of existing buildings, e.g. by insulating the roof or installing double-pane windows to minimise heat loss.
- Measures to improve heating and cooling equipment efficiency, such as the proper maintenance of central heating boilers (or their replacement whenever improvement measures would be ineffective) in order to increase heating efficiency; the use of solar protection techniques (sun shades, ceiling fans, night ventilation) to reduce the buildings' cooling load; the use of more efficient climatisation units, etc.
- Measures to improve electrical appliance and lighting efficiency, such as the use of more efficient appliances, especially domestic (washing machines, television and audio systems, etc.), the use of energy-saving compact fluorescent lamps (with only 25% of the energy consumption of incandescent ones), the installation of automatic lighting control systems (with occupancy sensors, light intensity meters that also take natural lighting into consideration to achieve optimal lighting, etc.). These measures also involve the usage —for lighting purposes— of (freely available) solar energy, as a way to avoid artificial lighting.
- RES penetration in both heating and electrical installations. With the exception of solar panel usage, the degree of RES exploitation still remains low, despite the abundant RES potential present in Greece's natural environment. As part of the effort to reduce emissions, measures should be taken to: increase the share of water heating needs met by solar-powered systems, expand the use of solar energy to space heating (as an auxiliary or back-up system to conventional main heating systems), develop biomass-fired district heating systems (with one central boiler instead of several individual ones), etc. Other measures include simplifying and standardising procedures for the installation and grid-connection of photovoltaic systems, in cases where high costs are not a deterrent (for instance, if alternative energy supplies are even more expensive).
- Expansion of the use of heat pumps, which are not only highly efficient but also use RES, for such purposes as heat recovery, the use of low-enthalpy geothermal energy, etc.
- Increase of the use of natural gas (provided that the distribution network is completed) by promoting a faster rate of natural gas penetration in space heating, as well as the installation of special gas-fired cooling systems.

Transport

The transport sector is responsible for a large part of Greece's CO_2 emissions (27% of total CO_2 emissions in 2010). This is a sector that —with the exception of electric powered means (trolleybuses, urban railway, tram, trains)— is predominantly dependent on liquid fuels, mostly refined from petroleum, and that till now did not have many alternatives to the internal combustion engine.

In the context of emissions reduction, the use of alternative technologies in the transport sector is recommended, especially in land transport, given that there is not much potential for the use of alternative technologies in sea and air transport.

Efforts to reduce emissions from air transport are taking shape with the inclusion of the sector in the Emissions Trading Scheme (ETS).

The scenarios developed in the present study anticipate that oil consumption in the road transport sector will be substituted for by electricity, which in the long term will be produced CO_2-free. The sector's use of electrical energy will increase as plug-in hybrid electric vehicles become more widespread.

Renewable energy sources can play an important role, as biofuels (mainly biodiesel and bioethanol) can be admixed with conventional fuels, thereby limiting emissions considerably as they are produced with second- and third-generation technologies, which reduce emissions along the entire biofuel production chain.

A plethora of other technologies, still at a trial stage and which research is trying to make more competitive, may be available in the future, such as hydrogen fuel cells.

Overall, the implemented measures for reducing emissions in the transport sector can be divided into the following categories:

- Vehicle-related interventions, involving the maintenance of cars and trucks (maintenance of the engine combustion, transmission and breaking systems),
- Measures involving transport system management, e.g. the promotion of urban transport usage, the use of gas-fired buses, better traffic lighting, as well as mild emissions reduction interventions,
- The use of new fuels (more specifically by expanding the use of biofuels) and the promotion of alternative, clean technologies with an emphasis on electricity and, in the longer term, on hydrogen, and
- The implementation of more stringent standards for CO_2 emissions per vehicle kilometre travelled, as well as for vehicle energy efficiency (this measure is expected to be crucial to the future reduction of emissions).

EU policy for reducing transport sector emissions

In 2007, the EU proposed (proposal COM (2007)/856) a Community strategy to reduce emissions from light-duty vehicles (passenger cars and light-commercial vehicles), having as an overall objective that by 2012 the average new car fleet should achieve CO_2 emissions of 120g CO_2/km (corresponding to a 25% reduction of emissions, relative to 2006). The purpose of this strategy is to mitigate emissions from both the production and the consumption side.

On the production side, the strategy provides for the adoption of legislation that will give car manufacturers incentives to reduce the emission levels of new vehicles and to increase the efficiency of vehicle components largely responsible for high fuel consumption, such as air-conditioning systems, special tires, etc. At the same time, fiscal incentives were considered to motivate consumers to purchase fuel-efficient vehicles and save energy.

In April 2009 (Regulation No. 443/2009) the target for average CO_2 emissions from the new car fleet in the Community was set at 130g CO_2/km, to be achieved by means of improvements in vehicle motor technology, while a further 10g CO_2/km reduction should be achieved by additional measures. In the longer-term, i.e. by 2020, the average CO_2 emissions target from the new car fleet should be lowered to 95g CO_2/km.

Industry

The measures taken to reduce the emissions from the industrial sector include:

- Promoting the use of natural gas, mainly as a substitute for crude and diesel oils. This substitution should not be limited to energy-hungry plants with high thermal needs, but should also be promoted in other manufacturing units and diesel-fired operations, while new distribution networks should be developed.
- Promoting the use of RES and heat pumps for the recovery of thermal energy in low- and middle-enthalpy uses.
- Expanding electricity and heat cogeneration to medium- and high-enthalpy applications.
- Promoting the use of biomass in thermal energy applications and in co-combustion furnaces.
- Adopting various energy-saving measures (energy management optimisation and modernisation interventions to reduce heat losses and to re-use the heat discarded by furnaces).

Electricity generation

Any drastic emissions abatement effort must first and foremost involve a total restructuring of electric energy generation. This sector is responsible for the largest part of CO_2 emissions (45% in 2010), but at the same time has the greatest room for emissions reduction, now that a plethora of alternative, clean and sustainable technologies can replace conventional solid fuel-fired stations, predominant today in Greece's electricity generation.

The target, in the fight against climate change, is to achieve almost carbon-free electricity generation. This will make electrical energy a suitable substitute for fossil fuels in final energy uses (through heat pumps in stationary energy plants and transport electrification).

The policy promoted today is focused in this direction and seeks to establish a legal framework that will pave the way to the gradual development of an electricity generation system totally free of carbon emissions. The key lines of this policy involve:

- Promoting wind farm installations, on land and at sea,
- Promoting small hydroelectric plant installations,
- Setting up central and decentralised photovoltaic plants,

- Developing the high-enthalpy geothermal potential,
- Promoting biomass and waste use in electricity generation and cogeneration,
- Enhancing and expanding electrical energy storage systems (pumped storage, in the long term hydrogen storage) and
- Expanding the operation of natural gas plants.

Waste management

In the waste management sector, there is room to reduce methane (CH_4) emissions. It should be noted that methane has an atmosphere warming potential 21 times more potent than CO_2 for a period of 100 years. Actions for the abatement of CH_4 emissions, though of limited potential relative to actions for the reduction of CO_2 emissions, are therefore deemed necessary to address climate change.

Agriculture

Agricultural activity is mainly associated with the emissions of nitrous oxide (N_2O), widely used as a fertiliser. The heat capacity of nitrous oxide is up to 300 times that of CO_2, while the largest part of N_2O emissions results from natural processes occurring in the soil. Biological cultures are being promoted, in order to reduce the use of nitrogen fertilisers and thereby to curb N_2O emissions.

Other policies for this sector involve using animal waste management systems, so as to limit CH_4 emissions from animal husbandry.

Industrial processes

Industrial processes (chemical processing, cooling sprays, aluminium electrolysis, etc.) are all associated with the emissions of fluorinated greenhouse gases, more simply known as f-gases (hydrofluorocarbons-HFCs, perfluorocarbons-PFCs, sulfur hexafluoride-SF_6). In 2000, emissions of these gases in Greece came to 3,744 kilotonnes of CO_2 equivalent. It is also worth noting that the sector of production, use, maintenance and final disposal of refrigeration, air-conditioning equipment, etc. makes up the most dynamic source of emissions, with an average annual growth rate of 20% over the period 2000-2010. In order to reduce these emissions, efforts are being made to: a) redesign the operation of chemical industries (high f-gas emitting plants) and b) recover HFCs from refrigerating and air-conditioning equipment.

4.3 Road map for a transition to a low-emissions economy

The road map for Greece's energy policy to meet the emissions reduction targets was quantified using the PRIMES energy model (E3MLab/NTUA). The model points out the optimal cost-effective way of achieving these targets by simulating the economic and technical decisions of energy producers and consumers, as well as their interactions with the energy markets. The results of the simulation include the optimal mix of energy forms, the penetration of new technologies, the extent of energy saving, the optimal investment programmes broken down per technology and per sector, as well as energy price and cost estimates.

4.3.1 The future course of Greece's energy system: assumptions and constraints

Scenario formulation for the PRIMES model

The scenarios developed using the PRIMES model reflect the optimal course toward a low emissions economy, by means of a near elimination of CO_2 emissions from power generation by 2050. These scenarios are consistent with the targets of reducing emissions at the European level by 40% in 2030 and 80% in 2050, relative to 1990.

In developing these scenarios, the following assumptions and constraints were adopted with regard to energy policy:

- Until 2020, the energy system evolves in such a way as to at least meet the targets and commitments set by the European Union[3] in 2008 and further elaborated by Greece's Ministry of Energy and Climate Change in its action plan for RES. The model simulates the behavioural patterns of energy producers and consumers, taking it as given that emission reduction targets will become more stringent after 2020, for instance by 40% in 2030, thus explaining why producers opt to make certain investments and decisions before 2030.
- For the period beyond 2020, the assumption was made that the pricing of CO_2 emissions is generalised to the entire economy. It was also assumed that the price of CO_2 is the same across all sectors and all EU Member States. Using the PRIMES model, a price for CO_2 was set at a pan-European level that helps achieve the targeted CO_2 emission reductions. It was then considered that Greece, as a small country within the EU, is not in a position to influence CO_2 price levels. These prices are presented in Table 4.1. It should be reminded that polluters subject to the EU ETS scheme will pay the State for their emission allowances, while it was assumed that other polluters (not subject to the EU ETS scheme) will take the price of emissions into account when making decisions, without actually incurring a fine if they don't reduce their emissions.
- Increasing energy consumption efficiency continues to be promoted through the implementation of a package of policy measures for energy saving and the promotion of more efficient appliances and equipment in all sectors. Particular emphasis is placed on energy saving in buildings through a large-scale programme specially devised for the energy

3 The EU climate and energy package, http://ec.europa.eu/clima/policies/package/index_en.htm

Table 4.1 CO_2 price (Euro/t CO_2, 2008 prices)

		2020	2030	2050
Mitigation Scenarios	ETS sectors	25.0	60.0	190.0
	Non-ETS sectors	25.0	60.0	190.0
Baseline Scenario	ETS sectors	16.5	36.0	50.0
	Non-ETS sectors	5.3	5.3	5.3

Source: PRIMES.

upgrading of houses and buildings. In compliance with EU Directives, tight energy efficiency standards are implemented for a wide range of appliances and industrial equipment, as well as for means of transport.

- The road transport sector undergoes a dynamic penetration of alternative technologies and biofuels, as the result of a specially devised policy, with e.g. strict emission limits per vehicle, mandatory admixture rates for second generation biofuels and mass transport improvement measures. The admixture of biofuels is extended to fuels used by airplanes and ships. In the long term, electricity gradually becomes the main source of energy, as a result of these measures and of advances in battery technology. The road map thus includes the large-scale development of vehicle charging stations immediately after 2020, the use of 'smart' meters and recourse to incentives to recharge during hours of low system load. Responsibility for the development of the system lies with the Network Operator and the costs are covered by a special tax.
- No binding targets are set for energy generation from RES beyond 2020. The support mechanisms for renewable energy sources remain as they are until 2020 and are gradually phased out in the following decade (2020-2030). However, due to the wide scope of the emission reduction targets and to emission pricing, RES continue to expand dynamically beyond 2020 and largely overshoot the 2020 target levels. On a longer horizon, low- and medium-voltage 'smart' grids are developed and thereby facilitate the development of very small-scale RES-fired power generation. In addition, electrical energy storage systems are developed, thanks mainly to pump systems with reservoirs and, in the long term, to hydrogen technologies. The assumption is made that hydrogen could be produced in small quantities in the long term via water electrolysis and mixed with natural gas to fire electricity-generating gas turbines. This way, hydrogen indirectly supports the development of large-scale RES in power generation, while at the same time serving as a storage medium.

The prices of CO_2 emission allowances were determined using the PRIMES model, just as they had been determined in earlier studies of all the EU Member States for the European Commission (2010). This was necessary, given that the auctioning of emission allowances will apply across the EU and its equilibrium will therefore lead to uniform CO_2 prices across the EU.

Given the uncertainty surrounding the future structure of the power generation system, which in any case will have to eliminate emissions in the long term, variations of the 'conducive to a particularly low GHG emissions economy' energy scenario were developed (corresponding to variations of the Mitigation Scenario).

This uncertainty concerns:

a) the upper limits of RES contribution to power generation on condition that an acceptable level of system reliability can be maintained, given that RES production depends on primary energy availability and is therefore stochastic;

b) the capacity to store CO_2 in geological formations, after its capture in large fossil fuel-fired plants (mainly for power generation), given the uncertainty about Greece's geological potential but also about public acceptance of the corresponding storage projects; and

c) the possibility of developing nuclear plants in Greece, which raises highly complex economic and organisational matters, as well as waste management issues.

It is not within the scope of the present study to resolve these technical and policy-related uncertainties. Instead of advocating specific options, we chose to investigate what the impact of the alternative scenarios would be —in terms of power generation costs and structure— assuming in each case that the relevant uncertainty has been resolved.

Three different Mitigation Scenarios were developed for Greece. Their difference, as detailed below, lies in how the country's almost emission-free power generation will be structured in the future:

I. The ***"RES" Mitigation Scenario***, which envisages high RES penetration in power generation and the development of storage techniques. Nuclear energy and carbon capture and storage (CCS) technologies remain absent.

II. The ***"RES and CCS" Mitigation Scenario***, which envisages the development of CCS technologies with carbon dioxide storage in geological formations in Greece. Once again, nuclear energy is absent, but CCS technologies and CO_2 transmission and storage systems are assumed to be available on the market from 2025 onward.

III. The ***"RES and nuclear energy" Mitigation Scenario***, which assumes that nuclear energy can be developed in Greece after 2030, whereas CO_2 storage sites (from CCS projects) are not available.

A ***Baseline Scenario*** was also developed, which assumes that the "20-20-20" policy is fully implemented through 2020, but that no further decisions are made, apart from the implementation of the emission allowances purchase scheme, which basically applies to power generation, large combustion facilities and aviation. The scenario extends until 2050 and can be summarised as follows:

- The Emission Trading Scheme (EU ETS) is implemented, under the further assumptions that: (a) the total number of emission permits issued is progressively reduced by 2050; (b) EU ETS regulations are extended to power generation, heavy industry and aviation; and (c) all emission permits are auctioned as of 2013. Non-ETS sectors are subject to certain emission caps as of 2015 (less stringent than under the EU ETS and constant through 2050).
- Greece's announced policy for RES is simulated by assuming that renewables account for close to 40% of power generation until 2020. Beyond 2020, however, no further binding targets are set, while subsidies for RES technologies are gradually phased out, particularly in cases where know-how is limited. The contribution of these technologies nonetheless remains high.
- The EU directives and regulations aimed at improving the energy efficiency of buildings, houses, electrical appliances and transport are adopted, but implementation is assumed to enjoy limited financial support and to be of moderate intensity, in contrast with the Mitigation Scenarios, under which financial support policies are developed to the maximum extent possible.
- With the exception of nuclear and CCS technologies, all other power generation technologies are considered to be available to Greece and eligible for investment.

To allow for comparability and for assessments of the policy contained in the Mitigation Scenarios, another scenario, the ***"No Policy" Scenario***, was developed which assumes that no emission reduction policies (including RES penetration and energy efficiency improvement) are implemented. This scenario is purely market-based, without any state intervention or policy targets.

Scenarios developed using the PRIMES model for the period 2010-2050

Baseline Scenario: the policy in effect in Greece and the EU remains in place until 2020 and is extended until 2050, without any ambitious emission abatement targets set. The EU ETS mechanism also remains in effect until 2050.

Mitigation Scenarios: CO_2 emission reductions by 2050 of 80% at the European level and of 75% for Greece. Alternative scenarios are envisaged with regard to the future structure of power generation:

- The *"RES"* Mitigation Scenario
- The *"RES and CCS"* Mitigation Scenario
- The *"RES and nuclear energy"* Mitigation Scenario

4.3.2 Scenarios concerning the evolution of the Greek energy system in response to the mitigation targets

Findings of the study using the PRIMES energy model

The quantification of the Mitigation Scenarios using the PRIMES model outlines a road map for achieving the target of an 80% reduction of greenhouse gas emissions by 2050. This road map includes:

- energy efficiency enhancement in buildings, electrical appliances, industrial processes, etc.;
- energy savings of 20% by 2030 and of 50% by 2050, relative to the “No Policy” Scenario;
- RES participation in final energy consumption above 20% by 2030 and 35% by 2050, against 13% in 2010,
- Participation of RES in power generation (14.5% in 2010) as follows:
  - 66% by 2030 and 83% by 2050 under the *“RES” Mitigation Scenario,*
  - 47% by 2030 and 43% by 2050 under the *“RES and CCS” Mitigation Scenario,*
  - 49% by 2030 and 51% by 2050 under the *“RES and nuclear energy” Mitigation Scenario,*
- Road transport electrification of 25% by 2030 and 85% by 2050,
- Production of 500,000 tonnes (of oil equivalent) biofuels by 2030 and 2,65 million tonnes by 2050 for admixture with diesel oil products, against 135,000 tonnes in 2010, and
- Infrastructure upgrading and expansion to ensure island interconnection, transport electrification and the connection of very small scale RES to low-voltage grids.

The methodology used for the simulation of the emissions reduction effort

The pricing of CO_2 can serve as a key incentive tool in promoting the transition to a low-emissions economy.

By steadily increasing CO_2 prices, energy producers are compelled to pay increasingly more for emission allowances, a cost which they pass on to consumers by charging higher prices for energy. Energy producers are thus motivated to “reconsider” their energy generation mix as a way of cutting back on costs and thus deliberately choose to spend more on energy forms that are more capital-intensive, but less carbon-intensive. This restructuring also benefits consumers, as the impact on energy prices is mitigated.

Consumers, on their side, are faced not only with higher energy prices, but also with higher costs from their own direct emissions. They are therefore motivated to “reconsider” their energy consumption mix, in favour of less carbon-intensive energy forms, while also proceeding to energy saving investments and purchases of electrical appliances, equipment and vehicles that cost more to purchase, but less to operate because of their greater energy efficiency and fewer emissions.

All energy market participants spend more on capital and less on operating costs, in comparison with the Baseline Scenario.

CO_2 pricing can thus serve as a motivational tool for substituting existing technologies with lower-emission technologies. Such a substitution cannot be perfect, which explains why total energy costs are higher under the Mitigation Scenario than under the Baseline Scenario.

The impact of the Mitigation Scenarios on GHG emissions

As shown by the results presented in Table 4.2, if no policy is adopted, Greece's greenhouse gas emissions would continuously increase and by 2050 would exceed 1990 levels by 55%, an outcome totally incompatible with a global effort to avert climate change.

Table 4.2 also gives a projection of current policies, reflected in the Baseline Scenario. In spite of the ambitious policies contained in this scenario, especially for the 2020 time horizon, the absence of additional climate policies makes this scenario insufficient in the context of the effort to avert climate change. In the Baseline Scenario, greenhouse gas emissions by 2050 are reduced by a mere 6% relative to 1990 levels, against the reduction target of 'minus 70-80%' adopted by the EU. Additional large-scale climate policies are thus required, particularly in the period beyond 2020, so as to bring Greece's emissions into line with the target for limiting the increase in the Earth's temperature to 2ºC.

These additional policies are outlined in the three variations of the Mitigation Scenarios that achieve a reduction in Greece's greenhouse gas emissions by between 58% and 63% in 2050, relative to 1990 levels, and equivalent to a reduction by about 70%, relative to the emission levels of 2005.

Using the mathematical model, we determined the optimal cost-effective distribution of the greenhouse gas emissions reduction among the sectors of economic activity (Table 4.3), taking into account each sector's emissions reduction potential through various actions. The model considered that the costs of each action increase in a non-linear manner depending on how it has developed relative to its potential. This way, the optimal distribution of the emissions reduction effort among the sectors includes all actions as well all sectors, without exhausting the potential. When trying to ensure maximum adaptation flexibility as well as a reduction in total costs, it is important that no actions be omitted, especially in the power generation sector. This is why, as mentioned above, alternative scenarios were examined.

The drastic abatement of greenhouse gas emissions was found to be similar in all three variations of the Mitigation Scenario (Figure 4.5).

Figure 4.6 illustrates how the reduction of CO_2 emissions from the energy sector, relative to 2005 emission levels, is achieved, by distributing this reduction among the different ways of achieving it, according to the modelling results for each Mitigation Scenario.

Of all the ways of reducing emissions, energy saving consistently makes the largest contribution, as it accounts, cumulatively over the period 2005-2050, for more than 40% of the total reduction. RES account for a share of 48% under the "RES" Mitigation Scenario and for 30% and 39%, respectively, under the other two Mitigation Scenarios. CO_2 capture and storage accounts for 19% of total emissions reduction, but is only developed under the "RES and CS" Mitigation Scenario. The contribution of nuclear energy, only envisaged under the "RES and nuclear energy" Mitigation Scenario, is small. Natural gas, as a substitute for other fossil fuels, accounts for between 9% and 12% of total emissions reduction.

Table 4.2 Greenhouse gas emissions by scenario derived with the PRIMES model in million tonnes of CO_2 equivalent

	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
No Policy Scenario													
Emissions from fossil fuel combustion	71.1	78.0	88.9	95.8	90.2	91.8	100.2	103.8	107.7	110.9	117.2	123.1	132.8
Industry	9.3	9.8	9.9	8.2	6.1	5.7	6.0	5.4	5.6	5.7	6.0	6.2	6.5
Household sector	4.6	4.8	7.5	9.7	9.8	9.7	10.6	11.9	12.6	12.9	13.0	13.0	12.8
Services	0.6	0.6	0.8	1.5	1.4	1.3	1.7	1.9	1.9	2.0	2.1	2.1	2.2
Agriculture	2.7	2.6	2.6	2.7	2.7	2.6	2.7	2.7	2.7	2.8	2.9	3.1	3.2
Transport	17.2	19.1	21.3	23.9	23.4	24.8	27.4	28.8	30.2	31.3	32.6	33.8	35.2
Electricity generation	34.1	39.0	43.9	46.3	44.0	44.9	49.0	50.0	51.5	53.1	57.6	61.7	70.0
Other energy industries	2.4	2.2	3.1	3.5	2.8	2.7	2.9	3.1	3.2	3.1	3.1	3.2	3.1
Emissions from non-energy related activities	30.3	30.8	31.6	31.8	25.0	22.7	22.8	23.0	23.1	22.2	22.7	23.5	24.2
CO_2 emissions from industrial processes	6.9	7.5	7.9	8.0	6.1	5.0	5.5	5.9	6.4	6.8	7.1	7.6	8.0
Other CO_2 emissions	0.2	0.2	0.2	0.3	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Emissions of other greenhouse gases	23.1	23.2	23.5	23.5	18.7	17.4	17.1	16.8	16.4	15.2	15.3	15.7	15.9
Total greenhouse gas emissions	101.4	108.9	120.5	127.5	115.1	114.5	123.0	126.8	130.8	133.1	139.9	146.6	157.1
Baseline Scenario													
Emissions from fossil fuel combustion	71.1	78.0	88.9	95.8	84.4	74.6	76.2	79.1	74.7	68.8	69.7	70.8	73.5
Industry	9.3	9.8	9.9	8.2	6.0	5.0	4.1	4.0	3.9	3.9	4.0	4.2	4.5
Household sector	4.6	4.8	7.5	9.7	9.7	9.3	9.8	10.4	10.7	10.4	10.0	9.6	8.9
Services	0.6	0.6	0.8	1.5	1.4	1.3	1.6	1.5	1.5	1.6	1.6	1.7	1.7
Agriculture	2.7	2.6	2.6	2.7	2.7	2.6	2.6	2.5	2.5	2.6	2.7	2.8	2.9
Transport	17.2	19.1	21.3	23.9	23.0	23.3	23.9	24.9	25.0	25.2	25.9	26.7	27.7
Electricity generation	34.1	39.0	43.9	46.3	38.7	30.4	31.9	33.4	28.6	22.8	23.2	23.5	25.5
Other energy industries	2.4	2.2	3.1	3.5	2.8	2.6	2.4	2.4	2.4	2.3	2.3	2.3	2.3
Emissions from non-energy related activities	30.3	30.8	31.6	31.8	25.0	22.2	21.0	21.2	20.5	20.3	20.6	21.2	21.7
CO_2 emissions from industrial processes	6.9	7.5	7.9	8.0	6.1	5.0	5.5	5.9	6.3	6.6	6.7	7.0	7.2
Other CO_2 emissions	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Emissions of other greenhouse gases	23.1	23.2	23.5	23.5	18.7	16.9	15.3	15.1	14.1	13.6	13.7	14.1	14.3
Total greenhouse gas emissions	101.4	108.9	120.5	127.5	109.3	96.7	97.3	100.4	95.2	89.1	90.2	92.0	95.1

Source: PRIMES.

Table 4.2 Greenhouse gas emissions by scenario derived with the PRIMES model in million tonnes of CO_2 equivalent *(continued)*

	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
RES Scenario													
Emissions from fossil fuel combustion	71.1	78.0	88.9	95.8	84.3	73.1	68.6	64.0	54.3	46.3	38.0	30.8	24.9
Industry	9.3	9.8	9.9	8.2	6.0	5.1	4.0	3.8	3.8	3.5	3.2	2.6	2.0
Household sector	4.6	4.8	7.5	9.7	9.7	9.1	9.3	9.8	9.9	9.0	7.5	6.0	3.9
Services	0.6	0.6	0.8	1.5	1.4	1.3	1.5	1.4	1.3	1.2	0.8	0.5	0.3
Agriculture	2.7	2.6	2.6	2.7	2.7	2.5	2.4	2.4	2.3	2.1	1.8	1.0	0.3
Transport	17.2	19.1	21.3	23.9	23.0	23.3	23.4	23.5	23.6	20.2	17.4	13.1	11.1
Electricity generation	34.1	39.0	43.9	46.3	38.7	29.2	25.6	21.0	11.2	8.5	5.8	6.2	6.2
Other energy industries	2.4	2.2	3.1	3.5	2.8	2.6	2.3	2.2	2.1	1.8	1.6	1.3	1.2
Emissions from non-energy related activities	30.3	30.8	31.6	31.8	25.0	20.6	20.4	20.4	19.1	17.7	15.9	13.3	12.7
CO_2 emissions from industrial processes	6.9	7.5	7.9	8.0	6.1	5.0	5.5	5.9	6.0	5.1	3.5	0.9	0.6
Other CO_2 emissions	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.0	0.0
Emissions of other greenhouse gases	23.1	23.2	23.5	23.5	18.7	15.4	14.7	14.4	13.0	12.6	12.3	12.3	12.1
Total greenhouse gas emissions	101.4	108.9	120.5	127.5	109.3	93.7	88.9	84.5	73.4	64.1	53.9	44.1	37.5
Combined RES and CCS Scenario													
Emissions from fossil fuel combustion	71.1	78.0	88.9	95.8	84.3	73.0	70.2	50.7	51.6	46.7	41.6	33.9	26.6
Industry	9.3	9.8	9.9	8.2	6.0	5.1	4.0	3.8	3.8	3.5	3.2	2.6	2.0
Household sector	4.6	4.8	7.5	9.7	9.7	9.1	9.3	9.8	10.0	9.1	7.6	6.1	4.0
Services	0.6	0.6	0.8	1.5	1.4	1.3	1.5	1.4	1.3	1.2	0.8	0.5	0.3
Agriculture	2.7	2.6	2.6	2.7	2.7	2.5	2.4	2.4	2.3	2.2	2.0	1.6	0.7
Transport	17.2	19.1	21.3	23.9	23.0	23.3	23.4	23.5	23.6	20.2	17.4	13.1	11.1
Electricity generation	34.1	39.0	43.9	46.3	38.7	29.2	27.2	7.6	8.5	8.8	9.1	8.6	7.4
Other energy industries	2.4	2.2	3.1	3.5	2.8	2.6	2.3	2.2	2.1	1.8	1.6	1.4	1.2
Emissions from non-energy related activities	30.3	30.8	31.6	31.8	25.0	20.6	20.4	20.4	19.1	17.7	15.9	13.3	12.7
CO_2 emissions from industrial processes	6.9	7.5	7.9	8.0	6.1	5.0	5.5	5.9	6.0	5.1	3.5	0.9	0.6
Other CO_2 emissions	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.0
Emissions of other greenhouse gases	23.1	23.2	23.5	23.5	18.7	15.4	14.7	14.4	13.0	12.6	12.3	12.3	12.1
Total greenhouse gas emissions	101.4	108.9	120.5	127.5	109.3	93.7	90.6	71.1	70.7	64.5	57.5	47.2	39.3

Source: PRIMES.

Table 4.2 Greenhouse gas emissions by scenario derived with the PRIMES model in million tonnes of CO_2 equivalent *(continued)*

	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Combined RES and Nuclear Energy Scenario													
Emissions from fossil fuel combustion	71.1	78.0	88.9	95.8	84.3	73.0	70.1	69.5	60.0	49.4	44.1	35.9	30.4
Industry	9.3	9.8	9.9	8.2	6.0	5.1	4.0	3.8	3.8	3.5	3.1	2.6	2.0
Household sector	4.6	4.8	7.5	9.7	9.7	9.1	9.3	9.8	10.0	9.1	7.6	6.1	4.0
Services	0.6	0.6	0.8	1.5	1.4	1.3	1.5	1.4	1.3	1.2	0.8	0.5	0.3
Agriculture	2.7	2.6	2.6	2.7	2.7	2.5	2.4	2.4	2.3	2.2	2.0	1.6	0.7
Transport	17.2	19.1	21.3	23.9	23.0	23.3	23.4	23.5	23.6	20.2	17.4	13.1	11.1
Electricity generation	34.1	39.0	43.9	46.3	38.7	29.2	27.1	26.4	16.9	11.4	11.6	10.7	11.2
Other energy industries	2.4	2.2	3.1	3.5	2.8	2.6	2.3	2.2	2.2	1.8	1.6	1.4	1.2
Emissions from non-energy related activities	30.3	30.8	31.6	31.8	25.0	20.6	20.4	20.4	19.1	17.8	15.9	13.3	12.7
CO_2 emissions from industrial processes	6.9	7.5	7.9	8.0	6.1	5.0	5.5	5.9	6.0	5.1	3.5	0.9	0.6
Other CO_2 emissions	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.0
Emissions of other greenhouse gases	23.1	23.2	23.5	23.5	18.7	15.4	14.7	14.4	13.0	12.6	12.3	12.3	12.1
Total greenhouse gas emissions	101.4	108.9	120.5	127.5	109.3	93.7	90.4	89.9	79.1	67.1	60.0	49.2	43.1

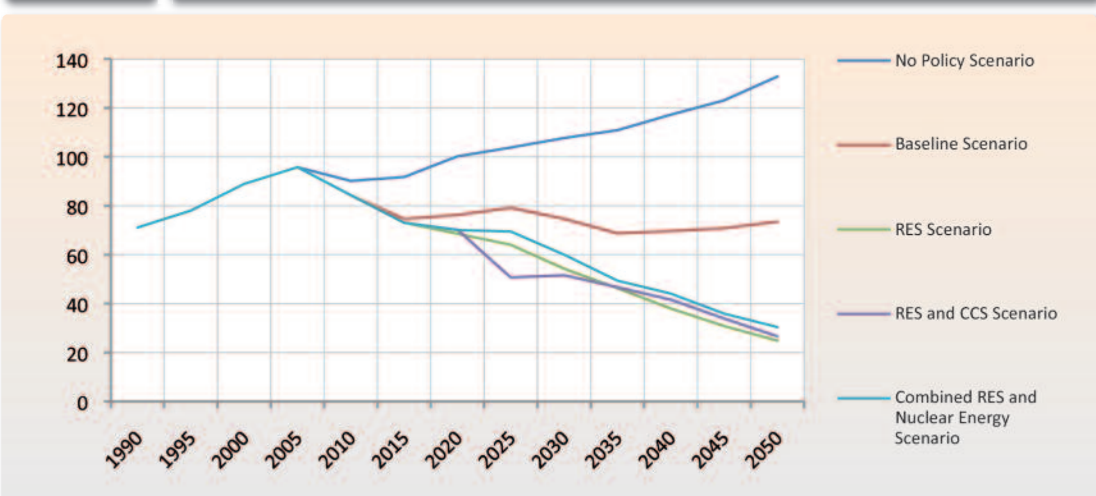
Source: PRIMES.

Table 4.3 **Reduction of greenhouse gas emissions under the Mitigation Scenario**

RES Scenario	Percentage change relative to the Baseline Scenario 2020			Percentage change relative to the No Policy Scenario		
	2020	2030	2050	2020	2030	2050
Emissions from fossil fuel combustion	-10.1	-27.3	-66.2	-31.6	-49.6	-81.3
Industry	-2.4	-3.6	-55.9	-33.6	-33.0	-69.6
Household sector	-4.5	-7.8	-56.9	-11.8	-21.5	-69.9
Services	-5.8	-13.1	-83.6	-11.6	-28.6	-87.0
Agriculture	-4.3	-8.9	-90.7	-7.6	-14.6	-91.5
Transport	-2.3	-5.5	-59.9	-14.7	-21.8	-68.4
Electricity generation	-19.7	-60.8	-75.7	-47.7	-78.3	-91.1
Other energy industries	-3.4	-10.5	-48.2	-18.1	-33.1	-62.1
Emissions from non-energy related activities	-3.2	-7.0	-41.4	-10.7	-17.1	-47.6
CO_2 emissions from industrial processes	-0.3	-5.2	-91.6	-0.5	-6.2	-92.5
Other CO_2 emissions	-7.0	-18.6	-77.9	-25.9	-47.8	-88.7
Other greenhouse gas emissions	-4.2	-7.6	-15.7	-13.8	-20.9	-24.4
Total greenhouse gas emissions	-8.6	-22.9	-60.5	-27.7	-43.9	-76.1

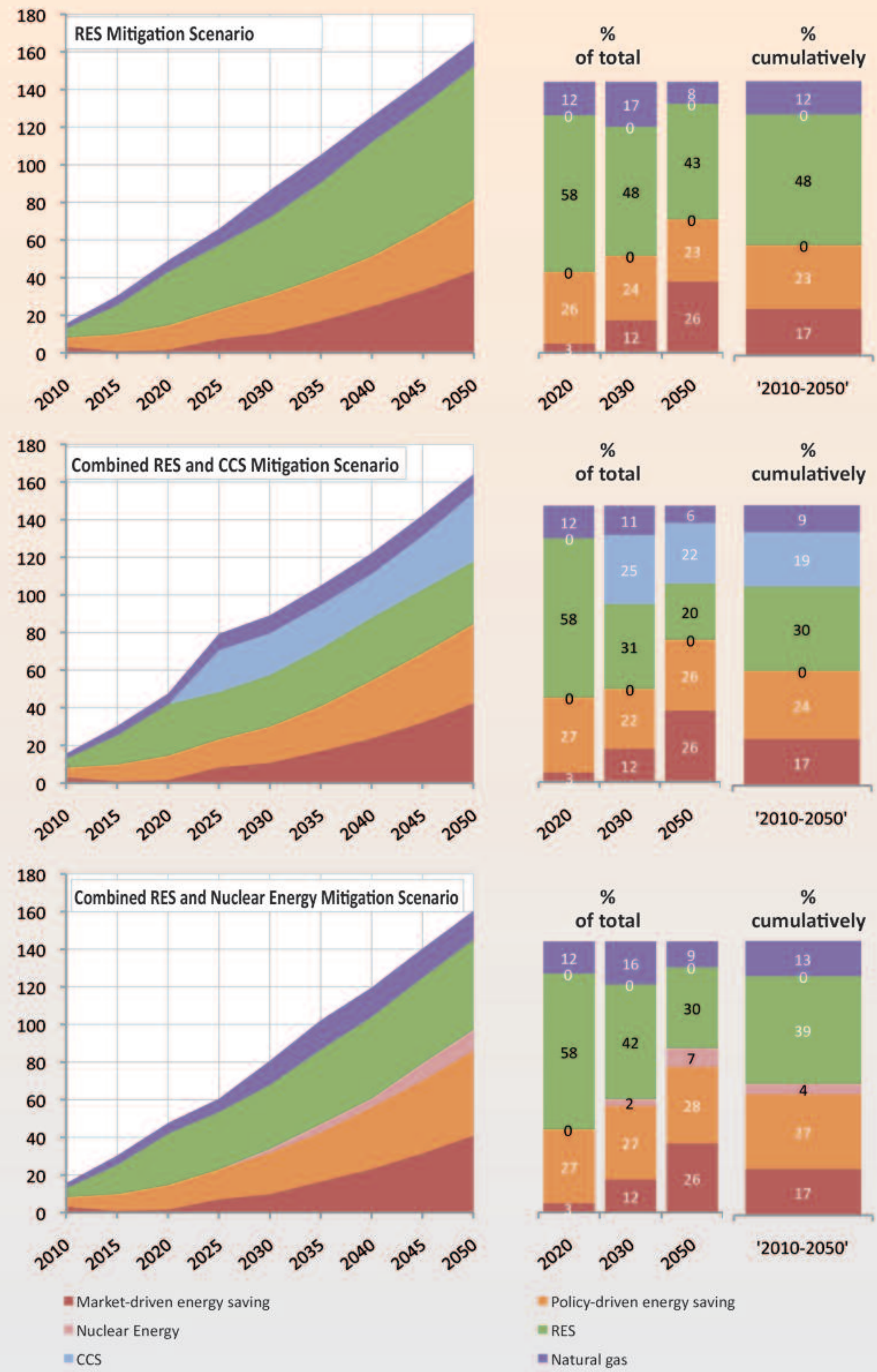
Source: PRIMES.

Figure 4.5 **Total greenhouse gas emissions in million tonnes of CO_2 equivalent**



Source: PRIMES.

Figure 4.6 **Breakdown of emission reduction options in the energy sector relative to 2005 levels in million tonnes of CO_2**



Source: PRIMES.

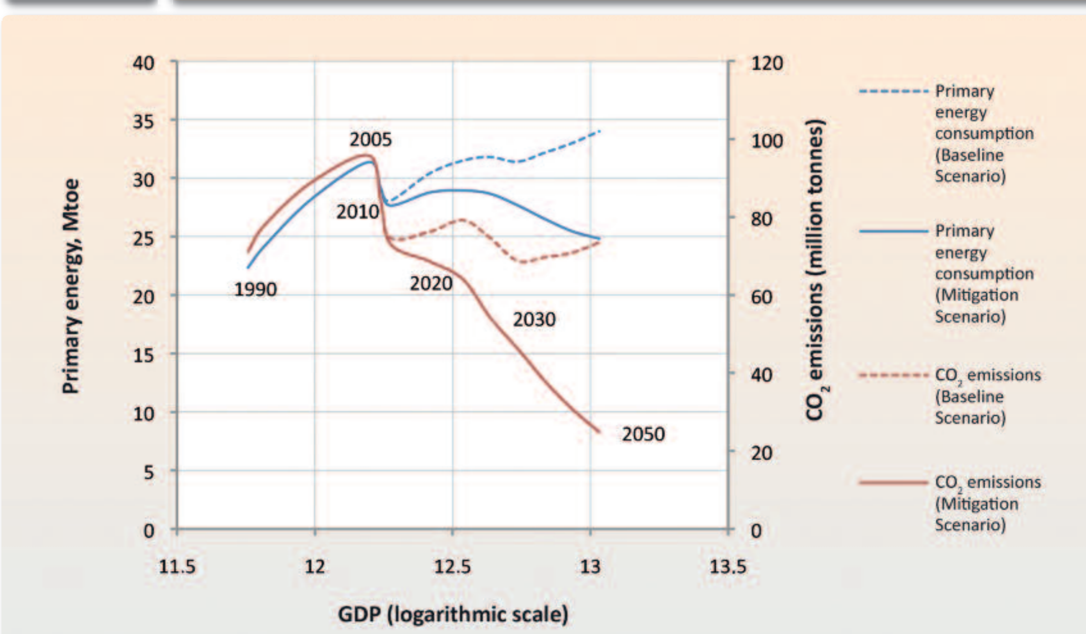
The importance of energy saving

Improving energy efficiency together with energy saving is probably the most important category of actions for reducing emissions: any decrease in energy demand produces the effect of reducing emissions both directly, i.e. in final consumption, and indirectly, i.e. in energy generation. It is also the most economical means of reducing emissions. There are, however, numerous obstacles to the adoption of extensive action for energy saving, which ensue from the fact that such decisions fall to individuals and small-scale businesses.

Energy saving is achieved whenever a consumer decides, for instance, to spend more on equipment or on a home upgrade with the expectation of having to paying less from that point on for the operation of such equipment. Such decisions are based on subjective criteria, usually including high discount rates (definitely higher than the ones used by large businesses or the state) and a risk factor resulting from inadequate information about new technologies and their efficiency. As a result of these factors, energy saving decisions, found to be efficient by feasibility studies, end up being rejected in practice.

To eliminate such obstacles, the state needs to take a decisive course of action with a series of policy measures that include: enforcing strict standards and regulations, launching extensive information campaigns, developing third party-financing mechanisms involving Energy Service Companies (ESCOs), and setting up a certificate trading scheme for energy saving projects, such as white certificates.

Figure 4.7 **Decoupling of GDP from CO_2 emissions and energy consumption**



Source: PRIMES.

Table 4.4 **Energy intensity and CO_2 emissions intensity indexes for the Greek economy under the Mitigation Scenarios**

	2010	2020	2030	2050
RES Mitigation Scenario				
CO_2 emissions (Mt)	84.36	68.58	54.26	24.85
Energy intensity (toe/M€05)	141.05	116.42	93.22	54.31
Correlation between emissions and GDP (t CO_2/M€05)	408.22	277.60	176.49	54.40
Carbon intensity of energy (t CO_2/toe of primary energy)	2.89	2.38	1.89	1.43
Combined RES and CCS Mitigation Scenario				
CO_2 emissions (Mt)	84.36	70.20	51.59	26.61
Energy intensity (toe/M€05)	141.05	117.59	102.72	62.71
Correlation between emissions and GDP (t CO_2/M€05)	408.22	284.16	167.84	58.25
Carbon intensity of energy (t CO_2/toe of primary energy)	2.89	2.42	1.63	0.93
Combined RES and Nuclear Energy Mitigation Scenario				
CO_2 emissions (Mt)	84.36	70.07	60.02	30.38
Energy intensity (toe/M€05)	141.05	117.46	96.63	57.93
Correlation between emissions and GDP (t CO_2/M€05)	408.22	283.61	195.24	66.50
Carbon intensity of energy (t CO_2/toe of primary energy)	2.89	2.41	2.02	1.15

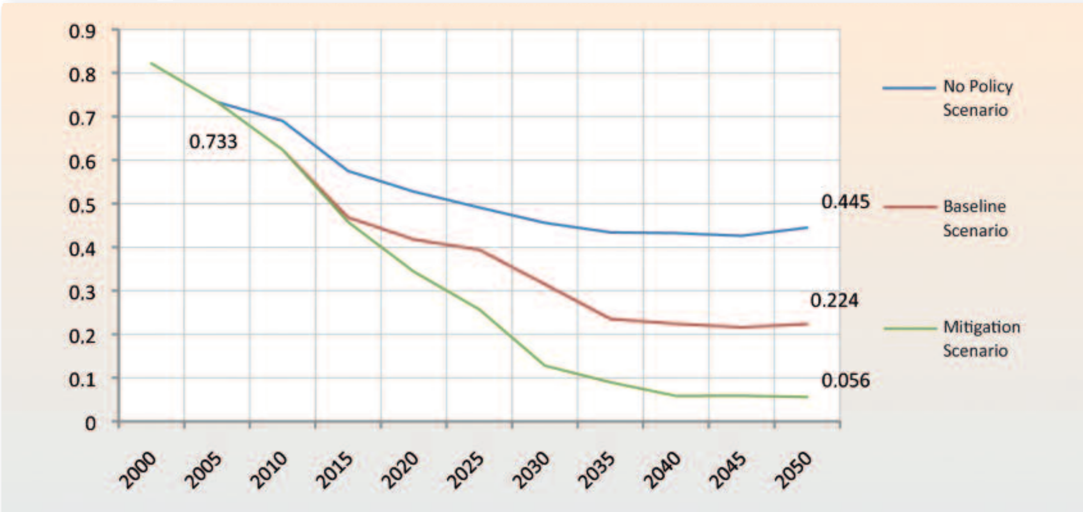
Source: PRIMES.

In pursuing the effort to reduce climate change-inducing emissions, as shown by the analysis, it is of the utmost importance that economic recovery and GDP growth take place in conjunction with a restructuring of the energy system that decouples GDP growth from an increase in emissions. Under the Mitigation Scenario, energy saving and increased energy efficiency in all sectors needs to reach levels such that total energy consumption is fully decoupled from GDP growth and total energy consumption is continuously reduced in absolute terms, relative to the levels of 2010. This decoupling from GDP in the Mitigation Scenario is immediately visible from Figure 4.7, which also illustrates that current policies (Baseline Scenario) are not sufficient to drive total energy consumption down to levels compatible with the Mitigation Scenario targets.

The pivotal role of electrical energy in the Mitigation Scenarios

As shown by the model analysis, electrical energy crucially affects the reduction of emissions to targeted levels, in three different manners: via the near elimination of CO_2 emissions from power generation; via the expansion of electrical energy to other final energy uses, thanks mainly to heat pumps and other methods; and via generalised road transport electrifi-

Figure 4.8 **Carbon intensity of electricity generation ($t\ CO_2/MWh$)**



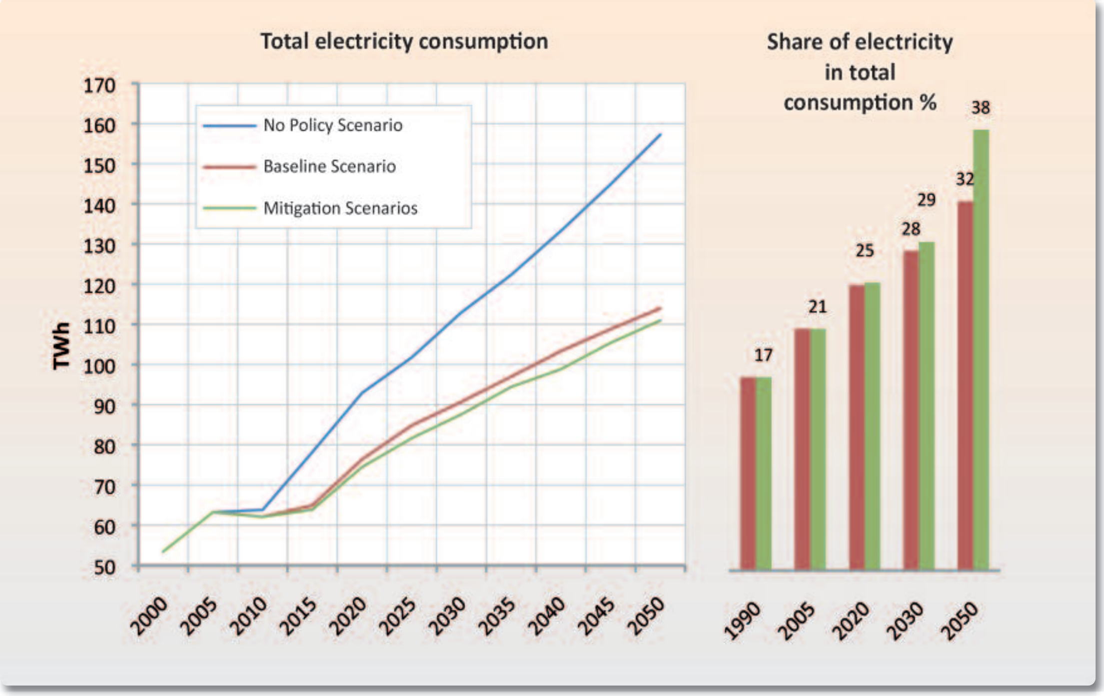
Source: PRIMES.

cation. The analysis also showed that the use of electrical energy in final energy uses leads to a spectacular improvement in energy efficiency across all sectors, including road transport. Expanding the use of electrical energy to final uses will require policy measures as well as new infrastructures, and would be pointless if not coordinated with a drastic reduction of emissions in power generation.

The carbon intensity of power generation (Figure 4.8) drops impressively in the Mitigation Scenarios, making electrical energy almost emission-free in the long run and therefore a suitable substitute for fossil fuels in final energy uses. The corresponding carbon intensity reduction in the Baseline Scenario (relative to the "No Policy" Scenario), though important, is not sufficient to drastically reduce total emissions in the energy system.

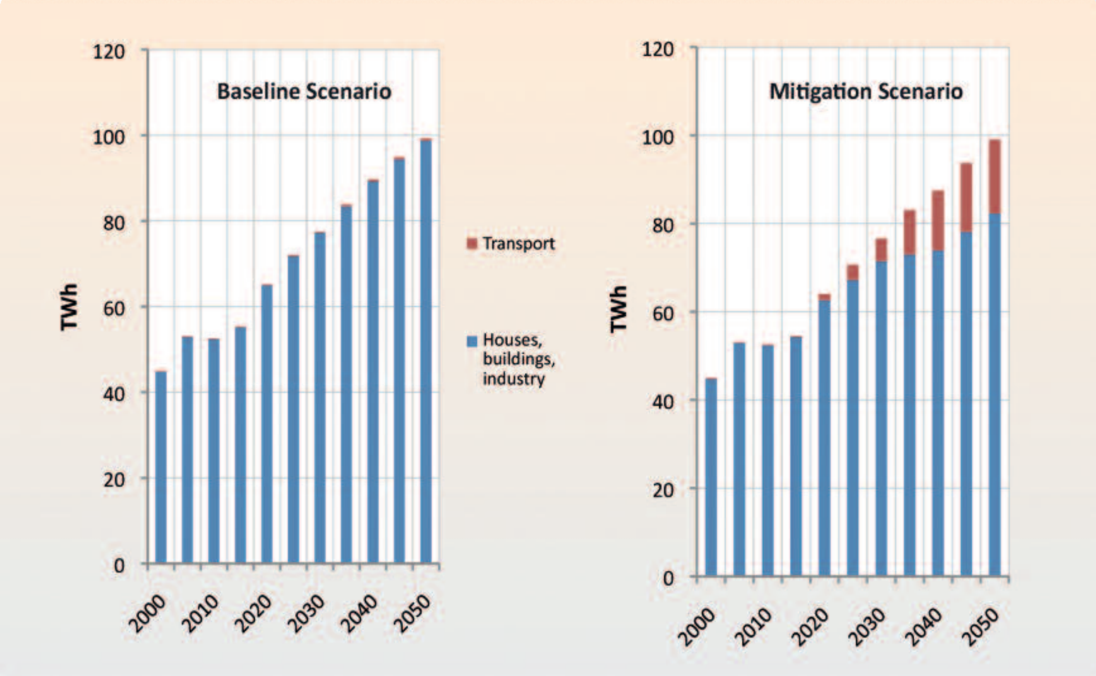
As shown by the results of Figure 4.9, electrical energy accounts for a larger share of total final energy consumption in all the variations of the Mitigation Scenario than in the Baseline Scenario. At the same time though, electrical energy consumption in absolute figures is lower in the Mitigation Scenarios than in the Baseline Scenario, and much lower than in the "No Policy" Scenario, on account of the greater effort under the Mitigation Scenarios to save energy and improve energy efficiency. Thanks to energy saving, energy consumption (including electrical energy consumption) decreases under the Mitigation Scenarios in the residential, buildings and industrial sectors, relative to the other scenarios. This decrease counterbalances the same-sized increase in electricity consumption in transport, which is spectacular under the Mitigation Scenarios, whereas under the other scenarios road transport electrification is not developed. Without the energy savings achieved under the Mitigation Scenarios, any additional

Figure 4.9 **Electricity consumption and share in final energy consumption**



Source: PRIMES

Figure 4.10 **Electricity consumption by sector**



Source: PRIMES.

energy consumption in transport would burden power generation and make the decoupling from CO_2 emissions more difficult (see Figure 4.10).

The Mitigation Scenario shows precisely what the results of a "systemic" approach in energy and environmental policy would be, when actions are coordinated across energy production and consumption sectors.

The decision to restructure power generation in the direction of a drastic reduction of emissions is, therefore, of pivotal importance, but will require time and perseverance to avoid any unwanted impacts on supply security and reliability. Apart from securing the right conditions for the realisation of the necessary investments in power generation, grid and interconnection infrastructure will have to be painstakingly developed over a number of years. Expenditure levels would therefore increase multifold, relative to today's levels.

Shifting away from fossil fuel dependence is a long and complex process, which needs to be tackled early on. The target of achieving near-zero carbon emissions in power generation proves to be feasible, but nonetheless hinges upon crucial strategic decision-making during the period 2015-2030. If such strategy adjustments are not made in time, the cost of achieving the Mitigation Scenario targets (in the form of cumulative greenhouse gas emissions in the period 2010-2050) will be considerably higher.

RES development is central to all the Mitigation Scenarios

Because of Greece's sizeable renewable energy source potential, all variations of the Mitigation Scenario assume a notable development of RES usage, particularly in power generation. Even the current policies, reflected in the Baseline Scenario, are centred on substantial RES development, relative to today's particularly low levels.

Table 4.5 presents the RES indicators, estimated in the same way as Eurostat's energy indicators, according to the modelling results obtained for the various scenarios. The European Commission uses these ratios to monitor Member State compliance with what is known as the "RES Directive".

The Baseline Scenario attains the RES-related targets by 2020 (see "overall RES indicator") and further improves them in the long term. All three variations of the Mitigation Scenario achieve considerably higher RES indicators relative to the Baseline Scenario, due, on one hand, to lower energy consumption as a result of extensive energy saving in these scenarios (consumption is part of the RES indicator denominator) and, on the other hand, to the drastic reduction of CO_2 emissions. Worth noting is the spectacular increase in the RES indicator in heating and cooling in the Mitigation Scenarios, as compared with the Baseline Scenario, as well as the strong increase in the RES indicator in transport, attributable in part to biofuels, but mostly to transport electrification in conjunction with the large share of RES in power generation.

Table 4.5 **Renewable energy indicators (by Eurostat) as a percentage of gross final energy consumption under the different scenarios**

	2000	2010	2020	2030	2040	2050
Baseline Scenario						
RES for heating-cooling	13.7	13.0	22.9	16.9	17.2	17.6
RES for electricity generation	7.1	14.8	38.7	45.6	48.3	44.4
RES for transport	0.0	2.2	8.1	9.0	9.6	9.5
General RES indicator	7.2	9.3	21.5	22.8	24.9	24.4
RES Mitigation Scenario						
RES for heating-cooling	13.7	13.0	23.8	19.6	23.3	34.8
RES for electricity generation	7.1	14.8	45.7	62.8	78.2	77.4
RES for transport	0.0	2.2	9.1	16.4	46.8	64.2
General RES indicator	7.2	9.3	23.8	29.3	45.4	61.6
Combined RES and CCS Mitigation Scenario						
RES for heating-cooling	13.7	13.0	23.8	19.1	21.8	32.6
RES for electricity generation	7.1	14.8	43.7	44.6	44.8	40.5
RES for transport	0.0	2.2	9.1	13.9	36.6	51.5
General RES indicator	7.2	9.3	23.3	23.8	31.5	41.1
Combined RES and Nuclear Energy Mitigation Scenario						
RES for heating-cooling	13.7	13.0	23.8	19.0	21.8	32.6
RES for electricity generation	7.1	14.8	43.8	49.9	51.7	46.1
RES for transport	0.0	2.2	9.1	14.7	38.9	53.7
General RES indicator	7.2	9.3	23.3	25.1	34.1	44.3

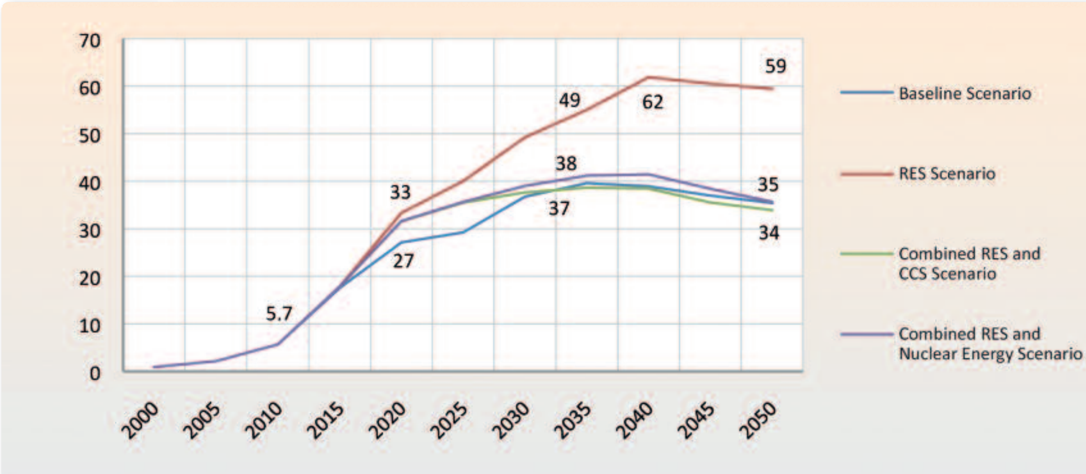
Source: PRIMES.

Organising Greece's future power generation system around a large participation of RES is a major economic and technical challenge. Stochastic RES generation (with wind turbines and solar panels) is determined by primary energy availability, and not by System Operator decision-making. A system with a high share of stochastic RES will require a large back-up thermal capacity or large storage systems. Insufficient storage capacity would mean that, during low load periods, stochastic RES generation would have to be cut back. Market organisation would also be different from today's, given that energy producers would be paid pre-determined feed-in tariffs.

These particular matters also apply to the Baseline Scenario, particularly for the 2020 time horizon, with 30% of generation projected to come from stochastic RES.

Under the *"RES" Mitigation Scenario*, the share of stochastic RES must be increased further to roughly 60% after 2035. Serious technical and financing matters will need to be resolved

Figure 4.11 **Stochastic RES in electricity generation (in percentages)**



Source: PRIMES

to ensure the reliability and cost-effectiveness of the electric system's operation. Our simulation with the mathematical model was based on the assumption that hydroelectric and hydrogen storage systems will be developed, in combination with 'smart' grids.

The alternative Mitigation Scenarios envisage lower shares of stochastic RES (below 40% over the entire period) and, from a technical and system operation standpoint, are therefore easier to implement. However, other types of uncertainty, associated e.g. with CO_2 storage or nuclear energy, come into play. The strategic problem surrounding generation development stems from the fact that conventional base load thermal generation, with its carbon emissions, is not sustainable under the Mitigation Scenario, even if lignite-fired generation were to be entirely substituted for by gas-fired generation. The near elimination of emissions from power generation is the deciding factor that will determine whether or not electricity can be used as a substitute for fossil fuels in final consumption, especially transport.

In the *"RES and CCS" Mitigation Scenario*, RES development is once again important, but base load generation is ensured by solid fuel-fired plants with CO_2 capture. There is much less uncertainty here concerning the system's reliability than under the "RES" Mitigation Scenario, because of the smaller share of stochastic RES in the generation mix. The use of CCS technologies, however, poses other problems that need to be addressed: public opposition (already voiced) to the location of future CO_2 storage sites and technical problems regarding geological storage.

Under the *"RES and nuclear energy" Mitigation Scenario*, base load generation is provided by nuclear energy (developed after 2030) and marked RES development. Although the system's reliability is ensured, the development of nuclear energy in Greece remains clouded in considerable uncertainty, due to a wide range of issues extending from radioactive waste management, safety standards throughout the entire process, additional construction costs (given Greece's lack of relevant know-how and the need for anti-seismic reinforcement) to the question of public acceptance, especially in areas close to the power plants. As things stand today, it is deemed that, in the case of Greece, the uncertainty surrounding nuclear energy largely outweighs the benefits that would arise from its use. In order to ensure the integrity of the present study, the relevant scenario was nevertheless quantified and assumed that the high uncertainty surrounding nuclear energy is dealt with successfully.

The strategic importance of natural gas in power generation

It is necessary to stress that the mathematical modelling results for all the variations of the Mitigation Scenario, without exception and for the entire projection horizon, point to the continued particular importance of natural gas in power generation (but also in final energy consumption).

Gas-fired power generation is maintained and expanded in all the Mitigation Scenarios. Natural gas does not account for a large share of total electrical energy generation, but gas-fired capacity accounts for a large share of total installed capacity. The reason for this is that gas-fired plants (especially those with flexibility to load increases) are a particularly suitable option for meeting back-up needs and ensuring system reliability, both under the scenario with the largest RES development and under the other variations of the Mitigation Scenario. All of these scenarios envisage large scale RES, heat or nuclear generation that can meet base load demands, but cannot respond to fluctuating loads. A large gas-fired capacity will therefore have to be maintained in all cases. One advantage to this is that —of all the conventional power generation plants— gas-fired plants are the lowest CO_2 emitters.

The importance of regional market integration

To ensure system reliability, greater flexibility will be needed with electrical energy imports so that the system of the wider region can help with load balancing.

The coordination of System Operators and the creation of a permanent mechanism for joint load balancing within the regional market of South-Eastern Europe are provided for under the current policy for the single European energy market, as well as by the Energy Community. Regional market integration takes on even greater importance in view of the restructuring of the electric systems in the context of drastic emission reduction and large-scale RES development. Our simulation by mathematical modelling was based on the assumption that load balancing at a regional level will be possible in the future, thereby reducing the cost of developing back-up systems in Greece. In spite of the joint load balancing, the Mitigation Scenario does not envisage a significant change in total imports of electrical energy to Greece.

Large-scale investments in energy infrastructure

Infrastructure investments in all energy sectors are both large-scale and of crucial importance to the restructuring of the energy system. The new infrastructures will be required to: ensure the interconnection of Greece's islands with the mainland grid; support the widespread development of small-scale RES at the end-consumer level with connections to the low- and medium-voltage grids; supply electrical energy to means of transport; be equipped with 'smart' grids so as to respond quickly to load and RES generation fluctuations; store energy; ensure a flexible and reliable gas supply; and, finally, have large flexible stand-by power generation plants in place.

From an economic standpoint, a major issue will be how to finance and attract capital for such large-scale infrastructure investments required under the Mitigation Scenario.

The part of the energy sector operating under conditions of natural monopoly and regulated prices will grow, while, given that RES will be under a mandatory purchase regime, the competitive part of the energy market will shrink considerably.

State intervention and regulation will thus be of great importance to maintaining the cost-effectiveness and reliability of the energy supply to consumers.

The evolution of final energy consumption

The model analysis confirms that there is ample room for reducing energy consumed, through energy saving measures in buildings and homes, promotion of more energy efficient appliance and equipment use by consumers, the dynamic penetration of new technologies in the transport sector and the substitution of more energy-efficient electricity for fossil fuels in all consumption sectors, especially transport.

A comparison with the results of the *"No Policy" Scenario* shows that a considerable reduction in final energy consumption is achieved under the *Mitigation Scenarios*, and, to some extent, under the *Baseline Scenario* (Table 4.6).

Energy saving involves shifting to more efficient heating and cooling in office buildings and homes, but also the use of more efficient electrical appliances in all sectors, including lighting. Heat pumps play an important role in meeting the heating, cooling and low-enthalpy heating needs in buildings, homes and industry. Heat pumps use air and/or low-enthalpy geothermal energy to extract renewable energy.

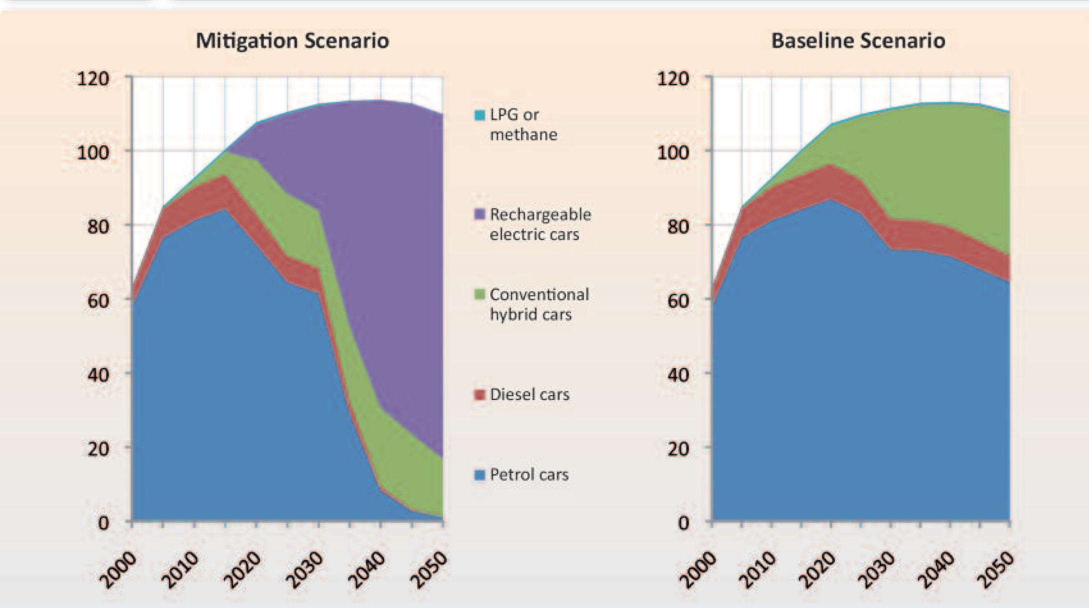
Despite the fact that roughly the same energy saving measures are adopted in the Baseline Scenario as well as in the Mitigation Scenarios, higher energy savings was recorded under the Mitigation Scenarios, in all sectors. The lower levels of energy consumption in industry, households and the tertiary sector under the Mitigation Scenarios were mainly the result of higher CO_2 prices imposed across all economic sectors. The lower levels of energy consumption observed in the transport sector are attributed to the more dynamic penetration of electricity, which is more energy-efficient than conventional or hybrid vehicle technologies.

Table 4.6 **Energy saving by sector: percentage change compared to the No Policy Scenario**

	RES Mitigation Scenario			Baseline Scenario		
	2020	2030	2050	2020	2030	2050
Final energy consumption						
Energy-intensive industry	-8	-15	-35	-8	-14	-19
Non-energy intensive manufacturing	-10	-13	-36	-10	-13	-12
Household sector	-11	-17	-43	-8	-15	-26
Tertiary sector	-16	-25	-62	-11	-17	-24
Transport	-12	-18	-45	-11	-16	-20
Houses and service buildings						
Heating/cooling	-10	-19	-50	-7	-14	-26
Electric uses	-21	-25	-55	-17	-20	-26
Energy intensity indexes						
Energy per m² in buildings	-7	-16	-48	-4	-12	-27
Energy consumption by cars per 100 km	-17	-20	-46	-13	-15	-20
Energy consumption by airplanes per 100 km	-10	-14	-38	-10	-14	-14
Specific energy consumption indicator for industry	-9	-14	-35	-8	-14	-16

Source: PRIMES.

Figure 4.12 **Structure of car fleet by technology (Million pkm)**



Source: PRIMES

Table 4.7 **Biomass consumption in various forms and sectors in ktoe**

		RES Mitigation Scenario			Baseline Scenario		
	2000	2020	2030	2050	2020	2030	2050
Transport fuel	136	477	501	2664	529	590	632
Biogasoline	59	269	269	476	312	356	359
Biodiesel	77	208	199	709	216	234	274
Biokerosene	0	0	9	632	0	0	0
Marine biofuel	0	0	24	846	0	0	0
Biofuel for electricity and steam	140	1001	1426	2174	962	1034	1240
Solid biomass	75	766	994	1638	740	606	803
Waste	29	100	246	321	100	246	226
Biogas	36	135	185	215	122	181	211
Biomass in other sectors	848	1214	844	1203	1181	762	517
Total biomass	1123	2693	2771	6040	2671	2386	2390
Share of biofuel in liquid transport fuel		4.3	4.5	33.0	4.7	4.9	4.7

Source: PRIMES.

Extensive changes are envisaged especially for the transport sector. In the short term, new 'conventional' cars will be required to have engines that meet EU emission requirements. In the medium term, hybrid vehicles take centre stage, with accumulator batteries that can be charged at low voltage. Finally, in the longer term, electric vehicles prevail (see Figure 4.12). Energy efficiency is also projected to improve in other means of transport, in particular heavy-duty vehicles, ships and airplanes. Also envisaged is the admixture of biofuels to petroleum fuels (Table 4.7).

Table 4.7 outlines the importance that biomass would assume under the Mitigation Scenario. New biomass and waste conversion technologies (e.g. the Fischer–Tropsch process) are expected to have reached commercial maturity before 2020 and to be implemented on an industrial scale. This means that ligno-cellulosic crops, which Greece's agriculture is capable of supporting on a large scale without adverse impacts on food production and without entailing serious emissions during the collection and processing stages, could become an important new sector of activity, boosting both agriculture and job creation.

The fuel mix of final energy consumption can be broken down as follows (Table 4.8):

- In the long term, the dynamic penetration of electricity use in the Mitigation Scenarios leads to major changes in the energy consumption mix. Electricity is a substitute mainly for oil, as a result of transport electrification.

Table 4.8	Final energy consumption by type of fuel in Mtoe						
		RES Mitigation Scenario		Percentage change compared to Baseline Scenario		Difference in percentage shares compared to the Baseline Scenario	
	2010	2030	2050	2030	2050	2030	2050
Solid fuels	0.23	0.20	0.00	-6	-98	0	-1
Oil	13.31	11.32	4.50	-9	-66	-3	-25
Gas	0.86	2.66	1.69	13	-31	2	0
Electricity	4.37	6.44	6.80	-1	-19	1	6
Steam distribution	0.19	0.08	0.28	3	3	0	1
RES	1.13	1.81	4.45	2	171	0	19
Total	20.10	22.52	17.73	-4	-32		

Source: PRIMES.

- The use of RES increases considerably relative to the Baseline Scenario, mainly in the energy consumption of industry, households and the tertiary sector, e.g. through the use of solar systems or biomass combustion in heating and other uses.
- Biofuel consumption increases in the transport sector, both in an effort to attain the targets for 2020 and afterward, with its consumption reaching 33% of the final energy consumption of the transport sector in 2050.
- Natural gas accounts for a large share of final energy consumption, although its upward trend is halted in the long term by the dynamic penetration of electricity.

Electricity becomes the dominant energy form in the Mitigation Scenarios. As substitution progresses in parallel with impressive improvements in energy efficiency, major savings in energy and electricity are achieved, especially in the energy consumptions of industry, residential and tertiary sector. In the transport sector, electricity penetration is rapid, reaching 5.4 TWh[4] in 2030 and 17 TWh in 2050. This penetration considerably improves the transport sector's energy efficiency and is counterbalanced by electricity-saving in other sectors, as analysed above.

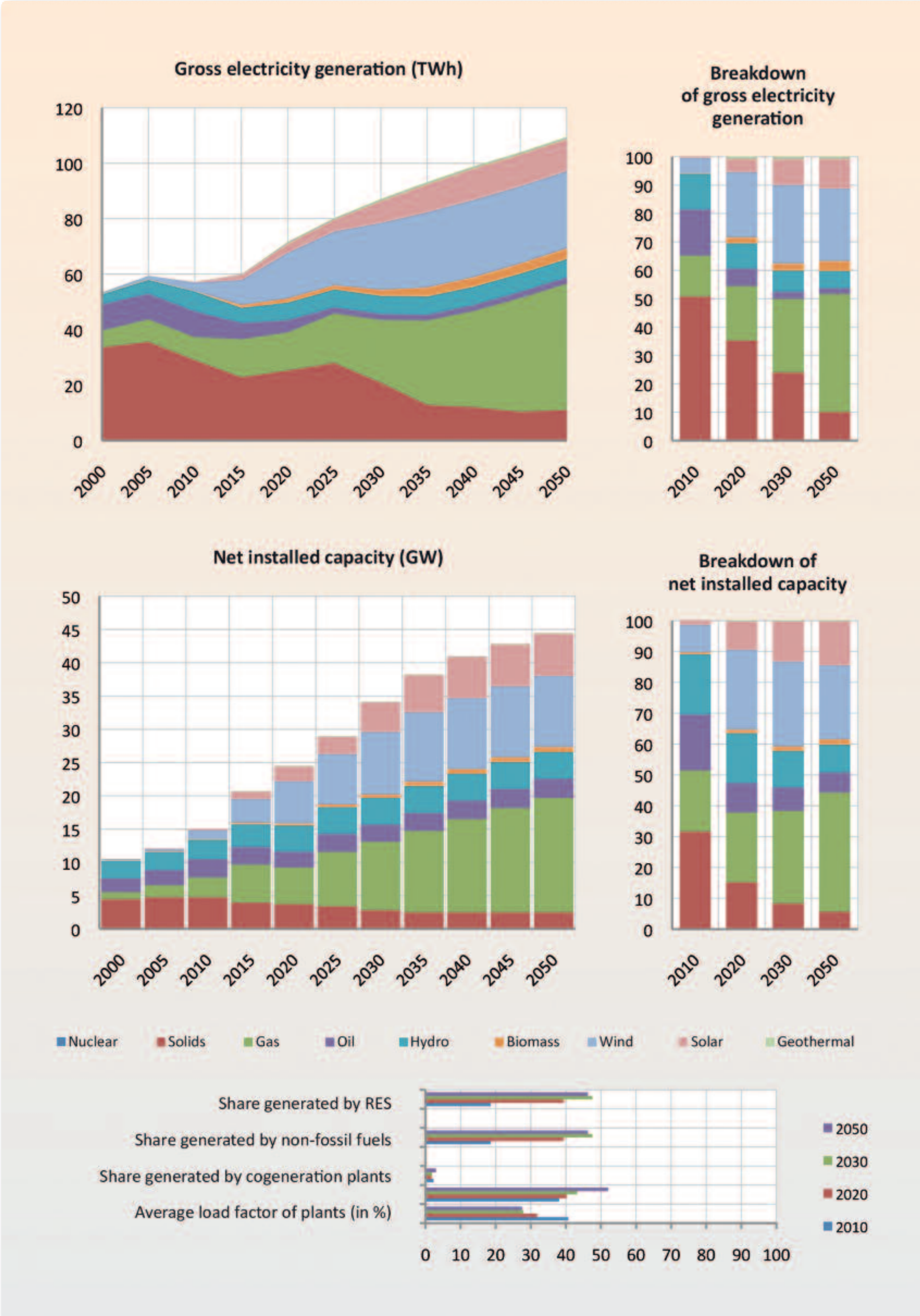
The evolution of power generation

The Baseline Scenario

In order for "20-20-20" targets to be met, the Baseline Scenario envisages a spectacular development of RES, particularly in the period up to 2020, and a decrease in the share of fossil fuel-fired plants in total power generation from 82% today to 60% in 2020 and further down

4 TWh = terawatt hours.

Figure 4.13 **Structure of electricity generation under the Baseline Scenario**



Source: PRIMES.

to 53% in the long term. Conversely, the share of RES in power generation is projected to increase from 39.5% in 2020 to 47% in 2050.

Power generation form lignite-fired plants is progressively reduced from 51% in 2010 to 35% in 2020 and 10% in 2050. The Baseline Scenario projections show that, based on current policies, Greece's power generation is radically transformed and is freed from its lignite dependence, a key element of the country's growth strategy from the 1970s to this day.

At the same time, power generation is also freed from its oil dependence, as a result of the decommissioning of outdated oil-fired plants made possible by the interconnected system and the gradual interconnection of islands.

The only fossil fuel to follow an upward trend under the Baseline Scenario is natural gas, with a share in power generation that rises from 14.5% in 2010 to 19.2% in 2020 and to 41.5% in 2050. Natural gas consumption for power generation will multiply by 2.2 by 2030 compared to today's levels, and by a further 1.8 by 2050.

In the long term, the power generation system under the Baseline Scenario will be structured almost exclusively around RES and natural gas. This restructuring ensues solely from Greece's commitments and compliance with the "20-20-20" policy, with its specific target for RES and the extension of the Emission Trading System (EU ETS) to all emissions from power generation.

Of the available RES, wind energy prevails, with an installed capacity of 6.5 GW[5] in 2020 and 10 GW from 2030 onward, followed by solar, mainly photovoltaic, systems, with an installed capacity of 2.2 GW in 2020 and over 6 GW after 2030. Other renewable energy sources are harnessed on a smaller scale, while biomass is extensively used in co-generation plants for the generation of electricity and steam.

The degree of RES penetration incorporated into the Baseline Scenario is technically feasible and does not compromise the reliability of the power system's operation. Present-day practices will obviously have to be changed considerably so that, from 2015 onward and no later than 2020, the electricity market can function with reliability with about 1/3 of the energy in the system coming from stochastic RES. Pumped-storage hydroelectric capacity will also have to be expanded to 1,000 MW by 2020. Required network investments by 2020 are also considerable.

The "RES" Mitigation Scenario

Under the Mitigation Scenarios, emissions from power generation are nearly eliminated in the long term. Given that the "RES" Mitigation Scenario does not envisage the use of carbon capture or nuclear technologies, ridding power generation of its carbon footprint will necessarily have to be achieved via a drastic reduction in the share of fossil fuel-fired plants.

5 GW = gigawatts.

Renewables already become the main source of power generation as soon as 2020, reaching 85.6 TWh (83% of total power generation) in 2050. The largest share of RES-generation is accounted for by wind power plants (wind farms), with an output of 44.9% of total power generation in 2050 and an installed capacity of 17.5 GW (4.6 GW of which offshore), while an important share is also covered by photovoltaic systems (18.4% of total power generation; capacity: 11 GW in 2050). Solar thermal systems reach 628 MW in 2050. Biomass and waste account for 9.7%, with a capacity of 2.4 GW in 2050. Biomass, together with natural gas, also plays an important role in steam generation from industrial boilers. Finally, Greece's geothermal potential is largely exploited as of 2015, accounting for 3.3% of power generation in 2050, with an installed capacity of 442 MWe.[6]

Natural gas retains a very important role under the "RES" Mitigation Scenario, because of its low emissions-intensity relative to other fossil fuels and its ability to support RES penetration in power generation (the capacity-increase flexibility and low capital-intensity of gas-fired plants makes them suitable as back-up plant investments). Electrical energy generation from natural gas under the "RES" Mitigation Scenario decreases after 2030 by more than 50% relative to the Baseline Scenario, but the size of installed capacity of gas-fired plants decreases less, because of the role played by these plants in the system back-up. By 2050, the share of natural gas in power generation falls to 17%, from 31% in 2030.

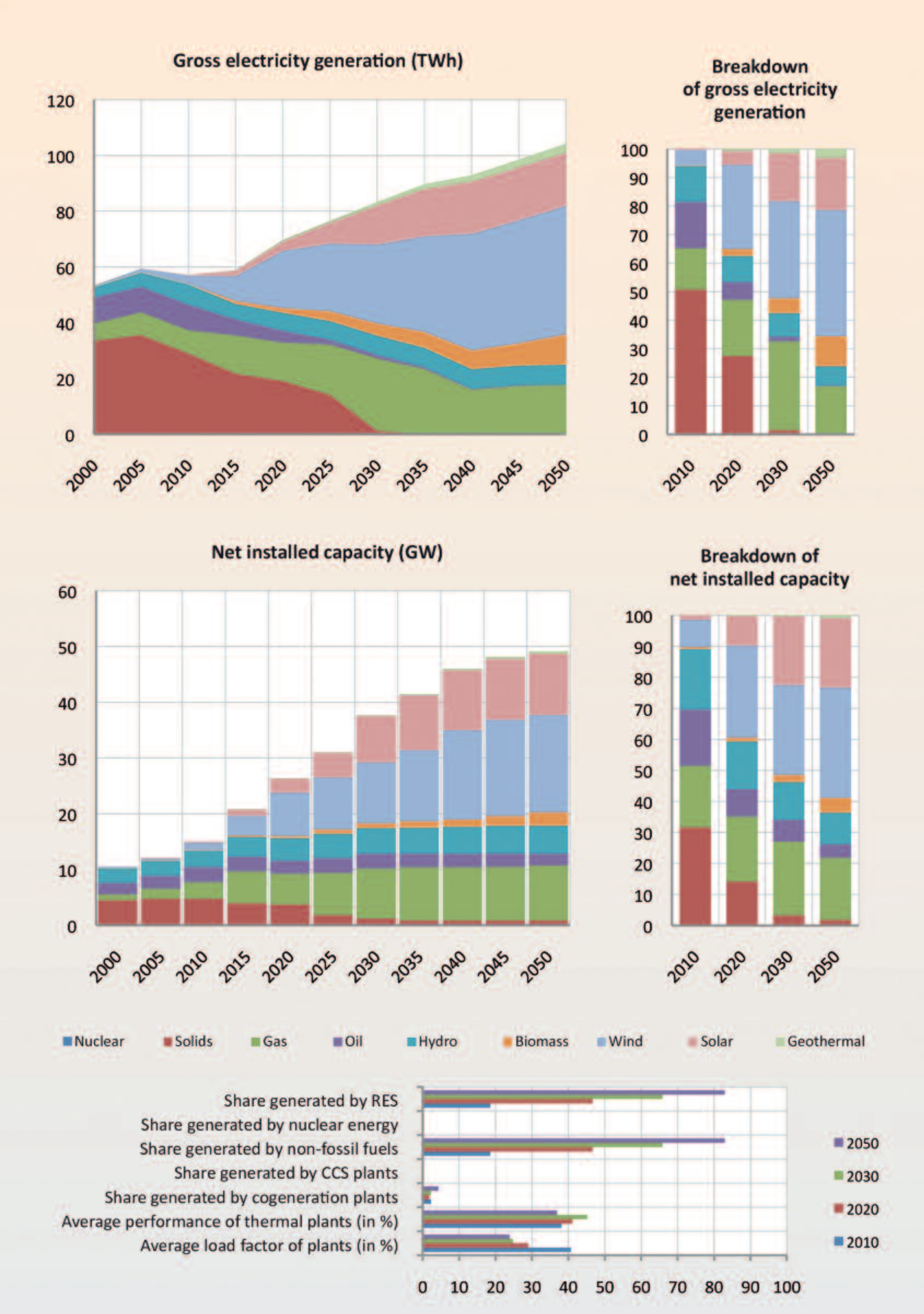
Power generation from oil-fired plants decreases to 100 GW in 2050 (1260 GWh in 2030), given that the full interconnection of islands is envisaged. Lignite-fired generation is totally ceased after 2030.

Under the "RES" Mitigation Scenario, storage systems are of great importance, given that pumped-storage hydroelectric capacity amounts to 1,900 MW in 2050 and that hydrogen systems (envisaged for after 2035) will, by 2050, require about 16 GWh of electrical energy per year for hydrogen generation. The hydroelectric plants, thermal plants and storage systems envisaged will be able to cover a maximum peak load of about 21 GW in 2050. As for load fluctuations and how they will be met, the assumption is made in the scenario that there will be considerable flexibility with electrical energy imports due to coordinated load balancing in the regional market.

The "RES" Mitigation Scenario includes the development of RES-powered power generation on a very small scale (small wind system capacity of 400 MW in 2050; photovoltaic system capacity in homes and buildings of 3,400 MW in 2050), connected to the low-voltage grid. The future of RES-powered generation will depend on the development of 'smart' grids and the realisation of other improvements and investments in the distribution system. In the specific scenario, it was assumed that such wind and photovoltaic systems will have reached commercial and technological maturity before 2030.

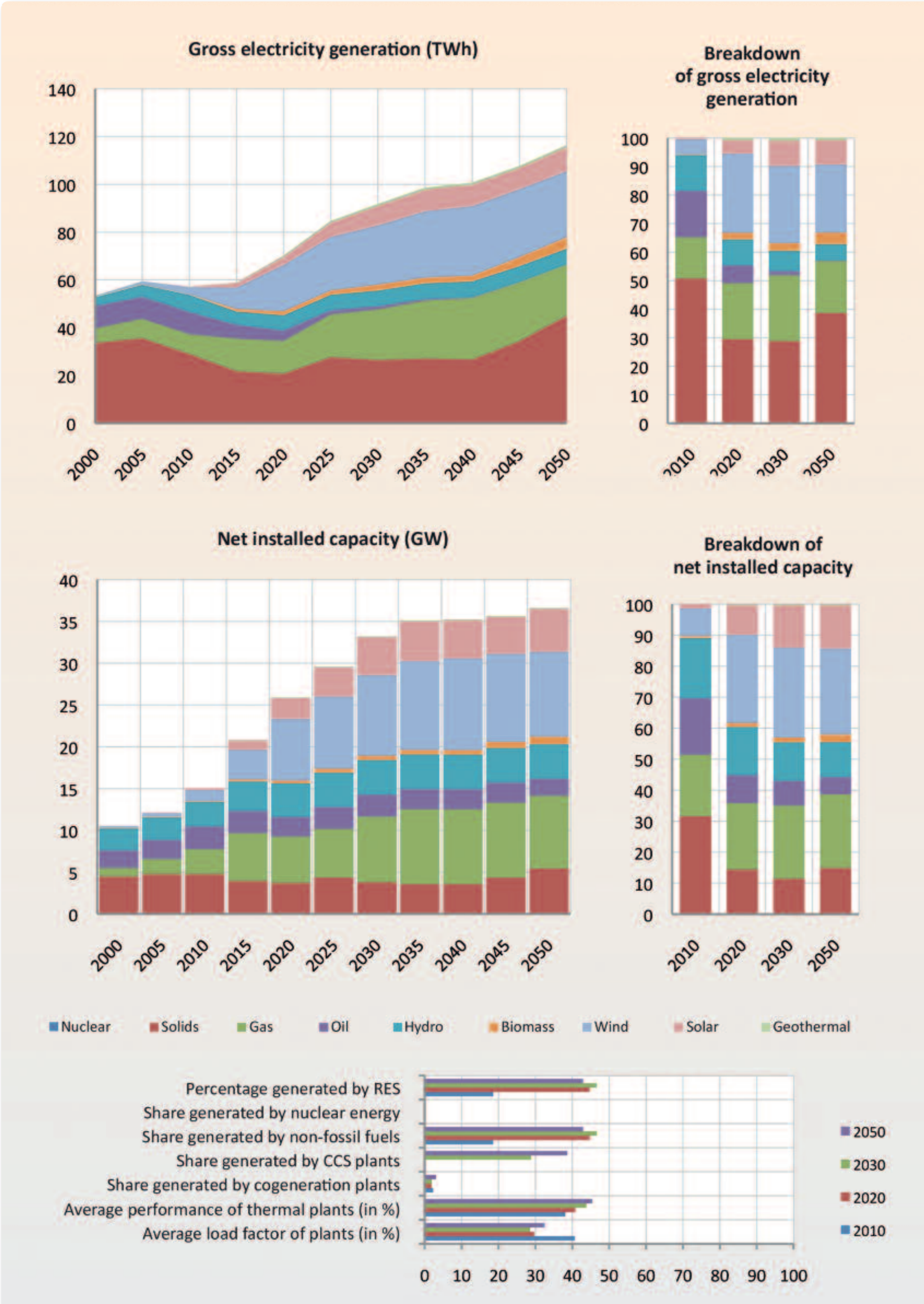
6 MWe = Megawatt electric.

Figure 4.14 Structure of electricity generation under the RES Mitigation Scenario



Source: PRIMES.

Figure 4.15 **Structure of electricity generation under the Combined RES and CCS Mitigation Scenario**



Source: PRIMES.

The “RES and CCS” Mitigation Scenario

This scenario is based on the dual assumption that CO_2 storage in geological formations is feasible (in Northern Greece, Western Macedonia and the region of Kavala) and that CO_2 capture technologies from fossil fuel usage have matured and become commercially viable. Given this assumption, the economic optimisation of future power generation, without disregarding the target of achieving a near elimination of CO_2 emissions into the atmosphere, produces different results than the ones produced by “RES” Mitigation Scenario. The “RES and CCS” Mitigation Scenario provides for the development of electrical energy generation with CO_2 capture and for a smaller development of RES than under the “RES” Mitigation Scenario.

Thanks to CCS technology, lignite-fired plants with CCS with a power output of some 2,500 MW will be incorporated into the system by 2025, in replacement of old plants. The total power output of lignite-fired plants in 2025 is roughly the same as in 2000 (approximately 4,400 MW). It then decreases to 3,500 MW (power output), as the old plants are decommissioned. In the decade 2040-2050, the scenario provides for the incorporation of an additional 2,100 MW of lignite-fired capacity with CCS. By 2050, as outlined by the scenario, a lignite-fired capacity of 5,450 MW (power output) will be in operation, of which 4,600 MW will be coupled with CCS. Lignite-fired power generation accounts for about 22-25% of total power generation in the period 2025-2045, against 51% today, and reaches 32.6% in 2050. As shown by the analysis, under the Mitigation Scenarios, the strategy of generating electricity from lignite is sustainable only if coupled with CCS technology. It goes without saying that all of the plants in existence today will have to be decommissioned and that all future plants will have to be coupled with CCS technology.

According to the scenario, lignite-fired plants with CCS with a power output of some 2,500 MW will be in operation in 2025 and 4,600 MW in 2050. The share in total clean power generation accounted for by CCS plants is projected to range between 28% and 38% in the period 2025-2050. Annual CO_2 storage will amount to some 23 million tonnes as of 2025, gradually increasing in the long term to 36 million tonnes in 2050. Total CO_2 storage over the period 2025-2050 is estimated to reach about 770 million tonnes.

Renewables once again play a very important role in this scenario, but their share in power generation only slightly exceeds 51% (in 2035) and even recedes to 47.5% in 2050 on account of the expansion of plants with CCS. RES-based power generation under the “RES and CCS” Mitigation Scenario is similar, quantity- and structure-wise, to that of the Baseline Scenario. Installed wind power capacity is projected to reach 7.4 GW in 2020 and to exceed 10 MW in the long term. Installed solar power capacity is projected to reach 2.5 GW in 2020 and to exceed 5 GW in the long term. The significant development of power plants fired by biomass, waste and geothermal energy is also envisaged under this scenario.

As under the previous scenarios, natural gas-fired plants play an important role in the system’s stability and in responding to load fluctuations. There is less of a demand here for natural gas-fired plants than under the "RES" Mitigation Scenario, for the simple reason that the new solid fuel-fired plants will be able to support the stability of the system, without burdening it with their high emissions footprint. The share of natural gas in total power generation remains at around 20% throughout the entire projection period.

The cumulative CO_2 emissions from power generation under the "CCS and RES" Mitigation Scenario were estimated to be 14% lower in the period 2010-2030, but 20% higher in the period 2010-2050 than under the "RES" Mitigation Scenario (in total, during the period 2010-2050, overall emissions under the "CCS and RES" Scenario are 6% lower than under the "RES" Scenario).

The "RES and nuclear energy" Mitigation Scenario

The use of nuclear technology is not envisaged for Greece either in the medium or in the long term. However, so as not to compromise the scientific integrity of our road map analysis for climate change mitigation, we used the PRIMES model to develop a scenario, postulating that nuclear plants could account for share of Greece's power generation after 2030 (as plants eligible for new investment). The scenario also postulated that CO_2 storage in geological formations within Greece is not feasible.

Due to the lack of know-how and to the absence of economies of scale, the cost of investing in nuclear plants in Greece was assumed to be higher than in countries where such technology has already been developed. In addition, suitable location sites for such plants would be limited. The cost and difficulty of developing sites for nuclear plants was simulated in the model with a non-linear cost curve. Account was also taken of the high costs associated with nuclear fuel and nuclear waste, by assuming that the nuclear waste would need to be exported to countries with waste management infrastructure. From an economic standpoint, these waste disposal costs pose an additional constraint on the possibilities for nuclear energy development.

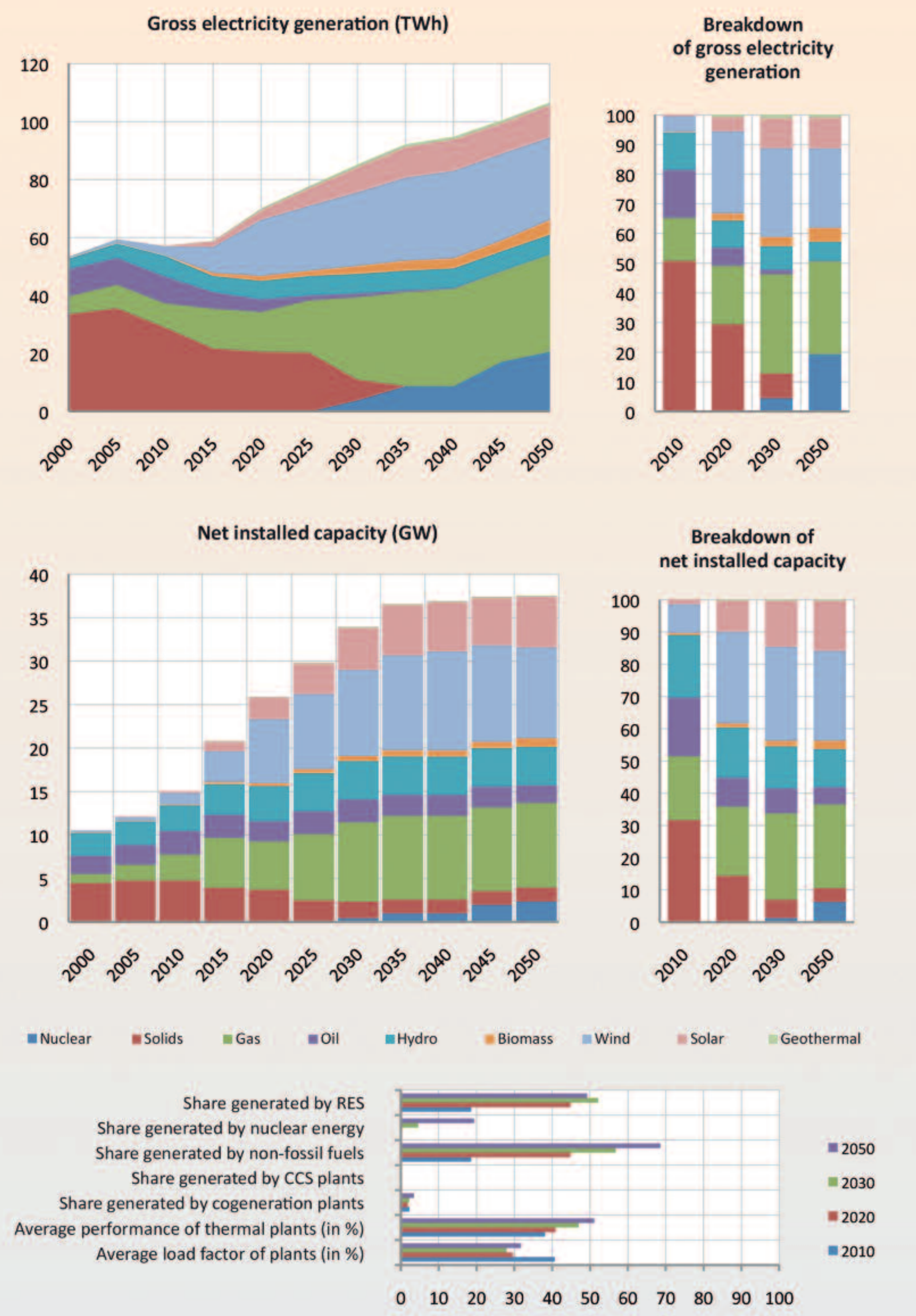
Based on these assumptions, an optimisation of power generation aimed at achieving a near complete elimination of emissions indicates that the development of a limited nuclear power generation programme in Greece would be cost-effective, with an initial installed capacity of 450 MW by 2030, additional 500 MW by 2035 and between 1,000 and 1,500 MW more by 2040, bringing the total capacity to some 2,500 MW by 2050. In other words, only part of the base load power after 2030 would be provided by nuclear energy, which in 2050 would account for 19% of total power generation (4.6% in 2030).

This scenario retains a significant development of RES, which, according to the results, will account for 50% to 53% of power generation over the entire period after 2020. Installed wind capacity will exceed 10 GW, while solar installed capacity will come close to 6 GW.

Natural gas maintains its strategic importance in power generation due to the flexibility of gas-fired plant and the cost feasibility of installing gas-fired back-up plants. Power generation from natural gas under the "RES and nuclear energy" Mitigation Scenario will be definitely

Figure 4.16

Structure of electricity generation under the Combined RES and Nuclear Energy Mitigation Scenario



Source: PRIMES.

4 Towards a low emissions economy

higher than under the “RES” Mitigation Scenario and even the “RES and CCS” Mitigation Scenario, because of the lack of flexibility of nuclear plants in responding to load fluctuations, for which gas-fired plants are needed (to complement the power generated from nuclear plants). In the “RES and nuclear energy” Mitigation Scenario, natural gas will account for 1/3 of total power generation from 2025 onward, up from 20% in 2020. In this scenario, lignite-fired power generation ceases after 2030, while oil-fired generation falls to very low levels.

The delay in developing nuclear energy, however justified for economic and technical reasons, has a negative effect on Greece’s emissions reduction capacity in the medium term. The cumulative emissions from power generation during the period 2010-2050 were estimated to be 25% higher in the “RES and nuclear energy” Mitigation Scenario than in the “RES” Mitigation Scenario.

Primary energy, imports

Under the Mitigation Scenarios, the demand for primary energy is considerably lower than under the Baseline Scenario due to extensive increases in energy consumption efficiency. The Mitigation Scenarios also project a wide substitution of fossil fuels, resulting in a significant decrease of the Greek energy system’s dependence on oil imports.

Table 4.9 outlines the substantial benefits that arise from the Mitigation Scenarios with regard to Greece’s energy dependence, which falls to around 50% in 2050, compared with present day level of 72% and the level of 75% projected under the Baseline Scenario for 2050.

Natural gas imports are lower under the Mitigation Scenarios than under the Baseline Scenario, thereby providing a margin of security with regard to the supply of natural gas, which remains of strategic importance in all the scenarios, as mentioned above.

Oil imports are reduced by half in the Mitigation Scenarios, relative to the Baseline Scenario, thanks to transport electrification, biomass use and energy saving.

The Mitigation Scenario outlines a course that would free Greece of its dependence on energy imports, particularly oil.

4.4 The cost of the Mitigation Scenario

The Mitigation Scenarios developed to simulate the course towards a low emissions economy involve a radical restructuring of the energy system. Such a restructuring entails considerable additional costs, as well a new allocation of these costs both between energy sectors and between capital and operating expenses.

The additional cost arises because all energy-efficient and emission-free power generation technologies are capital-intensive. Even though energy consumption and production under the

Table 4.9 **Primary energy supply and demand in million tonnes of oil equivalent (Mtoe)**

(Mtoe)	2010	Baseline Scenario 2020	Baseline Scenario 2030	Baseline Scenario 2050	RES Mitigation Scenario 2030	RES Mitigation Scenario 2050	Combined CCS and RES Mitigation Scenario 2030	Combined CCS and RES Mitigation Scenario 2050	Combined CCS and Nuclear Energy Mitigation Scenario 2030	Combined CCS and Nuclear Energy Mitigation Scenario 2050
Domestic production										
Oil & gas	0.10	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Solids	6.84	5.82	4.61	2.34	0.27	0.00	5.40	8.75	1.51	0.00
RES	2.01	4.96	6.01	6.97	7.67	13.65	6.24	8.36	6.39	8.61
Imports – Exports										
Solids	0.19	0.21	0.20	0.23	0.20	0.00	0.20	0.00	0.20	0.00
Oil	19.37	17.21	16.84	17.54	15.12	6.59	15.12	6.73	15.12	6.73
Natural gas	2.61	4.07	6.64	9.93	7.44	4.95	6.72	5.45	7.69	7.14
Electricity	0.42	0.41	0.31	0.38	0.36	0.57	0.36	0.57	0.36	0.57
Biomass	0.10	0.40	0.27	0.18	0.41	1.60	0.34	1.35	0.35	1.36
Domestic consumption	29.14	30.40	31.80	34.00	28.66	24.81	31.58	28.64	29.70	26.46
Solids	7.02	6.03	4.81	2.57	0.47	0.00	5.60	8.75	1.71	0.00
Oil	16.96	14.54	13.76	13.98	12.33	4.87	12.34	5.01	12.34	5.01
Natural gas	2.63	4.07	6.64	9.93	7.44	4.95	6.72	5.45	7.69	7.14
Nuclear energy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.89	4.62
Electricity	0.42	0.41	0.31	0.38	0.36	0.57	0.36	0.57	0.36	0.57
RES	2.11	5.35	6.28	7.14	8.05	14.41	6.56	8.86	6.71	9.12
Energy dependence rate (in %)	72	67	70	75	75	50	66	45	73	54

Source: PRIMES.

Mitigation Scenario involve significantly lower operating expenses as a result of the achieved energy conservation and lower fossil fuel consumption, the expenditure needed each year to cover the additional capital costs —determined using market discount rates— outweighs the reduction in operating expenses.

Therefore, the total annual costs of providing energy services (i.e. useful energy, such as heating, cooling, electrical uses, transport, etc.) are estimated to be higher under the Mitigation Scenarios than under the Baseline Scenario, which in turn entails higher costs relative to the "No Policy" Scenario.

Table 4.10 presents the estimates obtained with the mathematical model with regard to the costs of energy services incurred by energy end-consumers. The total cost appears in the upper part of the table and includes payments for the purchase of emission allowances under the EU ETS scheme. Implementation of current policies contained in the Baseline Scenario generates additional cumulative costs in the order of €288 billion (2008 prices) for the period 2010-2050,

Table 4.10 **Total cost of energy system (EUR billions, 2008 prices)**

Total cost of energy services, including payments for purchase of CO_2 emission allowances						
	Annual cost (EUR billions 2008)				Cumulative cost (EUR billions 2008)	Difference from No Policy (EUR billions 2008)
	2010	2020	2030	2050	2010-2050	
No Policy Scenario		39.0	47.1	54.0	1,779	
Baseline Scenario		43.6	55.1	65.1	2,067	288
Percentage change compared to No Policy Scenario		12	17	21	16	
RES Scenario	27.2	44.9	55.5	77.9	2,212	433
Percentage change compared to No Policy Scenario		15	18	44	24	
Combined RES and CCS Scenario		44.8	54.7	77.0	2,186	407
Combined RES and Nuclear Energy Scenario		44.8	54.8	77.0	2,187	408

Payments for purchase of CO_2 emission allowance (EUR billions 2008)						
		2020	2030	2050	Cumulatively 2010-2050	Percentage changes compared to Baseline Scenario
Baseline Scenario		0.66	1.48	2.10	52.05	
RES Scenario		0.85	1.39	1.76	42.61	-18.1
Combined RES and CCS Scenario		0.89	1.23	2.01	43.05	-17.3
Combined RES and Nuclear Energy Scenario		0.88	1.73	2.72	54.23	4.2

Additional cost of energy services as a percentage of GDP, not including payments for purchase of CO_2 emission allowance						
Percentage change between scenarios						Differential 2010-2050 (EUR billions 2008)
		2020	2030	2050	Cumulatively 2010-2050	
Baseline Scenario compared to No Policy Scenario		1.5	2.0	1.9	1.9	236
RES Scenario compared to Baseline Scenario		0.4	0.2	2.7	1.2	155
Combined RES and CCS Scenario compared to Baseline Scenario		0.4	0.0	2.5	1.0	128
Combined RES and Nuclear Energy Scenario compared to Baseline Scenario		0.4	-0.2	2.3	0.9	117

Total cost of energy services by sector of final consumption (EUR billions 2008)					
	2010	2020	2030	2050	Cumulatively 2010-2050
Baseline Scenario	27.2	43.6	55.1	65.1	
Industry	2.8	3.0	3.2	3.6	127
Houses and Buildings	14.6	22.6	27.7	31.3	1035
Transport	9.8	18.0	24.2	30.2	905
RES Scenario – percentage changes compared to Baseline Scenario		3.0	0.7	19.6	7.0
Industry		1.5	-1.2	22.3	1.2
Houses and Buildings		3.4	3.7	23.7	6.7
Transport		2.7	-2.6	13.3	7.6

Source: PRIMES.

relative to the No Policy Scenario. This additional cost represents about 2% of cumulative GDP at constant prices over the 40-year period. It should be recalled that the Baseline Scenario corresponds to the current commitments arising from EU membership and, despite its higher cost, does not achieve an emissions reduction consistent with climate change mitigation. The additional cost (on top of the costs of the Baseline Scenario) that energy consumers will incur for energy services under the Mitigation Scenarios was estimated at between €120 and €145 billion (2008 prices) for the period 2010-2050.

From a national economy perspective, payments for the purchase of emission allowances (whether direct or indirect by energy consumers) are a form of transfer payment, in the sense that the auctioning-off of emission allowances under the EU ETS scheme will allow governments to raise revenue. Therefore, when estimating the cost of the scenarios from a national economy perspective, payments for emission allowances need to be excluded. The Baseline Scenario assumes a much lower price for emission allowances, but projects the emission of much greater quantities of CO_2 in the sectors subject to the Eu ETS scheme, relative to the Mitigation Scenarios. Therefore, the total payments for allowances anticipated in the Baseline and Mitigation Scenarios are intercomparable. Specifically, cumulative payments for emission allowances over the period 2010-2050 are about 18% lower under the "RES" and "RES and CCS" Mitigation Scenarios than under the Baseline Scenario, while cumulative payments under the "RES and nuclear energy" Scenario are slightly higher than under the Baseline Scenario.

Excluding emission allowance payments, the Mitigation Scenarios give rise to additional cumulative costs of between €117 billion and €155 billion (2008 prices) over the period 2010-2050, which represents about 1% of cumulative GDP over the next 40 years. The additional cost of the Mitigation Scenarios, relative to the Baseline Scenario, is mainly recorded after 2030 and clearly burdens the residential, buildings and transport sectors more than the industrial branches.

Of the three variations of the Mitigation Scenario, the "RES" Scenario is slightly more costly (entailing about 1.2% higher cumulative costs than the other two variations, which correspond to additional costs of €27 billion, at 2008 prices, for the period 2010-2050), while the "RES and nuclear energy" Scenario has the lowest cost. Of course, the "RES" Scenario is, by far, more likely to be implemented than the other two Mitigation Scenarios, especially the one involving nuclear energy.

The total average cost of reducing greenhouse gas emissions under the Mitigation Scenarios is estimated at between €190 and €240/tonne of CO_2 (2008 prices), cumulatively for the period 2010-2050.

The restructuring of the electrical energy generation sector calls for extensive investment in RES plants, back-up plants, CCS plants (for the "CCS and RES" Mitigation Scenario), etc., all of which are highly capital-intensive. It also calls substantial investments in transmission and distribution network infrastructure, since the greater the share of RES, the larger these networks

Table 4.11 **Cost of electricity generation and supply in €/MWh (2008 prices)**

	2005	2010	2020	2030	2050	Percentage change compared to No Policy Scenario 2020	2030	2050
Baseline Scenario								
Average generation cost	68.6	80.6	99.7	107.2	90.1		16	24
Fixed cost	27.5	35.9	56.5	63.6	48.0		31	35
Variable cost	39.7	41.7	35.3	31.0	29.8		-17	-21
Taxes and ETS	1.4	3.0	7.9	12.7	12.2		2721	5835
Grid cost	12.6	24.1	34.4	36.3	33.6		19	19
Supply cost	81.2	104.7	134.1	143.5	123.7		17	22
	2005	2010	2020	2030	2050	Percentage change compared to No Policy Scenario 2020	2030	2050
RES Scenario								
Average generation cost	68.6	80.6	105.0	110.9	96.8	5	3	7
Fixed cost	27.5	35.9	63.4	77.0	67.0	12	21	39
Variable cost	39.7	41.7	31.9	25.5	18.6	-10	-17	-38
Taxes and ETS	1.4	3.0	9.7	8.4	11.3	23	-34	-8
Grid cost	12.5	24.3	36.7	41.6	40.7	7	15	21
Supply cost	81.2	104.9	141.8	152.6	137.4	6	6	11
Combined RES and CCS Scenario								
Average generation cost	68.6	80.6	104.4	107.0	92.8	5	0	3
Fixed cost	27.5	35.9	61.2	67.0	46.5	8	5	-3
Variable cost	39.7	41.7	32.9	33.7	33.0	-7	9	11
Taxes and ETS	1.4	3.0	10.3	6.3	13.3	30	-50	9
Grid cost	12.5	24.2	36.4	37.9	33.9	6	4	1
Supply cost	81.2	104.8	140.8	144.9	126.8	5	1	3
Combined RES and Nuclear Energy Scenario								
Average generation cost	68.6	80.6	104.4	106.2	93.0	5	-1	3
Fixed cost	27.5	35.9	61.3	66.1	49.4	9	4	3
Variable cost	39.7	41.7	32.9	27.6	23.5	-7	-11	-21
Taxes and ETS	1.4	3.0	10.3	12.4	20.0	30	-2	64
Grid cost	12.5	24.3	36.3	38.2	34.4	6	5	2
Supply cost	81.2	104.9	140.8	144.4	127.4	5	1	3

Source: PRIMES.

become. However, the more power generation is freed from its dependence on fossil fuels, the more the plants' operating costs will decrease.

Nevertheless, as can be seen from Table 4.11, the total cost of the energy system is higher both in the Baseline Scenario relative to the “No Policy” Scenario (by about 20%) and in the Mitigation Scenarios relative to the Baseline Scenario (by between 5% and 10% in the case of the “RES” Scenario). An important component of the additional cost is payments for emission allowances, which are also present in the Baseline Scenario, but absent from the “No Policy” Scenario.

Due to the higher cost of supplying electrical energy, consumer prices are higher in all the scenarios than in the “No Policy” Scenario. This increase (of the order of 20%) is already high in the Baseline Scenario.

The price increases under the Mitigation Scenarios, relative to the Baseline Scenario, are fairly limited until 2030, but become more pronounced thereafter.

Included in electricity prices, as estimated with the mathematical model, is the recovery in full of all costs for power generation and distribution, as well as the recovery of all RES-related subsidies, the cost of increased back-ups in proportion to the share of stochastic RES in power generation, etc. This explains why the prices of electricity under the “RES” Scenario are higher (by about 5% in 2030 and 10% in 2050) than under the other two variations of the Mitigation Scenario. Rapid transport electrification under the Mitigation Scenarios progresses in parallel with energy saving in other uses, a combination that evens out the load curve considerably, as the difference between base and peak load decreases. This flattening out has a beneficial effect on the average cost of power generation, particularly when produced in capital-intensive plants, as in the case of the “RES and CCS” and the “RES and nuclear energy” Scenarios.

Electricity prices are slightly higher under the “RES and CCS” Scenario, relative to the “RES and nuclear energy” Scenario, mainly because of the cost of carbon transmission and storage. As mentioned earlier in this chapter, considerable uncertainty surrounds the cost of developing and operating nuclear plants in Greece. All cost estimates regarding the “RES and nuclear energy” Scenario must therefore be treated with extreme caution, unlike those for the other two Mitigation Scenario variations.

The mathematical model contains detailed investment estimates per sector of activity.

Table 4.13 presents the estimated energy-related investments (purchase of equipment, appliances, vehicles, energy saving expenditure, investment in the electrical energy sector). Given that the Baseline Scenario contains significant actions both in the field of energy saving and for RES, investments are clearly higher than in the “No Policy” Scenario, by about €20 billion (2008 prices) in the energy demand sectors (excluding transport) and by about €15 billion (2008 prices) for the electrical energy sector for the period 2010-2050.

The “RES” Mitigation Scenario involves an even greater amount of investment, totalling €172 billion (2008 prices) in the demand sectors and €30 billion (2008 prices) in the power generation sectors, on top of the Baseline Scenario investments for the period 2010-2050. The

Table 4.12 **Consumer prices of electricity in €/MWh (2008 prices)**

	2005	2010	2020	2030	2050	Percentage change compared to No Policy Scenario 2020	2030	2050
Baseline Scenario								
Average price	88.3	114.9	147.1	157.3	135.4	17	23	24
Industry	55.9	76.3	97.2	103.0	93.0	10	17	21
Households	93.7	129.5	169.3	179.3	151.9	21	25	26
Services	111.6	129.8	151.0	157.9	133.7	18	23	25
	2005	**2010**	**2020**	**2030**	**2050**	**Percentage change compared to Baseline Scenario 2020**	**2030**	**2050**
RES Scenario								
Average price	88.3	115.1	155.8	168.0	169.4	6	7	25
Industry	55.9	75.7	100.2	103.4	92.7	3	0	0
Households	93.7	130.2	180.3	193.0	192.1	6	8	27
Services	111.6	130.0	159.8	167.4	161.5	6	6	21
Combined RES and CCS Scenario								
Average price	88.3	115.0	154.7	159.4	155.5	5	1	15
Industry	55.9	75.9	100.1	101.7	90.2	3	-1	-3
Households	93.7	130.0	178.6	181.2	174.9	6	1	15
Services	111.6	129.8	158.5	159.1	148.8	5	1	11
Combined RES and Nuclear Energy Scenario								
Average price	88.3	115.1	154.7	158.8	155.2	5	1	15
Industry	55.9	75.0	100.3	102.0	92.4	3	-1	-1
Households	93.7	130.5	178.6	180.5	174.5	5	1	15
Services	111.6	130.2	158.5	158.3	147.7	5	0	10

Source: PRIMES.

increased investments in the transport sector involve road transport electrification and include the additional cost of purchasing electric vehicles, the battery charging systems and other investments to upgrade public transport. The greater part of the additional investment in the electrical energy sector takes place after 2020. The investments for energy conservation in buildings and the additional cost of purchasing more energy-efficient appliances are estimated at €58 billion (2008 prices) for the period 2010-2050. The other two variations of the Mitigation Scenario involve total investment costs similar to those of the “RES” Scenario, but smaller total investments in the electrical energy sector.

Table 4.13 **Investments in the energy sector (EUR billions, 2008 prices)**

	2010-2020	2020-2030	2030-2050	2010-2050
Baseline Scenario				
Industry	2.9	2.9	5.8	11.6
Buildings	12.8	6.9	15.2	34.9
Transport (*)	174.3	190.3	415.0	779.6
Networks	9.8	10.8	20.7	41.3
Electricity generation	16.2	13.0	22.4	51.7
Total electricity sector	26.0	23.9	43.1	93.0
RES Mitigation Scenario: additional investment in relation to the Baseline Scenario				
Industry	0.1	0.0	1.6	1.7
Buildings	4.2	5.6	48.5	58.3
Transport (*)	5.1	7.7	99.6	112.4
Total for all energy demand sectors	9.4	13.3	149.7	172.4
Networks	1.1	3.4	4.1	8.6
Electricity generation	2.7	5.2	13.2	21.1
Total electricity sector	3.8	8.6	17.3	29.7

(*) Including not only energy-related investment, but also total expenditure for the purchase of means of transport equipment.

The additional investments in the "RES" Mitigation Scenario (relative to the Baseline Scenario) represent 0.7% of cumulative GDP for the period 2010-2050 excluding transport and 1.6% including transport.

In any event, the construction and operation of these new investments will benefit economic activity and employment, while the restructuring of the energy system will bring about environmental benefits, while improving energy supply security and reducing Greece's dependence on energy imports.

A low carbon emission Greek economy will have a much greater need for renewable energy sources, energy-efficient building materials, hybrid electric cars, 'smart' network equipment and low carbon energy generation. In order to make the transition to a low carbon economy and to be able to reap all of the ensuing benefits, such as, for instance, a lower oil import bill, Greece will have to spend €150 billion or 1% of GDP, on average, per year over the next four decades, in addition to the expenditures provided for under current policies (these policies attain the "20-20-20" targets, but do not suffice to mitigate climate change).

The additional investments would bring investment in Greece back to pre-crisis levels and promote growth across a wide range of production and service sectors. Payments for fuel imports could be largely replaced by expenditures for domestically produced goods and services. Intensifying pro-climate action would generate thousands of new jobs.

Transition to a low greenhouse gas economy would also yield important benefits for the local environment: acid rain and micro-particulate emissions would be nearly eliminated, while urban air quality would improve spectacularly with the expansion of electric vehicle use. Ridding the economy of carbon emissions by drastically reducing fossil fuel use would also bring about a spectacular reduction in Greece's dependence on imported energy, thereby improving the security of supply.

Bibliography on the PRIMES energy model

Capros, P. et al. (2011), “The PRIMES energy system model – Manual”, E3MLab, http://www.e3mlab.ntua.gr/e3mlab/index.php?option=com_content&view=article&id=58%3Amanual-for-primes-model&catid=35%3Aprimes&Itemid=80&lang=en and http://www.e3mlab.ntua.gr/e3mlab/index.php?option=com_content&view=article&id=221%3Aselected-applications-&catid=35%3Aprimes&Itemid=80&lang=en.

Capros, P. and Y. Antoniou (1999), “Decision Support System for the PRIMES Energy Model of the European Commission”, Vol. 12, Nos 1-6, special issue of International Journal of Global Energy Issues, Inderscience Enterprises, Geneva.

Capros, P., Guest Editor (2000), “Technology Evolution and Energy Modeling”, special issue of the International Journal of Global Energy Issues (IJGEI), Vol. 14-, Nos. 1-4, 2000, Inderscience Enterprises, Geneva.

Capros, P., L. Mantzos, V. Papandreou, N. Tasios and G. Klaassen (2009) “Model-based evaluation of European carbon capture and storage – policy options”, *European Review of Energy Markets*, Volume 3: Issue 2, ISSN 1782-1029, June.

Capros, P., L. Mantzos, N. Tasios et al. (2009), “European Energy and Transport Trends to 2030 – Update 2009”, European Commission, Directorate-General for Energy and Transport, http://ec.europa.eu/energy/observatory/trends_2030/index_en.htm.

Capros, P., L. Mantzos, L. Parousos, N. Tasios, G. Klaassen and T. Van Ierland (2011), “Analysis of the EU policy package on climate change and renewables”, *Energy Policy*, Volume 39, Issue 3, 1476-85, March.

Capros, P. et al. (2010), “Power Choices”, EURELECTRIC, http://www.eurelectric.org/download/download.aspx?DocumentFileID=63875.

European Commission, DG CLIMA (2011), “SEC (2011) 288: Impact Assessment for Roadmap 2050 (using model PRIMES)”, http://ec.europa.eu/clima/policies/roadmap/index_en.htm.

European Commission, DG MOVE (2011), “Impact Assessment for Transport White Paper (using model PRIMES)”, http://ec.europa.eu/transport/strategies/2011_white_paper_en.htm.