Chapter 3
The cost of climate change for Greece

3.1 Some economics of climate change*

3.1.1 Why markets fail to protect the environment

Mainstream economics explain the mismanagement of the environment primarily as the malfunctioning of a market economy when natural resources or environmental services are inadequately protected by property rights. When a firm emits pollutants into a river, it is using river services without having to pay for them. By altering the state of the river, it is damaging others who draw on the river's services for recreation, fishing, water extraction, life support, etc. If the river was protected by property rights, no one would be able to use it without the "owner's" consent. Essentially, all potential users of the river would have to compete for its use and the value of its services would be protected and command a positive price. Without some kind of institutional protection, the river will be overexploited by the polluting firm that treats it like a free (zero-priced) resource. This problem is known as an "externality", because the firm views the damages it causes others as being "external" to its own concerns. Not having to "pay" for the damages, it tends to over-pollute and destroy other important services of the river. For markets to work properly, all resources should be protected by property rights (private or public)[1] and command a positive price.

While many standard goods and resources are handled more or less effectively by the market, many environmental services have attributes that make them difficult for the market to manage.[2] The fact that the atmosphere is treated as a free unpriced resource is what prevents the market from protecting its many valuable services. Furthermore, because of the complex nature of many environmental services, it is much harder to formulate property rights to adequately protect them. Environmental services are often in the nature of public goods, in that improving the quality of the environment affects many people simultaneously, so that individuals will not offer to pay for a cleaner environment if they expect to reap benefits from others who will pay.

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1 Property rights are not necessarily private. They can also be state-owned. By imposing a usage tax or fee, a government can give the underlying resources a value or command a positive price for them. The institutional control of the use of state-owned resources is therefore of crucial importance.

2 For instance, oil extraction and distribution are subject to clearly defined property rights. As oil becomes more scarce, higher prices prevent the exhaustion of reserves or the irrational use of the resource.

In case of market failure with ill-defined property rights for oil, an important part of the solution can be simply to better define and protect rights for the resource. For many environmental services, standard property rights cannot be formed, and even when they can, they may not be a good way of protecting them. The functions and uses of the atmosphere cannot be parcelled out to individuals to sell and consume as they please. The atmosphere does not have self-evident physical limits that could serve to indicate a risk of depletion.

In the presence of these kinds of market failures, environmental economics try to determine what the "proper use" or "care" for the environment is. What substances can we dispose of into our atmosphere and at what levels? Which uses of the atmosphere are acceptable? How do we decide who should or should not be able to use the atmosphere to emit substances? In the context of climate change, the question becomes what level of greenhouse gases or how much climate change to allow. Economists attempt to shed light on this question by trying to determine the damage or cost that will result from emitting greenhouse gases, and comparing this to the cost of reducing emissions. If economists can help identify the right or acceptable level of emissions, the next question is usually to determine the most effective or least costly way of achieving this level.

3.1.2 How the economics of climate change differ

The causes and consequences of climate change are global. Greenhouse gases (GHGs) emitted from any location and any activity contribute to climate change. Though different countries and sectors of the economy may emit different amounts of GHGs, the impact of an incremental tonne of GHG is the same irrespective of its origin. In fact, the impact is global and not restricted to the emitting country. Almost every human activity and sector of the economy contributes directly or indirectly to GHG emissions, making climate change unprecedented in the breadth of activities implicated. Similarly, the impacts of climate change are so extensive that no part of our economies and societies remain untouched.

The way local climates respond to climate change may differ, but they all depend on the global climate system and how it is affected. The fact that climate change is associated with cumulative emissions over time is central to the economic analysis and to the timing of desired emission reductions.

Climate change impacts develop and persist over very long periods of time. GHGs stay in the atmosphere for hundreds of years and the climate system responds slowly to increased concentrations. Lags and inertia also define the way that the environment, economy and society respond to climate change. An understanding of the impacts and policy response need to deal with these complex time profiles. A particularly difficult issue is the way that benefits and damages are spread out over time. Most of the potential damages from climate change will fall on future generations, while the costs of taking action must be borne by the present ones.

The nature and depth of uncertainty involved in climate change and its impacts mean that the handling of risk and uncertainty is a major challenge and a central feature of the analysis of climate economics. It is important to note that, while many aspects of the impacts of climate change are uncertain, there is a near-consensus among scientists that man-made climate change is happening, and also about the range of possible increases in global mean temperature. This does not diminish the great uncertainties about many aspects of climate change and its impacts, like how high the temperature might rise including the possibility of catastrophic climate change, how countries will adapt to a changed climate, the nature and extent of physical and economic damages, etc.

Economic analysis of relatively small or marginal projects, impacts and market failures has a long history and has become quite sophisticated, but for large, non-marginal impacts affecting substantial portions of an economy or region, these methodologies confront serious strains. This extraordinary scope of causes and consequences of climate change, with so many complex interdependencies and dynamics, pushes the limits of any economic analysis. "The analysis must cover a very broad range, including the economics of: growth and development; industry; innovation and technological change; institutions; the international economy; demography and migration; public finance; information and uncertainty; and the economics of risk and equity; and environmental and public economics throughout" (Stern & Treasury, 2007).

All these special features make climate change by far the biggest and most complex institutional failure of all time in dealing with external costs. It also means that despite a growing wealth of economic analysis of climate change, climate economics often remain in unchartered lands, requiring innovative theoretical and empirical work.

3.1.3 Counting costs and benefits

Any economic analysis that attempts to understand how actions and their consequences affect human welfare unavoidably involves ethical judgments regarding, inter alia, such questions as resource allocation across social groups, countries and generations. Given the scale and breadth of impacts of climate change on many dimensions of human welfare, ethics and transparency about ethical assumptions need to be a central part of the analysis.

Most policy-oriented analysis of climate economics relies on a particular ethical framework that underlies standard welfare economics. Usually income and consumption are used as proxies for an individual's satisfaction. Since the consequences of policies often differ across people, time and space, attempts are made to find a common unit of costs and benefits so that they can be added up to give a measure of success. This framework is quite versatile and allows for a number of alternative ethical viewpoints, but still has serious limitations.

For instance, individual preferences are taken as given and no room is made for the possibility of a fundamental change in preferences. If people value cars highly, then an economy that produces more cars is good. The possibility of preferences being fundamentally altered by discourse or self-examination is not envisaged. There are alternative ethical frameworks that put less emphasis on preference satisfaction or give importance to rights and processes. The concerns and implications of other ethical perspectives should be explored even when these lack the analytical and practical tools of welfare economics. There are also fascinating alternative theories of economics and how economies may interact with the environment.[3] Many of these are deeply critical of mainstream economics and welfare economics. Though these theories can provide important insights and can influence mainstream economics, they usually lack the analytical tools to provide more fine-tuned policy support. It is important to keep in mind alternative ethical perspectives and theories of economy-environment interaction and the consequent limitations of welfare economics. The analysis conducted in this report follows mainstream welfare economics, inheriting its strengths and weaknesses.

When deciding on a course of action, it is almost second nature to weigh potential costs and benefits. It is certainly the way we often debate about whether to use nuclear energy, build a stadium or road, or regulate different pollutants. Cost-benefit analysis as a distinct approach begins with a demand that there be explicit valuation or full explication of the reasons for making a decision rather than relying on some implicit argument or conviction. Another basic principle is that costs and benefits are evaluated according to the consequences of actions. Consequences need not only include such things as happiness or satisfaction of preferences that utilitarians tend to focus on, but whether rights have been violated or certain actions performed. Cost-benefit analysis also tries to add up cost and benefits to determine whether the net benefits are positive or negative. This means that a common unit of measurement for all consequences is required, which raises the issue of how different things are given weights to translate them into a common unit (Sen, 2004).

A fundamental question for the economics of climate change has to do with whether the costs of acting to stop climate change are smaller than the benefits of averting climate change, or whether we should take strong action or follow a more gradual approach. The cost of action needs to be compared to the cost of inaction but this comparison is complex.

There is great uncertainty about many issues: technologies that will be available in the future and their cost, the ability of societies and ecosystems to adapt, the extent of climate change damages, climatic conditions, the temperature level, whether there are tipping points or thresholds beyond which catastrophic impacts occur, etc. Value judgments are raised in comparing distributional issues across time and space. Costs of mitigation borne by one generation bring benefits to future generations. Some areas will benefit more from reduced

3 “Ecological economics” challenge several assumptions of “environmental economics”. Alternative theories include: Institutional Economics, Evolutionary Economics, and Marxist Economics.

emissions and some may pay more for mitigation. Impacts on goods and services that are traded in markets can more easily be compared, but things become difficult when trying to compare these to impacts on goods and services that do not have market prices, like health, quality of life, ecosystems and biodiversity.

3.1.4 The new debate: the case for action

While there is broad consensus among scientists about climate change, there is far less agreement among economists about the economics of climate change and what action needs to be taken. The main area of disagreement among economists concerns the estimation of damages from climate change. The debate is not about whether we should take action, but how drastic and fast it should be. The answer depends mostly on how large we expect damages to be. Most models of the costs of climate change resulting from allowing emissions to increase without taking action (business as usual) have suggested a range between 1% and 2% of global GDP. The Stern review suggested a range of damages between 5% and 20% of global income.[4] It took a fuller account of impacts as well as a greater range of possible outcomes (a greater account of uncertainty) using an unusually low discount rate.[5] The inclusion of direct impacts on the environment and health (often not measured in some models) increased their measure of damages from 5% to 11% of global income. Inclusion of evidence that the temperature increase may be more sensitive to emissions increased the estimated damages to 14%. Finally, giving a higher weight to damages to poor regions pushed their damage estimate up to 20%.

The striking difference between the more traditional economic estimates of damages and the highly publicised results from Stern sparked a heated and continuing debate[6] about the underlying assumptions of models and how they could affect the results so drastically. Clearly, if damages are only expected to be around 1-2% of global income and costs to be less than 1%, it is worth taking action, but the action need not be too aggressive. If damages are likely to be 5-20% and there is a danger that, if we do not act soon, we are more likely to see catastrophic outcomes, then the case for strong and speedy action is overwhelming.[7] As long as economists are divided about the potential damages of climate change and the best course of action, it will be more difficult to achieve the kind of consensus needed for global political action.

The most prominent models all conclude that business as usual would be disastrous and that the benefits of stabilisation are greater than the cost of a warming of 2.5°C.[8] Economists tend

4 See Parry (2007), Chapter 2, for a more detailed review and comparison of economic estimates of costs of climate change impacts.
5 The matter of the discount rate is discussed later in Section 3.1.5.
6 The Wikipedia article on the Stern Review provides a good overview of this debate ("Stern Review", Wikipedia).
7 The need to take action at a much quicker pace is also related to the fact that, if emissions are allowed to rise early on, it will be more difficult to reduce concentration levels of greenhouse gases later on and there is a much greater danger of passing certain thresholds that could accelerate temperature increases.
8 See Nordhaus (2008).

to agree that the costs of mitigating GHG emissions are below 1% of global GDP, ranging from 0.3% to 0.7% (Sterner and Persson, 2008). There are far fewer studies and estimates of adaptation costs and this remains an important focus of present research efforts. Those advocating mild and gradual action to reduce GHGs find that an optimal target could be well above 3°C, though they acknowledge that the additional cost of attaining a target of, at most, 2°C would be less than 0.5% of GDP.[9] So even though economists may disagree about the urgency and strength of action or how important it is to keep the global mean temperature from rising above 2°C, there is agreement that the additional cost of lowering the target increase of global mean temperature from 3°C to 2°C is not that large.

Keeping global average temperature increases below 2°C requires strong and immediate action to reduce emissions by 50-80% by 2050 compared with 2005. Recently, economists have been focusing on a number of key issues and assumptions that provide a rationale for a strong and more immediate course of action. The way that damages from warming in the future are weighted and compared to costs of taking action in the present is being reconsidered in a way that strengthens the case for action. The implications of the distribution of impacts and costs between the poor and the rich, now and in the future, are also a critical factor determining the decision to act. How economists value non-market impacts on environmental services and health has substantial implications. The built environment has great inertia, which means that, if high-emission fixed capital is put into place today, the costs of reducing emissions in the future will be much greater. Recognition of the great uncertainty of potentially unimaginable catastrophic impacts suggests that an insurance perspective is the best way to approach climate policy.

3.1.5 Weighing costs and benefits across time

How benefits and costs are weighed over time has always generated a lot of debate and controversy among economists. When economists compare monetary values across time, they use a weighting system called "discounting" to translate values in the future to a present-day counterpart. The intuition can most easily be conveyed when considering how we would usually go about comparing two different sums of money we are to receive at different moments in time. If we had to choose between receiving €100 today or €100 in a year, we would choose the immediate amount. If the bank gives an interest on money deposited of 5%, we would only consider an amount above €105 to forego €100 today. Essentially, we would "translate" or "discount" €105 in the future to be equivalent or comparable to €100 today. If the monetary amounts to be compared are even further apart in time, the conversion of future into present values is even starker. The power of discounting can be dramatic, and this is seen especially

9 See Swiss Re (2007).

when considering climate change where benefits (avoided climate change costs) and costs (action costs) are unevenly spread over unusually long time spans. Though at first glance this sounds like a simple mathematical technique of monetary conversions, the issue of weighing values or translating monetary units across time raises many deep philosophical and ethical issues often concealed in the technical debate.

What then are the underlying issues in the discount debate? There are a number of reasons why we might give different weights to values at different times. One reason is called the "pure rate of time preferences". This is meant to capture a tendency that humans have to prefer things near in the future to things farther away. It is a kind of impatience. A principle of "consumer sovereignty" says that if individuals value consumption today more than an equivalent consumption in the future, then this preference should be respected. This would still leave the question of how big this discount rate might be. In the case where costs and benefits are spread across generations, many economists and philosophers argue that it is unfair to weigh the benefits and costs from the vantage point of one generation (that living in the present). The impatience of today's consumers over consumption in their lifetime should not affect the way we value consumption that will be enjoyed by future generations. It would be similar to placing different values on identical incomes of people who live in different locations. For this reason, many economists argue for a zero or near-zero pure rate of time preference value when considering reasons to discount benefits or costs far in the future.

Another reason we often value incomes of different people differently has to do with distributional ethics. An amount of €100 going to a rich person is often deemed less valuable than €100 going to a poor person. Depending on one's distributional ethic, one may prefer to give €1 to a poor person over giving €100 to a wealthy person. The rate at which an economist "converts" or discounts €1 going to a rich individual into €1 going to a poor person is called the "elasticity of marginal utility".[10] If the economy is expected to grow so that people become wealthier over time, this distributional ethic provides a rationale for giving less weight to future consumption relative to present consumption. If we expect people to be twice as rich as us in 100 years, then we may think it unfair for us to sacrifice even 1% of our income to spare a loss of 10% to wealthier future generations.

Because the benefits of climate action accrue primarily to future generations, while the cost of action is borne by the present generation, how we weight these different values is crucial. The weighting depends both on our distributional ethic (how egalitarian we are), as well as on

10 More formally, the elasticity of marginal utility tells us how, for a given individual, each additional unit of consumption translates into well-being or preference satisfaction. The standard assumption is that as we consume more, each additional unit does not generate as much satisfaction as the previous one. Since most growth models use a single representative agent to capture the preferences of society, the value of additional consumption falls as the economy grows over time and the representative individual becomes wealthier.

our expectations of how the economy will grow. If we think that the world per capita income will continue to grow at a rate of, say, 2% per annum, then people 100 years from now will be much richer than us and we will be less willing to sacrifice for them.

Taking these three possible reasons[11] to discount future values on their own and giving each a symbol gives rise to a well-known equation that captures the influence of each factor: ρ for the pure rate of time preferences, η for the elasticity of marginal utility of consumption and g for the rate of growth (which is uncertain).

The (total) consumption discount factor $r = \rho + \eta g$. This equation is actually derived from a simple model of optimal growth of an economy. It tells us that the higher the pure rate of time preference, the greater the elasticity of marginal utility (i.e. the more egalitarian we are), and the higher the growth rate of the economy, the lesser weight we will give to income or consumption in the future relative to today. The lesser weight we give to future damages relative to present costs of action, the less ambitious climate policy becomes.

Note that two factors determining the consumption rate of discount depend on ethical judgment. Whether we apply a pure rate of time preference across generations or how strongly we discount income going to wealthier individuals depend on ethics. The other critical factor is what we expect the wealth of future generations to be relative to ours, i.e. how much the economy will grow.[12]

3.1.6 Taking nature into account

The increasing scarcity of ecosystem services and wilderness could substantially increase their importance for future generations. Most economic models do not include environmental stock as a separate good in addition to produced and tradable goods. Even though it is difficult to assess the value of biodiversity and ecosystem services, we know that their value or "price" will increase as they become relatively and absolutely more scarce. In essence, the future damage from climate change would be much greater because a particularly scarce (and thus valuable) service is bearing the brunt. Modifying a well-known model to include environmental stock as a good (Gerlagh and Van der Zwaan, 2002) radically transforms the optimal transmission path of CO_2, completely overturning results that would otherwise warrant a gradualist approach to climate policy. Even with a high discount rate, its tendency to shrink future

11 Another factor that tends to reduce the discount rate is uncertainty about future climate changes. Heal (2008) points out that there is a non-zero probability that climate change will be far more severe than currently estimated. Indeed, the possibility of catastrophic consequences cannot be ruled out. Dealing with this uncertainty requires the inclusion of a risk premium. This, in turn, drives down the net discount rate. Gollier and Weitzman (2009) argue that when there is uncertainty about the choice of discount rate, we should discount the distant future at a declining rate that trends toward the lowest possible rate considered.

12 In many models, e.g. wealth optimising integrated assessment models or dynamic multi-sector general equilibrium models, the pure rate of time preferences and the elasticity of marginal utility are exogenously determined by the model, and the growth of consumption, as well as the consumption discount rate, are part of the solution of the model. In models where economic growth is determined through scenarios, the modeller chooses a consumption rate of discount to find present values.

damages is fully countered by the expanding damages that result from the loss of increasingly scarcer environmental services.[13]

3.1.7 Equity[14] across space

In many models, equity is captured by the elasticity of the marginal utility of consumption represented with the symbol η. The question arises as to whether future generations are expected to be wealthier than present ones and whether poorer generations will be willing to sacrifice less to avoid losses to future generations. Essentially, as long as we expect economies to grow, the more egalitarian we are, the less we will be willing to act against climate change. But climate damages, mitigation and adaptation costs are distributed unevenly not only in time, but in space as well, so that equity issues and assumptions must also be addressed when people in different places are affected in different ways.

The majority of accumulated GHGs have been put there by rich countries, and while developing countries will be changing this historical balance, the poorer regions of the world are the ones that will bear the greatest losses from climate change. From this geographical perspective, the stronger our equity sentiments, the more aggressively we need to act to prevent climate change that disproportionately harms the poor.

The implications of a greater desire for equity on policy action become ambiguous. In a growing economy, the time dimension will demand fewer sacrifices in the present, since people in the future will be wealthier, while the space dimension will require greater sacrifices in the present to prevent damages hitting the poor regions. A problem with most economic models of climate change is that they only reflect values of equity between generations treated as aggregates and take no account of how damages may affect different segments of the population or regions of the world. This is largely because they model the economy on one representative agent so there is no way to incorporate other kinds of distributional impacts. A fuller appraisal of distributional ethics would require a model with many agents to allow for representation of the rich and the poor.[15] It would also require a model with many goods, since the climate impacts on environmental services may be felt more by the poor than by the rich who have a greater capacity to substitute environmental losses with man-made goods. For

13 A similar argument has also been made by Weitzman (2007), who considers the implications of treating environmental goods as substitutes or complements to manufactured goods. If there is limited substitutability, the growing scarcity of environmental goods will lead to a rise in their value. This can also be seen from the perspective of multiple discount rates, where the discount rate on environmental stock can actually be negative.

14 The term "equity" means equal treatment and equal consequences across the board, whether we are speaking of social groups, countries or generations.

15 Models that maximise welfare for different regions are in principle able to consider equity across space, but they confront a difficult problem. If they follow the standard assumption on equity that gives less weight to future generations because they are wealthier, consistency requires that they recommend huge immediate transfers of wealth from rich to poor regions. In order to overcome this problem, they use a technique known as "Negishi weights" that effectively ends up treating human welfare as being more valuable in wealthier regions. See Stanton (2010) for a good discussion of this issue.

instance, the poor will be less able to avoid the consequences of more intense and frequent heat waves, while the wealthy will rely on air conditioning or travel to cooler regions.

3.1.8 Damage functions, irreversibility and tipping points

Most of the well-known cost-benefit analyses use damage functions that model monetary damages as rising smoothly with increases in temperature. There is no scientific basis for this functional form and mounting evidence suggests that natural systems could respond in non-linear or abrupt ways to climate change. There are numerous examples of reinforcing feedbacks. The thawing of permafrost could lead to the releasing of vast amounts of methane, further accelerating climate change. With the melting of ice and snow, a tipping point could be reached as the Earth's albedo or reflectiveness changes. As fewer of the sun's warming rays are reflected back out into the atmosphere, more energy is absorbed on the Earth's surface, further aggravating the melting and warming. The melting of the Greenland ice sheet could reach a threshold, where summer melt will not refreeze in winter, leading to a cycle of melting and ultimately a sea-level rise of six metres.

The way that monetary damages rise with a warming climate is not just related to natural systems, but also to the behaviour of socioeconomic systems. Housing, commercial buildings and infrastructure are designed and built to be robust to certain variations in weather extremes. If climate change pushes impacts beyond a certain level, the damages to the built environment may dramatically increase. The direct physical damages to an economy's infrastructure will give rise to indirect damages, like supply and business interruptions and negative macroeconomic feedbacks.[16] The presence of natural or socioeconomic thresholds or tipping points with irreversible consequences further strengthens the case for early strong action.

Natural and socioeconomic systems also exhibit inertia or irreversibilities and these are also important factors influencing the appropriate pace of action. Investment in mitigation involves a sunk or irreversible cost and some have argued[17] that this loss should be weighed against the irreversible damages resulting from climate change. When this is combined with a smoothly rising damage function and discounting, it tends to push policy towards greater flexibility and a "wait and see" policy stance as the large mitigation costs cannot be undone, while the damages from climate change are in the future and not too severe.

A problem with this reasoning, beyond the assumption of the shape of the damage function, is that it ignores that non-climate sensitive investment also involves inertia and locks society into long-term commitments to higher emissions.[18] When decisions to invest in standard coal

16 The direct losses from hurricane Katrina were assessed at $107 billion, with an additional $42 billion resulting from indirect losses (Pindyck, 2000).

17 Kolstad (1996), Fisher and Narain (2003) and Shalizi and Lecocq (2009).

18 See Stanton (2010) for the implications of long-term capital investments on climate policy.

power plants or conventional high energy buildings are made (essentially delaying mitigation), the economy becomes partly committed to higher emissions for the lifetime of the plants or buildings. If it were easy to retrofit a building or plant (or cheaply incorporate carbon capture and storage), then this might not be a problem, but generally retrofitting plants and buildings is far more expensive than designing them to have low emissions from the start.

3.1.9 Uncertainty and economics of extreme climate change

Uncertainty is a central fact in the analysis and understanding of climate change and its economics. Even though the underlying mechanisms driving the Earth's temperature rise are simple and well-understood, there are still fundamental uncertainties about such matters as the extent of the temperature rise, how the temperature rise will affect weather patterns like precipitation and wind, and how the various climate impacts will affect the economy and our welfare.

Economists regularly deal with uncertain outcomes when evaluating policy choices, since most aspects of economic life involve some degree of uncertainty. As long as the likelihood of different outcomes is known, modellers can use this information to evaluate the consequences of different courses of action. The problem with climate change is that the uncertainty is of a more fundamental kind in that we don't have enough prior information to even assign probabilities to possible outcomes.[19]

In a series of recent papers,[20] Weitzman argues that the particular nature of uncertainty regarding the probability of catastrophic climate change undermines attempts to meaningfully calculate benefits and costs and provides a strong rationale for taking immediate strong climate action.[21] When undertaking assessments of climate change, economists usually avoid the problem of uncertainty by focusing on the most likely or central forecasts of temperatures or damages as if they were certain.

One way in which modellers attempt to account for uncertainty is by varying certain parameters and seeing how "sensitive" results are to these changes.[22] In the rarer cases where their models formally incorporate uncertainty, it is usually done by using a probability

19 Whereas in most cases of uncertainty we either know the probabilities of possible outcomes or have "known unknowns", with climate change we don't even know the probabilities, so we are in the realm of "unknown unknowns".

20 Weitzman (2009a, b, c, d; 2010a, b) and Stern and Treasury (2007).

21 Weitzman questions the capacity of integrated assessment models to provide reasonably accurate estimates of costs and benefits as a guide to policy formation. On a broader or looser interpretation of benefits and costs, his argument can be seen as saying that the damages from low-probability catastrophic climate change could be so large that the benefits of action totally outweigh the costs.

22 Dietz et al. (2007) used the model PAGE2002, which is one of the best-known models incorporating uncertainty and follows the approach of varying parameters. It runs scenarios many times, each time randomly selecting parameters from ranges of possible values suggested by the scientific literature. The model output is a distribution of possible outcomes rather than a single most likely outcome. The inclusion of this kind of uncertainty increased the expected damages by 7.6% of world GDP relative to the same model without uncertainty (see Pindyck, 2007). Since the different parameters are chosen from normal distributions, this way of including uncertainty does not address the issue of non-zero, low-probability catastrophic events.

density function that associates probabilities with different outcomes.[23] Potential future damages are weighted by how likely they are to occur in order to arrive at an average or expected level of damages.

To calculate expected damages[24], very likely damages are weighted heavily and added to less likely, but more extreme, damages.

Clearly, the shape of the probability density function matters in the calculation of the expected damages. For many natural phenomena, like the height of adult humans, the normal distribution is a good representation of likely outcomes. Most economic models of climate change that have incorporated probability density functions have used the normal distribution.[25] A feature of normal distributions is that extreme outcomes (far from the average or most likely outcomes) are so unlikely that we can effectively ignore them. It is the thinness of the tails (or edges) of the normal distribution that reflects how unlikely extremes are.[26] In the context of climate change, Weitzman argues that scientists have so little prior knowledge of what might happen at high levels of GHG emissions that very extreme outcomes cannot be excluded or assigned a near-zero likelihood. Accordingly, the probability density function should be treated as having "fat tails". The probability of extreme climate change or catastrophic damage, while small, is not zero. Given the nearly unimaginable consequences, or enormity of the damages, even if these are "weighted" by a 1% (non-zero) chance of occurrence, it greatly augments the overall expected damages from climate change.

This argument rests on the nature and extent of scientific uncertainty regarding extreme climate change and damages. Weitzman says that there are so many deep uncertainties in every aspect of our understanding and assessment of climate change and its impacts that, when compounded, they allow for a far from insignificant possibility of catastrophe.[27] In defense of this position, he provides a few "exhibits" of the many areas of deep structural uncertainty.

23 Including an arbitrary truncation or cut-off of the tails of the probability distribution function. For reviews of how uncertainty is modelled in the economics of climate change, see Quiggin (2008) and Intergovernmental Panel on Climate Change (2007).

24 "Expected damages" refer to the notion of "expected value" in probability theory.

25 Also known as the "Gaussian distribution".

26 The standard shape of a probability density function is a bell curve, where the peak represents the most likely outcome (high density) and the edges or tails of the bell the less likely outcome (low density). These functions have only one peak. However, many non-linear extreme events correspond to multi-modal probability functions, i.e. probability density functions with more than one peak. In this case, there is no point in calculating the expected value.

27 "The economics of climate change consist of a very long chain of tenuous inferences fraught with big uncertainties in every link: beginning with unknown base-case GHG emissions; then compounded by big uncertainties about how available policies and policy levers will transfer into actual GHG emissions; compounded by big uncertainties about how GHG low emissions accumulate via the carbon cycle into GHG stock concentrations; compounded by big uncertainties about how and when GHG stock concentrations translate into global average temperature changes; compounded by big uncertainties about how global average temperature changes decompose into regional climate changes; compounded by big uncertainties about how adaptations to, and mitigations of, climate-change damages are translated into utility changes at a regional level via a 'damages function'; compounded by big uncertainties about how future regional utility changes are aggregated into a worldwide utility function and what should be its overall degree of risk aversion; compounded by big uncertainties about what discount rate should be used to convert everything into expected-present-discounted values. The result of this lengthy cascading of big uncertainties is a reduced form of truly enormous uncertainty about the form of an integrated assessment problem whose structure wants badly to be transparently understood and stress tested for catastrophic outcomes" (Weitzman, 2010a, pp. 3-4).

Exhibit A (Unprecedented increases in GHGs): The best data that exist in the science of paleoclimate from ice-core drilling show that carbon dioxide has never been outside a range of between 180 and 300 ppm during the last 800,000 years. We are already at 390 ppm. Humanity has increased GHG far beyond their natural range and at a stupendously rapid rate. The levels that may ultimately be attained have probably not existed for at least tens of millions of years and the rate of increase is likely to be unique on a time scale of hundreds of millions of years.

Exhibit B (Possible temperature response to unprecedented increase in GHGs): Climate sensitivity is a measure of how the Earth will respond to a doubling of GHGs. It is likely to be in the range of 2°C to 4.5°C with a best estimate of 3°C. Though climate sensitivity is not the same as temperature change, other things being equal, a higher climate sensitivity will lead to higher temperatures in the remote future. Weitzman (2009a) states that climate sensitivity "values substantially higher than 4.5°C cannot be excluded". Twenty-two peer-reviewed studies cited by IPCC-AR4 (2007) suggest that there is a roughly 15% chance of climate sensitivity surpassing 4.5°C, a 5% chance of it surpassing 7°C and a 1% chance of it surpassing 10°C. "Once the world has warmed by 4°C, conditions will be so different from anything we can observe today (and still more different from the last ice age) that it is inherently hard to say where the warming will stop."

Exhibit C (Unaccounted for bad-feedbacks): As the globe heats up, a number of bad-feedback components of the carbon cycle could be triggered that have not been accounted for by most general circulation models of climate change. Two examples are "the huge volume of GHGs currently sequestered in the arctic permafrost and other boggy soils" and the "yet more remote possibility of release of the ever-vaster deposits of CH_4 trapped in the form of hydrates". Including these would further augment the likelihood of extreme outcomes.

An additional source of uncertainty (or "fattening of the tail") that comes into the economic analysis of climate change is the way modellers attempt to translate potential temperature changes into damages to human welfare. The damage function used in most economic models assumes that damages increase gradually and continuously as the global mean temperature rises. It does not consider the possibility of abrupt changes (discontinuities) or accelerating damages at higher temperatures.[28] The decision to use this particular form of damage function is totally arbitrary and more a reflection of mathematical convenience than knowledge of the link between temperature increases, physical impacts and human welfare. Very plausible alternative specifications of damage functions can lead to totally different damage assessments from higher temperatures.

Low-probability catastrophic damages in the remote future might be tolerable if climate change was reversible in a short time span, but that is not the case. High stocks of CO_2 will

28 See Weitzman (2010b) and Gerst et al. (2010) for a lengthier discussion on the relevance of how the damage function is specified in the economics of catastrophic climate change.

persist for a very long time, making climate change effectively irreversible. Given the deep and multiple sources of uncertainty regarding extreme outcomes, a "wait and see" policy stance in the hope of resolving this uncertainty is not warranted. Weitzman does not just rely on the evidence and intuition of the deep uncertainty about extreme climate change, but develops theoretical arguments along with simple models that present the implications of including fat-tailed probability density functions in a formal analysis, strengthening the case that immediate and strong action is needed.[29]

Weitzman and others[30] are suggesting a different way of framing the decision for taking action on climate change than that of fine-tuned cost-benefit estimation, seeking an optimal trajectory of emissions. When considering the strength and speed of climate action, instead of focusing on the most likely outcome, we should be taking out insurance against low-probability catastrophic climate change. The focus should be on finding the temperature increase that can be tolerated while still eliminating any chance of future catastrophe.

This "precautionary" framework is similar to decisions about insurance against fires and floods or other kinds of calamities.[31] Being risk-averse, we are generally willing to pay to avoid a small probability of a big loss. If we focused only on the most likely events, we would not insure.[32] An insurance perspective that views climate action as a way to avoid a low-probability risk of catastrophic damages could easily justify paying 0.5% of GDP to insure against a 1% chance of disaster. Putting this in context, the world spent 3% of GDP on insurance in 2006.[33]

A question might arise as to how climate change risks compare to extreme risks from other "nightmare scenarios" of environmental disasters, like biotechnology, pandemics, nuclear proliferation or an asteroid hitting the Earth. Ultimately, these need to be compared and assessed in a similar fashion, but there are grounds for believing that climate change is unique among global environmental disaster scenarios.[34]

3.1.10 The case for action is strong

Economists will continue to debate about theory, models and the assumptions regarding the costs and benefits of taking action on climate change. Most models suggest that the additional

29 Ackerman et al. (2010) have shown how the incorporation of fat-tailed probability density functions into integrated assessment models (DICE) that "advocated" gradual and mild policy action is enough to make aggressive action optimal.

30 See Pindyck (2007) for a very accessible presentation of some of the main debates in the economics of climate change and a justification for an insurance perspective in making the case for action. Dasgupta (2008) and Weitzman (2009d) raise questions about the usefulness of cost-benefit analysis in the face of climate change uncertainty.

31 Similar approaches are used in US policy in countering terrorism, building anti-ballistic missile shields or neutralising hostile dictatorships possibly harbouring weapons of mass destruction. These matters correspond to highly unlikely possibilities, the avoidance of which would nonetheless entail huge benefits though at a considerable cost Weitzman (2009d).

32 Heal and Kriström (2002) consider what factors determine how much we would be willing to pay to avoid the risk of climate change.

33 World Bank Group (2009).

34 See Sunstein (2009) for a discussion on some of these other threats and how they differ to climate change risk. For a broader and non-technical discussion of how the public should make decisions in view of low-probability catastrophic events, see Posner (2005) and Weitzman (2010a).

costs to the world from taking more aggressive climate action are not that substantial. Given the many key assumptions of the ongoing debate, there are more ways to make a case for than against strong action.

A belief that we should not weight future damages less than present ones just because in our lives we prefer the immediate to the remote enhances the case for action. A stronger emphasis on equity may have an ambiguous impact if we expect the world to be wealthier in the future. The more importance we attach to the natural environment and its services, the stronger the case for action. The more account we take of thresholds and inertia in the climate system, the economy and society, the stronger the case for action. The more we take into account uncertainty in modelling, as well as the potential for low-probability catastrophic climate change, the stronger the case for taking strong action now.

Given that fundamental uncertainties are not likely to be resolved soon, there is a good case to be made that, when judging the case for action, the whole exercise of counting costs and benefits may be questionable. An insurance perspective is much more compelling. The main reason why we should take strong action is that it is worth paying a small price to avoid a non-negligible probability of an unimaginable global catastrophe.[35]

Even an insurance perspective still requires some understanding of costs and benefits, though it focuses on the potential costs and degree of likelihood of extreme climate change. Cost-benefit analysis (or economic analysis more generally) still helps us get a grasp of the more likely damages of climate change, its regional distribution, and the expense of taking different actions to limit emissions, or how these costs will be distributed across different sectors of the economy and population, among other things.

As long as we don't overly rely on the specific monetary estimates of costs and benefits to determine whether we should take action or not, but use these numbers and the analysis to inform ourselves of how we may need to adapt to a changing world or what kind of policies will be more effective or less expensive in reducing emissions, there is much to gain from a richer economic appraisal. Much of the debate about the economics of climate change remains pertinent in providing decision and discussion support for a whole range of issues and at every level of decision-making.

Given the global causes and consequences of climate change, analysis has often taken a world perspective. A world perspective will always be central in considering global action or even how action should be distributed across nations and sectors of the economy. The case for action is better addressed from a global perspective and it should underlie our motivation as citizens, local communities and nations of the world. Though the benefits and costs of climate

35 This holds even before we take into account many other potential benefits of taking action, like reduced atmospheric pollution, increased energy security, etc.

change may vary across countries, the same issues that make a case for action for the global community also make a case for action by individual countries.

For this reason, a country-level economic analysis of climate change has other main objectives. A country-level analysis requires a far more detailed analysis of how global climate change will affect local weather conditions, local sea level rise and frequency of extreme weather events. This detail provides a basis for understanding how the different regions of a country and sectors of an economy and society will be impacted by climate change through time. It provides the basis for being able to effectively design policies to adapt to climate change, as well as policies to minimise the costs of emission reductions. It will provide critical information for making investment decisions at all levels of decision-making. In short, it will help a country formulate its path to sustainable development.

3.2 Climate-economy modelling*

A wide range of models have been developed over the years to explore climate-economy interactions and to provide a basis for policy formation. Apart from climate models, developed to support the prediction of meteorological phenomena, there are also a number of special technical and economic models that project greenhouse gas emissions, taking into account ways to reduce them (e.g. energy sector modelling and manufacturing process modelling). Researchers often link climate models to energy sector and manufacturing process models to achieve an integrated study of emissions and their climate impact. Macroeconomic, multi-sector and economic growth models have all had to be extended, so as to incorporate mechanisms simulating greenhouse gas emissions, ways to reduce them and damage estimates derived from climate models. Scientists from different disciplines have worked together to develop interfaces between these models[36] so that the interactions between climate, energy, manufacturing processes and the economy could be investigated in greater depth. One of the results of these interlinking efforts was the development of the integrated Economy-Energy-Environment models.[37]

3.2.1 Key features of integrated assessment models

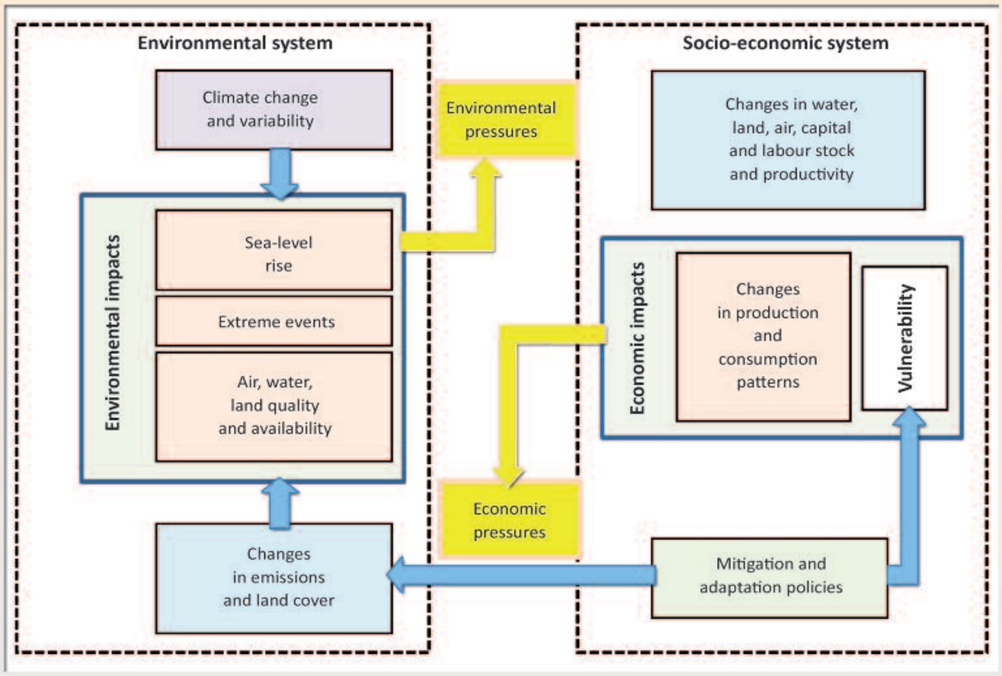
Integrated assessment models (IAMs) of climate change combine models of the climate system, climate impacts and the economic system that enable the evaluation of alternative

* Sub-chapter 3.2 was co-authored by A. Papandreou and P. Capros.

36 Weyant (2009) encourages greater communication between researchers (and model developers) across a wide range of disciplines.

37 Also known as the 3E models. See Capros (1995).

Figure 3.1 **Climate-economy dynamics**



Source: Bosello (2003).

policy responses. An economic assessment of the physical, biological and social aspects of climate change effectively involves translating the latter into monetary terms, which may be viewed as (or further transformed into) a measure of social welfare. The interlinked chain of interactions in these models is the following:

- Human-induced climate change results from an increase in GHG emissions and their levels of concentration in the atmosphere.
- The concentration levels of GHG affect the temperature, precipitation, cloud formation, wind and sea level rise, etc.
- These changes, in turn, result in various physical and biological impacts, such as changes in crop yields, water supply, biodiversity, ecosystems and even migration.
- These impacts can then be translated into monetary terms.
- Finally, impacts are aggregated to give a single measure of the economic cost of climate change.

Such interactions are examined in terms of their time dynamics. The economy is not only affected by climate change, it is also the perpetrator of climate change, as growth in production and consumption gives rise to more GHG emissions. Among the largest contributors to GHG emissions is the energy sector to the extent that it relies on fossil fuel combustion. Other major contributors are: agriculture, stock-breeding and manufacturing. Policies and reforms that reduce gas emissions can lead to lower concentration levels of GHGs in the atmosphere, thus mitigating climate change as well as their impact on the physical, biological, social and production system. Such policies typically entail action costs but, at the same time, allow part of the cost of climate change to be avoided.

While IAMs are often complex systems based on interlinking a number of special models,[38] there are also compact IAMs that integrate several conventional intertemporal optimisation models and simple relationships, which constitute representations of complex special models dealing with various aspects of climate change. These compact IAMs, developed mainly by W. Nordhaus[39] of Yale University and A. Manne[40] of Stanford University, have been used in the United Nations IPCC assessments of climate change.

The dominant modelling approach, as far as the economy module is concerned, is based on the neoclassical theory of general equilibrium, according to which agents (consumers) maximise their utility or satisfaction, firms (producers) maximise their profits and the economy is driven towards equilibrium under full market and full employment conditions. Different models can lead to substantially different results.

3.2.2 Computable General Equilibrium models

Computable General Equilibrium (CGE) models[41] are based on the general equilibrium paradigm of Arrow-Debreu and compute the equilibrium prices of goods, services and factors that simultaneously clear all markets, depending on the decentralised supply and demand decisions taken by agents.

CGE models are usually multi-sectoral and detailed, and it is in this respect that they differ from the compact IAMs mentioned above. They also differ in terms of their dynamic features: CGE models, whether static or dynamic, are imperfect foresight models, while IAMs perform inter-temporal optimisation with perfect foresight.

The main advantage of CGE models is that they can simultaneously model a number of sectors, capturing in detail exchanges between sectors, consumers and producers, as well between countries. CGE models are thus suitable for linking to other detailed models and for carrying out sectoral impact assessments. On the contrary, compact growth models have the disadvantage of representing less detail, but the long-term growth trends they project have a better theoretical foundation.

38 See Hope (2005), Füssel and Mastrandrea (2009), Tol and Fankhauser (1998), Weyant et al. (1999), Grubb at al. (2006), Hitz and Smith (2004), and Yohe (1999) for an overview of integrated assessment models.

39 See Nordhaus (2008) for a presentation of the DICE model.

40 See Manne et al. (1993) for a presentation of the MERGE model.

41 See Sue Wing (2010), Kehoe (1998) Sue Wing (2004) and Peng (2007) for simple descriptions of computable general equilibrium models and numerical examples.

Precisely because of their analytical and decentralised structure, CGE models are suitable for incorporating relationships that, to a certain degree of detail, (a) capture the energy sector, (b) link economic activities to emissions of GHGs and other pollutants, and (c) represent emission mitigation options (involving either a sectoral restructuring of the economy, substitutions, or direct emission abatement techniques), the mechanisms through which emissions impact the environment and the climate, the emissions levels of concentration in the atmosphere, and finally the various sectoral impacts of climate change. Moreover, thanks to their decentralised representation of goods and prices, CGE models incorporate environmental services represented as goods, as well as emission monitoring mechanisms through the purchase of tradable emission permits. CGE models, in their extended version,[42] can therefore integrate all the functions of IAMs, whereas the IAMs are more complex, since they interlink different mathematical systems.

3.2.3 Partial equilibrium models and the bottom-up approach

Partial equilibrium models,[43] as their name suggests, differ from general equilibrium models primarily in that they focus on a part (usually a sector) of the economy, without seeking to address the interactions with the rest of the economy. Partial equilibrium models are used either to estimate the impact that climate change has on specific sectors of the economy or conversely to calculate the GHG emission levels caused by specific sectors and to assess the cost and possibilities of reducing these emissions.

Energy sector models are partial equilibrium models that simulate supply and demand for different energy forms, usually in considerable detail and from a techno-economic perspective. Model designing has gone as far as to design detailed models for very specific manufacturing processes that estimate GHG emissions other than CO_2.

A form of partial equilibrium analysis is also used when attempting to monetise the impact of climate change on specific sectors, for instance, when the analysis of the biophysical impacts of climate change on agriculture is used jointly with a statistical and a market equilibrium analysis (see Mendelsohn et al., 1998, Adams et al., 2004, and Tol, 2010).

The above analysis can be applied to multiple sectors of the economy and is referred to as the "enumerative approach". The first step of this approach is to estimate the "biophysical effects" of climate change. Economic valuation methods are then used to place a monetary value on the biophysical impact. This approach, often referred to as "direct" or "first-order" valuation, can, depending on the case, rely on a variety of methods, from simple expert estimates to sophisticated analytical models. The direct costs are obtained for each sector to assess the total economic cost of climate change.

42 One such extended CGE model is the GEM-E3, see Capros et al. (1997).
43 For the theoretical founding of the partial equilibrium analysis, see Pigou and Aslanbeigui (2001) and Marshall (1997).

This approach is also known as the bottom-up[44] approach, as opposed to the top-down approach of the computable general equilibrium models.

All of the cost estimates presented in Chapter 2 are bottom-up estimates, calculated using an enumerative approach, whereas the cost estimates presented in Sub-Chapter 3.3 (below) are top-down estimates, obtained using a computable general equilibrium model. The cost estimates presented in Chapter 4 were obtained using a partial equilibrium model designed for the energy sector and manufacturing processes.

Theory does not suggest that adding up separate sectoral impacts will lead to the same result as evaluating total climate change impacts using a computable general equilibrium or macroeconomic model that incorporates all market interactions. The reason for this is that the computable general equilibrium model allows all of the indirect impacts on the economy to be estimated, taking into account the interactions between sectors and the rest of the economy.[45]

3.2.4 Using sectoral analysis data as inputs into computable general equilibrium models

Bottom-up estimates of sectoral impacts, as well as partial equilibrium estimates can be used to prepare data for subsequent feeding as inputs (as exogenous variables) into general equilibrium models. This was the method followed in the present report.

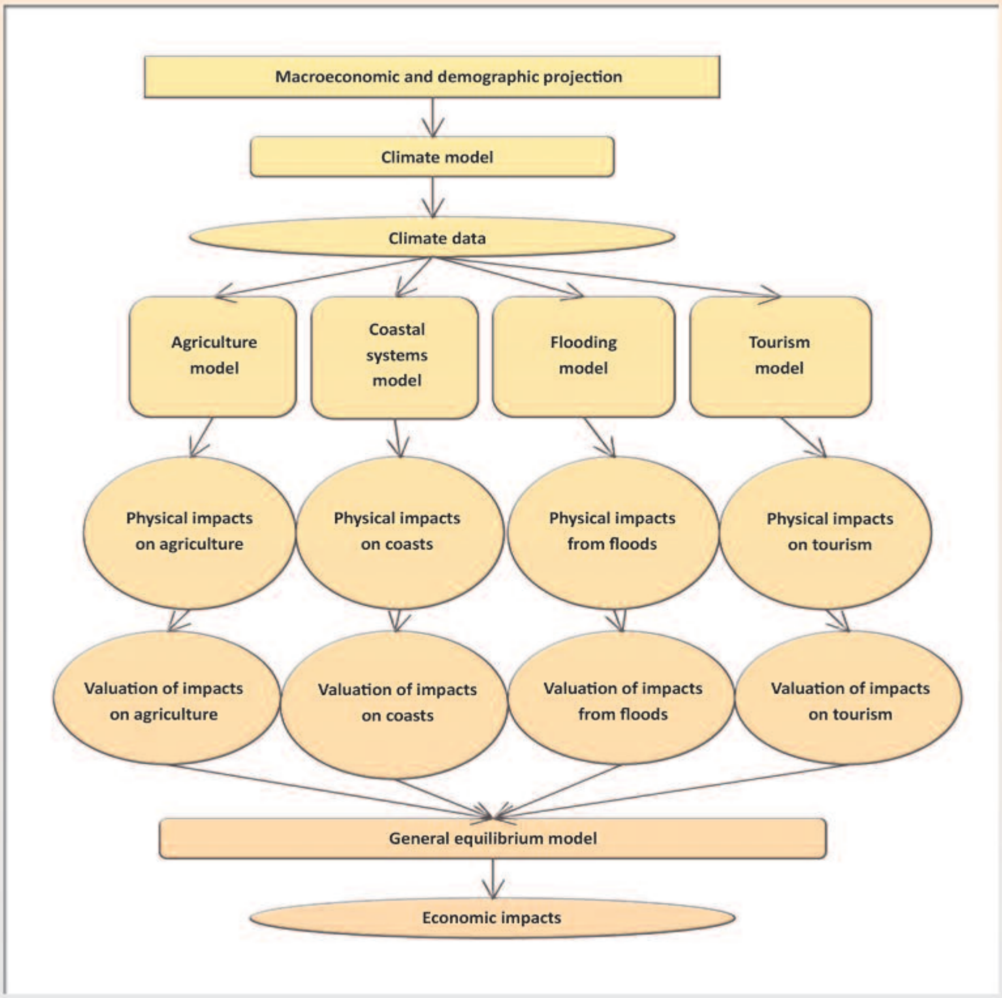
Jorgenson et al. (2004) with their Intertemporal General Equilibrium Model (IGEM) and Ciscar et al. (2009) under the European PESETA project, as well as many others, have carried out extensive cost-benefit analyses of climate change, by combining sectoral damage functions with computable general equilibrium models. This type of approach, drawing heavily on more detailed studies per sector, produces more refined and reliable assessments of first-order sectoral costs. It also has the advantage, compared with the enumerative approach, of ensuring consistency with cost-benefit assessment for the whole economy, taking sectoral interactions and indirect costs/benefits into account thanks to the use of the general equilibrium model. The PESETA project, which carried out an in-depth study of the costs of climate change for the European Union, used the GEM-E3 model, as did the research team that prepared the present report. The Garnaut Climate Change Review for Australia[46] (Garnaut 2008) is another important recent example of a detailed climate change assessment combining a bottom-up sectoral approach with a top-down computable general equilibrium model. It is worth noting that the Stern Review (Stern, 2008) also made use and recognised the importance of bottom-up or sectoral analysis of climate change impacts.

44 See Fankhauser (1994, 1995), Nordhaus (1994) and Tol (1995, 2002a, 2002b).

45 For examples, see Tsao et al. (2010) and Barket et al. (2009).

46 The entire review and all commissioned and supporting material can be found at the official site http://www.garnautreview.org.au/2008-review.html

Figure 3.2 **The PESETA integrated approach**



Source: Ciscar et al. (2009).

3.3 Assessment of the total economic cost of climate change using a general equilibrium model*

3.3.1 Introduction

Chapter 2 assessed the direct economic impacts of climate change on various sectors of the Greek economy. The present sub-chapter examines the overall impact of climate change on the

* The study for Sub-chapter 3.3 was carried out at the E3MLab laboratory of the NTUA, under the supervision of Prof. Pantelis Capros, by main researchers Marilena Zambara and Dr. Leonidas Paroussos, and by Zoi Vrontisi, Stella Tsani and Maria Papaioannou.

Greek economy, using the GEM-E3 (General Equilibrium Model for Economy, Energy and Environment interactions, Capros et al., 1997). The findings of the sectoral studies presented in Chapter 2 were used as inputs for the macroeconomic analysis presented in this sub-chapter.

Using the general equilibrium model, it is possible to quantitatively assess the overall impacts, both direct and indirect, on the economy. Assuming that climate change will indeed occur, the Greek economy will be affected in its entirety but, more particularly, in certain sectors. By comparing the quantitative assessment of this state against one without climate change, one can deduce the total cost of climate change for the Greek economy. This cost is expressed as a percentage change in Gross Domestic Product (GDP) and in household economic welfare, and is allocated to the different sectors of economic activity.

The general economic equilibrium model is, first, calibrated to replicate the state of the economy in the base year. Then, by introducing changes in the exogenous parameters, the model can compute a new equilibrium state of the economy. The changes to the exogenous parameters can either take place over time (dynamic evolution) or concern only the base year (static change). The conclusions drawn based on general equilibrium models are derived from the comparison of two states of an economy, once they have been quantitatively assessed. A comparison of two dynamic evolutions of the economy is referred to as scenario-based analysis. A comparison of two static states of the economy is referred to as counterfactual analysis. The model simulates the causal link between the introduced changes and their impact on the equilibrium state of the economy.

For the purpose of the present study, the analysis of the economic impacts of climate change was conducted using a comparative static methodology.[47] The reference basis was considered to be the quantitative representation of the economy in the base year, as simulated by the model. The counterfactual assumption was then made that climate change occurs, with direct impacts on different sectors of the economy, as established by the analyses of Chapter 2. A new quantitative representation of the economy was computed by the model, which incorporates those impacts. This new representation, when compared against the representation without climate change, yields differences that enable conclusions to be drawn about the total cost of climate change.

The reasons why the dynamic evolution approach, which involves the comparison of dynamic evolution scenarios, was not chosen are of a practical nature. Such an approach would have required the construction of a dynamic evolution scenario of the Greek economy until 2100, a process that would have been beset by a number of uncertain, but possibly crucial, assumptions for the assessment of climate change costs. The comparative static approach is simpler and has the advantage of being transparent.

47 The approach followed in the present study has also been adopted by other studies of the economic impacts of climate change (Ciscar et al., 2010, Fankhauser and Tol, 1996, Halsnaes et al., 2007). Bosello et al. (2007) adopt the alternative, dynamic approach.

Based on the climate scenarios presented in Chapter 1, the climate changes over the time horizon to 2050 are expected to be different from the ones projected for the longer horizon to 2100. The climate changes also depend on the global rate of accumulation of greenhouse gas emissions. Each case of climate change will have different economic impacts, which is why the total cost for the economy needs to be estimated separately for each case.

It is needless to say that the highest total costs are associated with the highest accumulation of GHGs under the Inaction Scenario for reducing global emissions. Even in this case, however, the intensity of climate change is projected to be lower in 2050 than it will be in 2100.

For the valuation of the total costs of climate change with the general equilibrium model, two landmark years —2050 and 2100— were used. Different representations of the economy were obtained depending on whether climate change as at 2050 or at 2100 was factored in, due to the different intensity of climate change in each of these landmark years. It is important to remember that the outcome of the model for 2050 and 2100 should not be taken as representing the state of the economy in 2050 or 2100, but as representing what the state of the economy in the base year would be, if the climate change intensity of 2050 and of 2100, respectively, were to occur in that year.

Similar total cost valuations were also made for the other climate change scenarios, including the Mitigation Scenario, under which drastic GHG emission reduction is achieved worldwide; this mitigation, though not sufficient to prevent all climate change, is nonetheless sufficient to reduce the intensity of climate change.

3.3.2 The general equilibrium model GEM-E3

The GEM-E3[48] (General Equilibrium Model for Energy-Economy-Environment interactions) follows a computable general equilibrium approach, taking into account the individual microeconomic decisions of producers and consumers, the simultaneous equilibrium between supply and demand in all markets for goods, services and production factors, and presuming that the algebraic sum of surpluses or deficits of all economic agents (government, firms, households, banks, external sector) is equal to zero.

Producers are classified according to sectors of economic activity. Each producer is assumed to be representative of all those in his respective sector. Furthermore, in seeking to maximise profits, producers determine the supply of goods and services, as well as the demand for production factors and intermediate goods and services. Households are modelled on one average household, which —motivated by utility maximisation— simultaneously determines the demand for goods and services, the supply of labour, and savings. The behaviour of the government in the areas of public investment, government consumption, taxation and income redistribution (through

48 A detailed description of the model can be found on the E3MLab website: http://www.e3mlab.ntua.gr/e3mlab/GEM%20-%20E3%20Manual/Manual%20of%20GEM-E3.pdf

social benefits) is exogenous. The supply and demand for capital are represented in a simplified manner through the balance of payments. The demand for goods and services is met by domestic production and imports, which are not perfect substitutes for each other. Depending on their competitiveness in the international market, part of domestic goods and services are exported. Each economic agent (firms, government, households, external sector) ends up with a cash surplus or deficit, depending on its decisions with regard to consumer spending, investment expenditure and savings. These decisions are interdependent, with the sum of the surpluses or deficits amounting to zero (Walras law). The prices of goods, services and production factors are the result of the interaction between market supply and demand and are determined simultaneously. These prices affect competitiveness in external trade and the decisions of the economic agents. The equilibrium in each market is computed depending on the assumptions made regarding the conditions of competition (perfect, oligopolistic, etc.) governing each one.

For the purposes of the present study, a variation of the GEM-E3 model was used that views the Greek economy as a small, open economy. The activity of the rest of the world economy is regarded as exogenous, but Greece's external trade is considered endogenous, as Greece is seen as not being in a position to influence the international prices of goods and services. As regards the state of competition, it is assumed that all goods and services markets operate under full and perfect competition and that the supply of these goods exhibits constant economies of scale. It is also assumed that the labour market is not characterised by perfect competition, but is in a state of equilibrium, with unemployment determined by an efficient wage mechanism (Shapiro and Stiglitz, 1984).

The model's main data set includes: social accounting matrices, with Input-Output Tables and income distribution tables; household consumption tables; and investment tables by sector and type of good. The nomenclature of production sectors follows a classification of 26 sectors, based on Hellenic Statistical Authority (ELSTAT) data.

3.3.3 Methodology for using the general economic equilibrium model

In order to estimate the cost of climate change using the general equilibrium model, it was first necessary to develop a Baseline Scenario, based on assumptions with regard to demographic trends, global economic developments, labour market participation, government policies (consumption, investment, taxation and income redistribution) and the level of technological progress contained in each production factor for every sector of economic activity. The Baseline Scenario used in the present study is consistent with the GDP and demographic trend projections contained in the "*2009 Ageing Report*" (European Commission, DG ECFIN).[49]

49 "The 2009 Ageing Report: Underlying Assumptions and Projection Methodologies for the EU-27 Member States (2007-2060)", in *European Economy* (2008).

Sector	Temperature increase and drought	Sea-level rise	Extreme weather events
1. Agriculture	*		
2. Forests	*		
3. Fisheries	*		
4. Coastal systems		*	
5. Transportation	*	*	*
6. Tourism	*	*	
7. Built environment	*		
8. Water resources	*		

The Baseline Scenario served as a reference only for the Mitigation Scenario, since the dynamic analysis required that the drastic GHG reduction scenario be compared to it (see Chapter 4). The economic assessment of the mitigation costs was based on this dynamic comparison and was expressed as percentage change in GDP. In order to ensure cost assessment comparability across different climate scenarios, the percentage changes in GDP were expressed in terms of base year GDP.

For the other scenarios, a base-year representation was used, as computed with the general equilibrium model, after exogenously changing the parameters to simulate the direct impacts of climate change on different sectors. A dynamic simulation was then performed using the general equilibrium model, to estimate the longer-term impacts.

Direct impact estimates of climate change were mainly drawn from the studies presented in Chapter 2, broken down into sectors and also referred to as "sectors of impact". The table that follows indicates the sectors of physical impact of climate change, for which costs assessments were made and taken into account in the general equilibrium analysis. It should be noted that sectors with direct impacts on health, biodiversity, ecosystems and the mining/quarrying industry were not included in the analysis.

The direct economic impact of climate change can be a loss of capital or a lower return on capital, variations in productivity (usually lower) in certain sectors of economic activity, variations in expenditure (usually higher) to obtain the same level of services, and changes in labour productivity.

The quantitative assessments from Chapter 2 with regard to the above direct economic impacts were integrated into the GEM-E3 model as changes in the numerical values of the corresponding exogenous parameters. The model was then run to estimate the new state of general (counterfactual) equilibrium corresponding to the economic conditions after the occurrence of climate change. As mentioned above, the analysis was conducted for different levels of climate change intensity, corresponding to landmark years 2050 and 2100 and to different climate change scenarios.

3.3.4 Overview of the climate change scenarios used in the study

The climate scenarios for which total costs were determined in the study are Scenarios B1, B2, A1B and A2 (see Chapter 1).

Each one of the four climate change scenarios incorporates different assumptions with regard to socioeconomic developments, which in turn determine the future level of carbon dioxide emissions and, by extension, the course of the climate change phenomenon.

- Scenario B1: Under this scenario, the carbon dioxide concentrations in the atmosphere increase at a slow rate, given the worldwide shift towards lower carbon-emitting energy sources and towards lower GHG-emitting processes. This is the climate change Mitigation Scenario that comprises a drastic reduction in global emissions. It should be stressed that, under this scenario, climate change is not prevented, but it is mitigated. Therefore, even under this scenario, there is a total economic cost attributable to (albeit limited) climate change.
- Scenario B2: This scenario anticipates moderate economic growth and, by extension, low energy consumption growth. Technological changes are not as intense as in the B1 Scenario; therefore, there is still some increase in GHG concentrations and, consequently, there are economic costs imputable to climate change.
- Scenario A1B: This is the Business-As-Usual (BAU) scenario. Technological advances lead to the use of more efficient energy production technologies, although conventional technologies remain in use. The scenario also projects rapid economic growth and increased consumption. As a result, there is a strong rate of increase in emissions concentrations, and costs definitely arise from climate change. The A1B Scenario can be considered a milder version of the A2 (Inaction) Scenario mentioned immediately below.
- Scenario A2: This is worst-case scenario in terms of emission increases, emission concentration levels, and the overall course of climate change. It anticipates slow technological advances, together with strong population and energy consumption growth. It corresponds to the Inaction Scenario.

3.3.5 Overview of the impacts of climate change on various sectors of the Greek economy

Agriculture is the sector that will suffer the strongest impacts from climate change. Changes in climatic conditions due to the carbon dioxide concentrations in the atmosphere will significantly affect crop growth rates as well as water availability, thereby negatively affecting agricultural productivity. According to the findings of the agriculture study (Sub-chapter 2.4) carried out using the AQUACROP model, crop yield changes will vary, depending on the crop type and the geographic location, from -75% to +26% by 2100.

Also directly dependent upon the climate are the production activities related to forests and water ecosystems. The production of timber will be negatively affected, while predominant drought, combined with higher temperatures, will considerably increase fire frequency.

The impact on the fisheries sector is expected to be negative, but of relatively limited magnitude. As estimated in the sectoral analysis, a 3.3°C rise in sea temperature by 2100 would cause fishing yields to drop by 2.5% (Sub-chapter 2.3).

The coastal systems, where a considerable share of the population and production activities (indicatively, 80% of all industrial activities, 90% of the tourism industry and 35% of agricultural activities; see Sub-chapter 2.2) are concentrated, will suffer from the gradual rise in sea level, as a result of the deterioration to coastal infrastructure and of capital losses. According to the analysis of the coastal systems sector (Sub-chapter 2.2), a 0.5 m rise in sea level would result in land loss (i.e. loss in tourism, residential and agricultural usage land, forests and wetlands) of a total value of €355.76 billion. To this, one would have to add the damage costs to port infrastructure and the cost of gradually relocating the coastal populations.

Tourism will not only suffer from the deterioration of coastal infrastructure, but will be further affected, given that climatic conditions are a decisive factor when people choose a vacation destination. According to the sectoral analysis of tourism (Sub-chapter 2.7), climate change could be of benefit to the sector, as climatic conditions in autumn and winter would improve. Nonetheless, tourist demand in Greece peaks in the summer, when protracted heat waves induced by climate change in the future would make Greece a far less appealing destination. As shown by the study's findings, if the tourism sector does not make the necessary adaptations to attract more tourists in seasons other than the summer, the impact on the demand for tourist services will be negative. For the regions of Crete and the Dodecanese alone, it is estimated that the annual loss of tourism receipts due to climate change would amount to €430 million.

As regards the transport sector, experience to date has shown that extreme weather events cause a lot of damage to networks and infrastructure. Climate change is expected to intensify such damage. The analysis of the transport sector (Sub-chapter 2.9) provides some very telling estimates about the impact of climate change on this sector: by 2100, due to the temperature rise, the cost of maintaining the road and railway networks will have increased by €140-375 million per year, compared to today. The expenditure needed to permanently or temporarily repair the damage caused to networks from flooding would amount to €85-300 million per year. By 2100, the sea level rise will have affected some 3.5% of the road and railway networks. Finally, extreme weather events and fires will cause road traffic delays, which will translate into economic loss due to the late arrival of commuters at work.

The cost imputable to climate change also includes the costs to the built environment (Sub-chapter 2.8). Warmer climate conditions will lead to lower energy demand in winter, but to significantly higher energy demand for air conditioning in the summer. As a result, the demand for oil will drop, but the demand for electricity from the residential and services sector will increase. The temperature rise will have a stronger impact on the microclimate of urban areas (heat island effect). The living conditions in urban areas will deteriorate, causing the value of the built environment in these areas to drop.

This brief overview outlines the climate change impacts taken into account in the study. Cost valuations were carried only for the impacts directly affecting production activities or reducing infrastructure value and translating into capital losses. Not included in the cost valuations was the impact on the natural environment and biodiversity, with the exception of the impact on productivity in the sectors of agriculture, forestry and fisheries. Also not included in the cost valuation was the burden to the health system, as well as the economic implications of increased workforce morbidity, likely to be caused by the temperature rise.

Table 3.1 presents the estimated direct economic impacts of climate change by sector, based on the findings of Chapter 2 and input into the general equilibrium analysis. The last column on the right lists the assumptions made about the adaptation measures and interventions aimed at preventing part of the impacts from climate change. The cost valuation of adaptation is presented later, in Sub-chapter 3.4.

3.3.6 Further processing of the sectoral analysis estimates and linking of these estimates to the parameters of the GEM-E3 model

This section looks at how the economic impact assessments per sector, presented in Table 3.1 were converted into changes in the exogenous parameters of GEM-E3.

As can be seen in Table 3.1, the sectoral analyses did not cover all of the climate scenarios. In order to produce a consistent valuation of sectoral impacts and to examine all the climate scenarios, further estimates were needed to complement the data estimates contained in the above-mentioned table.

More specifically, using data from Chapter 2 and estimates from the international literature,[50] we empirically constructed a function that links the rise in temperature (or in sea level) to the magnitude of economic impacts for each sector.

A non-linear interpolation of constant elasticity was chosen in the form of $y = a \cdot x\theta$, where x is the temperature (or the sea level), y is the level of the corresponding economic impact, and a, θ are empirically assessed numerical parameters. For the coastal systems sector, the rise in sea level was used for x, while for the other sectoral analyses x was the change in temperature.

All estimates given below are in € million, at 2008 prices.

50 Whenever needed, further estimates were based on the PESETA study, Ciscar (2009), for Southern Europe.

Table 3.1 Overview of the results of Chapter 2 sectoral analyses taken into account in the analysis based on the general equilibrium model

	Projection periods	Climate scenarios	Physical impacts	Economic impacts	2050				2100					Adaptation			
					B1	B2	A1B	A2	B1	B2	A1B	A2					
Water resources	2041-2050, 2091-2100	B2, A1B, A2	Water volume decrease (by up to 19% by2100)	Cost for water supply sector (EUR millions, in 2007 values)	n/a	2,191	2,077	3,070	n/a	4,345	2,795	4,862	/10 years	Cost of improving the efficiency of water abstractions: €68.4 million/year, with a benefit of €380 million/year			
	The impacts of water shortage on the water supply sector, including touristic and, in part, industrial uses, are examined. The impacts of reduced availability of irrigation water are taken into account in the examination of agriculture																
					B1	B2	A1B	A2	B1	B2	A1B	A2					
Agriculture	2040, 2090	B2, A1B, A2	Overall changes in climate	Percentage change of crop productivity	n/a	-4.9	-6.8	-9.0	n/a	-15.8	-17.6	-16.7					
				(more pessimistic estimates taking into account the impact of desertification)													
	Detailed results of the AQUACROP model are given for different crops and different areas. Data from ELSTAT on the distribution and production of various crops by area have been used to derive a mean total change in agriculture yield																
					B1	B2	A1B	A2	B1	B2	A1B	A2			B2	A2	
Forests	2050, 2100	B2, A2	Temperature increase	Percentage decrease in timber production	n/a	n/a	n/a	27	n/a	30	n/a	35		Additional management costs (EUR millions, in 2007 values)	30	50	/year
				Percentage decrease in grassland production	n/a	n/a	n/a	n/a	n/a	10	n/a	25		Cost of improving forest fire fighting (EUR millions, in 2007 values)	40	80	/year
				Additional cost of fire fighting and damage from fires (EUR millions, in 2007 values)	n/a	n/a	n/a	n/a	n/a	40	n/a	80	/year	Cost of construction works (EUR millions, in 2007 values)	2,250	4,700	one-off

n/a: non available data from sectoral analyses.

Table 3.1 **Overview of the results of Chapter 2 sectoral analyses taken into account in the analysis based on the general equilibrium model *(continued)***

	Projection periods	Climate scenarios	Physical impacts	Economic impacts	2050				2100				Adaptation
Tourism	2070-2100	A1B	Change in the Tourism Climate Index (TCI)	Percentage change in tourism revenue	B1	B2	A1B	A2	B1	B2	A1B	A2	10% additional expenditure on advertising
					n/a	n/a	n/a	n/a	n/a	n/a	5	n/a	
	The decrease in receipts from tourism results from the drop in tourist activity in the regions of Crete and the Dodecanese. Only hotel revenues are taken into account.												
Built environment	2041-2050, 2091-2100	B2, A1B, A2	Overall changes in climate		B1	B2	A1B	A2	B1	B2	A1B	A2	
				Percentage decrease in heating load	n/a	n/a	22	n/a	n/a	36	42	50	
				Percentage increase in cooling load	n/a	n/a	83	n/a	n/a	148	167	248	
Coastal systems	2100		Sea-level rise by 0.5 m, 1 m	Cost per land use type (EUR millions, in 2010 values)				Sea-level rise					Cost of implementing adaptation measures: from €381.6 million to €3,345.6 million
								0.5 m			1 m		
					Housing and touristic			347,738			630,842		
					Wetlands			138			247		
					Forests			0			1		
					Agriculture			7,884			18,253		
Fisheries			Sea surface temperature rise by 3.3 °C	Percentage decrease in fish catch	2.5								

n/a: non available data from sectoral analyses.

Table 3.1 **Overview of the results of Chapter 2 sectoral analyses taken into account in the analysis based on the general equilibrium model *(continued)***

	Projection periods	Climate scenarios	Physical impacts	Economic impacts	2050 B1	2050 B2	2050 A1B	2050 A2	2100 B1	2100 B2	2100 A1B	2100 A2		Adaptation		
					EUR millions, in 2010 values									Flood protection:		
Trans-portation	2011-2050, 2071-2100	B1, A1B, A2	Rise in temperature	Loss for road transportation	50	n/a	100	150	100	n/a	200	300	/year	The costs of flooding in the adjacent column include the cost of temporary or permanent restoration of flood damages. The two types of cost have been distinguished on the basis of data on flooding in the Prefecture of Magnesia (see the complete text of the study on transportation in the relevant page of the Climate Change Impacts Study Committee (CCISC) on the Bank of Greece website (www.bankofgreece.gr)). The cost of temporary restoration (8%) has been used as the cost of Inaction and the cost of permanent restoration (92%) has been used as the cost of Adaptation.		
				Loss for railway transportation	20	n/a	30	37	40	n/a	55	75	/year			
			Floods	Loss for road transportation	60	n/a	120	200	85	n/a	200	300	/year			
				Loss for railway transportation	–	n/a	n/a	184	n/a	n/a	n/a	276	/year			
			Decreased snowfall	Benefits to road transportation	-15	n/a	-25	-40	-30	n/a	-50	-80	/year	**Protection from sea-level rise (EUR millions, in 2010 values)**		
				Benefits to railway transportation	-0.01	n/a	-0.07	-0.05	-0.1	n/a	-0.15	-0.2	/year	Protection for road transportation	3,000	once
			Extreme weather events	Hours of delay in the road network	103	n/a	154	308	154	n/a	219	513	/year	Protection for railway transportation	300	once
				Hours of delay in the railway network	5	n/a	8	16	8	n/a	12	27	/year	Protection for sea transportation	600	once

		Distance from shoreline (m)			
		25	**50**	**75**	**100**
Sea-level rise by 0.5 m, 1 m	Affected percentage of road network	0.72	1.80	2.70	3.47
	Affected percentage of railway network	0.32	0.83	1.38	1.98

n/a: non available data from sectoral analyses.

Table 3.2 Temperature change and sea-level rise in different climate change scenarios

	B1	B2	A1B	A2
Temperature change				
Climate change intensity in 2050	1.57 °C	1.98 °C	1.95 °C	2 °C
Climate change intensity in 2100	2.41 °C	3.11 °C	3.51 °C	4.46 °C
Sea-level rise				
Climate change intensity in 2050	up to 0.18 m			
Climate change intensity in 2100	up to 0.6 m			

Agriculture

For the agricultural sector, use was made of the results of the AquaCrop model for the sectoral study on agriculture (Sub-chapter 2.4). The sectoral study distinguished two cases, one including and one excluding desertification developments, and estimated the extent of crop yield change due to climate change.

In order to carry out the GEM analysis, we used the upper limits of the range of changes obtained with the AquaCrop model, for the simple reason that AquaCrop does not capture the amplification of desertification induced by climate change. In this sense, the AquaCrop model underestimates the actual impact of climate change on agriculture. To carry out the analysis using the general equilibrium model, we accepted that desertification will take place in parallel with climate change and will intensify because of climatic changes.

The AquaCrop model produced detailed results for four crops and four regions of Greece. Statistics on crop distribution per geographic area from the Hellenic Statistical Authority were used to determine the average total change in the agricultural sector's yield (Table 3.3).[51]

The decline in agricultural yield presented in Table 3.3 was integrated into the GEM-E3 model as an exogenous change in the agricultural sector's total productivity.

Climate change is also expected to lead to reduced availability of irrigation water, due to lower precipitation, on one hand, and to the prolongation of the dry season. This impact was integrated into the GEM-E3 model as an increase in the agricultural sector's expenditure for access to irrigation water (e.g. higher expenditure for land improvement works). This impact was not taken into consideration in the analysis of impacts on agriculture, but instead on the analysis of impacts on water reserves.

51 It was necessary to assess the average change in total agricultural productivity, as the GEM-E3 model does not distinguish between different crops.

Table 3.3 Percentage decrease in crop yield due to climate change, as applied in the GEM-E3 model

	B1	B2	A1B	A2
Climate change intensity in 2050	1	5	7	10
Climate change intensity in 2100	11	17	19	21

Table 3.4 Impact of climate change in the tourism sector of Southern Europe

	2.5 °C	3.9 °C	4.1 °C	5.4 °C
Annual drop in tourism revenue by 2080 in Southern Europe (EUR millions)	1,789	2,599	9,459	12,853

Source: PESETA (2009).

Tourism

As shown by the analysis of impacts on tourism (Sub-chapter 2.7), revenues from tourism (specifically, hotel services) will decrease on account of the new climatic conditions. It is estimated that by 2100 the receipts of the tourism industry in the regions of Crete and the Dodecanese will have declined by €430 million (under Scenario A1B, for the last decades of the 21st century), an amount equivalent to 5% of total tourism receipts. Considering that these two regions account for 40% of total tourism receipts (Sub-chapter 2.7), it was estimated that the total decrease in tourism receipts countrywide would amount to roughly 13%. This impact was integrated into the GEM-E3 model as an exogenous decrease in the demand for tourist services.

In order to determine the impacts on tourism under the other climate scenarios and for the year 2050, use was made of the estimates produced by the PESETA study (Amelung and Moreno, 2009) of the anticipated decrease in tourist demand in Southern Europe[52] (Table 3.4). More specifically, use was made of the PESETA study's correlation of the rise in temperature and the drop in demand for tourist services. The final estimates of the decrease in tourist demand are given in Table 3.5.

In the GEM-E3 model, tourist expenditures form part of households' consumer expenditure. They include both domestic and foreign tourist expenditure, since the Input-Output Tables do

52 We maintained Greece's percentage share in the total tourism receipts of Southern Europe (Portugal, Spain, Italy, Greece, Bulgaria), based on World Bank data. http://data.worldbank.org/indicator/ST.INT.RCPT.CD

Table 3.5 Percentage decrease in tourism revenue due to climate change, as applied in the GEM-E3 model

	B1	B2	A1B	A2
Climate change intensity in 2050	1	2	2	3
Climate change intensity in 2100	4	9	13	24

not distinguish between Greek and foreign households. Such a distinction in terms of revenue origin is only made in the Social Accounting Matrix, where the expenditures of foreign tourists are recorded as transfer payments from the rest of the world.

In order to simulate the decrease in demand for tourist services from Greek households, the parameters of the model's consumption function were exogenously adjusted, whereas the decrease in demand for tourist services from foreign tourists was simulated by applying a decrease in transfer payments, corresponding to a decrease in the demand for tourist services in Greece from the rest of the world.

Fisheries

As shown by the analysis of fisheries (Sub-chapter 2.3), climate change will have a limited, but definitely negative, impact on fishery production. As estimated, a 3.3°C rise in sea surface temperature would cause the fishery production to drop by 2.5%. This change was assumed to take place under the worst-case climate scenario (A2) for 2100. It was also assumed that there is a linear relationship between the rise in temperature and the drop in fishery production, so that the decrease in production could be calculated for the other climate scenarios and time horizons.

This decrease in fishery production was simulated in the model by applying a corresponding change in the productivity of the fisheries sector.

Table 3.6 Percentage decrease in the productivity of fisheries, as applied in the GEM-E3 model

	B1	B2	A1B	A2
Climate change intensity in 2050	0.7	0.8	0.8	0.8
Climate change intensity in 2100	1.0	1.3	1.5	2.5

Table 3.7	Economic impact of climate change on the forest sector, as applied in the GEM-E3 model			
	B1	**B2**	**A1B**	**A2**
Percentage decrease in the productivity of forests				
Climate change intensity in 2050	21	25	25	27
Climate change intensity in 2100	28	30	34	35
Additional government expenditure to address fires on an annual basis (EUR millions)				
Climate change intensity in 2050	11	17	16	17
Climate change intensity in 2100	24	39	49	78

Forestry

For the forestry sector, the decrease in timber production was simulated by applying a corresponding decrease in the productivity of forestry and logging. The costs of fire outbreaks[53] are considered to be borne entirely by the State and are simulated as increases in government expenditure for forest fire fighting and forest protection.

Coastal systems

As regards coastal systems (Sub-chapter 2.2), the costs from the loss of tourism-related and residential land, wetlands, forests and agricultural land as a result of a sea level rise were estimated as the commercial value of the affected areas, which would obviously yield less than in the event of no climate change. The cost from the loss of forests and wetlands is relatively small and was omitted from the rest of the study.

The value of the losses in tourism-related and residential land was broken down into corresponding categories on the basis of equivalence coefficients established from statistical data.

For tourism and agriculture, the loss of coastal land was integrated into the general equilibrium model as a loss of productive capital. In order to annualise the value of this loss, it was assumed that the capital reserves of these sectors would yield an annual 8% for tourist land and 6% for agricultural land. Based on this assumption, the annual equivalent loss in capital yields in tourism and agriculture ranges between 2% and 4%, depending on the climate scenario and the year to which climate change intensity refers.

53 The forestry study group produced estimates of the additional burned areas that would arise from the increased frequency of fires due to climate change, and of the share of forest areas that would be affected by the sea level rise. These forest area losses (which appear to be limited relative to the country's total forest areas, e.g. a burned area of 20,000 hectares is estimated under the B2 Scenario, i.e. 0.3% of the country's total forest areas) could be integrated into the model by applying a decrease to the forestry and logging sector's capital. However, these burned areas do not necessarily constitute productive capital for forestry. For this reason and, also because of their limited size, they were left out of the general equilibrium analysis.

Table 3.8 **Value of coastal land loss due to sea-level rise (EUR millions, cumulatively by 2100)**

Sea-level rise	0.5 m	1 m
Housing and touristic lands	347,738	630,842
Wetlands	138	247
Forest lands	0	1
Agricultural lands	7,884	18,253

Table 3.9 **Percentage decrease in ROC in the sectors of tourism and agriculture on an annual basis, as applied in the GEM-E3 model**

	B1	B2	A1B	A2
Tourism services sectors				
Climate change intensity in 2050	2	2	2	2
Climate change intensity in 2100	2	3	3	4
Agricultural sector				
Climate change intensity in 2050	2	2	2	2
Climate change intensity in 2100	2	3	3	4

It was assumed that the loss of coastal residential land brings about a loss of income for households, either directly, in cases where the land and buildings produced a financial yield for their owners, or indirectly, because of the expenses that owners would incur to replace the land or land use services lost. In both cases, the impact was integrated into the general equilibrium model as an additional household expenditure, necessary for households to enjoy the same level of services from their land and buildings as prior to the sea level rise. The cost of the coastal residential land loss was annualised based on the assumption of an annual yield equal to 6% of the land value.

To these costs, it was necessary to add the cost of relocating the coastal populations because of the sea level rise, which was estimated according to the PESETA study (Richards and Nicholls, 2009).

Table 3.10 presents the additional annual household expenditure attributable to the impact of climate change on coastal residential areas. This additional expenditure is incurred without additional income and therefore presupposes a cut-back of other consumer expenses and/or a decrease in savings.

Table 3.10 Additional expenditure of households as a result of loss of residential land and population movements due to sea-level rise

	B1	B2	A1B	A2
Increase in household expenditure (EUR millions)				
Climate change intensity in 2050	2,872	3,401	3,379	3,415
Climate change intensity in 2100	6,322	7,471	8,272	10,590

Table 3.11 Percentage decrease in ROC in sea transportation due to sea-level rise

	B1	B2	A1B	A2
Loss of capital in sea transportation				
Climate change intensity in 2050	1	2	2	2
Climate change intensity in 2100	3	5	7	15

Port infrastructure

The analysis of the transport sector (Sub-chapter 2.9) comprises an assessment of the cost of protecting port infrastructure, which —because of its preventive nature— is included in the cost of adaptation to climate change. However, an estimate of the cost corresponding to the loss of port infrastructure due to the sea level rise must be envisaged for the Inaction Scenario. It was assumed that the loss of port infrastructure under the Inaction Scenario (Scenario A2) would amount to 30% of the infrastructure value. This loss was integrated into the general equilibrium model as a loss of capital in the sea transport sector.

The built environment

For the built environment sector, an estimate was made of the cost arising from changes in heating and cooling needs, as analysed in Sub-chapter 2.8. The analysis projects a decline in the heating load, which will affect the consumption of oil and natural gas, and an increase in the cooling load, which will affect the extent of air conditioner use and, thereby, electricity consumption.

The changes studied in Sub-chapter 2.8 were further analysed using the PRIMES energy model (see Chapter 4), which made it possible to estimate the total reduction in heating need-related oil and natural gas consumption, as well as the total increase in electricity consumption in the residential and services sector. The impact of the Inaction Scenario on the structure of the total energy consumption of this dual sector is significant, as shown in Table 3.12.

Table 3.12 **Changes in energy consumption in the built environment due to climate change, as calculated with the PRIMES model**

	Climate change intensity in 2050				Climate change intensity in 2100			
	B1	B2	A1B	A2	B1	B2	A1B	A2
Percentage change in total energy consumption by households for residences and passenger cars								
Oil	-8	-10	-9	-10	-12	-15	-18	-21
Electric power	4	7	6	7	9	12	14	21
Natural gas	-16	-20	-19	-20	-24	-31	-36	-43
Change in total energy consumption in the services sectors								
Oil	-16	-20	-19	-20	-24	-31	-36	-43
Electric power	6	10	10	10	13	18	21	31
Natural gas	-19	-23	-22	-24	-28	-36	-42	-50

Table 3.13 **Additional expenditure to compensate for the loss of value of the built environment in urban heat islands (EUR millions, on an annual basis)**

	B1	B2	A1B	A2
Climate change intensity in 2050	28	50	48	51
Climate change intensity in 2100	81	154	228	400

These estimates were integrated into the general equilibrium model as exogenous changes in household and service sector consumption. The impact on energy purchase expenditure is calculated by the general equilibrium model, but the total impact is small (and, in some cases, even yields a small benefit), because the additional expenditure for air conditioning electricity is offset by reduced expenditure for heating oil and natural gas.

A significant economic impact on the built environment is expected to be exerted by the climate change-induced intensification of the heat island effect in urban centres. Such a phenomenon would bring about an important decrease in house and service building value in those parts of urban centres that would experience high temperature increases. For the Inaction Scenario, it was assumed that some 20% of houses and buildings in urban centres will lose value, which translates into a decline of about 3% in total house and building value by 2100. This cost was annualised by assuming an annual return on capital of 6%. The corresponding loss of income from the return on capital was integrated into the general equilibrium model as an additional expenditure to be borne by households and the services sectors. This expenditure corresponds to the cost of making up for the loss of capital, so that services rendered by such real estate remain unchanged.

Water reserves

Climate change will lead to reduced water availability in the future. Based on the analysis of the water reserves sector (Sub-chapter 2.1), it was estimated that the water supply will not suffice to meet part of the demand. This strain on the water supply sector was simulated in the general equilibrium model assuming a corresponding decrease in the sector's productivity.

Along with the water supply sector, reduced water availability will also significantly affect irrigation and, by extension, agriculture. The analysis of the agricultural sector (Sub-chapter 2.4) comprises an assessment of the impact of reduced water availability on crop yields. However, it does not take into account the increased irrigation costs needed to meet irrigation needs (e.g. drilling to greater depths, additional land improvement works, etc.). In the present analysis, it was assumed that, under the worst-case scenario (Scenario A2), irrigation costs will increase by as much as 120% by 2100. The simulation of this increase in irrigation costs was achieved by applying an appropriate change (increase) in the unit cost of the agricultural sector production factors corresponding to irrigation.

Table 3.14 Percentage decrease in the productivity of the water supply sector, as applied in the GEM-E3 model

	B1	B2	A1B	A2
Climate change intensity in 2050	13	16	16	16
Climate change intensity in 2100	20	26	30	39

Table 3.15 Percentage change in irrigation costs in the agricultural sector

	B1	B2	A1B	A2
Climate change intensity in 2050	39	50	49	51
Climate change intensity in 2100	62	81	93	120

Table 3.16 **Economic impacts in the transportation sector, as applied in the GEM-E3**

	Climate change intensity in 2050				Climate change intensity in 2100			
	B1	B2	A1B	A2	B1	B2	A1B	A2
Additional government expenditure on infrastructure (EUR millions, on an annual basis)	46	68	66	69	95	149	186	288
Drop in government expenditure on snow removal operations (EUR millions,on an annual basis)	-9	-14	-13	-14	-19	-30	-37	-58
Loss of work hours due to delays (annual number of hours per employee)	36	57	54	108	54	67	77	180
Percentage loss of capital in the land transportation sector due to SLR	0.01	0.01	0.01	0.01	0.01	0.05	0.08	0.11

Transport

Climate change will have significant consequences on transport sector infrastructure. Higher expenditures will be required for road surface maintenance on account of the rise in temperature, as well as extraordinary expenditure to repair flood-induced damage. These additional outlays were integrated into the general equilibrium model as additional public works expenditure for the state, to be carried out by the construction sector. The analysis for the transport sector identified a small benefit arising from the reduced expenditure for snow clearing, which was integrated into the general equilibrium model as a decrease in the corresponding State expenditure.

The impacts of the sea level rise on port infrastructure are examined together with the impacts on the coastal systems.

As regards the impacts of the sea level rise on land transport infrastructure, the sectoral analysis provides data concerning the sections of the road and railroad networks located within 25 to 100 metres of the coastline and expected to be affected by the rise in sea level. These data made it possible to estimate the extent of the damage to land transport infrastructure attributable to the rise in sea level. The value of this damage was then integrated into the general equilibrium model as loss of capital for the land transport sector.[54]

The sectoral analysis for transport also estimated the number of delay hours for commuters, as a result of the impact of extreme weather events on their transport routes to work.

54 The damage levels estimated by the work group on transport have not taken into account data relevant to the network's altitude. In the general equilibrium model, it was assumed that part of this estimate corresponds to a loss of capital.

For a number of reasons, it would be incorrect to consider the sum of these hours as a loss of labour productivity. For the analysis with the general equilibrium model, it was assumed that part of these hours (about 1/3) corresponds to a definite inability to provide work. This loss was integrated into the general equilibrium model as a decrease in the available workforce.

3.3.7 The total cost of climate change per climate scenario

As mentioned in the introduction to the present sub-chapter, the costs of climate change for the Greek economy were estimated using the GEM-E3 model, into which estimates concerning the direct economic impact of climate change on various sectors of activity were entered as exogenous changes. Table 3.17 summarises the numerical values of the exogenous changes introduced into the GEM-E3 model.

The general equilibrium model was used to calculate the costs for the Greek economy under different scenarios with regard to the intensity of climate change and the relative intensity of climate change in years 2050 and 2100.

The costs of climate change for the Greek economy were estimated by applying the exogenous changes to the state of the economy in a base year, as represented by the general equilibrium model for that specific year. Therefore, the cost assessments refer to the size of the base year economy, and not to the size that the economy could have in 2050 or 2100. In other words, the euro-denominated costs should be assessed against the present size of the economy.

The cost assessments for the economy were performed in a time-dynamic manner. In other words, the exogenous changes were applied to the base year, so that the general equilibrium model simulated the dynamic evolution of the economy (over ten years), as affected by these changes, e.g. by factoring in changes in investment and capital accumulation. The assessment of the costs of climate change is based on a comparison between this simulation and the simulation in which no exogenous changes attributable to climate change are introduced. The comparison is performed both for the base year (corresponding to static costs) and the last year of the dynamic simulation (corresponding, in this case, to long-term costs). The period of simulation does not refer to the years 2050 or 2100, for which only the intensity of climate change is of interest.

The exercise using the general equilibrium model provides an answer to what the static and the long-term impact on Greek economy would be, if the climate change intensity of 2050 or of 2100 (for different climate scenarios) was to occur in the present state of the economy.

The costs for the Greek economy were estimated both for the economy as a whole and separately per sector. Using the general equilibrium model, the costs were measured as the change in Gross Domestic Product (GDP) at constant prices and as the welfare equivalent variation. The general equilibrium model also provides detailed estimates of the impact of climate change per sector of economic activity, as well as the impact on investment, consumption, prices, the labour market and foreign trade.

Table 3.17 **Consolidated table of exogenous assumptions entered in the GEM-E3 general equilibrium model to assess the cost of climate change scenarios**

	2050				2100			
	B1	B2	A1B	A2	B1	B2	A1B	A2
Agriculture	Percentage decrease in crop yield (productivity)							
	1	5	7	10	11	17	19	21
Tourism	Percentage decrease in tourism revenue							
	1	2	2	3	4	9	13	24
Fisheries	Percentage decrease in the productivity of fisheries							
	0.7	0.8	0.8	0.8	1.0	1.3	1.5	2.5
Forests	Percentage decrease in the productivity of forests							
	21	25	25	27	28	30	34	35
	Additional government expenditure to address fires on an annual basis (EUR millions)							
	11	17	16	17	24	39	49	78
Coastal areas	Percentage decrease in ROC in the tourism sector due to sea-level rise							
	2	2	2	2	2	3	3	4
	Percentage decrease in ROC in the agricultural sector due to sea-level rise							
	2	2	2	2	2	3	3	4
	Additional expenditure of households as a result of loss of residential land and population movements due to sea-level rise (EUR millions, on an annual basis)							
	2,872	3,401	3,379	3,415	6,322	7,471	8,272	10,590
	Percentage decrease in ROC in the sea transportation sector due to sea-level rise							
	1	2	2	2	3	5	7	15
Water resources	Percentage decrease in the productivity of the water supply sector							
	13	16	16	16	20	26	30	39
	Percentage increase in irrigation costs in the agricultural sector							
	39	50	49	51	62	81	93	120

Table 3.17 **Consolidated table of exogenous assumptions entered in the GEM-E3 general equilibrium model to assess the cost of climate change scenarios *(continued)***

	2050				2100			
	B1	B2	A1B	A2	B1	B2	A1B	A2
Built environment								
	Percentage change in total consumption of energy by households for residences and passenger cars							
Oil	-8	-10	-9	-10	-12	-15	-18	-21
Electric power	4	7	6	7	9	12	14	21
Natural gas	-16	-20	-19	-20	-24	-31	-36	-43
	Percentage change in total consumption of energy in the services sectors							
Oil	-16	-20	-19	-20	-24	-31	-36	-43
Electric power	6	10	10	10	13	18	21	31
Natural gas	-19	-23	-22	-24	-28	-36	-42	-50
Built environment	Additional expenditure to compensate for the loss of value of the built environment in urban heat islands (EUR millions, on an annual basis)							
	28	50	48	51	81	154	228	400
Transportation sector	Additional government expenditure on infrastructures (EUR millions, on an annual basis)							
	46	68	66	69	95	149	186	288
	Decrease in government expenditure on snow removal operations (EUR millions, on an annual basis)							
	-9	-14	-13	-14	-19	-30	-37	-58
	Loss of work hours due to delays (annual number of works per employee)							
	36	57	54	108	54	67	77	180
	Percentage loss of capital in land transportation due to sea-level rise							
	0.01	0.01	0.01	0.01	0.01	0.05	0.08	0.11

Table 3.18 **Annual impact of climate change on GDP and prosperity**

	Climate change intensity in 2050				Climate change intensity in 2100			
	B1	B2	A1B	A2	B1	B2	A1B	A2
Impact in the baseline year								
Percentage change in GDP	-0.90	-1.56	-1.77	-2.03	-2.69	-4.03	-4.77	-6.50
Welfare equivalent variation (EUR millions, on an annual basis)	-1,696	-2,831	-3,072	-3,409	-4,888	-7,638	-9,404	-14,207
Impact in the final year of the dynamic simulation								
Percentage change in GDP	-0.90	-1.53	-1.74	-2.00	-2.67	-3.92	-4.57	-6.01
Welfare equivalent variation (EUR millions, on an annual basis)	-2,963	-4,803	-5,144	-5,666	-8,391	-13,002	-16,018	-24,435

The welfare equivalent variation is estimated, using the model, as the income that would need to be taken away from or given to consumers (households) so that consumer utility under the climate change scenario would be equal to that of the Baseline Scenario, based on the price levels of goods under the Baseline Scenario. A negative equivalent variation means that the prices of goods under the climate change scenario cause consumer utility to fall below that of the Baseline Scenario, a situation equivalent to a decline in household income, if the prices of goods in the Baseline Scenario were to apply. It should be noted that, in general equilibrium models such as the GEM-E3, welfare variation is a measure that enables total impact to be assessed, given that the model is structured in such a way as to optimise consumer utility.

According to the general equilibrium analysis, the GDP losses range from -0.9% to -2% for the climate change conditions of 2050, and from -2.7% to -6% for the climate change conditions of 2100. The welfare equivalent variation of households ranges from €3 billion to €5.7 billion for the climate change conditions of 2050 and from €8.4 billion to €24.4 billion for the climate change conditions of 2100. The upper limits of these ranges correspond to the Inaction Scenario, the total cost of which was estimated at €5.7 billion per annum for the climate change intensity of 2050 and at €24.4 billion per annum for the climate change intensity of 2100.

The impact of climate change was found to be more adverse on household consumption than on investment. The unavoidable expenses that not only households, but also the State, will incur to counter losses caused by climate change are mainly investment expenditures. However, the decrease in capital yields and the decline in productivity in various sectors, coupled with reduced demand for tourist services, lead to slower growth and to reduced real household income, which in turn causes a greater decline in consumption than in investment. Another factor behind the slowdown in economic activity is the structure of the investments made necessary because of climate change, which have to be directed towards sectors with a smaller multiplier effect on the economy. The negative impact on economic activity is strongest in the sectors of services, agriculture and consumer goods. These variations lead to a small increase in real interest rates and a decrease in real wages.

3.3.8 The total cost of climate change per impacted sector

The analysis using the general equilibrium model was also conducted separately for each of the respective sectors of impact, i.e. for each sector found to suffer a direct impact from climate change. The results presented in Table 3.19 and in Figure 3.3 express the impact from climate change in terms of percentage change in GDP. The results presented in Figure 3.4 express the impact of climate change in terms of welfare equivalent variation.

These results indicate what the impact on the economy would be if climate change were only to affect one sector at a time.

The general equilibrium results per sector show that the most negative effects on the economy are caused by the impact of climate change on agriculture and coastal systems. The negative effects on the economy as a result of the impact on tourism were also found to be considerable, though only with regard to the climate change intensity of 2100 (the effects associated with the climate change intensity of 2050 were definitively on a smaller scale, compared with the effects projected for 2100 and with the effects on other sectors). Similar differences in the magnitude of the effects were also observed with regard to the economic effect on the transportation and built environment sectors. This is due to the non-linearity of impacts: climate change intensity by 2100, especially under the worst-case scenarios, such as the A2 Inaction Scenario, corresponds to temperature and sea levels with a greater than proportional impact on the corresponding sectors and, consequently, on the economy.

Agriculture, the productive sector most vulnerable to climate change, will, in the long run, account for the largest loss in GDP. The decline in the sector's productivity will lead to a steep rise in production costs, resulting in a large decrease in exports, a decrease in domestic consumption and an increase in agricultural imports.

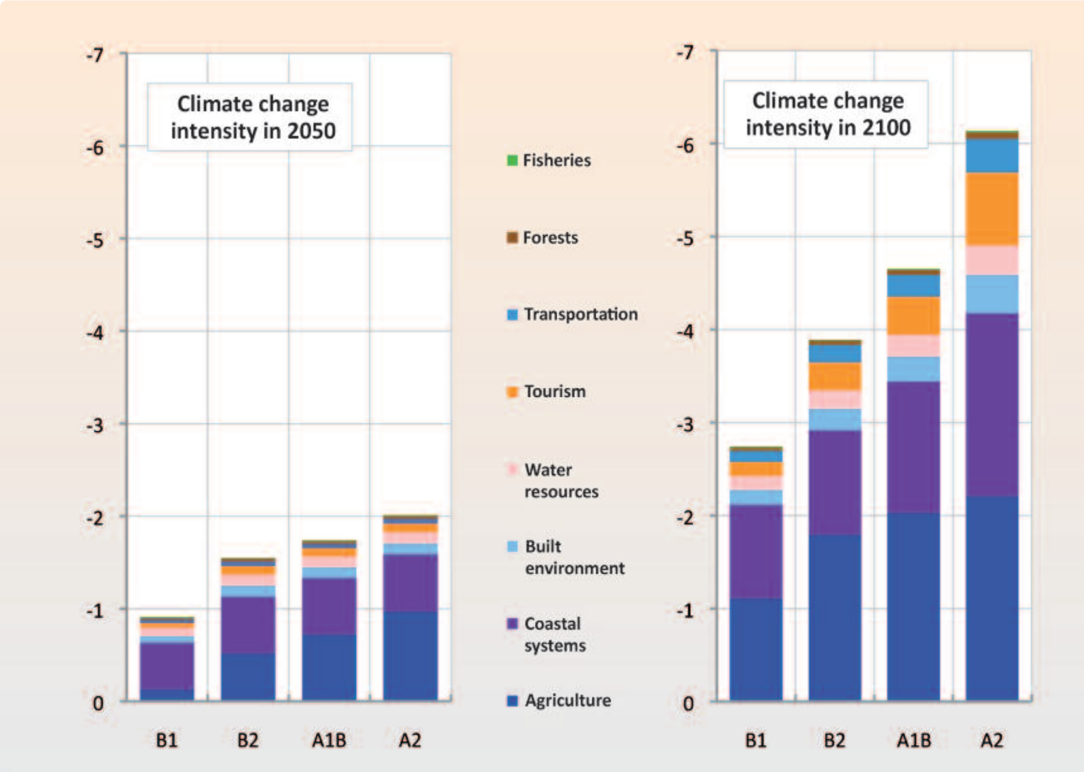
The impact on the tourism sector becomes more pronounced when considered in terms of welfare equivalent variation. The drop in the demand for tourist services leads to decreases in employment, real wages and household income.

The impact on coastal systems, in terms of capital losses, does, on the one hand, generate an increase in investment, but the losses in terms of residential land have negative effects on household income and lead to a drop in consumption. The impact from the rise in sea level is negative across all sectors of economic activity, with the exception of the construction sector, where activity increases slightly due to the investment expenditure for damage restoration. Similar effects were also found within the transportation sector, with transportation-related

Table 3.19 Annual impact of climate change on GDP and prosperity

	Climate change intensity in 2050				Climate change intensity in 2100			
	B1	B2	A1B	A2	B1	B2	A1B	A2
Sector	Percentage change in GDP							
Agriculture	-0.13	-0.52	-0.72	-0.97	-1.11	-1.79	-2.03	-2.21
Forests	-0.02	-0.03	-0.03	-0.03	-0.03	-0.04	-0.05	-0.06
Fisheries	0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02
Coastal systems	-0.50	-0.61	-0.61	-0.62	-1.01	-1.12	-1.41	-1.97
Transportation	-0.04	-0.05	-0.05	-0.05	-0.12	-0.19	-0.24	-0.37
Tourism	-0.05	-0.09	-0.09	-0.09	-0.15	-0.30	-0.41	-0.78
Built environment	-0.07	-0.12	-0.11	-0.12	-0.16	-0.23	-0.27	-0.41
Water resources	-0.09	-0.12	-0.12	-0.12	-0.15	-0.20	-0.23	-0.32
All sectors	**-0.90**	**-1.53**	**-1.74**	**-2.00**	**-2.67**	**-3.92**	**-4.57**	**-6.01**
Sector	Welfare equivalent variation (EUR millions, on an annual basis)							
Agriculture	-173	-701	-983	-1,324	-1,517	-2,485	-2,821	-3,077
Forests	-28	-35	-35	-38	-42	-51	-60	-75
Fisheries	-7	-8	-8	-8	-10	-13	-15	-26
Coastal systems	-1,287	-1,553	-1,541	-1,560	-2,637	-3,020	-3,623	-4,939
Transportaiton	-63	-94	-91	-96	-180	-284	-354	-548
Tourism	-616	-1,129	-1,085	-1,160	-1,888	-3,683	-5,063	-9,548
Built environment	25	-30	-35	-33	-80	-162	-210	-476
Water resources	-192	-247	-243	-249	-308	-413	-477	-639
All sectors	**-2,963**	**-4,803**	**-5,144**	**-5,666**	**-8,391**	**-13,002**	**-16,018**	**-24,435**

Figure 3.3 Percentage GDP change as a result of climate change by sector affected

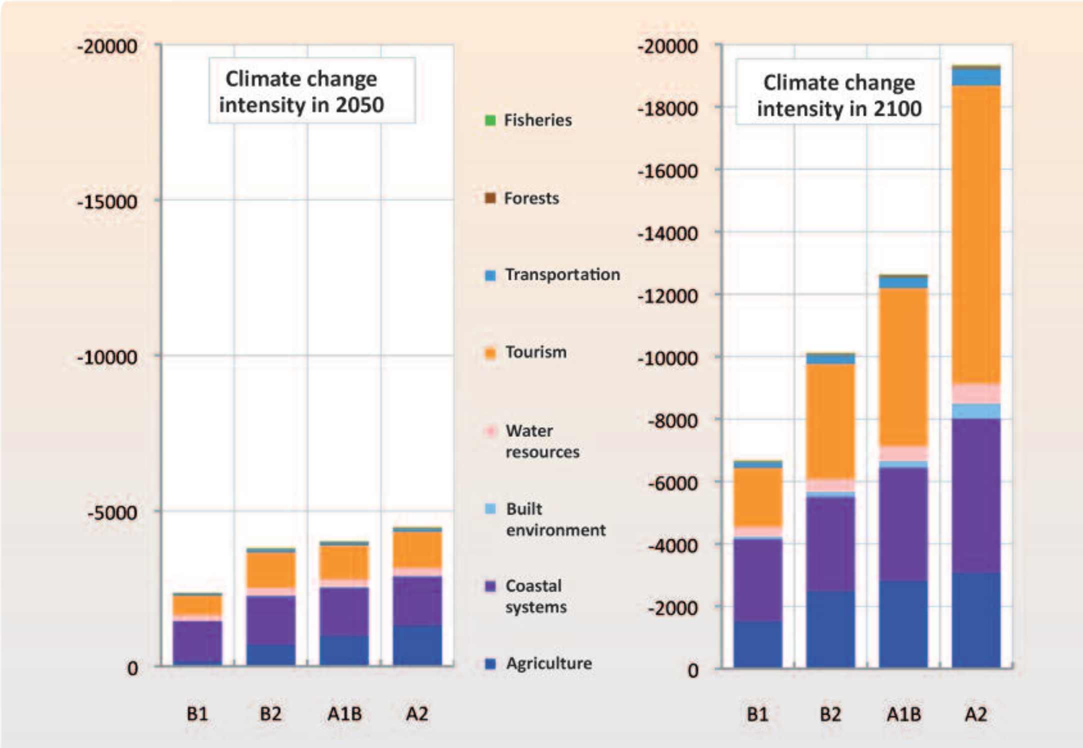


construction increasing slightly due to the increased need to restore damage caused to the transportation network by floods and the temperature rise.

The impact on the built environment has a relatively limited negative effect on the economy, as part of the capital loss costs caused by heat islands is offset by the (small) energy cost savings for households, as a result of the decrease in fuel consumption for heating, given the smaller increase in the use of electricity for air-conditioning purposes, made possible by the improved performance of heat pumps.

Smaller negative effects on the economy were attributed to the impact of climate change on forest ecosystems and fisheries. The impact of climate change on these sectors will obviously have serious repercussions on biodiversity and ecosystems, the cost of which has not been included in the general equilibrium analysis (similarly, the additional cost to the health sector has also been excluded). These repercussions are presented in detail in the relevant chapters of the present volume; however, due to the considerable uncertainty surrounding the economic implications of this impact per sector of activity, they were not incorporated into the general equilibrium analysis.

Figure 3.4 **Welfare equivalent variation in million euro on an annual basis as a result of climate change by sector affected**



3.3.9 The total cost of the Inaction Scenario

By applying the percentage change in GDP to the level of GDP in the base year (2008), it is possible to calculate the total costs of climate change with respect to the various climate change intensity cases reflected in the different scenarios, as well as with respect to the climate change intensity projected for the years 2050 and 2100. These total cost estimates are presented in Table 3.20.

Based on the results of the general equilibrium analysis, the costs of climate change under the Inaction Scenario (Scenario A2), relative to base year GDP (2008), amount to an annual €5.9 billion for climate change intensity of year 2050 and to €17.8 billion for climate change intensity of year 2100.

In spite of the drastic reduction in greenhouse gas (GHG) emissions under the Mitigation Scenario (emissions reduction achieved at the global level), climate change does occur, though of clearly lesser intensity than under the Inaction Scenario. The total costs (in base year GDP values) attributable exclusively to climate change under the Mitigation Scenario (mean temperature increase maintained at 2°C beyond 2100), was estimated, using the general equilibrium analysis, at an annual €2.7 billion for the climate change intensity of 2050 and at an annual €5.9 billion for the climate change intensity of 2100.

Table 3.20 **Total cost of climate change in relation to GDP level in the baseline year (2008)**

	Climate change intensity in 2050				Climate change intensity in 2100			
	B1	B2	A1B	A2	B1	B2	A1B	A2
Impact in the baseline year								
GDP fall (EUR millions, in 2008 values, on an annual basis)	-2,133	-3,703	-4,191	-4,816	-6,364	-9,556	-11,302	-15,403
Impact in the final year of the dynamic simulation (10 years later)								
GDP fall (EUR millions, in 2008 values, on an annual basis)	-2,671	-4,536	-5,143	-5,919	-7,919	-11,605	-13,535	-17,805

In other words, the Mitigation Scenario achieves annual cost savings from climate change (in base year 2008 GDP terms) of €3.2 billion per annum for the climate change intensity of 2050 and of €11.9 billion per annum for the climate change intensity of 2100.

Based on estimates concerning the total costs of climate change relative to the climate change intensities of years 2050 and 2100, an attempt was then made to estimate the total cumulative costs through 2100. Given that the analysis presented in earlier sections of this sub-chapter only concerned years 2050 and 2100, it was necessary to estimate the rates of decline in GDP for the entire time period. This was done using a sigmoid function for interpolation, the parameters of which were determined empirically. The percentage changes in GDP were applied to the base year GDP. Consequently, the total cost estimates for the Greek economy refer to base year GDP values. In order to calculate the cumulative costs and convert these estimates into present value terms, a discount rate of 0% was used. Table 3.21 also shows the cumulative costs using a non-zero discount rate.

Table 3.21 presents the total cumulative costs of the Mitigation Scenario (attributable exclusively to climate change, without taking into account the cost for the economy of implementing GHG emission reduction measures),[55] which, from a climatic viewpoint, corresponds to a variation of the B1 Scenario, in which the mean temperature increase remains at 2°C until —but also beyond— 2100, thanks to the global reduction in GHG emissions. The cost of climate change under the Mitigation Scenario is lower than that of the B1 Scenario, which corresponds to a slightly higher rise in temperature.

The total cumulative costs of the Inaction Scenario were estimated (using a discount rate of 0%) at €701 billion (in 2008 terms) for the period 2011-2100. The Mitigation Scenario ensures cumulative cost savings of €407 billion over the period extending till 2100, relative to the

55 See Chapter 4 and Sub-chapter 5.3 for an analysis of the full costs of the Mitigation Scenario.

Table 3.21 **Total cumulative cost of climate change**

Period	Cumulative cost (EUR billions, in 2008 values) B1	B2	A1B	A2	Mitigation Scenario (2 °C)
Discount rate 0%					
2011-2050	21	59	68	79	17
2051-2100	343	444	509	622	277
2011-2100	363	503	577	701	294
Discount rate 2%					
2011-2050	10	30	35	41	8
2051-2100	90	117	133	161	75
2011-2100	101	147	168	202	83

Inaction Scenario. Using a discount rate of 2%, the cumulative cost savings achieved over the period extending till 2100 by the Mitigation Scenario amount to €119 billion (in 2008 terms).

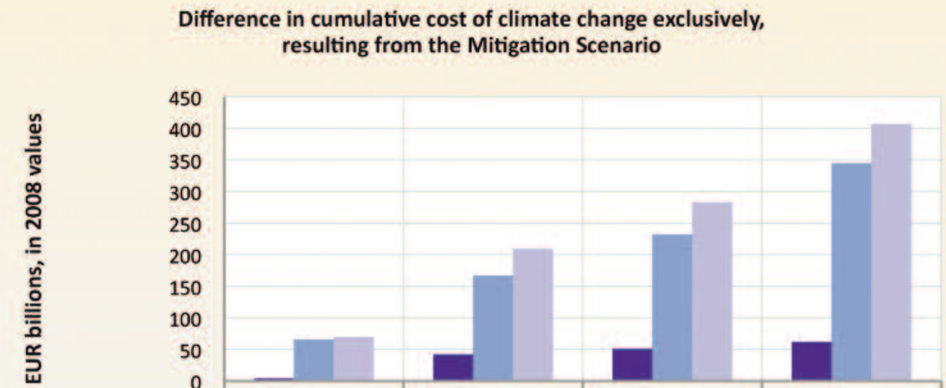
As the figures of Table 3.21 clearly show, the total costs of climate change escalate for the most part after 2050. These costs are therefore particularly low in present value terms when a non-zero discount rate is used.

It is important to stress that the cost of climate change will continue to rise beyond 2100, given that, under all the climate scenarios except for the Mitigation Scenario, climatic conditions will continue to deteriorate beyond that point. Only under the Mitigation Scenario are the climatic conditions presumed to remain unchanged after 2100. The additional costs incurred after 2100 have not been included in the estimates given in Table 3.21.

As is well known, the impacts of climate change are surrounded by considerable uncertainty. The more extreme the climate scenarios become, the higher the degree of uncertainty about the precise magnitude of climate change impacts. Under the extreme climate scenarios, such as the Inaction Scenario (A2, but also A1B), the occurrence of extreme impacts, such as high-frequency extreme weather events, is considered likely, impacts which, under today's conditions, would be catastrophic. In other words, there is a non-zero probability of occurrence of unpredictable natural events with profoundly catastrophic and irreversible, non-linear impacts. The economic costs of such "catastrophic" impacts have not been included in the general equilibrium model analysis (see Sub-chapter 3.1).

Consequently, given that the costs of climate change beyond 2100, the costs of possible catastrophic climate events and some of the impacted sectors (e.g. biodiversity, health) have not

Figure 3.5 Reduction in cumulative cost of climate change by 2100 achieved by the Mitigation Scenario (Discount rate 0%)



	B1	B2	A1B	A2
2011-2050 period	4	42	51	62
2051-2100 period	66	167	232	345
2011-2100 period	70	209	283	407

been included in the analysis, the estimated costs of the Inaction Scenarios presented in the present sub-chapter should be seen as a lower bound of the real costs for the economy.

3.4 Policies and cost of adaptation to climate change*

3.4.1 Introduction

From a country point of view, it is not judicious to associate the mitigation of climate change impact exclusively with emissions reduction, since mitigation can only be achieved if all countries, the world over, combine their efforts to drastically cut back on emissions, starting immediately and over a long period of time. Such an alignment of all countries on an aggressive and immediate plan of action is desirable, but highly uncertain. In the event that such a global effort should fail, even if only partially, then, as shown by the relevant analyses, some sort of climate change will occur.

It is therefore in a country's own interest to include future climate change in its contingency planning and to take protective measures in good time to reduce the harshness, for the country,

* The study for this sub-chapter was carried out at the E3MLab laboratory of the NTUA under the supervision of Prof. Pantelis Capros by main researchers Marilena Zambara and Dr. Leonidas Paroussos, and with the participation of researchers Zoi Vrontisi, Stella Tsani, and Maria Papaioannou. The text on the adaptation measures was written by Prof. Anastasios Xepapadeas.

of the climate change impacts. A clear distinction must be made between policies aimed at mitigating the impact of climate change, referred to as adaptation policies, and policies aimed at reducing the possibility of a climate change occurrence, examined in Chapter 4.

Even if climate change mitigation is achieved through global action to reduce emissions, climate change will still occur to some extent. In the best-case scenario, this change will involve a temperature increase of just 2°C, but if global action is delayed or only partly successful, the temperature increase is likely to be higher. Such an eventuality is considered under Scenarios B1 and B2 (see Section 3.3 above). It is therefore crucial for a country to arm itself against this uncertainty with a range of adaptation policies to possible climate change developments.

Climate change adaptation policies consist in taking appropriate action to address the damages and negative effects considered most likely to arise from climate change.

These adaptation policies need to target the sectors of activity most vulnerable to climate change. Because of their preventive nature, these policies obviously need to be developed prior to the actual occurrence of climate change effects. Furthermore, in order to reduce their costs, such adaptation policies need to be developed gradually and not under tight time constraints. Since adaptation policies depend on the State's initiative and intervention for their implementation, their effectiveness can be maximised if formulation and planning is based on analytical studies and if the relevant decisions are made in close cooperation with the parties concerned.

The overall intensity of the adaptation policies will depend on the expected intensity of climate change. At the same time, though, the more intensified and successful mitigation measures are at the global level, the less the adaptation policies will cost. It is therefore difficult to determine beforehand what the optimal strategy would be in terms of adaptation policy intensity for a given country.

The adaptation measures should, first of all, be selected conservatively, giving strict priority to identifying which adaptation measures would be indispensable under all cases of climate change (even if mitigation succeeds). These measures are usually of an institutional nature, involving e.g. the incorporation of appropriate provisions and specifications in legislation, and do not require specific works or costly interventions. If, as time goes by, there are delays in global mitigation action, then additional adaptation measures would have to be adopted in time. Such additional measures would entail costs and require special works, and would need to be implemented well before the uncertainties about the expected intensity of climate change can be resolved. Nevertheless, these expenditures should be perceived as a safeguard against future dangers from climate change.

Adaptation is therefore a long and ongoing process that concerns all sectors of the economy and society and calls for close cooperation and coordination between all parties concerned. The efficient adoption of adaptation measures presupposes timely planning and a strategic approach.

It is up to policy-makers to determine what the consequences of climate change are likely to be, and to develop and implement policy forms that ensure the best possible levels of adaptation.

3.4.2 Adaptation categories and measures

Adaptation to climate change can take on numerous forms. It is important to distinguish between spontaneous and planned adaptation. Spontaneous adaptation is the adaptation made at an individual level by economic agents, consumers and producers, without any State intervention, in response to climate change and to the ecological changes in natural systems. Planned adaptation, on the other hand, is the result of deliberate policy decisions and involves State intervention, in the form either of regulation enactments, direct public investment, or incentives and disincentives.

Both types of adaptation aim to mitigate the negative impacts of climate change and take place before climate change actually manifests itself on a wide scale.

It is obvious that priority in adaptation must be given to those sectors expected to be most negatively affected by climate change, and to averting those impacts that would entail the highest costs for the economy. According to the analyses presented in Chapter 2 and the general equilibrium analysis presented in Sub-chapter 3.3, agriculture would be the sector in Greece most affected by climate change, while household incomes and the economy as a whole would be most seriously affected by the impact on agriculture, tourism and coastal systems. The water reserves sector is of special importance, because of its repercussions on both agriculture and the water supply. The adaptation policies must therefore be focused on the above sectors and the implementation of appropriate actions must be properly planned time-wise, so as to mitigate the likely negative impacts.

Immediately below is a list of indicative climate change adaptation measures, chosen from among relevant studies in the international literature.

Table 3.22 **Types of adaptation**

Types of adaptation		Decision making level
Spontaneous	Decisions taken individually by producers and consumers without any intervention by the State (e.g. the manner in which farmers would try to enhance their crops by differentiating cultivation techniques or households' choice of location for their summer residence).	Individual
Planned	Adaptation measures taken by the government (legislation, investments, incentives and disincentives), including investment in the protection or preservation of resources (e.g. water storage), definition of policy on saving natural resources (e.g. water pricing), changing national standards (e.g. building code).	National and local

1. Agriculture and forests

1.1 Measures designed to improve crop yields:

- Measures to control and reduce soil erosion;
- Expanding the use of appropriate fertilisers;
- Introduction of new crops;
- Development of "resistant" crops (to drought, higher temperatures, salt, insects, pests, etc.);
- Soil enrichment so as to preserve or improve soil fertility;
- Adjusting the times of farm operations (sowing, spraying, harvesting, etc.);
- Recourse to crop rotation and land fallowing systems;
- Recourse to no-till farming practices, which help to contain erosion, etc.

1.2 Public works:

- Dam construction, extensive land reclamation, grey-water reuse systems, etc., as means to improve irrigation systems;
- Protection of forest biodiversity, as a means to enhance the resilience of ecosystems to climate change;
- Reinforcement of forest protection infrastructure, as a means to prevent forest fires.

1.3 Protection mechanisms:

- Development of early warning systems (to mitigate the effects of unexpected and extreme weather variations and to facilitate fire protection);
- Prolongation of the forest protection period, due to the increased number of days with a high risk for forest fire occurrence;
- Improvement of forest fire-fighting infrastructure and methods for a faster and more effective response to forest fires.

2. Water supply

2.1. Measures to increase water resource availability:

- Better management and maintenance of the existing water supply systems and relevant infrastructure;
- Watershed protection and water loss control;
- Protection of groundwater sources;
- Groundwater/rainwater collection and desalination;
- Promotion of rainwater collection systems (e.g. for watering);
- Reuse of treated wastewater in non-potable uses (e.g. toilet flushing, landscape irrigation, production of concrete for construction projects);
- Public works to access remote water sources;
- Seawater desalination (preferably using renewable energy sources).

2.2 Measures for rational water use:

- Modifications to relevant policies, such as water pricing and irrigation regulations;
- Installation of water-saving fixtures (e.g. low-flow water taps and shower heads, water metres to control consumption, infrared sensor water taps, etc.);
- Replacing plants in public spaces and streetscaping with low water-consuming plants;
- Setting of strict water-saving requirements for all new infrastructure.

3. Protection against floods

3.1 Public works:

- Infrastructure and housing protection works in riverside areas;
- Reinforcement and protection of ground areas serving as natural barriers against flooding.

3.2 Protection mechanisms:

- Planning for the participation of individuals in risk management;
- Specification of criteria for granting compensation to the flood-afflicted;
- Institutional measures;
- Flood forecasting and early warning systems.

4. Biodiversity and ecosystems

4.1 Management and protection systems:

- Improvement of ecosystem management systems, including deforestation control and reforestation;
- Promotion of agro-forestry;
- Identification and development of species resilient to climate change;
- Development and proper management of seed banks;
- Reinforcement or restoration of affected ecosystems (e.g. artificial dispersal of seeds, protection of pollinations, use of pesticides);
- Reinforcement of the ecosystems' natural resistance to climate changes, by reducing overexploitation, eutrophication, pollution, alien species invasion, etc.

4.2 Public works:

- Creation of parks, protected areas and biodiversity zones;
- Development/improvement of fire protection systems.

5. Coastal areas

5.1 Public works:

- Construction of dikes/flood defence systems to protect productive activities and residential areas situated along the coast;

- Transfer of economic activities away from the coastal areas (especially in cases where their protection cannot be ensured);
- Beach nourishment;
- Protection of vulnerable marine ecosystems (coral reefs, mangroves, seagrass, coastal vegetation).

5.2 Institutional measures:

- Incentives, spatial planning interventions and institutional measures to facilitate the transfer of economic, tourist and residential activities and investments away from the coastal zones. The departure of economic activities from the coast will in the long run enable the regeneration of the natural coastal ecosystems, which provide natural protection by dissipating much of the energy of storm waves, and help contain soil erosion in coastal areas, etc.

6. Transport and industry infrastructure

6.1 Public works:

- Relocation and reinforcement of port infrastructure;
- Airport relocation or protection works;
- Road relocation or protection works;
- Works for network infrastructure protection (electricity, telecommunications);
- Works for the protection of industrial and mining facilities against floods and extreme weather events.

6.2 Maintenance works:

- Use of maintenance materials and methods to protect road surfaces and other infrastructure against extended drought and extreme weather events;
- Use of suitable materials and methods for the maintenance of industrial and mining facilities.

7. Tourism

7.1 Private sector investment:

- Investment in existing tourism infrastructure to counter the physical consequences of climate change, such as higher temperatures and the shortage of drinking water;
- Preparation by the tourism industry of a shift of the tourist season from summer to autumn and spring.

7.2 Public works:

- Works to protect tourism facilities against floods and extreme weather events.
- Works to protect or relocate tourism facilities in vulnerable coastal areas.

8. The built environment

8.1 Public works:

- Creation and protection of "urban green spaces" that can mitigate the heat island effect, provide shade, improve the air quality, etc.

9. Energy-saving interventions in buildings through incentives, institutional measures and funding schemes. Indicatively:

- Use of building materials that naturally enhance the thermal insulation of buildings;
- Construction of air circulation as well as natural ventilation and cooling systems that help maintain a steady indoor temperature and save energy;
- Equipping building façades with special shading systems that produce a cooling effect;
- Promotion of the installation of ground-water heat pumps (GWHPs) which, apart from meeting thermal needs, also provide cooling;
- Creation of "green roofs" that provide cooling in the summer and insulation in the winter, thus saving energy.

10. Human health

- Improvements and changes to the health system infrastructure (e.g. air-conditioning in hospitals, improvement in equipment needed to treat specific diseases likely to spread on account of climate change);
- Disease monitoring (setting-up of suitable infrastructure, laboratories, etc., specialised training for new recruits in the healthcare sector, etc.);
- Investment in research on diseases likely to become more frequent on account of climate change, as well as in ways of prevention;
- Improving the quality of the living environment (e.g. air, water supply);
- Adjustment of conditions in the workplace, so as to minimise workforce productivity losses due to the temperature rise, and/or an adjustment of working hours/periods;
- Closer medical surveillance of workers/provision of medical assistance at the workplace;
- Development of early warning systems (to mitigate the effects of unexpected and extreme weather changes, e.g. heat waves).

The sectoral analyses in Chapter 2 provide more information and outline additional sector-specific adaptation measures.

3.4.3 Assessment of the costs of adaptation using the GEM-E3 general equilibrium model

The present section provides a quantitative assessment of the total costs —for the Greek economy— of adapting to high-intensity climate changes, as described in Scenario A2.

The considerable uncertainty surrounding the future intensity of climate change and the fact that the adaptation measures would need to be adopted beforehand make it very difficult to propose an optimal adaptation policy. Excessive adaptation measures could be judged a posteriori to have been unnecessary and therefore responsible for the squandering of financial resources. However, even small-scale adaptation measures may prove a posteriori to have been ineffective, thereby requiring the adoption of ad hoc and costly 'last-minute' measures.

In the light of these difficulties, we have chosen not to perform a full quantitative assessment of all the adaptation policy options available, but to focus solely on the case of high-intensity climate change (Scenario A2).

This quantitative assessment will also enable us to perform a cost-benefit analysis, and to compare the cost of adaptation (present section) with the cost of mitigation (Chapter 4) and the cost of inaction (Sub-chapter 3.3).

The Adaptation Scenario was drawn up based on the sectoral analyses (Chapter 2) and on the report "*Assessing the costs of adaptation to climate change*" (Parry et al., 2009). This report provides an overview of all the studies made by the United Nations Framework Convention on Climate Change (UNFCCC) on the subject of adaptation to climate change.

According to the report, adaptation to climate change would be very worthwhile, with a mean benefit/cost ratio of 20 in the aggressive abatement scenario and 60 in the business-as-usual A2 Scenario. After adaptation, the impacts of climate change would be reduced by 28% to 33%, compared to the case of no action either for mitigation or for adaptation.

The methodology used in the present section to assess the cost implications of the Adaptation Scenario for the Greek economy can be summarised as the following steps:

- The total cost of adaptation for the Greek economy was taken as the costs of adaptation measures plus the costs attributable to climate change.
- The costs of the adaptation measures were first estimated as direct expenditure for adaptation works and interventions; the total costs or benefits that these expenditures entail for the Greek economy were then estimated, taking into account all the indirect impacts on the economy, as simulated using the general equilibrium model GEM-E3.
- The direct costs of the adaptation measures were estimated either with data from the sectoral analyses presented in Chapter 2 or —whenever such quantitative assessments were not provided by the said analyses— with data from the international literature.
- The costs attributable to climate change were estimated, first, by assessing the extent to which the adaptation measures will succeed in mitigating the negative impacts of climate change in various sectors.
- The containment of the climate change effects, achieved thanks to adaptation, was then subtracted, on a sector-by-sector basis, from the direct cost estimates of climate change presented in Sub-chapter 3.3.

- The general equilibrium model was then used to estimate the total costs for the Greek economy of the reduced, thanks to the adaptation measures, climate change impacts.
- Lastly, the total cost of the Adaptation Scenario was obtained from the combined application, in the general equilibrium model, of the direct costs of the adaptation measures and the reduced impacts of climate change.

Only planned adaptation measures (Table 3.22), i.e. those involving actions and works undertaken by the State, are exogenously taken into consideration as adaptation measures. Spontaneous adaptation measures taken by consumers and producers are not represented as exogenous changes in the parameters of the general equilibrium model. However, it should be considered that part of these spontaneous measures are indirectly included in the analysis through the endogenous change in behaviours, as simulated by the consumption and production functions incorporated in the general equilibrium model.

Estimates of the direct cost of adaptation measures were drawn from the data of Chapter 2 only for the sectors of water reserves, forests, transport, tourism, the built environment and coastal systems. These estimates, schematically presented in Table 3.1 (Sub-chapter 3.3), are detailed in Table 3.23. For the sectors of agriculture and fisheries, data was used from the international literature. The sectors of biodiversity, ecosystems and health have been excluded from the analysis of adaptation costs. Part of the expected expenditure for protection against extreme weather events and floods, especially in the industry, mining activities and network infrastructure sectors, has also been excluded from in the analysis.

The assumption was made that the adaptation measures will for the most part be implemented during the period 2025-2050 (1st phase of adaptation). The assumption was also made that additional expenditure for adaptation measures will be required during the period 2050-2070 (2nd phase of adaptation), but that these additional expenditures will not be as extensive, i.e. about 50% lower than in the 1st phase. An exception was made for the transport sector, for which the exact adaptation cost provided by the analysis in Sub-chapter 2.9 was taken.

Despite the adaptation measures, some negative climate change impacts will still occur. The magnitude of these impacts will, however, be smaller than under the Inaction Scenario (i.e. Scenario A2, as analysed in Sub-chapter 3.3). Different assumptions were accepted for each sector regarding the reduction of the direct impacts achieved thanks to the adaptation measures, with the percentage reduction of the direct costs of climate change ranging from 30% to 70% depending on the sector. More details are provided in Table 3.23.

For the agriculture sector, estimates of the direct costs of adaptation measures were mainly based on "*Adaptation Options for Agriculture, Forestry and Fisheries*" by McCarl (2007), a study which refers to the A1B Scenario and assesses that adaptation measures would amount to a 2% increase in the sector's capital formation (along with an increase in research). The assumption was also made that the current expenditure in the agricultural sector for purposes such as addressing desertification and promoting soil denitrification and land reclamation works will increase in the future, in the context of adaptation measures implementation.

In the tourism sector, the cost estimates of adaptation measures are somewhat uncertain. For one, the costs of measures for protection and relocation away from coastal areas are recorded under the coastal systems sector. Secondly, any additional adaptation measures specific to the tourism sector would primarily need to be taken by the private sector, thereby leading to an increase in the non-labour costs of provided tourist services. The available international literature on the subject of tourism adaptation options focuses mainly on the potential offered by winter tourism, with its greater elasticity and room for adaptation. Summer tourism, in cases such as Greece's, offers far fewer possibilities for adaptation, because of its direct dependence on coastal areas vulnerable to climate change, where most of the sector's infrastructure is concentrated (Fischer, 2007). Expenditure will, however, be needed to promote tourism and extend the tourist season into the shoulder periods, as well as to upgrade buildings, with a view in particular to adjusting facilities to warmer temperature conditions.

As can be clearly seen from Table 3.23, the greater part of the cost of adaptation involves public expenditure. This expenditure was entered into the general equilibrium model as additional public investment and consumption in the sectors corresponding to each adaptation measure (public works for transport, expenditure for agriculture, forests, etc.). Some of the adaptation measures, e.g. in the tourism sector, involve private sector funding, which, after being annualised, was entered into the model as an increase in the non-labour unit costs of provided tourist services. Other adaptation measures involve investment expenditure by publicly controlled production sectors, such as in the case of the water supply. For these sectors, the costs of the adaptation measures were entered into the model as an additional public expenditure.

As regards the cost of adaptation measures concerning the energy efficiency upgrading of homes and buildings in urban centres, the assumption was made that the additional costs will be covered out of higher indirect taxes levied on energy products. It was ensured in the model that additional revenue from energy taxation covered exactly the additional expenses for the energy upgrading of homes and buildings. This, of course, ultimately places the cost of the energy upgrade on households. However, these same households are the ones that will benefit from the relevant expense avoidance (for the purchase of energy products).

The estimates of the direct cost of the adaptation measures were entered into the general equilibrium model as exogenous changes to parameter values.

Given that a large part of the adaptation measures corresponds to public expenditure, the additional budgetary cost will have macroeconomic implications for the Greek economy. It was assumed in the analysis using the general equilibrium model that the budgetary burden will occur in the future by which time the current public debt crisis will have been addressed and

Table 3.23 **Consolidated table of estimates of the direct cost of adaptation measures (EUR millions, in 2010 values, unless otherwise stated)**

Sector	Adaptation measures	1st adaptation stage, 2025-2050	2nd adaptation stage, 2050-2070	Unavoided impacts of climate change
Transportation	Expenditure for removing a part of the road and railway network at a greater distance from the shoreline	3,300	–	The cost of maintenance of the road network due to the temperature rise is not avoided.
	Expenditure for the protection of the land transportation network from flooding	184 on an annual basis	276 on an annual basis	The cost resulting from the sea-level rise and extreme weather events is avoided.
Coastal systems	Expenditure for the protection of coastal systems (except ports)	1,864	1,482	60-70% of the impact of climate change is avoided.
	Expenditure for raising the level of breakwaters in ports	600	–	
Water resources	Expenditure on works and interventions intended to restore resources and ensure the rational use of resources	70* on an annual basis	42 on an annual basis	A total cost of €390 million is avoided.
Forests	Additional management cost	50 on an annual basis	30 on an annual basis	The bulk of the impacts on forests is avoided.
	Expenditure for the improvement of forest fire fighting	80 on an annual basis	46 on an annual basis	
	Cost of protection works	4,700	2,800	
Tourism	Percentage increase in the cost of tourism services, excluding labour costs	10%	10%	20-30% of the loss of tourism receipts is avoided.
Agriculture and fisheries	Expenditure on irrigation works and protection works	72 on an annual basis	42 on an annual basis	The bulk of impacts on fisheries is avoided.
	Cost of the promotion of improved production practices and of the protection of wetlands systems	100 on an annual basis	60 on an annual basis	The decline in the productivity of the agricultural sector would reach 6% by 2050 (30% improvement) and 15% by 2100 (21% improvement).
Built environment	Cost of energy upgrade of building stock and of developing green islands	20,000	–	Reduction of energy consumption for cooling purposes by 20% compared to the Inaction Scenario.

* The analysis of the water resources sector stresses that this cost does not fully reflect the cost of realising this particular policy. However, in the absence of further information, the present analysis used this partial cost.

therefore that the financing of the public expenditure for adaptation measures at competitive market rates will be possible.

On the basis of this assumption, the general equilibrium model simulates the future path of the real interest rate as a shadow price of the balance of payments constraint, considering that the balance of payments will be burdened, in the first place, by this public expenditure. One of the impacts of the adaptation measures will therefore be an increase in the real interest rate. The results of the model showed this increase to be of 1 percentage point, at most.

The increase in the real interest rate has an adverse effect on private investment. In other words, the additional public expenditure for adaptation measures has a partial crowding-out effect on private investment, which in turn has a negative impact on economic growth. This impact is simulated in the model through the setting of the real interest rate.

At the same time, though, the increase in public expenditure for adaptation measures also has a boosting effect on different branches of economic activity and, thereby, on private investment. The additional public expenditure translates into an increased demand for goods and services needed to carry out public works and to implement the relevant expenditure for protection against climatic impacts. The additional demand for such goods and services has a multiplier effect on the economy and is simulated in the model by the Leontief multiplier. The additional economic activity resulting from the public expenditure for adaptation has a positive impact on employment which, through labour market equilibrium, has an increasing effect on real wages. Moreover, the sectors of activity that benefit from the sectoral allocation of the additional public expenditure invest more, as compared to the situation without this additional expenditure. Greater pressure is therefore exerted on the capital market, something which translates into trends towards a further increase in the real interest rate. As a result of the pressure exerted on the capital and labour markets, the model simulates an upward trend in the prices of goods and services.

These changes, however, namely the increased economic activity stemming from additional public expenditure, as well as the upward trend in prices of goods and services, have a negative impact on the trade balance, which is burdened by the increase in imports and the decline in exports. Increased domestic activity has a crowding-out effect on export activities. Since the model simulates the maintenance of the trade balance at the same level as in the situation without adaptation measures, the real interest rate is redetermined by the model and has a negative effect on consumption.

Private spending and investment associated with some of the adaptation measures have further adverse impacts on the economy. The relevant branches, as well as private consumption, transfer funds to pay for adaptation measures at the expense of other expenditures with a greater multiplier effect for the economy. The simulation by the model shows that the negative consequences of this crowding-out effect outweigh the positive effects for the economy of the additional demand for goods and services needed to carry out the corresponding adaptation measures.

The simulation with the general equilibrium model reveals that the impact from the increase in public expenditure through the crowding-out of investments and exports is greater than the impact with a multiplier effect on economic activity; this, as estimated by the model, will lead to an eventual decline in GDP, compared to the situation without adaptation measures, as well as to declines in private consumption and (to a lesser extent) in private investment and to a marginal change in employment. As mentioned above, private adaptation measures are accountable for part of the decline in GDP.

The impact is not uniform across the sectors of economic activity considered. The expenditure for adaptation has a positive impact on such sectors as construction, the production of non-metallic minerals and construction materials, the production of ferrous and non-ferrous metals, and banking services. However, the impact on the other productive sectors of the economy is negative.

In the course of time, the economy will also suffer the negative impacts of climate change. Thanks to the adaptation measures taken, however, the intensity of these impacts will be limited, compared to the ones envisaged under of the Inaction Scenario. The macroeconomic mechanism of these impacts is the same as the one described in Sub-chapter 3.3.

3.4.4 Assessment of the total costs of adaptation

The analysis of adaptation using the general equilibrium model presents several limitations, as it does not capture the full range of adaptation measure options and because the assessment of the benefits arising from the reduction of climate change impacts is quite uncertain.

In spite of these drawbacks, the GEM-E3 general equilibrium model, using the data and the assumptions mentioned in the previous section, makes it possible to assess the economic (macroeconomic and sectoral) effects of the combined application of adaptation measures and of the (lesser) damage arising from climate change. Separate assessments were made for the total costs of adaptation measures and for the lesser damage from climate change. By comparing this last cost figure to the total cost of the Inaction Scenario (A2, see Sub-chapter 3.3), one can deduce the total benefit of the adaptation measures for the Greek economy.

For this simulation, the limited-intensity climate change corresponding to the years 2050, 2070 and 2100, as well as the range of adaptation measures corresponding to those three years, were applied to the state of the economy in the base year. The reason why three reference years were chosen was to better capture the different dynamics of the adaptation measures and damages from climate change.

Using the abovementioned assumptions with regard to the adaptation measures and the ensuing benefits from the reduction of the climate change damage corresponding to Scenario A2, the simulation with the general equilibrium model yielded the following conclusions:

The adoption of adaptation measures over the period 2025-2050 corresponds to an annual expenditure of roughly 1.5% of GDP, on top of the expenditure under the Baseline Scenario. The expenditure for adaptation measures subsequently decreases, to 0.9% of GDP during the period 2051-2070 and to 0.1% of GDP during the period beyond 2070.

Table 3.24 **Total cost of the Adaptation Scenario for the Greek economy, in accordance with the results of the GEM-E3 general equilibrium model**

		Climate change intensity in 2050	Climate change intensity in2070	Climate change intensity in 2100
Percentage GDP change				
Implementation of adaptation measures only	initial simulation year	-0.92	-0.55	-0.07
	final simulation year	-1.10	-0.66	-0.08
Unavoided climate change impacts	initial simulation year	-0.96	-2.16	-3.96
	final simulation year	-0.97	-1.99	-3.59
Combined adaptation measures and climate impacts	initial simulation year	-2.11	-3.02	-4.03
	final simulation year	-2.30	-2.96	-3.67
Change in the level of baseline year GDP (EUR millions, in 2008 values, annually)				
Implementation of adaptation measures only	initial simulation year	-2,177	-1,303	-174
	final simulation year	-3,249	-1,952	-250
Unavoided climate change impacts	initial simulation year	-2,272	-5,125	-9,393
	final simulation year	-2,863	-5,897	-10,646
Combined adaptation measures and climate impacts	initial simulation year	-4,989	-7,156	-9,553
	final simulation year	-6,804	-8,764	-10,883
Welfare equivalent variation of the baseline year (EUR millions, in 2008 values, annually)				
Implementation of adaptation measures only	initial simulation year	-857	-513	-72
	final simulation year	-1,689	-1,013	-135
Unavoided climate change impacts	initial simulation year	-1,132	-3,618	-7,246
	final simulation year	-1,922	-6,136	-12,504
Combined adaptation measures and climate impacts	initial simulation year	-2,278	-4,431	-7,311
	final simulation year	-4,056	-7,656	-12,627

These additional expenditures, in the end, have a negative impact on the economy, as explained in the previous section, and lead to a decline in GDP that is smaller in absolute terms than the expenditure for adaptation measures.

Despite the adaptation measures, the economy still suffers losses from climate change, which evolves according to Scenario A2. The residual (unavoided) damage from climate change is small at the start and middle of the simulation period, but becomes more important later on, i.e. 2070-2100. According to the model's results, the decline in GDP caused by these losses is, however, definitely smaller, in absolute terms, than the one calculated under Scenario A2 (Inaction) in Sub-chapter 3.2. Expressed in terms of their contribution to the change in GDP, the residual (unavoided) climatic impacts on the economy, after implementation of the adaptation measures, amount to 48% of the loss in GDP projected for year 2050 under Scenario A2 and to 60% of the loss in GDP projected for year 2100.

Nevertheless, the expenditure for adaptation measures combined with the, albeit lesser, climatic impact has a cumulative GDP-reducing effect on the economy. According to the model's results, the total decline in GDP corresponding to the Adaptation Scenario amounts to -2.3% for the year 2050, -2.96% for the year 2070 and -3.67% for the year 2100.

Figure 3.6 **Total annual cost for the Greek economy on the basis of the Adaptation Scenario and the Inaction Scenario, according to the results of GEM-E3 general equilibrium model**

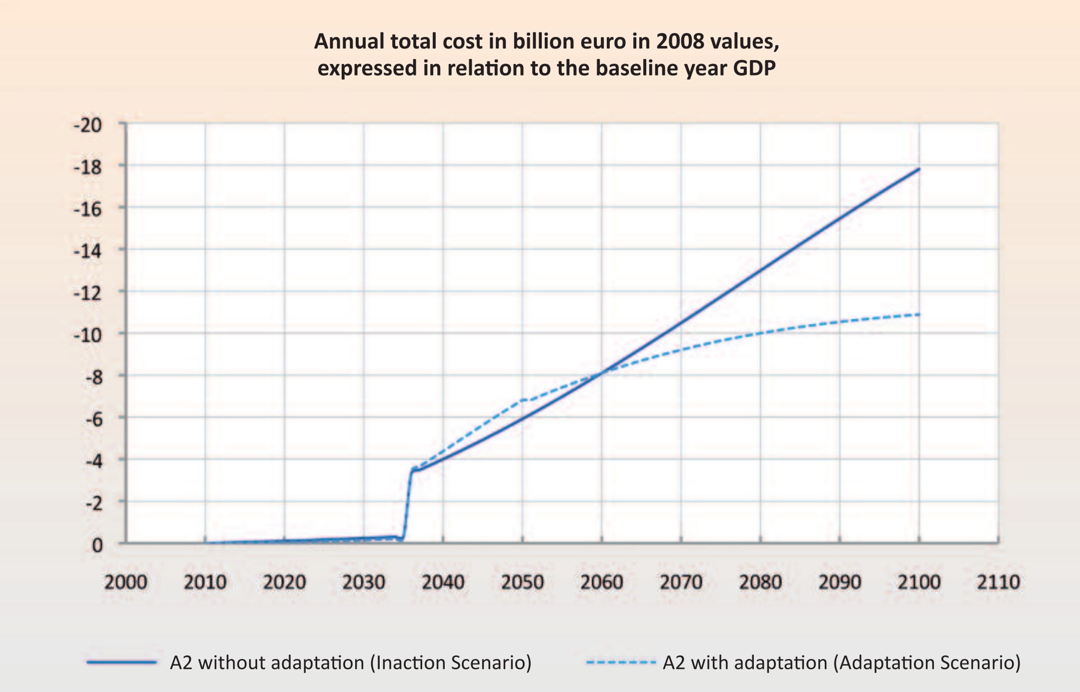


Table 3.25 Cumulative cost for the Greek economy on the basis of the Adaptation Scenario and the Inaction Scenario, according to the results of the GEM-E3 general equilibrium model
(EUR billions, in 2008 values)

Period	A2 without adaptation (Inaction)	A2 with adaptation (Adaptation Scenario)	Cost differential between Adaptation and Inaction
Discount rate 0%			
2011-2050	78.9	85.7	-6.8
2051-2070	182.3	177.5	4.7
2071-2100	439.4	314.4	125.0
2011-2100	700.5	577.7	122.8
Discount rate 2%			
2011-2050	40.5	43.6	-3.0
2051-2070	65.0	63.8	1.2
2071-2100	96.1	70.0	26.1
2011-2100	201.6	177.3	24.3

The results of the model point to a decline in welfare equivalent variation, of the same scale as the changes in GDP.

As mentioned earlier, the impacts differ across sectors of the economy, with sectors such as construction and construction materials suffering a small-scale contraction in output, whereas agriculture and tourism suffer a larger-scale negative change.

An attempt was also made to calculate the cumulative costs for the Greek economy, according to the methodology described in Sub-chapter 3.2, using an interpolation based on a sigmoid function.

Given that the timing of the expenditure for adaptation measures does not coincide with the time at which the economic impacts induced by climate change take place (see Figure 3.6) and, more specifically, that the relevant expenditure precedes climate-induced damage, the cumulative costs of the Adaptation Scenario are similar to those of the Inaction Scenario during the period up to 2070. However, from 2070 onwards, the cumulative costs of Inaction are far greater than the costs of Adaptation.

The Adaptation Scenario (in terms of the cumulative decline in GDP over the entire period until 2100) would cost the Greek economy €123 billion less than the Inaction Scenario (at constant prices of 2008). This result was obtained using a zero discount rate, relative to base year GDP. However, even when an annual discount rate of 2% was used, the

Adaptation Scenario, on a cumulative basis, still cost the Greek economy some €24 billion less than the Inaction Scenario.

Despite the uncertainty surrounding the adaptation measures and their cost implications for the Greek economy, the results of the cost-benefit analysis on the basis of the general equilibrium model should be considered safe. What this means in practical terms is that it is possible to draw up a suitable adaptation programme that would cost less than the cost savings to be achieved, for the simple reason that adaptation reduces the economic impacts of climate change. This analysis did not take into account the benefit arising from the fact that adaptation, as a preventive policy, serves as a safeguard against climate change-induced extreme implications for the economy. It is, once again, necessary to underscore the great difficulty involved in determining the optimal mix and time planning of adaptation measures. The State should therefore ensure that the adaptation strategy is supported by systematic and proper consultation procedures. This would allow for the strategy to be fine-tuned along the way.

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