Chapter 2
The risks and impacts of climate change by sector*

2.1 Climatic changes and impacts on Greece's water systems**

2.1.1 Introduction

The concept of water resources derives from the relationship between the water required for various human activities (water needs) and the availability or search for water flows and reserves (water resources) in the natural environment that would be fairly easy to exploit to meet these needs.

From another perspective, water resources can be seen as the environment's capacity for water supply. The above relationship can concern different spatiotemporal and economic spheres. Supply (water resources) and demand (water needs) are both characterised by:

(a) location;

(b) quantitative variability over time (e.g. variation in quantity of water in a flow or reserve; and

(c) quality.

With regard to quality, distinctions are made between:

(a) the quality *supplied*, determined by the physical and chemical properties of the water in its natural environment, generally affected by the importance of the flow and depending on its characterisation according to use (criterion of needs from the natural environment); and

(b) the quality *required*, expressed in terms of the specifications that apply to each water use. Specifications tend to evolve with the increase in awareness in the fields of toxicology, medicine (water supply), biotechnology (irrigation), technology (industrial use) and ecology.

In economic terms, water resources are characterised by adequacy, overabundance and shortage, while with a view to ensuring the best possible allocation of water resources for each use an additional distinction is made between:

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* The bibliographies for all sub-chapters can be found at the end of Chapter 2.

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Table 2.1 **Anthropogenic impact on water balance**

Type of impact	Impact	
	Impact on inflows (deposits)	Impact on outflows (runoff)
Increase	Input of water (transfer). Capture of surface or underground water by an adjacent environment.	Decrease of real evapotranspiration, drainage. Output of water (partial phenomenon).
Decrease	Enhancement of real evapotranspiration. Decrease of active precipitation.	Consumption.

– the cost of *supply*, adjusted to each specific case of supply and demand in function of the above parameters (location, regime, and quality); and

– the cost of *needs*, expressed with different measures of 'water value' (value added, use value, etc.).

A system of water resources provides an ideal setting for the formulation and presentation of a water balance, quantified with respect to a specific time frame. The effects of anthropogenic activities on the components of this balance are summarised in Table 2.1.

2.1.2 State of play of Greece's water reserves

The state of Greece's water reserves and water management is of specific interest, with certain particularities indicative of the level of actual development and organisation. With regard to these particularities, Greece presents a wide variety and complexity of situations, the most predominant of which are:

– the uneven temporal distribution of precipitation, with over 85% of total precipitation falling during the winter (wet season) and the rest occurring in the summer (dry season);

– the highly uneven spatial distribution of precipitation, with higher rates of precipitation reported in Western Greece (west of the Pindos mountain range) and lower rates reported in Eastern Greece;

– the fact that the northern part of Greece is (quantitatively and qualitatively) affected by transboundary waters, with four major rivers originating in neighbouring countries, i.e. three in Bulgaria (the rivers Evros, Nestos, Strymon) and one in FYROM (the river Axios);

– an important period of water demand imbalance, with peak abstraction for irrigation and tourism typically occurring in the summer months when water availability is generally at a minimum (almost no rainfall).

– the highly uneven spatial distribution of demand, as a result of overconsumption associated with the excessive concentration of people in urban centres, the coastal zone and other areas;

– the country's complex configuration, both in geological terms (aquifer and surface flow) and geomorphological terms (surface flow generation);

– the tremendous length of Greece's coastline (approximately 16,300 km), relative to the country's total area, which, combined with the over-pumping of coastal aquifers, favours inland seawater intrusion; and

– the conditions specific to most of the Aegean Sea's many islands (low levels of rainfall, small overall surface, rough topographic relief with high surface runoff and low soil infiltration).

In terms of water reserves, Greece rightly qualifies as a 'rich' country, in comparison, of course, with the rest of the broader Mediterranean region, and this for a number of reasons associated with, and responsible for, the atmospheric precipitation regime. Quite remarkably for a country situated in the Mediterranean basin, Greece's mean annual precipitation is in the order of 800 mm, both on account of more general factors shaping the country's climate and weather patterns and on account of the country's complex topographic relief. A key factor in this respect is the Pindos mountain range, which receives moist winds from the west. Thus, precipitation west of the Pindos ridge is far heavier than in the regions to the east.

Greece's varied topographic relief offers favourable ground for the emergence of a dense surface drainage network, with particularly dense hydrographic networks and final recipients a number of large rivers (for a country the size of Greece) that drain surface and part of underground waters, to the extent that spring water discharges enhance surface flow. The rivers of Northern Greece represent a special case, as their upper courses, as previously mentioned, are in neighbouring countries (the rivers Evros, Nestos, Strymon originate in Bulgaria, and the river Axios in FYROM). The only river flowing in the opposite direction is the river Aoos, which originates in Greece and discharges in Albania. Greece's underground aquifers are also considerable, given that much of the country consists of permeable rock allowing primary or secondary infiltration. Such are the cases of the large inland and deltaic alluvial basins, and the carbonate rocks of karstic aquifers (limestone, dolomite, marble, gypsum, etc.).

Although none of the country's 13 water districts faces imminent water shortage, there are indications —as shown in Chapter 1— that the country's water potential is decreasing. According to the results of the ENSEMBLES research project,[1] Central and Northern Greece have seen their precipitation levels decrease over the last five decades, with the decrease per decade starting at 30 mm and regionally reaching 150 mm. At the same time, a comparison of river flows between 1971-1998 and 1900-1970 shows water flow to have decreased by 5-10% countrywide, save for the Epirus region where the decrease was found to be 2-5% (Milly et al., 2005).

1 http://www.ensembleseu.org

2.1.3 Conflict and mismatch between water requirements and water resources

The conflict between water requirements and water supply can be conceptualised by comparing (in qualitative and quantitative terms) the actual water requirements for specific uses, on one hand, with the water resource system (the properties of given water resources). The purpose of this exercise is mainly to determine resource adequacy and to identify possible water shortage risks.

The spatial examination of water sufficiency on a regional or national scale is where the concept of available water reserves comes into play. These reserves represent resources minus water abstraction on a local scale, and resources minus consumption on a national (or drainage basin) scale. One fundamental reason for this distinction is that water abstracted (for instance, at a local scale) may re-enter the system, thus becoming available for re-use, meaning that the available water resources need to be 'recalculated' to take any water re-entrances into account. In any event, management programmes need to distinguish between "water transfer" (from one basin or sub-basin to another, which alters the regional distribution of natural and exploitable natural resources) and "water addition" (transfer of water from a site of withdrawal to another area for use).

From a temporal perspective, the average amounts of water withdrawal are compared to the exploitable water resources, a method that makes it difficult to identify the impacts of variability over time on both sides of the equation. Such changes are determined by temporary inadequacies and all relevant problematic conditions (annual or seasonal), due to inadequate supply (drought) or excessive requirements. It is therefore necessary to determine the minimum values of the exploitable resources for a given acceptable time period and to establish, at a readjustment level, the local exploitation index (total water abstraction as a percentage share of natural resources), the regional exploitation index (total consumptions as a percentage share of natural resources), as well as other parameters, essential for elaborating a suitable and viable water management programme.

When examining water as a natural resource in adequacy terms, a clear distinction needs to be made between two very different concepts, sometimes confused even by specialists and policy makers. The first concept, *drought* or *aridity*, refers to a deficiency in the water supply to the environment – either direct (rainfall) or indirect (surface and underground), relative to the measurements of past time series. The second concept, *water scarcity*, refers to a decrease in available water potential, in comparison with present or anticipated use. Water scarcity can be a result of a drought (in which case the two concepts may quantitatively coincide), but can also occur at a time of normal or above-average water supply, as a result either of water mismanagement or of incorrect water use planning.

When discussing water availability issues, another major consideration is the breakdown of consumption by sector. At the global level, agriculture is the prime consumer of water: water consumption driven by agricultural needs has not only risen exponentially, it is projected to exceed 3,000 million m^3 by 2025, i.e. six times the consumption of the early 20th century. The industrial sector, second in terms of quantities consumed, also accounts for a steady rise in water consumption. By 2025, the water consumed by the global industrial sector is projected to be in the order of 1,000 million m^3. Water consumption by households, i.e. the sector that has always had the smallest consumption, is also projected to increase significantly.

Typical cases of water scarcity are presented by the Greek islands, especially the smaller ones, but also by the Attica region. Several islands (for instance the Cyclades) used to have sufficient water resources, despite low precipitation levels, small total surface area (hence limited potential for water accumulation) and high temperature and sunshine levels (thus high evaporation).[2] However, the shift in land use away from traditional agriculture, stockbreeding, etc. to tourism activities, the sharp influx of tourists during the summer, improved living standards (more frequent showering and laundering, etc.) and changes in lifestyle (swimming pools, car washing, gardening, etc.) generate a higher demand for water, which the existing water potential cannot meet. The problem is further exacerbated by the uneven distribution of rainfall, both temporal and spatial. Similar in nature is the problem faced by the Attica region, which includes the wider urban area of Athens and Piraeus and the surrounding municipalities. As a result of intense rural migration and residential, economic and administrative centralisation, the Attica basin at the end of the 1990s accounted for over 40% of the total national population[3] and close to 70% of total national economic activity.

At the European level, it is estimated that one third of the EU territory and at least 100 million residents of the EU have been affected by water scarcity to date. As recently underlined by the European Environment Agency in its 2009 annual report on water resources (EEA, 2009), overconsumption for certain uses in several regions has put the needs of other uses at risk. The EEA report also notes that the cases of saline intrusion into coastal aquifers throughout Europe are increasing, thus reducing the water reserves available for consumption.

2.1.4 General observations on freshwater availability in Greece

The estimation of water reserves refers to a specific area and time span or, on average, to a specific period of the hydrological year. The reserves are distinguished into (a) surface waters (surface flow, hydrographic network, etc., lakes, glaciers, snow cover), (b) subsurface (i.e. groundwater, unsaturated zone moisture) or (c) underground water (aquifer reserves). The fact

2 Quite tellingly, it was not uncommon for some of the islands to carry the name ‘Hydroussa’, literally meaning “abundant in water”.

3 Apart from the permanent residents, the wider Athens area attracts millions of foreign visitors each year (drawn by its world famous archaeological sites), millions of domestic visitors (for financial, work-related, administrative, health-related reasons), as well as tens of thousands of businessmen. In addition to surface waters, EYDAP, the Athens Water Supply and Sewerage Company, keeps back-up underground water supplies (water well drillings) in surrounding areas (e.g. Kalamos).

that all water reserves, especially underground water, vary over time, must be taken into direct consideration at the water resource management level (exploitation, qualitative protection and quantitative replenishment). This variability stems from changes in the water budget (inflows and outflows, or water entering the system and consumptions). The variability of reserves can be expressed as a percentage of variable reserves relative to constant reserves. These are often referred to as "regulatory and permanent reserves" – a rather inaccurate wording from a hydrogeological perspective, which has, in the past, led to water resource misuse.

The relationship between the reserve of a given —surface or underground— water reservoir and the average flow running through it determines the reserve's replenishment rate. The importance of a water reservoir should not be rated on the basis of the resource's replenishment (static water reservoirs with very low rates of replenishment are nonetheless water reserves). The level or rate of replenishment of a water resource must be co-assessed with the

Table 2.2 **General annual water balance, by water district**

Water district	Area (km²)	Precipitation volume[1] (million m³)	Evaporation[1] (million m³)	Water potential (million m³)	Supply[2] (million m³)	Demand[2] (million m³)	Remarks[2]
01 Western Peloponnese	7,301	8,031	3,614	4,417	73	55	In surplus
02 Northern Peloponnese	7,310	6,404	2,824	3,580	122	104	In surplus
03 Eastern Peloponnese	8,477	6,563	3,290	3,273	56	67	In deficit
04 Western Central Greece	10,199	13,973	5,310	8,663	415	82	In surplus
05 Epirus	10,026	17,046	6,818	10,228	193	33	In surplus
06 Attica	3,207	1,642	1,150	492	56	54	Marginally in surplus[3]
07 Eastern Central Greece	12,341	9,516	5,257	4,259	128	187	In deficit[4]
08 Thessaly	13,377	10,434	6,260	4,174	210	335	In deficit
09 Western Macedonia	13,440	10,470	5,654	4,816	159	136	In surplus
10 Central Macedonia	10,389	6,068	3,034	3,034	137	130	Marginally in surplus[3]
11 Eastern Macedonia	7,280	4,917	2,722	2,195	354	132	In surplus
12 Thrace	11,177	8,574	5,325	3,249	424	253	In surplus
13 Crete	8,335	7,500	4,874	2,626	130	133	Marginally in surplus[5]
14 Aegean Islands	9,103	5,192	3,104	2,088	7	25	In deficit
Total Greece	131,962	116,330	59,236	57,094	2,464	1,726	

Source: Operational Programme "Environment and Sustainable Development" (2007).
1 Values are relatively overestimated.
2 Values and their characteristics refer to the month of July.
3 Water resources are basically transferred from adjacent districts.
4 Irrigated areas according to NSSG seem to be overestimated and for this reason this district appears to be in high deficit, although it currently has marginally sufficient resources.
5 Current demand is insufficiently met by wells and drillings.

level or rate of its utilisation, with the dual objective of meeting the water requirements of various uses and preserving the water component of the environment (the role of water in the ecosystem). It should be noted that the latest principles of water management call for the specification of minimum river flows, lake levels and aquifer levels, characterised and treated as water uses needed to ensure the systems' ecological requirements and the 'ecological services' that these systems provide.

Despite the long-standing efforts of public authorities and organisations, all of the data needed for a comprehensive and reliable estimate of the country's total water potential have yet to be collected. An estimate of the country's general hydrological balance on an average annual basis is presented in Table 2.2. This estimate was calculated using fairly reliable data from the analysis of the country's water districts. These data were collected from other individual studies, and from measurements of hydrological balance components and, as mentioned above, are only of relative reliability. Reliability decreases when the figures are aggregated to the national level (by adding the quantities of each district).

2.1.5 Physical impacts of climate change on Greece's water sector

The hydrological cycle begins with evaporation and atmospheric precipitation (rainfall, snowfall, hail, etc.). Upon reaching the earth's surface, precipitation waters are separated at a primary stage into evaporation/transpiration (through vegetation), drainage (through the hydrographic networks), and infiltration. At a secondary stage, the picture becomes more complex, as drained water may, further down the line, either evaporate or partly infiltrate and, conversely, infiltrated water may flow out to the surface through spring discharges, only to undergo surface drainage and partial evaporation. These processes can occur several times. Moreover, before recharging the underground aquifer, infiltration water first satisfies the water needs of the ground and underground zones and of the root system (detained, adsorbed, capillary water), where plant and animal organisms grow. Therefore, any change in the atmospheric precipitation regime inevitably entails significant changes in the entire hydrological cycle, as well as in hydrological (surface) and hydrogeological (underground) water balances.

Greece has a total area of roughly 130,000 km^2, one fifth (20%) of which corresponds to its approximately 3,000 islands. Two thirds of this area is mountainous and the country's complex topographic relief also features the longest coastline of any country in Europe (~16,300 km in length), 5% of which corresponds to regions of unique ecological value.

The primary factor that determines the distribution of total annual precipitation in Greece, which averages 800 mm, is the presence of the Pindos mountain range, to the West of which precipitation levels are considerably more important than in Eastern Greece. The water deficit is normal, with the distribution of surface drainage broadly matching rainfall distribution (see Figure 2.1).

Figure 2.1

Rainfall and surface runoff time series in the water district of Thessaly (From a mix of software programmes and measurements, Ministry of Development, 2003)

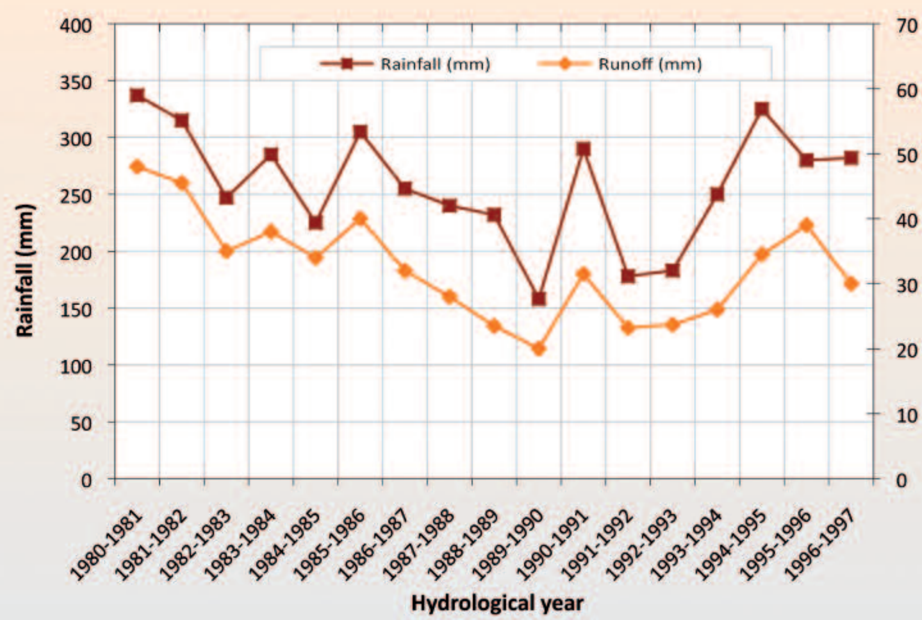


Figure 2.1 concerning the Thessaly water district and covering an extensive time period, including the critical hydrological years 1989-1990 and 1990-1991 during which substantially lower rainfall levels (-40%) were recorded countrywide, allows us to make the following interesting observations: the increase in rainfall from 130 mm in 1989-1990 to 170 mm in 1990-1991 (increase of about 30%) resulted in an increase in drainage from 26 mm to 50 mm (increase of about 90%). The decrease in rainfall from 170 mm to 140 mm (decrease of about 17%) brought about a decrease in drainage, from 50 mm to 33 mm (decrease of about 70%). This seems to indicate that an increase in rainfall is associated with a three-fold increase in drainage, whereas a decrease in rainfall is associated with a roughly similar decrease in drainage.

Three factors —geographical location (winward/leeward), morphology and geology— determine water accumulation, both in surface water bodies (lakes) and underground (extensive karstic fields). The vulnerability of karstic formations to pollution means, however, that there can be degradation in water system quality. Climate change is expected to result in increased evaporation and transpiration, increased needs for irrigation and, perhaps, tourism, and increased pollution concentrations, due to decreased dilution (increased load in smaller water volumes) (Stournaras, 2007).

Evapotranspiration represents an important hydrological loss, occurring both on the surface and in upper soil layers. Evapotranspiration rates in Greece are high, particularly in the drier eastern regions. A indicator widely used when characterising regional climates is UNESCO's indicator of dryness, defined as the ratio of the mean annual precipitation to the corresponding potential evapotranspiration. The distribution of this indicator in Greece underlines the severity of the drought situation in the SE regions and the Aegean islands (see Chapter 1).

Distinguishing between surface and underground renewable water resources is only of theoretical value, since both components of total flow are interconnected (secondary infiltration and runoff). When considering the water entering a regional system in the form of precipitation, account is taken of surface flow and infiltration into the aquifer. When considering the water leaving the system, account is taken of surface and underground flow. At the local or supralocal level, any separate estimate of surface and underground resources would risk overlooking secondary phenomena (infiltration, runoff) and incorrectly estimating the water entering or exiting the regional system. In fact, natural water resources, as determined by surface (measured or estimated) flow, and the respective water resources, as determined based on water entering the aquifer, should not be added, except in marginal cases. Generally speaking, they are only partly addable, depending on the scale of study and on the natural, climate and (secondarily) geological conditions affecting the relationship between a region's aquifers and surface flow.

The impacts of climatic change on water systems (mainly underground water systems) can be summarised as follows:

1. An overall decrease in aquifer infiltration and recharge, as a result of decreased rainfall and higher evapotranspiration.

2. Increased salinity of coastal and subsea aquifers, particularly karstic ones, as a result of the advance of the sea-water intrusion farther inland due to the decline of groundwater levels caused by lower inflow and overpumping.

3. Higher pollutant load concentrations in coastal water bodies and the sea, due to decreased dilution.

4. Faster degradation of deltaic regions, in cases where degradation has already begun as a result of transversal dam construction upstream (reduced drainage and sediment discharge) and parallel levee construction in the flat zone of the deltas (debris channelled to a single outlet).

5. Contamination or drainage of coastal wetlands.

6. Amplification of the desertification phenomenon as a result of water deficits and soil changes (compaction, sealing, etc.).

2.1.5.1 Observations and assumptions for estimating water availability variations in Greece as a result of climate change

In order to estimate the possible variations in Greece's water potential by 2100, we estimated the hydrological balance for 2021-2050 and 2071-2100 under Scenarios A1B, A2 and B2

Table 2.3 **Processing of climate change data (Scenario A1B, 2021-2050, mainland part of water districts)**

WD	CZ	A (km²)	P (m)	P (mm)	V (million m³)	Etr (m)	Etr (mm)	Etr (million m³)	R (million m³)	Imperme-able formations	Semi-permeable formations	Alluvial formations	Karstic formations	I (million m³)	I+R (million m³)
										2,331 km²	1,300 km²	1,230 km²	2,440		
1	WP	7,301	0.82	816.14	5,958.6	0.51	512.50	3741.8	1,231.04	3%	3%	10%	40%		
										57.1	31.8	100.4	796.6	985.8	2,216.9
										1,634 km²	838 km²	1,012 km²	4,993		
3	EP	8,477	0.50	503.80	4,270.7	0.37	373.13	3,163.0	-121.06	3%	5%	10%	45%		
										24.7	21.1	51.0	1,132.0	1,228.8	1,107.7
										8,034 km²	1,138 km²	1,456 km²	9,583		
4.5	WG	20,211	1.11	1,108.39	22,401.7	0.57	565.93	11,438.0	5,717.53	3%	3%	10%	45%		
										267.1	37.8	161.4	4,779.8	5,246.1	10,963.7
										10,310 km²	3,500 km²	6,904 km²	8,349		
6.7.8	CEG	29,063	0.47	470.96	13,687.5	0.37	366.06	10,638.8	1,200.78	2%	3%	10%	35%		
										97.1	49.5	325.2	1376.2	1,847.9	3,048.7
										8,139 km²	5,298 km²	7,343	3,052		
9.10	WCM	23,832	0.58	575.50	13,715.3	0.40	400.13	9,535.9	2,673.47	3%	5%	10%	45%		
										140.5	152.4	422.6	790.4	1,506.0	4,179.4
										10,377 km²		5,567	2,513		
11.12	EMT	18,457	0.66	659.17	12,166.3	0.46	460.48	8,499.1	2,523.84	4%		7%	37%		
										273.6		256.9	612.9	1,143.4	3,667.2
Total					72,200			47,017	13,226					11,958	25,184

WD: water district, CZ: climate zone, A: area, P: precipitation, V: water volume, Etr: real evapotranspiration, R: surface runoff, I: infiltration, I+R: water potential.
WP: Western Peloponnese, I: Ionian, EP: Eastern Peloponnese, WG: Western Greece, CEG: Central and Eastern Greece, WCM: Western and Central Macedonia, EMT: Eastern Macedonia and Thrace.
Water district and lithological formation areas, as well as infiltration ratios, were taken from Management Studies of the Ministry of Development.

Table 2.4

Processing of climate change data (Scenario A1B,2071-2100, mainland part of water districts)

WD	CZ	A (km^2)	P (m)	P (mm)	V (million m^3)	Etr (m)	Etr (mm)	Etr (million m^3)	R (million m^3)	Imperme-able formations	Semi-permeable formations	Alluvial formations	Karstic formations	I (million m^3)	I+R (million m^3)
										2,331 km^2	1,300 km^2	1,230 km^2	2,440 km^2		
1	WP	7,301	0.67	672.10	4,907.0	0.45	453.84	3,313.5	781.67	3%	3%	10%	40%		
										47.0	26.2	82.7	656.0	811.8	1,593.5
										1,634 km^2	838 km^2	1,012 km^2	4,993 km^2		
3	EP	8,477	0.42	418.13	3,544.5	0.33	330.51	2,801.7	-277.05	3%	5%	10%	45%		
										20.5	17.5	42.3	939.5	1,019.8	742.8
										8,034 km^2	1,138 km^2	1,456 km^2	9,583 km^2		
4.5	WG	20,211	0.95	946.76	19,135.0	0.53	533.09	10,774.3	3,879.57	3%	3%	10%	45%		
										228.2	32.3	137.8	4082.8	4,481.1	8,360.7
										10,310 km^2	3,500 km^2	6,904 km^2	8,349 km^2		
6.7.8	CEG	29,063	0.41	413.39	12,014.4	0.34	339.06	9,854.1	538.21	2%	3%	10%	35%		
										85.2	43.4	285.4	1,208.0	1,622.0	2,160.3
										8,139 km^2	5,298 km^2	7,343 km^2	3,052 km^2		
9.10	WCM	23,832	0.51	510.63	12,169.3	0.37	369.08	8,795.9	2,037.22	3%	5%	10%	45%		
										124.7	135.3	375.0	701.3	1,336.2	3,373.4
										10,377 km^2		5,567 km^2	2,513 km^2		
11.12	EMT	18,457	0.58	584.39	10,786.1	0.43	426.41	7,870.2	1,902.17	4%		7%	37%		
										242.6		227.7	543.4	1,013.7	2,915.8
Total					62,556			43,410	8,862					10,285	19,147

WD: water district, CZ: climate zone, A: area, P: precipitation, V: water volume, Etr: real evapotranspiration, R: surface runoff, I: infiltration, I+R: water potential.
WP: Western Peloponnese, I: Ionian, EP: Eastern Peloponnese, WG: Western Greece, CEG: Central and Eastern Greece, WCM: Western and Central Macedonia, EMT: Eastern Macedonia and Thrace.
Water district and lithological formation areas, as well as infiltration ratios, were taken from Management Studies of the Ministry of Development.

Table 2.5 Processing of climate change data (Scenario A2, 2021-2050, mainland part of water districts)

WD	CZ	A (km²)	P (m)	P (mm)	V (million m³)	Etr (m)	Etr (mm)	Etr (million m³)	R (million m³)	Imperme-able formations	Semi-permeable formations	Alluvial formations	Karstic formations	I (million m³)	I+R (million m³)
										2,331 km²	1,300 km²	1,230 km²	2,440 km²		
1	WP	7,301	0.59	589.49	4,303.9	0.49	494.94	3,613.6	-21.75	3%	3%	10%	40%		
										41.2	23.0	72.5	575.3	712.1	690.3
										1,634 km²	838 km²	1,012 km²	4,993 km²		
3	EP	8,477	0.41	411.29	3,486.5	0.35	351.73	2,981.6	-498.23	3%	5%	10%	45%		
										20.2	17.2	41.6	924.1	1,003.1	504.9
										8,034 km²	1,138 km²	1,456 km²	9,583 km2		
4.5	WG	20,211	0.78	779.64	15,757.3	0.51	513.63	10,381.0	1,686.21	3%	3%	10%	45%		
										187.9	26.6	113.5	3,362.1	3,690.1	5,376.3
										10,310 km²	3,500 km²	6,904 km²	8,349 km2		
6.7.8	CEG	29,063	0.43	433.62	12,602.3	0.39	392.30	11,401.4	-500.53	2%	3%	10%	35%		
										89.4	45.5	299.4	1,267.1	1,701.4	1,200.9
										8,139 km²	5,298 km²	7,343	3,052		
9.10	WCM	23,832	0.50	496.39	11,830.0	0.40	404.52	9,640.5	890.51	3%	5%	10%	45%		
										121.2	131.5	364.5	681.7	1,298.9	2,189.4
										10,377		5,567	2,513		
11.12	EMT	18,457	0.54	538.85	9,945.6	0.45	452.24	8,347.0	663.88	4%		7%	37%		
										223.7		210.0	501.0	934.7	1,598.6
Total					57,925.5			46,365.1	2,220.08					9,340	11,560

WD: water district, CZ: climate zone, A: area, P: precipitation, V: water volume, Etr: real evapotranspiration, R: surface runoff, I: infiltration, I+R: water potential.
WP: Western Peloponnese, I: Ionian, EP: Eastern Peloponnese, WG: Western Greece, CEG: Central and Eastern Greece, WCM: Western and Central Macedonia, EMT: Eastern Macedonia and Thrace.
Water district and lithological formation areas, as well as infiltration ratios, were taken from Management Studies of the Ministry of Development.

Table 2.6 **Processing of climate change data (Scenario A2, 2071-2100, mainland part of water districts)**

WD	CZ	A (km²)	P (m)	P (mm)	V (million m³)	Etr (m)	Etr (mm)	Etr (million m³)	R (million m³)	Imperme-able formations	Semi-permeable formations	Alluvial formations	Karstic formations	I (million m³)	I+R (million m³)
										2,331 km²	1,300 km²	1,230 km²	2,440 km²		
1	WP	7,301	0.50	504.37	3,682.4	0.47	465.63	3,399.6	-326.40	3%	3%	10%	40%		
										35.3	19.7	62.0	492.3	609.2	282.8
										1,634 km²	838 km²	1,012 km²	4,993 km²		
3	EP	8,477	0.35	349.46	2,962.4	0.33	326.86	2,770.8	-660.74	3%	5%	10%	45%		
										17.1	14.6	35.4	785.2	852.3	191.6
										8,034 km²	1,138 km²	1,456 km²	9,583 km²		
4.5	WG	20,211	0.68	682.58	13,795.6	0.49	490.99	9,923.4	641.50	3%	3%	10%	45%		
										164.5	23.3	99.4	2,943.5	3,230.7	3,872.2
										10,310 km²	3,500 km²	6,904 km²	8,349 km²		
6.7.8	CEG	29,063	0.39	392.09	11,395.3	0.39	390.28	11,342.7	-1,485.86	2%	3%	10%	35%		
										80.8	41.2	270.7	1,145.7	1,538.5	52.6
										8,139 km²	5,298 km²	7,343 km²	3,052 km²		
9.10	WCM	23,832	0.44	442.92	10,555.7	0.38	382.37	9,112.6	284.01	3%	5%	10%	45%		
										108.1	117.3	325.2	608.3	1,159.0	1,443.0
										10,377 km²		5,567 km²	2,513 km²		
11.12	EMT	18,457	0.47	470.28	8,680.0	0.42	421.60	7,781.5	82.75	4%		7%	37%		
										195.2		183.3	437.3	815.7	898.5
Total					51,071			44,331	-1,465					8,206	6,741

WD: water district, CZ: climate zone, A: area, P: precipitation, V: water volume, Etr: real evapotranspiration, R: surface runoff, I: infiltration, I+R: water potential.
WP: Western Peloponnese, I: Ionian, EP: Eastern Peloponnese, WG: Western Greece, CEG: Central and Eastern Greece, WCM: Western and Central Macedonia, EMT: Eastern Macedonia and Thrace.
Water district and lithological formation areas, as well as infiltration ratios, were taken from Management Studies of the Ministry of Development.

Table 2.7 Processing of climate change data (Scenario B2, 2021-2050, mainland part of water districts)

WD	CZ	A (km^2)	P (m)	P (mm)	V (million m^3)	Etr (m)	Etr (mm)	Etr (million m^3)	R (million m^3)	Imperme-able formations	Semi-permeable formations	Alluvial formations	Karstic formations	I (million m^3)	I+R (million m^3)
										2,331 km^2	1,300 km^2	1,230 km^2	2,440 km^2		
1	WP	7,301	0.61	614.97	4,489.9	0.54	543.20	3,965.9	-218.85	3%	3%	10%	40%		
										43.0	24.0	75.6	600.2	742.8	524.0
										1,634 km^2	838 km^2	1,012 km^2	4,993 km^2		
3	EP	8,477	0.47	471.15	3,993.9	0.41	405.50	3,437.4	-592.61	3%	5%	10%	45%		
										23.1	19.7	47.7	1,058.6	1,149.1	556.5
										8,034 km^2	1,138 km^2	1,456 km^2	9,583 km^2		
4.5	WG	20,211	0.88	876.55	17,716.0	0.51	513.37	10,375.7	3,191.42	3%	3%	10%	45%		
										211.3	29.9	127.6	3,780.0	4,148.8	7,340.2
										10,310 km^2	3,500 km^2	6,904 km^2	8,349 km^2		
6.7.8	CEG	29,063	0.47	467.55	13,588.4	0.40	396.47	11,522.6	231.25	2%	3%	10%	35%		
										96.4	49.1	322.8	1,366.3	1,834.5	2,065.8
										8,139 km^2	5,298 km^2	7,343 km^2	3,052 km^2		
9.10	WCM	23,832	0.55	550.10	13,110.0	0.43	430.02	10,248.2	1422.26	3%	5%	10%	45%		
										134.3	145.7	403.9	755.5	1,439.5	2,861.7
										10,377 km^2		5,567 km^2	2,513 km^2		
11.12	EMT	18,457	0.62	618.31	11,412.1	0.49	485.82	8,966.8	1,372.86	4%		7%	37%		
										256.6		240.9	574.9	1,072.5	2,445.4
Total					64,310			48,517	5,406					10,387	15,794

WD: water district, CZ: climate zone, A: area, P: precipitation, V: water volume, Etr: real evapotranspiration, R: surface runoff, I: infiltration, I+R: water potential.
WP: Western Peloponnese, I: Ionian, EP: Eastern Peloponnese, WG: Western Greece, CEG: Central and Eastern Greece, WCM: Western and Central Macedonia, EMT: Eastern Macedonia and Thrace.
Water district and lithological formation areas, as well as infiltration ratios, were taken from Management Studies of the Ministry of Development.

Table 2.8 **Processing of climate change data (Scenario B2, 2071-2100, mainland part of water districts)**

WD	CZ	A (km²)	P (m)	P (mm)	V (million m³)	Etr (m)	Etr (mm)	Etr (million m³)	R (million m³)	Imperme-able formations	Semi-permeable formations	Alluvial formations	Karstic formations	I (million m³)	I+R (million m³)
										2,331 km²	1,300 km²	1,230 km²	2,440 km²		
1	WP	7,301	0.58	584.03	4,264.0	0.55	547.14	3,994.7	-436.13	3%	3%	10%	40%		
										40.8	22.8	71.8	570.0	705.5	269.3
										1,634 km²	838 km²	1,012 km²	4,993 km²		
3	EP	8,477	0.44	440.76	3,736.3	0.40	401.68	3,405.0	-743.72	3%	5%	10%	45%		
										21.6	18.5	44.6	990.3	1,075.0	331.3
										8,034 km²	1,138 km²	1,456 km²	9,583 km²		
4.5	WG	20,211	0.85	849.10	17,161.2	0.52	521.96	10,549.3	2,592.94	3%	3%	10%	45%		
										204.7	29.0	123.6	3,661.6	4,018.9	6,611.8
										10,310 km²	3,500 km²	6,904 km²	8,349 km²		
6.7.8	CEG	29,063	0.45	447.23	12,997.8	0.40	402.40	11,695.0	-451.92	2%	3%	10%	35%		
										92.2	47.0	308.8	1,306.9	1,754.8	1,302.9
										8,139 km²	5,298 km²	7,343 km²	3,052 km²		
9.10	WCM	23,832	0.53	531.73	12,672.2	0.43	430.79	10,266.6	1,014.19	3%	5%	10%	45%		
										129.8	140.9	390.4	730.3	1,391.4	2,405.6
										10,377 km²		5,567 km²	2,513 km²		
11.12	EMT	18,457	0.59	593.21	10,948.9	0.49	487.41	8,996.1	923.78	4%		7%	37%		
										246.2		231.2	551.6	1,029.0	1,952.8
Total					61,780			48,907	2,899					9,975	12,874

WD: water district, CZ: climate zone, A: area, P: precipitation, V: water volume, Etr: real evapotranspiration, R: surface runoff, I: infiltration, I+R: water potential.
WP: Western Peloponnese, I: Ionian, EP: Eastern Peloponnese, WG: Western Greece, CEG: Central and Eastern Greece, WCM: Western and Central Macedonia, EMT: Eastern Macedonia and Thrace.
Water district and lithological formation areas, as well as infiltration ratios, were taken from Management Studies of the Ministry of Development.

Table 2.9 Estimated percentage change in parameters V (precipitation volume) and I+R (water potential) of the general water balance by climate scenario and time period (in percentages)

	A1B		A2		B2	
2021-2050	V	I+R	V	I+R	V	I+R
	-8	-14	-8	-22	-3	-14
2071-2100	V	I+R	V	I+R	V	I+R
	-20	-37	-19	-54	-7	-30

(Scenario B1 was omitted). The processing of the results led to the formulation of two estimates for the following hydrological balance parameters: P (precipitation), Etr (evapotranspiration), I (infiltration) and R (runoff). In the first case, we were not able to obtain acceptable results for evapotranspiration and runoff, due to excessive evapotranspiration in littoral regions). In the second case, however, we were able to calculate all of the hydrological balance parameters in question. It must be noted that in the first case the geographical delineation of regions was such as to include *part mainland, part island* (except in the case of Water District 14, consisting entirely of the Aegean Islands), whereas in the second case, the delineation was such as to include *only mainland.* This distinction was made to evaluate result representativeness.

In processing the hydrological balance parameters, use was made of the infiltration coefficients for the respective lithological formations encountered in Greece, based on the data from the Management Studies (Master Plan) of the Ministry of Development (2003).

The results of our analysis for the mainland part are presented in Tables 2.3 to 2.8. A comparison of the results of each hydrological balance parameter under each envisaged scenario led to the results presented in Table 2.9.

As shown in Table 2.9, in the period 2021-2050, precipitation volume (V) is expected to decrease countrywide by between 3% (Scenario B2) and 8% (Scenario A2) and water potential (Infiltration + Runoff) by between 14% (Scenario B2) and 22% (Scenario A2). In the period 2071-2100, precipitation volume is expected to decrease by between 7% (Scenario B2) and 20% (Scenario A1B) and water potential by between 30% (Scenario B2) and 54% (Scenario A2).

In light of the fact that the demand for irrigation water corresponds to roughly 75-80% of the country's total water potential, it becomes apparent from these results that climate change would, together with changes in agricultural practices, have direct implications on crop type and area.

2.1.5.2 Correlation between rainfall, infiltration and surface runoff

Figures 2.2, 2.3 and 2.4, based on the processing of results obtained for the hydrological balance parameters for the periods 2021-2050 and 2071-2100, illustrate the relationship between

Figure 2.2 **Change in precipitation volume (V) and water potential (I+R), 1961-2100, Scenario A1B**

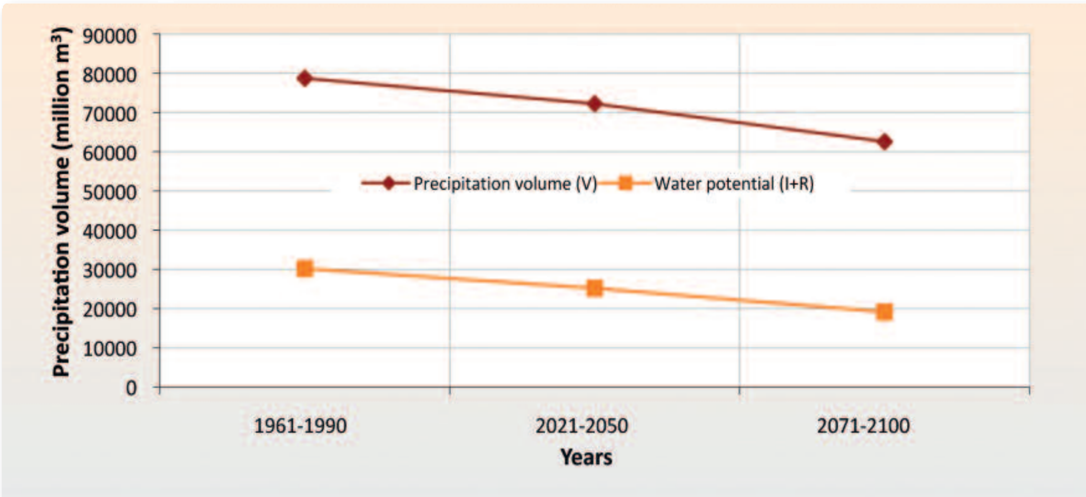
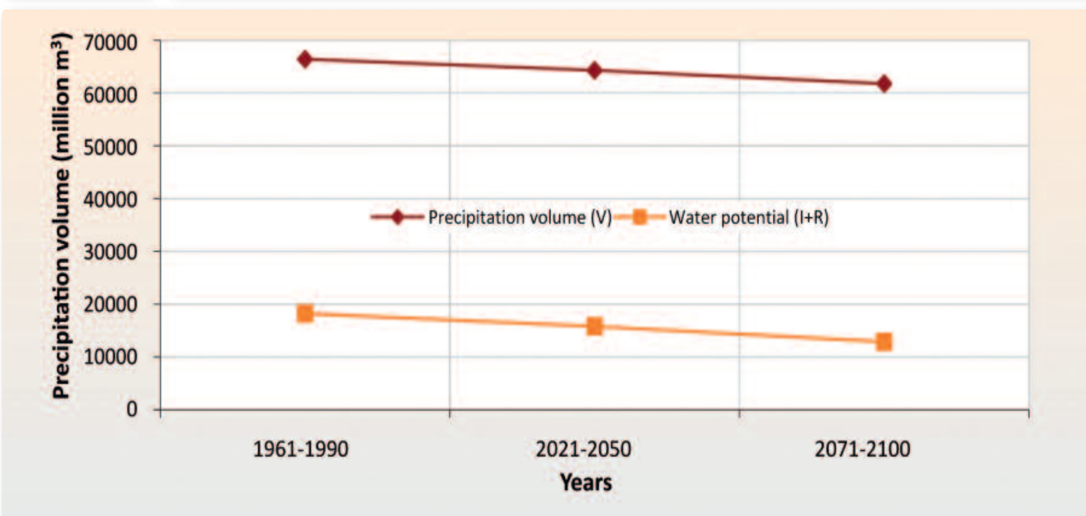


Figure 2.3 **Change in precipitation volume (V) and water potential (I+R), 1961-2100, Scenario B2**

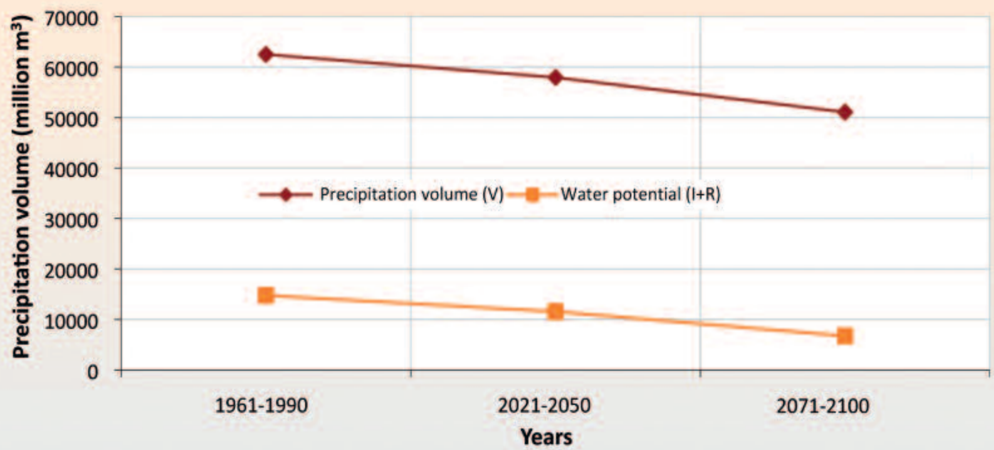


rainfall (V, in million m^3), infiltration (I, in million m^3) and surface runoff (R, in million m^3) under the respective scenarios (Scenarios A1B, B2 and A2).

2.1.6 Economic impacts of climate change on Greece's water reserves

Having estimated the physical impacts of Scenarios A1B, A2 and B2 on Greece's hydrological cycle and water reserves, we proceeded to an economic valuation of the impacts from cli-

Figure 2.4 **Change in precipitation volume (V) and water potential (I+R), 1961-2100, Scenario A2**



mate change. Due to time and data availability constraints, we narrowed our focus to the impacts on the public water supply, which includes many tourism and industrial uses, but excludes irrigation[4] and 'ecological purposes'.[5]

2.1.6.1 A typology of the economic impacts of water use

Water resources provide goods and services, the management of which has an economic and a socio-political dimension, and concerns several sectors of the economy. The possible economic impacts of climate change on freshwater availability are, thus, likely to affect a wide range of activities highly important to society, with additional repercussions further down the line. The major economic impacts expected include:

1. Lower productivity on account of the shortage (and, as a result, the poorer quality) of water resources in sectors where water is a major input in the production process (agriculture, hydroelectric power plants, industry, forestry, pisciculture, etc.).
2. Increased cost of pollution and wastewater treatment.
3. Increased risks (flooding, fires, etc.).
4. Decrease in benefits from recreation activities.
5. Loss of benefits due to damage to water ecosystems.
6. Higher cost of extracting underground waters.

4 The use of water for irrigation is indirectly estimated in Sub-chapter 2.4 which deals with the impact of climate change on agriculture.

5 'Water for ecological purposes', defined as the minimum quantity and quality of water reserves required in situ for ecosystems and species *not* to be endangered, represents a major use for water reserves in the light of climate change.

7. Increased risk of further seawater intrusion into underground aquifers.
8. Impacts on human health.
9. Negative impact on welfare, as a result of possible restrictions on water use.

The intensity of these economic impacts is, of course, expected to vary in function of the severity of the respective climate changes.

2.1.6.2 General framework for estimating the cost of climate change

Estimating the cost implications of climate change on water resources is a process of successive stages, which form the basis of economic valuation. The first stage consists in identifying the major stresses on water bodies likely to be induced by climate change. In a second stage, the repercussions of these stresses on water resources are assessed in volumetric, chemical and ecological terms. In a third stage, the damage sustained by the water systems and water users are identified and, where feasible, quantified, with 'damage' defined as the difference between the reference state (status quo) and the state expected to arise in the wake of climate change, taking in account both the impact on the supply and quality of water services *and* the increased risk. The risk increase rate is determined by a number of parameters, such as the probability of occurrence of severe flooding, aquifer salinisation (as a result of saline intrusion), health-related incidents (as a result of the poorer quality of water resources) and the smaller availability of water for fire-fighting use. The final stage involves the monetary valuation of the anticipated damage, drawing on methods for valuating both market and non-market goods and focusing in particular on the loss of welfare induced by changes in supply and in the quality of goods and services.

There are several ways to assess environmental impacts and climate impacts in particular (Papandreou and Skourtos, 2000). The economic assessment of non-market goods and services involves the monetary valuation of goods and services not traded in markets. Depending on the welfare measure used (price, cost or willingness-to-pay), the available methodologies can be classified into three categories: *pricing, costing (cost accounting)* and *valuing*. The first group consists of market methods, in which market prices serve as value proxies. Such methods are only suitable for measuring direct use value. The estimated prices represent a lower bound of the goods' 'true' values (maximum willingness-to-pay). The second group, i.e. costing methods, are based on the existence of a relationship ('weak complementarity') between environmental quality and private market goods. The third group, i.e. valuing or valuation approaches, are based on consumer preferences, and are further distinguished today into two sub-categories: (a) indirect or 'revealed' preferences for goods and services provided by the environment and (b) direct or 'stated' preferences for such goods and services.

On account of budget and time constraints, decision makers are rarely in favour of primary studies for the economic assessment of environmental goods and tend to prefer the 'benefit transfer' assessment method, which consists in 'transferring' the results of previously conducted economic assessments from the 'study site' to a new, but similar case, called 'policy site' (Navrud and Ready, 2007). This overcomes the need for primary field research. The use of the benefit transfer method for the economic assessment of environmental impacts has become quite widespread in recent years, due among other factors to the accessibility of large databases of valuation studies.

2.1.6.3 Water reserves, climate change and the economic cost of non-action in Greece

Published research on the economic assessment of water resources in Greece covers a wide range of goods and services. Unfortunately, the heterogeneity of the units used to measure the impacts makes the use of the relevant results for 'benefit transfer' problematic. Furthermore, the monetary valuations available from Greek studies do not seem to serve even 'conservative' estimates. Therefore, the economic valuation, performed in the present study, of the impacts of climate change on water services will be based on a costing method. Of all water uses, only domestic water use (including tourist use) was examined.

The economic valuation of climate-induced damage to water reserves was carried out using the following approach: First, the future demand for water resources was identified per year and water district. Second, assuming that the price of water is already an underestimate of its full value, we estimated in value terms the cost or benefit that would arise from the variation in water demand in 2041-2051 and 2091-2100. Third, we estimated what the future annual cost or benefit would be to the sector from the impact of climate change on the supplied quantities of water resources. After estimating the changes in demand and supply of water reserves, we were able to calculate the net result, which consists in subtracting the value of the variation in supply due to climate conditions from the value of the variation in demand. Finally, the process was completed with the calculation in monetary terms of the Net Present Value (NPV) of the loss.

As already mentioned, three scenarios (A1B, A2 and B2) were considered, using the market price of domestic water supply as a 'lower bound' of the resource's value to society. In Greece, the needs of the Attica and greater Thessaloniki areas are met, respectively, by the Athens Water Supply and Sewerage Company (EYDAP) and the Thessaloniki Water Supply and Sewerage Company (EYATH). In all other regions, the domestic water supply is managed either by a Municipal Water Supply and Sewerage Company (DEYA) or, otherwise, by a similar municipal service. These companies are usually able to recover their operating and administrative costs, plus part of the capital costs of the water supply and sewerage networks and of municipal well drillings, if needed (Ministry for the Environment, Physical Planning and Public Works, 2008). In brief, from the perspective of the Greek consumer, there is a wide disparity in what water bills actually cover and which body they are payable to, while from the perspective of the water companies only part of their total costs are recovered. In order to estimate the impacts at a Water District level, we used reference values corresponding to the average prices charged by the DEYAs for 1 m^3 of water (Hellenic Union of Municipal Enterprises for Water Supply and Sewerage, 2007) as follows:

- €1.54 in the Western Peloponnese, the Northern Peloponnese and the Eastern Peloponnese;
- €1.26 in Western Central Greece and Eastern Central Greece;
- €1.90 in Epirus;
- €1.08 in Thessaly;
- €0.73 in Attica;
- €1.67 in Western Macedonia;
- €1.20 in Central Macedonia;
- €1.09 in Eastern Macedonia and Thrace;
- €1.77 in the Aegean Islands; and
- €1.29 in Crete.

These prices concern 2007 and were obtained from data published by the DEYAs. The estimates produced for this study are prone to a number of uncertainties that arose at different stages of the estimation exercise, i.e. uncertainty regarding the estimation of a) climate data, b) the future distribution of water reserves, and c) Greece's future population. Meanwhile, in order to estimate the costs from climate change the following research assumptions were adopted: a) to estimate future demand, average expected water consumption was set at 200 litres daily per person for permanent residents and at 300 litres per person and overnight stay for tourists; b) the number of overnight stays in future was considered to remain stable, i.e. the same as today's; c) the price of water was also considered to remain stable. The cost estimates are given both undiscounted and discounted using discount rates of 1% and 3%.

The estimated cumulative cost of climate change in the water supply sector is presented in Table 2.10 for two different decades (2041-2050 and 2091-2100) and under the three considered scenarios. During the decade 2041-2050, the impact of climate change on the water supply sector alone would cost from 0.89% of GDP (Scenario A1B) to 1.32% of GDP (Scenario

Table 2.10 **Cost of climate change in the water supply sector**

	Cumulative cost of climate change			
	2041-2050		2091-2100	
Scenario	€ (prices 2007)	% GDP	€ (prices 2007)	% GDP
A1B	2,077,099,481	0.89	1,189,116,259	0.51
A2	3,069,725,843	1.32	4,284,065,911	1.84
B2	2,191,388,771	0.94	1,383,394,988	0.59

Source: Estimates of the authors.

Table 2.11 **Net Present Value (V) of total damage to water reserves, by scenario and discount rate**

	i=0%		i=1%		i=3%	
Scenario	€ (prices 2010)	% GDP	€ (prices 2010)	% GDP	€ (prices 2010)	% GDP
A1B	3,266,215,740	1.40	1,937,702,529	0.83	786,655,612	0.34
A2	7,353,791,754	3.16	3,926,853,946	1.69	1,355,659,735	0.58
B2	3,574,783,759	1.53	2,098,537,132	0.90	839,785,746	0.36

i=discount rate
Source: Estimates of the authors.

A2). During the decade 2091-2100, the decline in GDP would start at 0.51% in the best case (Scenario A1B) and climb as high as 1.84% of GDP (Scenario A2).

The final stage of the economic valuation process consisted in estimating the cost of the climate change impact in Net Present Value (NPV) terms. As can be seen from Table 2.11, the NPVs were estimated both undiscounted and discounted (using discount rates of 1% and 3%). When discounting was used, the total cost for the Greek economy was found to be greatest at 1.69% of GDP under Scenario A2 at a discount rate of 1%, and lowest at 0.34% of GDP under Scenario A1B at a discount rate of 3%. The climatic zones most vulnerable from an economic point of view were shown to be Central Macedonia and Central, Eastern and Western Greece.

2.1.7 Potential for adaptation and for addressing the impacts of climate change

Adaptation can prove to be a decisive option in light of the inevitable impacts of climate change, already being felt worldwide. Considering, first and foremost, that climate change mitigation policies call for concerted global action, and, secondly, that the Greek economy is not large enough to 'make a difference at the global level' in terms of greenhouse gas (GHG) emissions, the implementation of targeted adaptation actions presents itself as the only way for Greece to reduce the damage and costs it will sustain from climate change.

Adaptation is expected to play a major role in developing countries, likely to be affected both more severely and sooner by climate change. In the absence of adaptation measures, Greece would be faced with a situation similar to the one of developing countries, given its lack of an even basic integrated water management plan. The problem generated by this shortcoming would, aside from the general impacts of climate change (reduced rainfall, and increases in temperature, evaporation and water consumption needs), be further compounded by the irrational use of water for irrigation in the summer months (e.g. water irrigation canons and flood irrigation), water loss due to obsolete systems in urban water supply networks, the rising demand for water associated with population increases (influx of tourists, permanent population) and improving living standards (increased number of second/summer homes, parks, better everyday life conditions, etc.). To this overall situation, one would also have to add the acute impacts from increased evapotranspiration, increased irrigation and rising water consumption brought about by land use changes, notably the conversion of former farmland into resort areas.

The need for vigilance and to address the issue promptly and comprehensively is imperative. In the field of water systems, what is needed is the elaboration of a comprehensive integrated water management plan and corrective interventions to reduce the considerable loss of water (e.g. in public distribution and supply networks or via evaporation). Particular attention should also be drawn to specific small-scale instances (i.e. certain islands or a sector such as tourism) that could seriously undermine the overall water management effort (unregulated operation of private, licensed or unlicensed water well drillings).

Uncoordinated and unplanned adaptation poses a major risk to water systems in countries like Greece, where water management is one of many sectors suffering from deficient legislation (lack of water abstraction protection zones, incomplete restrictions on private water well drilling, etc.) and where violation and abuse of legislation are commonplace. Due to the inability of the State to meet water supply and irrigation needs in an efficient and well-regulated manner, what has come to prevail, with regard to water, is a kind of 'each man for himself', as illustrated by the number of unlicensed water well drillings, illegal connections and the frequent cases of overpumping, contamination and unregulated water trading. Policy-led adaptation, in order to be reliable and effective and to entail minimal side-effects, must be based on a comprehensive integrated water management plan and corrective interventions to reduce water loss.

Such a management plan should include:

- an elaborate national land-use plan, with a delineation and description of the uses of all surface and underground water bodies and lands;
- the implementation of a national water management plan, adjusted to prevailing conditions, with a permanent monitoring of implementation;
- a modernisation of irrigation systems;
- a modernisation of urban water supply systems;
- the establishment and protection of minimum, ecologically sound, freshwater reserves;
- the regulation of water abstractions, with restrictions applicable to each case;
- the reuse of water (e.g. for park irrigation);
- the artificial recharge of groundwaters (aquifers); and
- the establishment of water abstraction protection zones, at least for abstractions intended to public water supply needs, either directly (networks) or indirectly (bottling).

There is a wide and complex range of adaptation options available, belonging to two main categories depending on whether their purpose is (a) to satisfy demand, or (b) to manage, i.e. curb, demand. Policies geared towards satisfying total demand rely on large hydraulic infrastructure as their main tool, opting for such projects as dam construction, water transfer projects[6] (within a basin or between basins), aquifer recharge works and —when technically feasible— desalination. Policies geared toward managing, i.e. curbing, water demand, on the other hand, almost entirely rely on water pricing. The principle underlying this approach is that the rational pricing of water, in accordance with Directive 2000/60/EC on Water Resources, will provide an incentive for efficient water use. At the same time, an adequate pricing policy can ensure revenue much needed to ensure the maintenance of water supply infrastructure and the solvency of water companies. The complexity of the whole endeavour lies in the need to strike a balance between the two policy orientations.

The economic effectiveness of adaptation policy hinges upon a planning ability taking into account the technical and economic adaptation potential, and the specificities of each case. Cost/benefit analysis has been shown to be the most appropriate tool for choosing and applying the optimal mix of adaptation actions. However, alternative forms of adaptation policy can be assessed as to their cost and effectiveness only if the necessary specialised data for water resource management is available.

To give a particularly telling example, a study of data on water loss from network leakages, collected from a large sample of Municipal Water Supply and Sewerage Companies ("DEYAs") covering one fifth of the population of Greece, showed that the quantity of water lost corresponds to more than 60% of demand. Assuming that the water loss rate is similar in other water supply systems and that it could be reduced to an acceptable 10% (through network renewal and preventive maintenance), the average benefit from this adaptation action would, depending on the scenario, amount to some €240 million per year. One definite obstacle to the adoption of such a policy is the cost of implementation.[7]

Another good example to consider is the future cost effectiveness of water abstractions, under climate change conditions, from existing and potential water sources. Assuming that water abstraction costs remain unchanged for the municipal water companies (DEYAs) and that annual investments of roughly €68.4 million (± €7.8 million) are made, the estimated average annual benefit per climate scenario would come to €380 million (± €47 million). Once again, however, the cost of implementation would be a major obstacle.[8] A study of the cost effectiveness of adaptation could lead to the selection of alternative optimal policy mixes for each time period.

Listed immediately below are some of the more advisable adaptation actions (in terms of the benefits they would yield), the implementation costs of which have yet to be established:

6 Water transfers are associated with such environmental impacts as reduced river flow and decreased estuary sedimentation. The EU has formulated a series of considerations (COM (2007) 414 final) to be taken into account for inter-basin water transfers. In accordance with these considerations, particular attention is focused on water demand —both present and future— at the 'donor basin' level, in light of water scarcity likely to be induced by climate change. Moreover, the EU recommends studying the social and environmental impacts, at both the 'donor basin' and the 'receiving basin' level. The actual cost of the water transfer infrastructure is, of course, not to be overlooked.

7 The assessment of the cost effectiveness of the specific action exceeds the scope of the present study.

8 Once again, the assessment of the cost effectiveness of the specific action exceeds the scope of the present study.

- the preservation (non-use) of underground water reserves, suitable for future use in public water supply, in priority those situated near present-day consumptions;
- the water conservation potential on the users side, e.g. from the use of water saving appliances; and
- various institutional actions, such as pricing, incentives to reduce consumption, information/education/awareness campaigns, and the gradual banning of particularly water-consuming urban uses.

2.1.8 Conclusions

Climate change is expected to have the following negative impacts on the water resource sector in all of Greece's water districts and under all the scenarios considered:

- An overall decrease in aquifer infiltration and recharge, as a result of decreased rainfall and higher evapotranspiration;
- Increased salinity of coastal and subsea aquifers, particularly karstic ones, as a result of the advance of the sea-water intrusion farther inland due to the decline of groundwater levels caused by lower inflow and overpumping;
- Higher pollutant load concentrations in coastal water bodies and the sea, due to decreased dilution;
- A faster degradation of deltaic regions, in cases where degradation has already begun as a result of transversal dam construction upstream (reduced drainage and sediment discharge) and parallel levee construction in the flat zone of the deltas (debris channelled to a single outlet);
- Contamination or drainage of coastal wetlands; and
- Amplification of the desertification phenomenon as a result of water deficits and soil changes (compaction, sealing, etc.).

As shown earlier in Table 2.9, the period 2021-2050 is projected to see precipitation levels decrease countrywide by between 3% (Scenario B2) and 8% (Scenario A2) and total water potential by between 14% (Scenario B2) and 22% (Scenario A2). The period 2071-2100 is projected to see precipitation decrease by between 7% (Scenario B2) and 20% (Scenario A1B) and total water potential by between 30% (Scenario B2) and 54% (Scenario A2).

Considering that the demand for irrigation water corresponds to roughly 75-80% of the country's total water potential, it becomes apparent from these results that climate change would, together with changes in agricultural practices, have direct implications on crop type and area.

From a financial perspective, the highest, discounted damage for the Greek economy incurred in Scenario A2 reaching 1.69% of GDP at a discount rate of 1%. The lowest damage incurred in Scenario A1B reaching 0.36% of GDP at a discount rate of 3%. In annual terms, the damages range between €81.1 million (Scenario A2) and €69.3 million (Scenario A1B).

The most vulnerable climate zones for which the heaviest cost estimates was recorded were found to be Central, Eastern and Western Greece and, in the northern part of the country, Central Macedonia. However, there appears to be considerable leeway for adaptation measures.

The estimates produced for this study are clouded by a number of uncertainties that arose at different stages of the estimation exercise, i.e. uncertainty regarding the estimation of climate data, the future distribution of water reserves, and Greece's future population. It must furthermore be stressed that the use of water prices as reference values in economic valuation largely underestimates the real cost of climate change impacts. In fact, as shown by the implementation in Greece of Directive 2000/60/EC, the recovery rate of the full cost of water uses is so low that the prices charged for water cannot cover the financial costs or, a fortiori, the full costs of water use. It is broadly estimated that if the full cost of Greece's water resources had been estimated and used as a reference value in the present study, the cost of climate change would have been found to be three times higher.

2.2 Climate change risks and impacts from sea level rise*

2.2.1 Introduction

Throughout the course of modern history, coasts have been a substantial means of human development and an ever-growing number of people still continue to colonise the coasts worldwide. The rate at which human activities have been moving to the coastal zone has rightfully been described as "one of the greatest human migrations of modern times" (Tibbetts, 2002). Coasts make up dynamic and complex socio-ecological systems, encompassing a variety of biotic and abiotic elements. Their dynamic nature is responsible for their high productivity, leading to both periodic changes and gradual mutation.

The importance of coastal resources for the prosperity and wellbeing of coastal areas lies precisely in the ecosystem services and goods that they provide and that support human life (Daily 1997; Turner et al., 2001). A classification of coastal services and goods is presented in Table 2.12.

However, the anthropogenic activities ensuing from industrialisation and economic growth have brought coastal areas under intense pressure. Climatic change further exacerbates these pressures and has made mean sea level rise (SLR) one of the most predictable and alarming impacts globally (Church et al., 2001; Nicholls, 2007). To make things worse, SLR has, for roughly two decades now, been known to be rather inelastic to reductions in greenhouse gas

* Sub-chapter 2.2 was co-authored by: Areti Kontogianni, Christos Tourkolias, Michalis Skourtos, Dimitrios Papanikolaou, Maria Papanikolaou, and Serafim Poulos.

emissions (OECD, 2006), a phenomenon known as "commitment to SLR": even if drastic global mitigation policies succeed in stabilising the climate, SLR and the accompanying phenomena of coastal erosion and storm surges will continue to occur for centuries (Meehl et al., 2005; Wigley, 2005).

The present sub-chapter examines the impacts of SLR on Greece's coastal zone and assesses their economic dimension. Researchers engaged in studies like this are confronted with two important issues. The first is the quantification of the economic impacts (damages) caused by coastal land loss due to SLR. The second is the ex ante estimation of welfare gains from reducing SLR risks, since this estimation constitutes an important input for decision-making regarding policy and engineering measures (mitigation and adaptation measures). Cost-benefit analysis is used as a tool for prioritising different policy goals. Therefore, methodologically, it must succeed in associating economic estimates with measurable physical indicators, so that researchers are well aware of exactly what is being appraised (Kontogianni et al., 2010a; Sonderquist et al., 2008). Changes in physical indicators mostly refer to non-tradeable environmental goods (e.g. human health, biodiversity conservation, quality of ecosystems etc.). Due to the difficulty in appraising their economic value, they are usually not taken into consideration in decision-making, therefore they constitute an external cost.

Climate change is a source of vulnerability for natural systems (climate, coasts, oceans, forests, soil productivity, etc.). A multidisciplinary approach, in order to be integrated and successful, must deal with the co-evolutionary aspects of natural and socio-economic systems, known together as 'socio-ecological' systems (Folke et al., 2002).

2.2.2 State of play of Greece's coastal zone[9]

With a total shoreline of roughly 16,300 km, Greece has the most extensive coastal zone of any country in Europe. Almost half of this coastal zone is located in continental Greece, with the remaining half dispersed among Greece's 3,000 islands (or 9,800, if islets are included). The four main categories of coastal goods and services provided in abundance by Greece's coastal area are listed in Table 2.12.

About 33% of the Greek population resides in coastal areas within 1-2 km of the coast. If we define 'coastal population' as the population residing within 50 km of the coast, Greece's coastal population represents 85% of the total.

Twelve of Greece's total 13 administrative regions (prefectures) qualify as coastal (only one administrative region is landlocked). Located in the coastal zone are: (a) the country's largest urban centres (Athens, Thessaloniki, Patras, Heraklion, Kavala, Volos), (b) 80% of national industrial activity, (c) 90% of tourism and recreation activities, (d) 35% of the country's farm-

9 The information in this section is from the Ministry of the Environment, Physical Planning and Public Works (2006).

Table 2.12 **Categorisation of ecosystem services and goods provided by the coastal/marine environment**

Supportive services	1 Biogeochemical cycling	Regulating services	1 Atmospheric regulation
	2 Primary production		2 Local climate regulation
	3 Food web dynamics		3 Sediment retention
	4 Diversity		4 Biological regulation
	5 Habitat		5 Pollution control
	6 Resilience		6 Eutrophication mitigation
Provisioning services	1 Food	Cultural services	1 Recreation
	2 Inedible resources		2 Aesthetic values
	3 Genetic resources		3 Science and education
	4 Chemical resources		4 Cultural heritage
	5 Ornamental resources		5 Inspiration
	6 Energy resources		
	7 Waterways		

Source: Adapted from Garpe (2008) and MEA (2005).

land (usually highly productive), (e) the country's fisheries and aquaculture, and (f) an important part of the country's infrastructure (ports, airports, roads, power and telecommunication networks, etc.). The value added generated in the coastal zone includes:

- the operation of 20 ports, handling an annual total of over 1 million tonnes of cargo;
- a total fishery production of 96,000 tonnes;
- a total fishing fleet of 19,000 vessels (representing 20% of the EU-25 total);
- a total aquaculture production worth €258,000 (or 10% of the EU-25 total); and
- the majority of hotel beds in the tourism sector. During the tourist season (summer), it is not unusual for the population of some Greek islands to increase 2- to 10-fold, due to the influx of domestic and foreign tourists.

The fishery and aquaculture sectors are important due to their contribution to Greek GDP, but mostly due to their role in fostering and preserving the social and economic cohesion of the coastal areas. The fishery sector in 1999 employed 40,000 and had a total output of 231,000 tonnes, while aquaculture employed 4,800 directly and more than 7,500 indirectly.

The coastal zone encompasses important habitats, which contribute to the conservation of biogenetic reserves. Indicatively, over 6,000 different species of flora, 670 species of vertebrates, and 436 species of avifauna are found in the coastal zone.

Marine ecosystems, by sequestrating carbon, play a major role in regulating the climate, while phytoplankton through the process of photosynthesis releases oxygen into the atmosphere.

Coastal areas help generate and preserve microclimates. The presence of coastal forests and wetlands ensures the minimisation of floods, erosion and other natural disasters, and offers valuable regulating and supporting ecosystem services.

The last 20 years have seen a boom in the construction of summer houses in Greece's coastal areas. The total urbanised area in the coastal zone is estimated at 1,315 km^2, or 1.31% of the total area of Greece.

All of the aforementioned coastal resources contribute to the production of cultural services, such as leisure, aesthetic values, the potential for scientific and educational activities, the conservation of cultural heritage and cultural capital, while also providing sources of artistic/philosophical inspiration. The coastal ecosystem services therefore support and supply, in both natural and cultural terms, the transfer of social capital from one generation to the next on a scale that surpasses the local level and historically extends to the European and global level.

From all the above, it becomes evident that the coastal zone, as an important natural resource, merits our respect and protection.

The threats to the Greek coastal and marine environment can be natural (e.g. erosion), but mostly stem from anthropogenic driving forces (e.g. overexploitation of natural resources, urbanisation, pollution, eutrophication, invasive species).

One major problem of the Greek coastal zone is the high rate of coastline erosion: over 20% of the total coastline is currently under threat (EUROSION, 2004), making Greece the 4th most vulnerable country of the 22 coastal EU Member States. The main reasons for the increased erosion are the particularly strong winds and storm surges in the Aegean Sea, anthropogenic interventions —e.g. dams that reduce sediment discharge (Llasat et al., 2010)— and the geomorphology of the coastline substrate: 2,400 km (15% of the total shoreline) correspond to non-consolidated sediment deposits, while 960 km (6% of the total shoreline) correspond to coastal deltaic areas.

Erosion is expected to increase in the immediate future (Velegrakis, 2010), due to (a) the anticipated rise in mean sea level; (b) the intensification of extreme wave phenomena; and (c) the further reduction of river sediment discharge as a result of variations in rainfall and the construction of river management works.

2.2.3 Changes in sea level and geomorphology/geodynamics

A reliable assessment of the potential risk associated with SLR should not limit itself to the trends and rates of SLR, but also consider such local factors as tectonics, sediment supply (from inland), and coastal geomorphology/lithology. The **role of tectonics** is especially important in tectonically active zones (Vött, 2007), as it can counterbalance the relative SLR when there is a tectonic uplift, or conversely, amplify the SLR when there is tectonic subsidence. Typical examples include the coastal zone of the Northern Peloponnese (with an uplift rate of 0.3 to 1.5

mm/year), Crete (with 0.7 to 4 mm/year) and Rhodes (with 1.2 to 1.9 mm/year). Thus, a supposed average SLR rate of 4.3 mm/year would be reduced to 3.5 mm/year due to the counteraction of a mean tectonic uplift of 0.8 mm/year. **Changes, i.e. increases in fluvial sediment discharge and deposition** in deltaic plains can result in the advance of the shoreline and locally offset the sea level rise (Poulos et al., 2002). Conversely, reduced fluvial sediment discharge can reinforce the incursion of the sea following a sea level rise.

An important factor in the vulnerability of coastal areas to SLR is coastal morphology (i.e. slope and lithological composition), directly related to the rate of erosion. The latter can range from very high (several m/year) in the case of low-lying land to low (a few mm/year) in the case of hard coastal limestone formations (e.g. cliffs).

Using maps of a scale of 1:50,000 and basing ourselves on the SLR recorded in past decades, it was possible to indicatively map Greece's coastal areas according to their vulnerability to a potential SLR of 0.2 to 2 m by 2100. As can be seen from Image 2.1, three main categories were identified:

1) **Deltaic coastal areas.** Represented in red, these low-lying coastal areas are formed of loose, unconsolidated sediment deposits and are highly vulnerable to sea level rise.

2) **Coastal areas consisting of non-consolidated sediments of Neogene and Quaternary age.** Represented in green, these coastal areas, usually of low altitude, are prone to recessional erosion and present medium vulnerability to sea level rise.

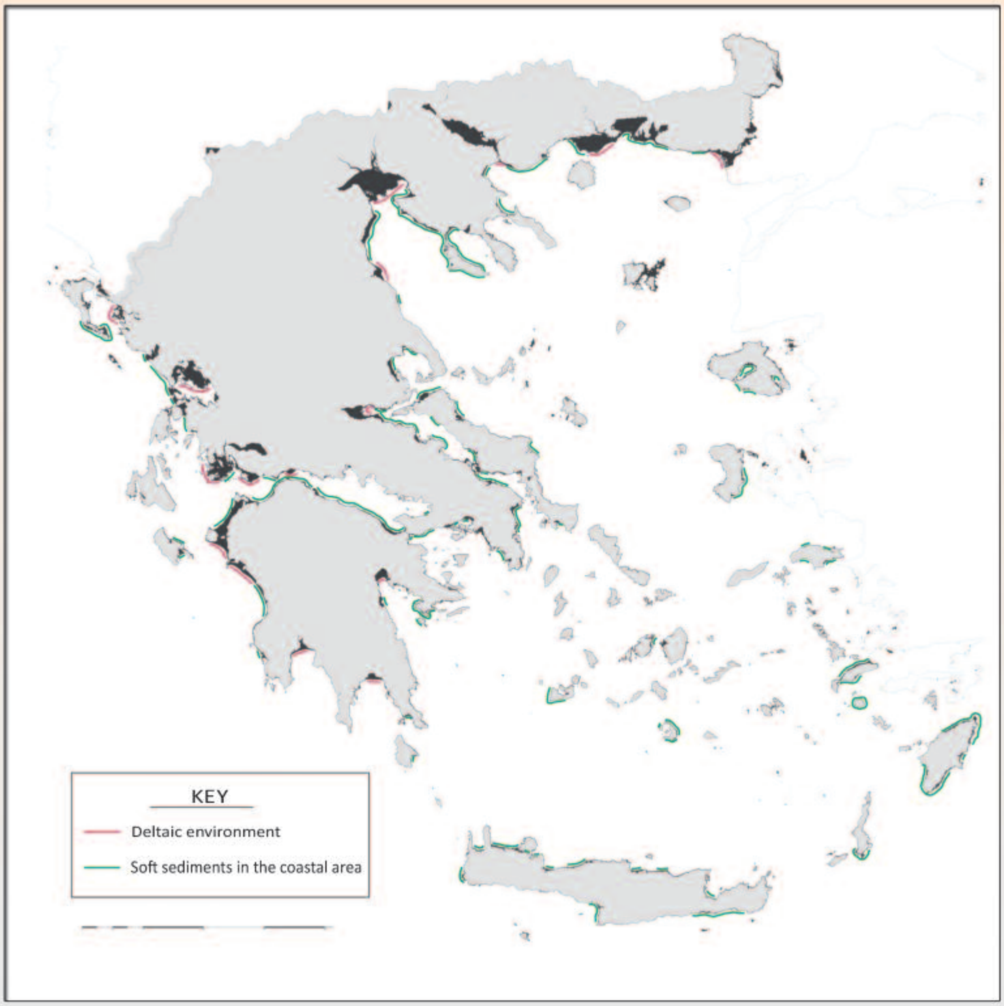
3) **Rocky coastal areas** (without any specific colouring/marking in Image 2.1). These coastal areas, sometimes of high altitude, consist mostly of hard rock of low vulnerability to erosion and SLR, and form the bulk of Greece's coastline.

Based on the above categorisation, the 'high risk' coastal areas of Greece include the deltaic areas of the following rivers: Evinos (Messolonghi); Kalamas (Igoumenitsa); Acheloos; Mornos (Nafpaktos); Pineios; Alfeios (Ilia); Aliakmon and Axios (in the Thermaikos gulf); Pineios (NW Aegean, near Platamon); Strymon (near Amfipolis); Nestos (towards Abdera); Evros; as well as the deltaic regions in the Malliakos, Amvrakikos, Lakonikos, Messiniakos and Argolikos gulfs. All of the other coastal areas are characterised as being of 'low vulnerability' and usually consist of rocky and high altitude coastal formations. The areas father inland and marked heavily in black in Figure 2.1 represent areas lower than 20 m in altitude, with typically loose sedimentary depositions.

Assessing the severity of SLR impacts on coastal areas involves uncertainties with regard to:

(a) The intensity of the sea level rise, ranging between 0.2 m and 2 m. SLR is determined by the interaction of several parameters, natural (e.g. astronomical) and anthropogenic (e.g. greenhouse gas forcing). The severity of each factor will affect the overall development of the climate cycle we are currently in, which seems to be at the peak of the current 'warm' interglacial period.

Image 2.1 **Coastal areas in Greece**



Coastal areas in Greece with medium (green colour) and high (red colour) vulnerability. Black colour indicates areas with altitudes below 20 m, usually of loose sedimentary deposits.
Source: Papanikolaou et al. (2010).

(b) The relationship between tectonic uplift and eustatic SLR. Quite important in several areas of Greece, the tectonic uplift may be significant enough to offset or locally even exceed SLR.

(c) The sedimentation of clastic materials in coastal areas, determined by geological and climatic conditions, as well as by human intervention (e.g. dams, river sand mining) and capable, e.g. in the case of river deltas, of altering the vulnerability to SLR (Velegrakis et al., 2008).

An estimation of the length of these three types of coastal areas showed that from a total of 16,300 km, 960 km (6%) correspond to deltaic areas of high vulnerability (marked in red),

Table 2.13 **Shoreline retreat and inundated area for potential SLR of 0.5 m and 1 m***
(For the case studies examined in this study)

Coastal area	SLR (m)	Shoreline retreat	Shoreline retreat due to		Total shoreline retreat (m)	Inundated area (10^3 m²)	Source
		Bruun model (m)	SLR (m)	Coastal erosion (m)			
Skala Eressos, Lesvos	0.3	-	-	-	-	28	Doukakis (2008)
Gulf of Nafplio	0.5	-	-	-	-	4,200	Doukakis (2005a)
	1	-	-	-	-	8,700	
Kotychi lagoon	0.5	-	-	-	-	720	Doukakis (2003)
	1	-	-	-	-	1,760	
Hersonissos, Crete	0.5	-	-	-	290	4,700	Doukakis (2004)
	1	-	-	-	320	5,200	
Aigio, Achaia	0.5	-	-	-	5-900	1,070	Doukakis (2005b)
	1	-	-	-	30-1300	1,800	
Lambi, Kos	0.5	-	-	-	114-153	35	Papadopoulou and Doukakis (2003)
	1	-	-	-	179-223	52	
Kardamaina, Kos	0.5	-	-	-	15-81	19	
	1	-	-	-	34-109	33	
Tingaki, Kos	0.5	-	-	-	28-101	161	
	1	-	-	-	69-167	322	
Afantou, East Rhodes	0.5	-	-	-	74 - 275	375	
	1	-	-	-	20 - 296	439	
Vartholomio, Ilia	0.5	-	-	-	31-107	190	
	1	-	-	-	68-154	300	
Acheloos River Delta	1	-	-	-	-	72	Doukakis (2007)
Plain of Thessaloniki	1	-	-	-	-	37,100	Kanellakis and Doukakis (2004), and Doukakis (2007)
Abdera, Macedonia	1	-	-	-	-	716	Doukakis (2007)
Lake Alyki, Lemnos	1	-	-	-	-	2,041	Pliakos and Doukakis (2004), and Doukakis (2007)
Kitros saltmarsh, Pieria	0.5	-	-	-	-	9,450	Stergiou and Doukakis (2003)
	1	-	-	-	-	11,800	

* Except for Skala Eressos, Lesvos (SLR: 0.3 m).

Table 2.13 **Shoreline retreat and inundated area for potential SLR of 0.5 m and 1 m *(continued)* (For the case studies examined in this study)**

Coastal area	SLR (m)	Shoreline retreat: Bruun model (m)	Shoreline retreat due to: SLR (m)	Shoreline retreat due to: Coastal erosion (m)	Total shoreline retreat (m)	Inundated area (10^3 m²)	Source
Porto Heli, Argolis	0.5	-	-	-	-	36	Seni and Karibalis (2007)
	1	-	-	-	-	161	
Ermioni, Argolis	0.5	-	-	-	-	19	
	1	-	-	-	-	278	
Evinos River Delta	0.5	-	-	-	-	12,500	Karibalis and Gaki-Papanastasiou (2008)
	1	-	-	-	-	21,300	
Mornos River Delta	0.5	-	-	-	-	2,580	
	1	-	-	-	-	3,710	
Kalamas River Delta	0.5	-	-	-	-	7,020	
	1	-	-	-	-	10,060	
Pineios River Delta	0.5	-	-	-	-	6,530	
	1	-	-	-	-	14,780	
Alfeios River Delta (northern part)	0.5	51.1	175	15	190	224	Poulos et al. (2009)
	1	102.2	810	-110	700	683	
Alfeios River Delta (southern part)	0.5	54.5	15-30	0-15	30	35	
	1	109	10-100	400	400-450	344	
Axios River Delta	0.5	52.7	250-2000	0	250-2000	10,825	
	1	213.6	2000-2500	0	2000-2500	28,482	
Aliakmon River Delta	0.5	63.6	50-1750	0	50-1750	4,875	
	1	195.4	250-2500	0	250-2500	8,950	
Loudias-Aliakmon deltaic plain	0.5	-	500-2750	0	500-2750	8,900	
	1	-	5000-6500	0	5000-6500	25,575	
South Euboean Gulf	0.5	-	-	-	-	7,890	Roussos and Karibalis (2009)

2,400 km (15%) correspond to non-consolidated sediments of medium vulnerability (marked in green), with the remaining 12,810 km (79%) corresponding to rocky coastal areas of low vulnerability. The total length of coastline presenting 'medium to high' vulnerability to SLR therefore roughly amounts to 3,360 km (21% of Greece's total shoreline).

Presented in Table 2.13 are approximate estimates of shoreline retreat and inundated area (excluding possible corrections of tectonics and geodynamics) in the event of an SLR of 0.5 m and 1 m in 'high risk' areas. The table data were drawn from 27 case studies, identified during a review of the Greek and international literature for the needs of the present study. The shoreline retreat likely to result from a hypothetical sea level rise of 0.5 m ranges from 15 m to 2,750 m, while the respective range for a hypothetical rise of 1 m is from 400 m to 6,500 m.

2.2.4 Storm surges – wave storms

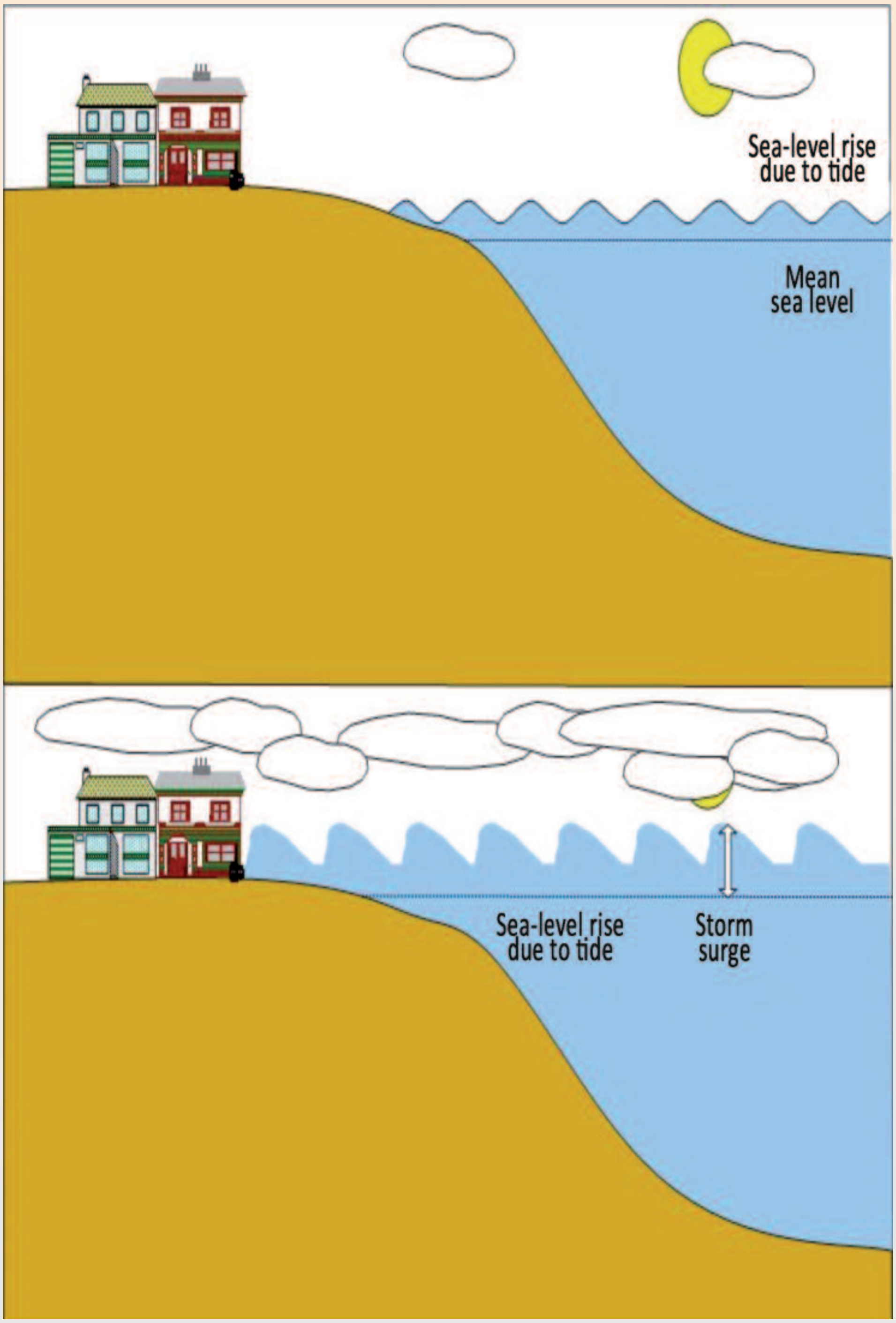
Apart from long-term SLR, other climate phenomena capable of causing coastal erosion are the anticipated increase in storminess and frequency of storm surges (IPCC, 2001, 2007). The strong coastal waves caused by stormy winds (and accompanying wave currents) cause erosion, whereas the normal, low-mid energy waves cause sediment deposition (Komar, 1998). Storm surges and SLR are distinct phenomena. However, SLR (which is caused by the thermal expansion of seawater as it warms and the melting of continental ice) may increase the intensity and frequency of storm surges. Changes in mean sea level and in storm intensity (amplified by climate change) may cause extreme wave phenomena and potentially serious damage to coastal areas. The reason for this is that strong winds affect larger water masses which unleash more energy in storm surges, while the height of the waves increases relatively to the mean sea level rise. As a result, the waves penetrate further into the coastal areas, producing significant impacts on coastline morphology (Krestenitis et al., 2010). The impacts of storm surges include (Karambas et al., 2008):

- flooding of coastal areas;
- destruction of coastal infrastructure (roads, coastal engineering works, etc.);
- coastal erosion; and
- intrusion of salt water in coastal habitats, lagoons, river, estuaries, etc.

2.2.5 Social perceptions of climate change, SLR and storm surges

Awareness of the vulnerability and adaptability to climate change —not only of natural systems but of the social system as well— is a crucial turning point for planning adequate policy. Adaptation is closely related to the notion of vulnerability, defined in the glossary of the IPCC Third Assessment Report as "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes". Vulnerability is a function of the nature, range and rate of climate change to which the system is

Image 2.2 Sea-level rise due to storm surge



Source: Kourogeni and Karambas (2010).

exposed, as well as of the system's sensitivity and adaptability. Reducing vulnerability therefore falls under the goals of preventive adaptation. The recent literature on vulnerability and adaptation stresses the need for measures and policy planning at two levels: (a) the technological level and (b) the institutional and behavioural level. Vulnerability and risk assessment (to be used as an input in decision-making) must also be conducted at two levels, i.e. objective and subjective. By subjective assessment of risk, we mean the social perceptions of risk, which are not necessarily identical to the objective assessment (Kontogianni et al., 2008).

For a more thorough understanding of the social perceptions of risk due to climate change in Greece, two research projects were designed and carried out, one in Lesvos in 2010 and one in Crete in January 2011. Their findings were comparable and show the dynamics in the respondents' perceptions, compared with a similar research project, conducted for the first time in Greece by the authors of present sub-chapter in 2003-2004 in Southern Euboia (Kontogianni et al., 2010b, c, 2011). Among the issues investigated by these projects were: whether the respondents were aware of climate change; whether they were aware of the causes and what they believed the causes to be; their level of trust in institutions; how important they assessed the various climate change impacts to be; whether they were prepared to cope with them; and whether they were willing to incur costs in order to protect themselves from the impacts.

2.2.6 Economic impacts of mean sea level rise in Greece[10]

2.2.6.1 Designing and assumptions of the present study

As time and other constraints in the context of the present study did not allow for a recording and valuation of all the potential impacts of SLR on Greece's coastal zone, we chose to focus on quantifying and assessing the impacts of SLR on the coastal land uses for:

- housing;
- tourism;
- agriculture;
- wetlands; and
- forestry.

One main reason for this selection was the availability of data from 27 case studies of Greece's coastal zone (Table 2.13). At a second level, an estimate was also made of the equally important aesthetic value of each area.[11] The estimated value of each 'coastal system' was taken as corresponding to the (future) cost to be incurred from its loss due to SLR. To properly appraise a

10 Detailed data and calculations for each case examined can be found (in Greek) in the full versions of the sea level study (Kontogianni et al., 2010a, b; Papanikolaou et al., 2010) posted on the webpage of the Climate Change Impacts Study Committee (CCISC) on the Bank of Greece website (www.bankofgreece.gr).

11 Some other services (e.g. coastal fishing) are discussed in other sub-chapters of the present study.

‘coastal system’ and its total economic value, *all* of the ecosystem services and goods it provides, as categorised in Table 2.12, would need to be evaluated. The results presented here therefore reflect only part of the value of the Greek coastal zone, taking into consideration the potential impact of SLR on the previously-mentioned five coastal land uses (tourism, housing, forestry, wetlands and agriculture). Our valuations of the ‘coastal zone’ resource represent a lower bound and an underestimate of its real value. The fact that the value of a coastal system is underestimated entails that the estimated future costs to be incurred due to SLR are also underestimated.

For a more thorough approach to the issue, we focused on assessing two different categories of economic impacts: **the long-term effects of SLR (by 2100)** and **the short-term effects of extreme weather events** (annually, base year: 2010). The valuation of long-term SLR damage took into consideration gradual SLR as specified by the IPCC scenarios, whereas the valuation of short-term SLR damage took into consideration the increased frequency of storm surges as an impact of climate change, taking place in parallel with SLR. It was considered important to include the impacts of short-term SLR in the present study, first because in accordance with IPCC methodology short-term SLR is associated with climate change, and second because several leading experts (Th. Karambas, Y. Krestenitis, A. Velegrakis and E. Doukakis in personal communications) concur that climate change increases storm surge intensity and frequency. Therefore, from a socioeconomic impact standpoint, a recurring phenomenon leading to short-term SLR and causing important economic damage is equally important as long-term and accelerating SLR (over a horizon of 90 years). To our knowledge, economic impact studies of past storm surges in Greece are rare and their results can therefore not be extrapolated to the entire coastal zone. For this reason, an additional stated preference survey economic assessment was conducted to assess the social cost of storm surges (Kontogianni, 2011).

In order to estimate the impacts of long-term SLR —on the basis of the 27 case studies— we calculated the total land area that would be lost for each of the five uses under study and the total loss of coastal area. A market pricing approach was then used for housing, tourism and agriculture uses, in order to estimate unit and total financial loss from inundation due to SLR. For wetlands and forestry, we relied on the widely used application of value transfer. The value transfer approach was also used to estimate the loss of aesthetic values. Loss of public infrastructure (airports, ports) and industrial zones were not taken into account.[12] More specifically:

- **The loss of farmland use**

The cost of farmland loss was estimated by multiplying the lost area with the Special Basic Value (SBV) of farmland in each investigated location. The SBV represents the value per square metre (m^2) of non-irrigated farmland for yearly crop cultivations. The SBV applies only to areas facing roads or located within 800 m of the sea.

12 For the cost valuation of damage to transport infrastructure, see Sub-chapter 2.9.

• **The loss of wetland use**

The cost of wetland loss was based on estimated wetland value. More specifically, the total area of wetlands expected to be lost to SLR was multiplied with their unit value. The wetland unit value (€4.8 million/km^2) was 'transferred' from Darwin and Tol (2001), a well-known study of SLR impact assessment.

• **The loss of forest use**

The cost of forestland loss was estimated by multiplying the total area of forestland expected to be lost with its unit value (€89.25/ha), as determined by Merlo and Croitoru (2005) for Greek forests.

• **The loss of housing and tourism uses**

The cost assessment of these impacts —both in the case studies where data was available on the present built environment and in the wider coastline area— was achieved by multiplying the total area lost in each case by the mean market value of property in the specific area. Using this assumption, we estimated the total tourist value of the coastline. Owing to the sparse data regarding land uses in the case studies and the wide variation of land prices, we adopted a mean estimated market value of property of €1,200/m^2, which properly reflects the mean land value for housing and tourism uses.

Using the cost assessments of the impacts attributable to the loss of housing, tourism, wetland, forest and agriculture land uses, as well as the total length and area of coastline examined in each case study, we then calculated a cost index, which estimates the financial cost of SLR per km or km^2 of coastline, depending on the data available in each case. All unit values used were adjusted across locations (to Greece) and time (2010) on the basis of the Purchasing Power Parity Index (PPPI) and the Consumer Price Index (CPI) (Pattanayak et al., 2002).

Lastly, we estimated the net present value of the losses by discounting the total amounts at rates of 1% and 3%. Choosing the proper (social) discount rate is crucial in such long-term assessments. Economic theory and practice cannot provide a definite answer, as the discounting rate issue is in essence an ethical one, involving intergenerational equity. Thus, in the OECD countries, the proposed discount rates range from 3% to 12% (OECD, 2007). The European Commission recommends a rate of 4% for medium- and long-term investments, but also accepts the use of lower rates in the case of extended timelines, like in the case of climate change (European Commission, 2005).

2.2.6.2 Results

2.2.6.2.1 Economic impacts of long-term SLR

The total loss of coastal land under the SLR scenarios of 0.5 m and 1 m, as estimated based on the methodological approaches of the case studies examined, is presented in Table 2.13. The total losses and the cost indexes were calculated for SLRs of 0.5 m and 1 m and for the five land

Table 2.14 Average cost coefficients and total length/area of shoreline per land use

Land use	Average cost coefficient		Length/ area of shoreline
	SLR 0.5 m	SLR 1 m	
Housing & tourism	€144,891 10^3/km	€262,851 10^3/km	2,400 km
Wetlands	€138 10^3/km²	€247 10^3/km²	1,000 km²
Forests	€0.04 10^3/km²	€0.13 10^3/km²	4,000 km²
Agriculture	€222 10^3/km²	€514 10^3/km²	35,511.5 km²

uses under study (housing, tourism, wetlands, forestry and agriculture).The total losses were calculated as the area to be flooded times the respective unit value for each specific land use. The cost indexes were calculated by dividing the total losses with the length of coastline in the case studies. The cost indexes therefore represent quantified indicators of total land loss, which is 'incorporated' and expressed per kilometre of coastline for the five land uses under investigation. The estimated financial losses from the case studies were then extrapolated to the national level. The values used as average cost indexes, as well as the length and area of coastline per land use, are presented in Table 2.14.

The total cost of the impacts of SLR by 2100 for Greece as a whole is presented per land-use in Table 2.15.

The present values of the estimated total costs by 2100, calculated using discount rates of 1% and 3%, are given in Tables 2.16 and 2.17, respectively.

It should be recalled here that the estimated losses presented in Tables 2.15, 2.16 and 2.17 essentially express 'use values', except for wetlands, for which the estimated cost index also

Table 2.15 Total economic cost of SLR in 2100 per land use (EUR thousands)

Land use	SLR 0.5 m	SLR 1 m
Housing & tourism	347,738,400	630,842,400
Wetlands	138,000	247,000
Forests	160	520
Agriculture	7,883,553	18,252,911
Total	355,760,113	649,342,831

Table 2.16	Present value of total economic cost of SLR per land use (Discount rate 1%, EUR thousands)	
	Present value (2010)	
Land use	SLR 0.5 m	SLR 1 m
Housing & tourism	142,013,297	257,630,475
Wetlands	56,358	100,873
Forests	65	212
Agriculture	3,219,574	7,454,328
Total	145,289,294	265,185,888

Table 2.17	Present value of total economic cost of SLR per land use (Discount rate 3%, EUR thousands)	
	Present value (2010)	
Land use	SLR 0.5 m	SLR 1 m
Housing & tourism	24,316,576	44,113,412
Wetlands	9,650	17,272
Forests	11	36
Agriculture	551,279	1,276,386
Total	24,877,517	45,407,106

partly includes 'non-use' values. However, the 'non-use' (e.g. cultural and spiritual) value of many coastal ecosystems is a non-negligible part of their total economic value. A similar approach is the widespread use of 'hedonic pricing' in the real estate market, according to which the price of non-built land also encompasses such location factors as view, proximity to areas of cultural and spiritual importance, etc.

In line with this approach and in an attempt to express the magnitude of the possible cost from land value loss to SLR, we subsequently attempted to quantify the aesthetic/recreational and cultural/heritage values of residential and tourism land and wetlands. This was done based on value transfer from the study by Brenner et al. (2010), which estimates in economic terms the aesthetic/recreational and cultural/spiritual value of sandy and wetland coastal areas of Catalonia, Spain. To avoid double counting, these values were not taken into account when calculating the final loss figures attributable to SLR, but are nonetheless presented in the conclusions to this sub-chapter to give a sense of the real coastal values at stake.

2.2.6.2.2 Economic impacts of storm-driven wave and surge events: the short-term aspect of SLR

Storm-driven wave and surge events, which make up the short-term aspect of SLR, account for substantial annual impacts on the coastal area. Recording such impacts under the present study was considered important, due both to their economic weight and to the possibility of annual recurrences, making them factors of increased coastal vulnerability. Given, however, the limited data from on site research and, as a result, of the inability to generalise the losses to the entire coastal zone, an open-ended contingent valuation survey was conducted on the economic assessment of loss (damage) from short-term SLR (Kontogianni, 2011). The participants were asked about their 'willingness to pay' (WTP) for the construction of storm surge protection works in their area. The mean willingness to pay was estimated at €200.7 per household (standard deviation: €286).

According to the Report of Greece on Coastal Zone Management (Ministry of the Environment, Physical Planning and Public Works, 2006), the country's coastal population amounts to 9,293,982 or 85% of the total population (10,934,097 inhabitants). Assuming an average of three members per household, the total number of Greek households comes to 3,674,381, of which 3,097,994 live in coastal areas. Using a mean willingness to pay of €200.7 per household and extrapolating it to the Greek coastal population, the total value of protection from short-term SLR for Greek households comes to €621,767,426.

2.2.6.3 Adaptation policies

As estimated by the authors, the impacts on Greece's coastal areas of gradual long-term SLR and of storm-driven wave and surge events are expected to be particularly important in the next decades. The implementation of a coordinated adaptation policy is thus warranted to ensure the protection of Greece's extensive coastline of 16,300 km. As pointed out in the latest national report submitted to the UNFCCC regarding climate change (Hellenic Republic, 2006), no coordinated effort to assess the long-term impacts of SLR and to design appropriate adaptation policies has, as yet, been conducted in Greece. The basic adaptation policy suggested involved a total estimate of the risk that Greece's coastal regions face on account of climate change and SLR.

A number of studies have already presented interesting data on the cost of implementing adaptation policies.[13] For instance, the Scottish Natural Heritage (SNH, 2000) estimated the cost of various 'soft' and 'hard' engineering works for effective shoreline management against the impacts of erosion impacts. In the US, the Mississippi-Alabama Sea Grant Consortium (MASGC, 2007) has estimated the cost of shoreline protection products. Estimates of costs for coastline protection works can also be drawn from Sorensen et al. (1984), while both Koch

13 See footnote 10.

(2010) and the study for the valuation of SLR impacts on the coasts of California financed by the California Energy Commission (CEC, 2009) used identical cost estimates for selected adaptation policies. Finally, the adaptation policies studied under the PESETA programme (Richards and Nicholls, 2009) were dike construction and beach nourishment.

Greek case studies on adaptation to SLR

In the context of the present study, four case studies were selected for a cost/benefit analysis of selected adaptation policies to the SLR impacts. The study sites and adaptation measures considered were:

- Case Study 1 (CS1): Groynes, in the Lambi area on the island of Kos.
- Case Study 2 (CS2): Artificial beach nourishment, in the Kardamaina area on the island of Kos.
- Case Study 3 (CS3): Placement of riprap revetments and geotextile filter, in the Afantou area on the island of Rhodes.
- Case Study 4 (CS4): Concrete seawall, in the Tingaki area on the island of Kos.

Figure 2.5 Cost and benefit of adaptation measures in the case studies (CS) (EUR thousands)

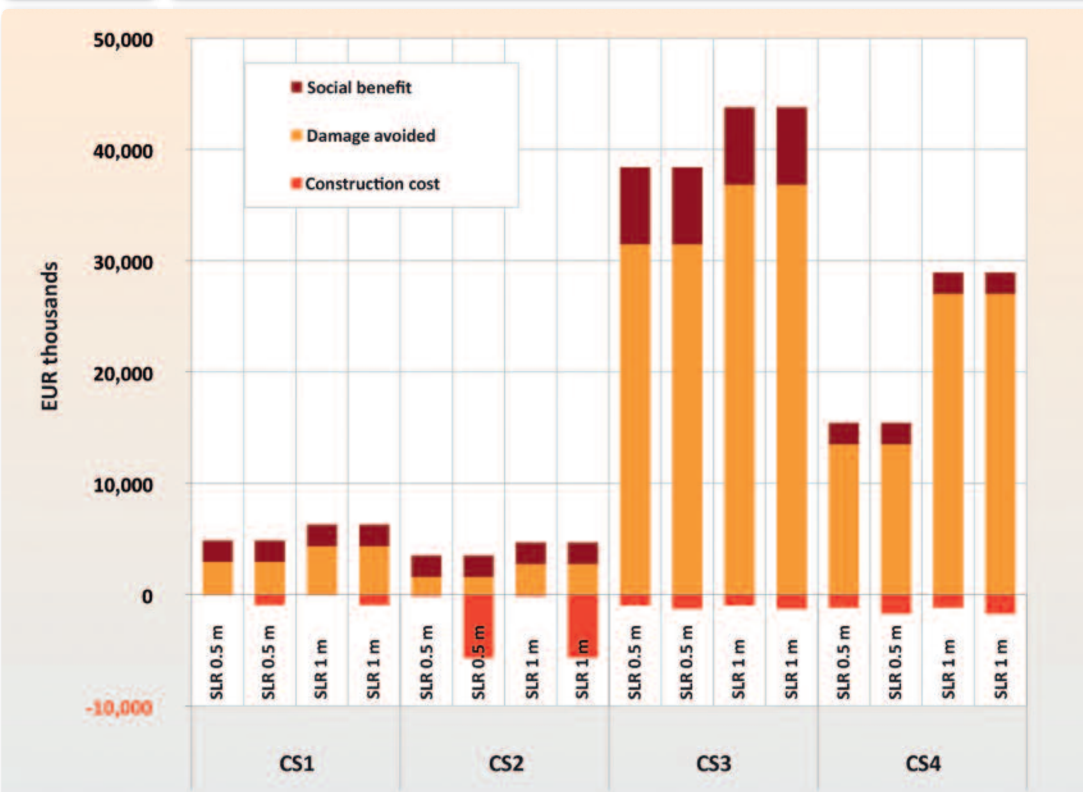


Table 2.18 Damage avoided as a result of breakwater construction in medium vulnerability areas (Discount rate 1%, EUR thousands)

Land use	Present value (2010)	
	SLR 0.5 m	SLR 1 m
Housing & tourism	142,013,297	257,630,475

Table 2.19 Damage avoided as a result of breakwater construction in medium vulnerability areas (Discount rate 3%, EUR thousands)

Land use	Present value (2010)	
	SLR 0.5 m	SLR 1 m
Housing & tourism	24,316,576	44,113,412

As can be seen from Figure 2.5, which illustrates the cost effectiveness of the adaptation measures considered, the **net benefit is positive** in all cases, except for the artificial beach nourishment in CS2 where the net benefit was negative only when a discount rate of 3% was used (which, by the way, is rather high) and only for the upper estimates of the work under construction. This figure is a visual representation of the cost/benefit analysis using a 3% discount rate, in which: the 'construction cost' is the implementation cost of the adaptation measure for coastal protection, 'damage avoided' from long-term SLR is equal to the estimated value of the land area saved as a result of protection works, and the 'social benefit' is the benefit for society (measured by the WTP) arising from the adoption of measures to avoid short-term impacts such as storm surges.

The cost effectiveness of adaptation measures can be easily substantiated at a countrywide level. As a working hypothesis, we examined the construction of breakwaters as an adaptation to climate change impacts (short- and long-term SLR) along the entire length of coast (2,400 km) consisting of newly-formed soft sediments of medium vulnerability. Considering that the cost of breakwater constructions was estimated at between €558/m and €1,394/m by the SNH (2000) and between €159/m and €613/m by the MASGC (2007), we set the minimum cost of breakwater construction at €159/m and the maximum cost at €1,394/m. The total cost of the measure's implementation was thus estimated to amount to between €381.6 million and €3,345.6 million.

The corresponding avoided losses in present values, given in Tables 2.18 and 2.19, confirm that the benefits of adaptation are clearly higher than the corresponding costs, even when benefits are discounted at a relatively high rate (3%).

2.2.7 Conclusions

The Greek coastline is already subject to serious erosion problems, which are likely to be compounded by two major threats from climate change: long-term and short-term SLR. The impacts are as much a concern to the built environment and human populations as to major environmental systems. Given the importance of the coastal zones in the economy of Greece —a country with some 16,300 km of coastline, 12 of its 13 administrative regions open to the sea, and coastal tourism accounting for 15-18% of national GDP— to consider 'business as usual' a viable option would be irrational, to say the least.

The present study attempted to assess the economic impact of climate change from SLR for the entire Greek coastal zone. After a brief presentation of the main characteristics of the Greek coastal zone and its uses, we analysed the main long-term and short-term impacts to be expected and, in Image 2.1, mapped out the areas of low, medium and high vulnerability. The forecasts of SLR by 2100 ranged between 0.2 and 2 m.

The estimated economic losses from the 27 case studies examined (for 'housing', 'tourism', 'wetland', 'forest' and 'agricultural' land uses) were then extrapolated to the national level using the respective cost coefficients. The results are presented in Table 2.20.

The costs estimated so far essentially correspond to the *use* values of coastal ecosystem services. For the sake of completeness, we therefore made a **separate estimate** of the costs likely to arise from the coastal loss of aesthetic/recreational and cultural/spiritual values. To avoid any double counting, the estimates of these **non-use impacts were not included** in Table 2.20, but presented separately in Table 2.21.

We then estimated the economic impact of storm-driven wave and surge events as an expression of the short-term aspect of SLR. Having estimated the mean 'willingness to pay' to be €200.7 per household and extrapolated this figure to the entire coastal population, the **total value of protection from short-term SLR** for Greek households was estimated at €621,767,426 per year.

Table 2.20 **Total economic cost of long-term SLR in the Greek coastal zone (EUR thousands)**

	SLR 0.5 m	SLR 1 m
Total loss (2100)	355,760,113	649,342,831
Net present value (1%)	145,289,294	265,185,888
Net present value (3%)	24,877,517	45,407,106

Table 2.21 **Total economic cost of SLR as a result of the long-term loss of aesthetic/recreational and cultural/spiritual values in the Greek coastal zone (EUR thousands)**

	SLR 0.5 m	SLR 1 m
Total loss (2100)	847,340	1,538,100
Net present value (1%)	346,046	628,146
Net present value (3%)	59,253	107,556

As indicated by the estimates this far, the impacts on Greece's coastal areas from both gradual SLR and storm-driven wave or surge events are expected to be particularly important in the next decades. The implementation of a coordinated adaptation policy is thus considered necessary to ensure the protection of Greece's extensive coastline of 16,300 km. The four case studies for which adaptation costs and benefits were estimated show a clear cost effectiveness of the adaptation measures considered (in almost all cases the net benefit was positive). If, as a working hypothesis, the coastal protection measures are extrapolated to a national scale (specifically, to the 2,400 km of shoreline consisting of newly-formed soft sediments of medium vulnerability, and excluding the 960 km of shoreline corresponding to deltaic coastal areas of high vulnerability), the evidence (presented in Tables 2.18 and 2.19) once again supports the cost effectiveness of adopting immediate coastal protection measures.

The estimated value of each 'coastal system' was taken as corresponding to the (future) cost to be incurred from its loss due to SLR. To properly appraise a 'coastal system' and its total economic value, *all* of the ecosystem services and goods it provides, as categorised in Table 2.12, would need to be evaluated. The results presented in this study therefore reflect only part of the value of the Greek coastal zone, taking into consideration the potential impact of SLR on five coastal land uses (tourism, housing, forestry, wetlands and agriculture). Our valuations of the 'coastal zone' resource represent a lower bound and an underestimate of its real value. The fact that the value of a coastal system is underestimated entails that the estimated future costs to be incurred due to SLR are also underestimated.

Our study found a pressing need for a study of the Greek coastal areas at high risk of inundation. This need should extend to a detailed diagnosis/forecasting of coastal zone vulnerability also due to changes in frequency/intensity of extreme weather phenomena (storm surges). At an institutional level, the EU Member States are required, in accordance with Directive 2007/60/EC, to have undertaken by 2011 a preliminary assessment of river basin flood risk (including the coastal zone), with a view to identifying areas where flooding is likely to occur. Moreover, the EU Member States are required to have completed flood hazard maps and flood risk maps of these areas by end-2013, and to have completed and published flood risk management plans for these areas by end-2015.

With regard to the impact valuation performed, its reliability depends first and foremost on the reliability of the physical primary data. For the purposes of the present study, all available case studies of the physical impact valuation of SLR in Greece were consulted in a first attempt at a valuation of the phenomenon. If, for instance, the physical impacts of long-term SLR (inundated area) are overestimated, this would mean that the economic impacts are also overestimated. In order to minimise overestimating our economic assessments, we adopted conservative estimates of the economic losses. An effort was also made to avoid any double counting. For instance, reference could also have been made to the additional economic losses pointed out by the IPCC, while the authors also chose not to take into account —due to the uncertainty surrounding SLR data and forecasts— the change in economic values in cases where, owing to incomplete knowledge, the consequences of SLR are uncertain. Given that the housing/tourism land use value of the coastal zone represents an important measurable parameter in our damage estimates, and that the analysis of social vulnerability showed the social perception of risk from SLR to be rising, it is fairly safe to presume that, if the coastal real estate market were to discount and internalise the future risk of coastal disasters, coastal land values would gradually depreciate, solely as a consequence of coastal risk anticipation. The need for immediate adaptation measures therefore becomes all the more imperative, in the light of the scientific confirmation of short-term and long-term risks from SLR.

2.2.8 Recommendations

There are three main lines of approach to policy planning for adaptation to SLR-induced impacts (Nicholls 2007a, IPCC-CZMS, 1990; Bijlsma et al., 1996; and Klein et al., 2001; see also Image 2.3):

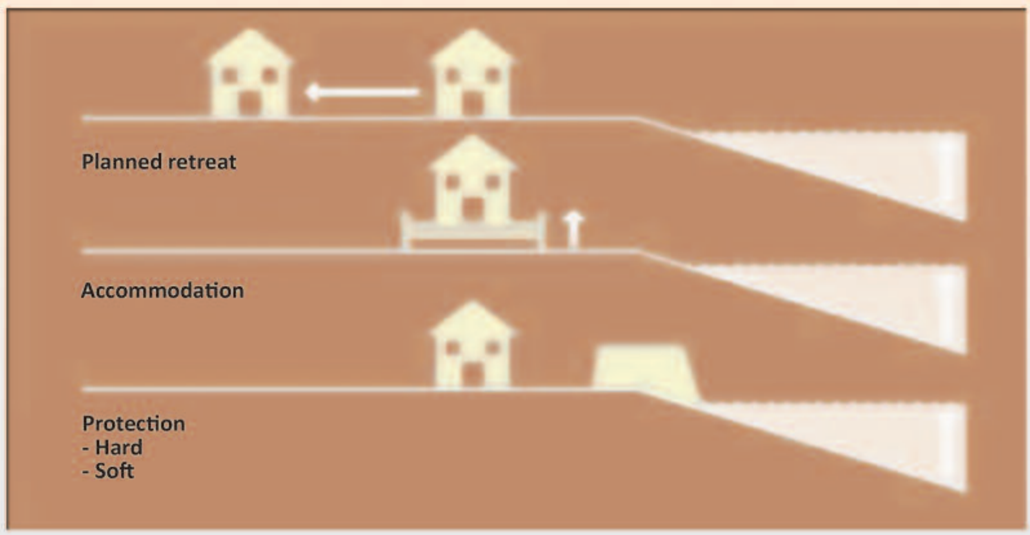
I. Retreat: SLR materialises and the impacts on society are minimised through a managed retreat from the affected coastal areas of all human activities and uses.

II. Accommodation: SLR materialises, and the impacts on society are minimised accordingly in the affected coastal areas through a modification of human activities and uses.

III. Protection: SLR materialises, and the impacts are addressed through soft and hard protective engineering, which minimises the social impacts that would have otherwise occurred.

Protection via coastal engineering works was discussed earlier in the study. Managed retreat from the coastal areas is one available option for an effective adaptation to SLR-induced risk

Image 2.3 **An illustration of the possible adaptation responses to sea-level rise**



Source: Nicholls (2009).

and losses, and for a prevention of a potential coastal squeeze on ecosystems. Some managed retreat actions are:

- The planning and development of protection zones between the shoreline and the residential development zone.
- Discouraging residential and business development in coastal areas at a high risk of erosion, and even prohibiting land use (where necessary) in threatened coastal areas.
- Evacuating coastal areas facing immediate risk.
- Relocating buildings and facilities to safer locations and higher grounds. All new constructions in coastal areas would, from the start, have to be relocatable.

Immediate adoption and implementation of a national adaptation plan is necessary to reduce the impacts of SLR. The main pillars of such an integrated plan should include: the elaboration a coastal cadastre; the designation of high-, medium- and low- risk zones depending on the characteristics of each coastal area so that soft or hard engineering works can be envisaged; the proper selection and construction of the necessary engineering works, and the setting-up of a permanent coastal monitoring system. Determining the implementation costs of the different adaptation policies is necessary to establish their cost effectiveness. Aside from engineering works, a national adaptation plan also has to recognise the need, and support the relevant potential, for mild institutional and behavioural adaptation policies, to encourage the relevant markets to internalise the risks from SLR and to bolster all efforts geared towards enhancing the country's social capital in the management of its coastal resources.

2.3 Fisheries and aquaculture*

2.3.1 Introduction

The main factors of climate change that will affect the goods and services provided by the country's fisheries and aquaculture sector are related, first, to the expected rise in temperature and in CO_2 dissolved in various water bodies, and, secondarily, to rising sea levels. A reliable estimate of these changes should, apart from direct measurements (very few of which exist today) also take changing ecological and physico-chemical parameters into account. Sustainable ecosystem management when applied to fisheries and aquaculture must aim to conserve the ecosystem structures and ensure the livelihood of the local human population, while also focusing on water quality parameters (e.g. nutrients, biodiversity at different trophic levels, plant/animal species production, temperature, stratification, transparency, dissolved oxygen and carbon dioxide concentrations, pH, ammonia) and the interactions between them (Papoutsoglou, 1981, 1990).

Overexploitation and non-selective fishing gear, together with pollution and aquatic environment disruption (e.g. seafloor disturbance) are the main reasons for the reduced yield of natural fisheries. In addition, the impacts of changing climate on the physico-chemical and biological properties of water bodies (rivers, lakes, lagoons, seas) are expected to have different repercussions in each case on output potential and uses. The aim of present sub-chapter is to estimate the likely impacts of climate change on fisheries and aquaculture production.

2.3.2 The current productive capacity of Greece's water bodies

2.3.2.1 Fisheries production

2.3.2.1.1 Inland water bodies

The total approx. area of Greece's lake water bodies is roughly 910 km^2 (natural lakes: 580 km^2; artificial lakes: 330 km^2). The seven largest natural lakes (Trichonis, Volvi, Vegoritis, Vistonis, Koronia, Little Prespa and Great Prespa) are situated for the most part in the plain areas of Northern Greece, while the five largest artificial ones (Kremasta, Polyphytos, Kerkini, Kastraki and Plastiras) are situated in mountainous/semi-mountainous areas of the country's central districts. The ecological status of most lakes in Greece (30-32) has not been fully determined. The average fish production capacity of Greek lakes is estimated at 20-25 kg/ha per year (Kagalou et al., 2008; Konstantinou et al., 2006; Markou et al., 2007; Mitraki et al., 2004; Ministry of Agricultural Development and Food, 1986-2005).

* Sub-chapter 2.3 was co-authored by: Sofronios Papoutsoglou, Costas Papaconstantinou, Phoebe Koundouri, Kyriaki Remoundou, Stefanos Kavadas, Areti Kontogianni, Kostas Eleftheratos and John Kapsomenakis.

Of Greece's 26 rivers, three (i.e. rivers Evros, Nestos and Strymon) have their source in Bulgaria, one (river Axios) has its source in FYROM, while another one (river Aoos) has its source in Greece (in the northern part of the Pindos range) but its estuary in Albania. The total length of rivers within Greek borders is 2,780 km, the longest river being river Aliakmon (297 km). The total average annual discharge for all rivers combined is 800 m^3/sec, with the highest flows recorded by the rivers Evros, Acheloos, Strymon and Axios, in that order. In terms of total riverbed area, the five largest rivers are rivers Evros (~54 km^2), Axios (~25 km^2), Strymon (~17 km^2), Pineios (~11 km^2) and Aliakmon (~9 km^2). The overall ecological status of Greek rivers can be described as unstable and unpredictable, particularly in the plain regions they run through. Most rivers support organisms of the upper trophic levels, mostly fish. Due to limited data availability, safe conclusions cannot be drawn about river fish production (Iliopoulou-Georgudaki et al., 2003; Konstantinou et al., 2006; Skoulikidis, 2009; Vieira et al., 2008; Ministry of Agricultural Development and Food, 1986-2005).

2.3.2.1.2 Lagoon areas

Mainland Greece comprises a total of 76 lagoons, covering a total area of roughly 350 km^2 (72% landlocked). Messolonghi (86.5 km^2) is the largest, followed by lagoons Vistonis (45 km^2) and Logarou (35 km^2). The overall ecological status of the above lagoons can be described as unstable due to their varying physico-chemical properties and their level of eutrophication. More predominant are the euryhaline species of fish, followed by certain stenohaline (marine) species, various invertebrates, and in some cases freshwater species. Greece's lagoons are an important present or potential source of fisheries and aquaculture production. Official data on fisheries production using fishing gear other than traditional traps are not available (Dassenakis et al., 1994; Kagalou et al., 2008; Markou et al., 2007; Ministry of Agricultural Development and Food, 1986-2005).

2.3.2.1.3 Coastal and marine areas

Greece has the longest coastline of all the countries of the Mediterranean and the EU, with a total length of roughly 16,300 km and a total 1,354 gulfs and bays. The total sea area of Greece (470,000 km^2) is 3.6 times its total land area. Administratively, the country is divided into 13 regions, 12 of which are coastal (only one is land-locked). The length of coastline prone to erosion has been estimated at 3,945 km (28.6%). More than 85% of the total population lives within 50 km of the coast, and 69% of the national GDP (€140,268 million) is produced there.

Greece's larger gulfs – such as the Thermaikos, Pagassitikos, Saronikos (Saronic), Corinthiakos (Corinth), Evoikos (Euboean), Amvrakikos – are the more ecologically degraded. Some of the more closed gulfs, such as the Thermaikos, experience seasonal toxic phytoplankton blooms. The marine environment's ecological degradation is primarily due to the disposal of

Table 2.22 **Annual fish catches, 1990-2009 (In tonnes, fishing vessels with horsepower >20 HP)**

Year	SST*	Benthic	Small pelagic	Mesopelagic	Large pelagic	Total
1990	19.22	70,397	25,812	13,508	2,726	112,442
1991	18.95	78,986	28,189	13,872	2,716	123,763
1992	18.93	88,215	32,887	17,749	2,473	141,324
1993	19.05	93,946	35,858	22,715	2,757	155,276
1994	19.87	109,834	38,864	29,749	3,572	182,019
1995	19.40	92,987	35,320	18,716	3,124	150,146
1996	19.03	92,203	35,237	18,638	2,637	148,714
1997	19.06	92,391	36,580	15,471	3,253	147,695
1998	19.61	57,304	38,005	8,807	2,826	106,942
1999	20.16	65,925	33,669	7,553	2,371	109,517
2000	19.72	49,299	27,434	8,406	2,925	88,063
2001	20.05	44,652	27,854	7,720	3,036	83,261
2002	20.06	45,482	29,206	8,981	2,242	85,910
2003	20.02	51,059	24,252	7,849	1,913	85,072
2004	19.69	53,160	25,220	8,030	1,526	87,936
2005	19.60	52,395	24,475	9,143	1,890	87,903
2006	19.36	52,905	28,312	9,316	1,886	92,419
2007	19.72	51,939	28,418	8,464	1,526	90,348
2008	19.47	47,480	29,843	7,187	991	85,501
2009	19.76	45,396	26,533	6,917	1,208	80,054
Mean value	19.53	66,798	30,598	12,439	2,380	112,215

* Sea-surface temperature.
Source: NSSG.

solid and liquid waste from the coast, navigation (e.g. crude oil tankers), and overfishing, and, to a lesser extent, to the unorthodox use of floating cages in coastal fish farming. The open seas are, on the other hand, less affected by human activities, and their overall ecological status is satisfactory to very good.

The few measurements of physico-chemical and biological properties available are sporadic measurements of temperature, salinity, dissolved oxygen, nutrients, primary production and benthic species. Heavy metals were measured in the previous decade, under the UNEP programme. POSEIDON —a marine environmental monitoring, forecasting and information system for the Greek seas— provides in situ measurements of a large number of physical parameters, as well as wave height data. In their vast majority, the fish species encountered in the Greek

Table 2.23 **Greek sea fisheries production and percentage share of the 10 most commercially important fish species, at 5-year intervals, 1987-2009 (Production in tonnes, fishing vessels with horsepower >20 HP)**

Year	Northern Aegean		Central Aegean		Southern Aegean		Ionian Sea		Total	
	Production	%	Production	%	Production	%	Production	%	Production	%
1987	56,178.0	42.60	18,960.1	54.32	26,165.9	41.87	5,022.6	51.67	106,326.6	46.78
1992	78,631.9	41.05	25,097.6	65.19	25,371.4	45.65	12,177.1	63.57	141,278.0	48.10
1997	74,624.3	38.06	20,213.6	52.49	38,192.7	50.80	14,658.0	48.97	147,688.6	44.41
2002	46,529.9	56.14	9,254.5	67.34	17,867.6	39.76	12,259.5	43.22	85,911.5	52.09
2007	47,483.5	52.70	17,355.7	63.33	14,828.2	45.67	10,682.7	49.13	90,350.1	53.17
2009	36,732.3	57.11	17,906.9	61.89	15,716.6	45.71	9,699.2	52.54	80,055.0	55.39

%: Percentage share of the 10 most commercially important fish species: sardines, anchovies, chub mackerels, cods, bogues, red mullets, horse mackerels, mackerels, tunas and monkfish.
Source: NSSG.

seas are stenohaline and relatively stenothermal. It should be noted that in recent years the Greek seas have seen a gradual increase in warmer-water species (mostly phytoplankton and jellyfish), as well as fish and other aquatic organisms. These invasive species are presumed to be in competition with species native to the Greek seas. Their appearance in recent years and faster expansion northward in the Aegean may be related to a rise in Greek sea temperature and to underlying climatic changes (Pancucci-Papadopoulou et al., 2005). The 'Lessepsian' migrants present today in Greece's seas include 28 fish, 11 crustacean and 1 cephalopod species, and a larger but unspecified number of phytoplankton and zooplankton species (ELNAIS, 2010).

An analysis of the variations in total annual catch production over the period 1990-2009 (Table 2.22) for fishing vessels >20 HP reveals that almost all categories of catches peaked in the years 1993-1997. Since then, production has been trending downward across all categories, except small pelagic fish, with the 2009 catch levels in the more important categories falling below 50% of earlier peaks. Over the same period, the fishing fleet decreased by roughly 27% and sea surface temperature (SST) rose by 0.7ºC.

The abundance distribution of the 10 most commercially important species fished by boats >20 HP, presented in Table 2.23 at 5-year intervals from 1987 to 2009, is rather difficult to interpret, basically because of the statistical data collection method used. As of 2002, all EU Member States are required to collect fisheries data using a specific methodology, as outlined in Council Regulations (EC) Nos 1543/2000 and 199/2008. Greece, however, has not been very compliant in this respect, hence the lack of a complete time series from 2002 onward (Kavadas et al., 2007).

Table 2.24

Freshwater fish production, 2006 (in tonnes)

Type of catch	Number of enterprises	Annual production
Rainbow trout	94	2,450
European eel	8	375
Common carp	9	110
Atlantic salmon	5	5
Total	126	2,950

2.3.2.2 Aquaculture production

2.3.2.2.1 Freshwater fish production

The total production of freshwater fish farmed in controlled intensive aquaculture systems is rather limited (Table 2.24), yet gradually increasing (1980: 2,150 tonnes; 2006: 2,950 tonnes).

The farming of rainbow trout and Atlantic salmon requires very clean waters, high levels of oxygen saturation, and temperatures of 13-17ºC. The common carp and the European eel can tolerate less clean water conditions, lower oxygen levels and a temperature range of 6-28ºCand above 12ºC, respectively. The fish farming tanks must have a depth of at least 1-1.5 m, except in the case of the European eel where shallower waters can be used (~50 cm, D'Orbcastel et al., 2008; Papoutsoglou, 1997; Papoutsoglou, 2004; Ministry of Agricultural Development and Food, 1986-2005; Greek Fishing Development Corporation; Hellenic Statistical Authority).

2.3.2.2.2 Production of euryhaline and stenohaline species

The production of euryhaline and stenohaline fish species is limited in extensive aquaculture production systems in coastal sea regions (2,000 tonnes/year), but far more important in modern intensive systems (~120,000 tonnes/year), with the production of gilthead sea bream and European bass accounting for 48% of the European total. Greece counts some 100 private companies (with 318 operating units) using floating cages. Compared with their extensive counterparts, the intensive aquaculture systems obviously pose a greater threat to the environment, although this impact is highly localised (Anagnostou et al., 2005; Cochrane et al., 2009; Daw et al., 2009; Papoutsoglou, 1996; Papoutsoglou et al., 1996; Vieira et al., 2008; Papoutsoglou, 1992; Ministry of Agricultural Development and Food, 1986-2005; Greek Fishing Development Corporation; Hellenic Statistical Authority).

The controlled mass production of mussels (24,000-25,000 tonnes/year) is practiced in a total area of ~40 ha, mainly in the coastal areas of Northern Greece (Thermaikos gulf, Pieria prefecture) which yield 80-90% of total national production. More than 400 companies in

Greece use floating or suspended facilities in eutrophic areas, i.e. areas of high primary production. The ecological status of these areas is fragile and their management calls for particular attention, as noted by the Ministry of Agricultural Development and Food (1986-2005), the Greek Fishing Development Corporation and the Hellenic Statistical Authority.

2.3.3 Physical impacts of climate change on Greece's fisheries production

The apparent rise in temperature, combined with lower precipitation levels, can lead to unexpected fluctuations in river flows and to unpredictable ecological degradation downstream, as competition for water obviously reduces water availability. Numerous lakes are also projected to be at similar risk, particularly at times of prolonged drought. This is expected to lead to a degraded environment for the ichthyofauna and to a possible decrease in the productive potential of inland waters (Allison et al., 2009; Bobori and Economidis, 2006; FAO, 2008; Mavrakis et al., 2004).

The rise in sea temperatures is likely to accelerate the growth rate of poikilothermal aquatic animals. It is difficult, however, to predict whether this could translate into higher fisheries production, given that verification would require an area that is not fished and that the fisheries status of an area is predominantly determined today by overfishing, rather than by natural factors. Interestingly, despite the fact that the SST of the Aegean has risen in recent decades by 1.5ºC, catches have not increased (in fact, they have decreased). It has been estimated that for every increase of 1ºC in SST over the period from 1990 to 2008, the average fish production in almost all categories fell by 0.8% (taking into account the reduction in the fishing fleet, and leaving all other factors unchanged). These lower production levels may, apart from overfishing, also be attributable to changes in nutrient levels in the Greek seas.

The temperature rise will in addition to a sea level rise (SLR) also bring about changes in biodiversity, fishing ground characteristics (biological, physical, chemical and hydrological) and available stocks of commercial importance. The total area of wetlands, which provide important spawning and nursery grounds, would be greatly diminished. The rise in temperature would also affect the migration of fish to and from their spawning and feeding grounds. A generalised change in sea temperature could quite possibly cause changes in water circulation (surface, toward the coast, upward, downward, coastal currents), with all that this would entail for the ecological/productive capacity of different water bodies. At this stage, it should be pointed out that changes in rainfall seem to affect only cephalopods and malacostraca (with decreases of 20 mm in rainfall translating into 2% less production).

2.3.4 Physical impacts of climate change on aquaculture in Greece

The continued use of intensive aquaculture production systems is soon expected to generate serious ecological/environmental problems, particularly in cases where coastal floating cages are used. As a result, production is likely to decrease. In addition, the increased frequency and intensity of extreme weather events, e.g. tornados, could cause considerable damage not only to fishing boats and floating cages, but also to fish and mussel farming facilities along the coast (Anagnostou et al., 2005; Pagou, 2005; Papoutsoglou, 1991; Papoutsoglou and Tsiha, 1994; Papoutsoglou, 1996; Papoutsoglou, 1997; Papoutsoglou, 2004).

Finally, because of the apparent rise in sea and lagoon water levels, aquaculture systems and methods are likely to be seriously reconsidered (e.g. the need to avoid coastal areas). The rise in coastal sea levels is also likely to affect the reproduction and growth of various species of fish, as well as the overall level of fisheries productivity (Doukakis and June, 2004; European Commission, 2008; FAO, 2008; Flemming and Woodworth, 1988).

2.3.5 Analysis of fish catch variations in Greece and future estimates

In order to determine the link between SST variation and fisheries yields, we analysed fish catch data from a large statistical sample of 2,244,304 tonnes, collected by the Hellenic Statistical Authority (ELSTAT) for the period 1990-2009. Fish catches were categorised as benthic, small pelagic, mesopelagic and large pelagic (see Table 2.22). Relative to total catches, benthic fish accounted for 60% (1,335,953 tonnes), small pelagic fish for 27% (611,967 tonnes), mesopelagic fish for 11% (248,789 tonnes), and large pelagic fish for 2% (47,595 tonnes).

The ELSTAT statistical catch data were used both to analyse catch variation in relation to SST variation and to measure certain catch variations against rainfall variation.

The analysis was conducted at the countrywide level for the period 1990-2009, using the annual of fish catch quantities presented in Table 2.22 and monthly mean values, adjusted for seasonality. This analysis only omitted the effect of overfishing over time, due to changes in the fishing fleet and not to long-term changes in fish populations. The main results can be summarised as follows:

(a) Analysis of fish catch variations in Greece in relation to SST variations, and future estimates

We analysed the annual catch quantities for the period 1990-2009, adjusting for the declining trend in the fishing fleet, estimated at 1.34% per year. The statistically significant variation trends in catches were as follows: Total fish catches amounted to 2,244,304 tonnes/year, with an overall decrease of 2,491 tonnes/year. Benthic fish catches decreased by 1,854 tonnes/year, mesopelagic fish catches decreased by 571 tonnes/year and large pelagic fish catches decreased by 66 tonnes/year. In contrast, small pelagic fish catches increased by 0.3 tonnes/year. The variation in SST over the 1990-2009 period was 0.035ºC/year or 0.7ºC in total over the two decades. The variation in catches over 1990-2009 are presented in Table 2.25.

Monthly catch time series, adjusted for changes in fishing fleet size and for seasonality, were used to calculate the effect of each 1ºC rise in SST on catch variation. As shown in Table 2.26,

Table 2.25 Total fisheries production and variations, 1990-2009 (in tonnes)

Types of fish	Total	Annual variation	Variation over 20 years
Benthic	1,335,953	-1,854	-37,080
Small pelagic	611,967	+0.3	+6
Mesopelagic	248,789	-571	-11,420
Large pelagic	47,595	-66	-1,320
Total	2,244,304	-2,491	-49,814

Table 2.26 Variation in fish catches with each 1°C rise in SST (in tonnes)

Types of fish	Variation, in tonnes
Benthic	-724 *
Small pelagic	+12
Mesopelagic	-160 *
Large pelagic	+12
Total	-859 *

* Statistically significant changes, at 99% confidence interval.

for every 1ºC rise in SST, benthic fish catches decrease by 724 tonnes (1.1% of the mean) and mesopelagic fish catches decrease by 160 tonnes (1.3% of the mean).

An increase of 3.3ºC in SST by 2100 (according to the climate model simulations, Chapter 1) would, based on the foregoing analysis, translate into decreases in Greece of benthic fish catches by 3.6% of the mean and of mesopelagic fish catches by 4.2% of the mean. Large and small pelagic fish catches would increase by 40 tonnes respectively, i.e. by 1.7% and 0.13% of the mean. Total catches would fall by roughly 2.5% of the mean.

(b) Correlating catch variations with variations in rainfall

Our investigation of possible correlations between different catch categories and rainfall in Greece showed that there is no statistically significant correlation between rainfall and fish and invertebrates/bivalve molluscs. In contrast, statistically significant correlations with rainfall (around 0.15) with a lag of 11 and 17 months, respectively, were found for cephalopods and malacostraca. Based on these correlations, we estimated that a 20% decrease in rainfall (corresponding to Scenario A1B) would lead to a decrease in cephalopod and malacostraca catches in the order of 2%. For all other species, reduced rainfall was not found to have an impact on production.

The impacts of anthropogenic climate change on fisheries production, as estimated on a global scale by the Intergovernmental Panel on Climate Change (IPCC), can be summarised as follows:

1. Changes and local fluctuations in sea and inland water fisheries production are to be expected, as well as a mixing of different species.

2. The stock of sea fish species that reproduce in inland waters (e.g. the European eel) or needing low salinity wetlands is also expected to decrease.

2.3.6 Measures and strategies for mitigating climate change impacts

The impacts of rising temperatures on marine ecosystem structures and fish populations have already been felt with the 'El Niño' phenomenon off the coasts of Peru. In the early 1960s, Israel was forced to modify its fishery targets and techniques because of the 'Lessepsian migrants' invasion, basically at the expense of native species. Similarly, the appearance of the comb jelly species *Mnemiopsis leidyi* in the Black, Caspian and Aral Seas drastically reduced the anchovy population because the invader feeds on anchovy eggs and larvae. The anchovy population has since recovered, implying that a natural enemy of the *Mnemiopsis leidyi* may have appeared and/or that the *Mnemiopsis leidyi* may have been affected by the dwindling numbers of anchovy. Further down the line, such changes in fish populations inevitably impact employment levels in the fisheries sector as well as consumer options.

This is what makes the timely designing of strategies and measures geared towards mitigating the ecological, economic and social impacts of climate change so important. The following actions are needed:

1. Fishery production determinants and the sector's employment potential must be recorded, and the active involvement of those employed in fisheries ensured through open dialogue and cooperation to achieve best possible information and awareness levels.
2. Institutional mechanisms and bilateral international agreements need to be established to activate or expand fisheries interests beyond national borders, with a view to spreading out the fishing power and making more resources available.
3. Emergency plans need to be designed for specific fisheries sectors (e.g. artisan fishing) that are unable to relocate and are likely to be most affected by climate change.
4. Fisheries management must be coupled with broader coastal zoning to ensure that coastal protection measures also include spawning and nursery ground protection.
5. Provisions for coastal protection and for maintaining aquaculture productivity, resilience and viability must be handled under a framework of ecological regional development. Provisions will also be needed for changes in production systems, including possible relocation, as well as for possible changes in species farmed.

6. Research funding needs to be redirected to the analysis and study of local and regional problems, adaptation, fishing fleet/gear size and composition, and interdisciplinary research.
7. Adaptation infrastructure for new species or fish populations needs to be provided for and designed. Fishing vessels will need to be replaced with larger ones and their onboard catch-processing capacity increased to achieve greater catch management efficiency.
8. Coastal regions must be clearly delineated (zoning) to ensure that aquaculture does not infringe on other activities (e.g. tourism).
9. Incentives must be given for various fishery activities to relocate.
10. Incentives will also have to be given for hyper-intensive systems, mainly for farming sea fish and euryhaline species in land/coastal facilities of closed and semi-closed water systems.
11. Regulations must be established and enforced to prevent the misuse/disruption of water bodies and to cultivate an ecological conscience in present and future generations.

2.3.7 Economic impacts

The present study has combined market information with benefit transfer estimates to assess the total economic cost of climate change for fisheries and aquaculture in Greece. The study has performed a cost valuation of the loss of domestic biodiversity (as a result of the spread of invasive alien thermophilic species) and the loss of income for the human populations employed in fisheries activities (as a result of fishery resource depletion) (Greek Biotope/Wetland Center, 2010). The fact, however, should not be overlooked that the settlement of stocks of a higher economic value, associated with higher water temperatures, is likely to increase fishermen income or at least to limit income loss.

With respect to the economic cost assessment of climate change for commercial fisheries, the average annual volume of fish catches between 1990 and 2009 came to 112,215 tonnes (Table 2.22). Assuming that this average annual fish catch volume will remain unchanged until 2100 and based on our earlier estimates that a 3.3ºC rise in SST by 2100 would entail reduced total catches by 2.5% (or 2,805.37 tonnes) and that, according to NSSG data (2009), 2007 catch prices ranged from €0.6 to €25.1 (with a mean of €5.3 and a median of €4.2), the income loss at 2007 prices in 2100 would amount to €14,868,461 (based on the mean), or €11,782,554 (based on the median). The present value of these income losses based on mean and median figures and assuming discount rates of 1% and 3%, as well as the corresponding equivalent annual costs (annuities) are presented in Table 2.27.

To elicit the monetary cost associated with the decrease in biodiversity levels, a benefit transfer approach was adopted. Of all the benefit transfer methods available, we chose the single value transfer approach, which consists in transferring estimates from the field where the primary study was conducted to the field of interest, after making the necessary adjustments

Table 2.27 **Present Value (PV) and Annuities (A) of the loss of income in fisheries due to climate change (Euro, 2007 prices)**

Discount rate	Mean		Median	
	PV	Mean	PV	A
0%	14,868,461		11,782,554	
1%	6,072,148	102,638	4,811,891	81,336
3%	1,039,719	33,537	823,928	26,576

Source: GEM-E3.

(Navrud and Ready, 2007; Ready and Navrud, 2006; Brouwer, 2000). This method has the advantage of being reliable and of significantly reducing transfer errors when available data are insufficient to describe the quality and quantity of the valuated good in the field of interest. For the purpose of the present study, we searched for studies carried out in Europe (European Turkey, Sweden, Ukraine), where climatic characteristics are similar to those of Greece.

The welfare loss due to the effect of climatic changes on biodiversity is estimated at €37.91/person according to Remoundou et al. (2010), and at €602/household according to Egger and Olsson (2009). The difference between these estimates is due to the fact that Remoundou et al. (2010) use the redistribution of present taxation as a payment vehicle in their valuation study. A review of the relevant literature shows that, in this case, estimates are higher than in studies where new taxes are used to finance the good in question. Consequently, when carrying out a cost/benefit analysis, it is preferable to use the more conservative estimates of Egger and Olsson (2009). We defined the relevant population affected by the climate change-related impacts on marine biodiversity to be the population living within 50 km of the coast. By extrapolation, the total economic cost due to biodiversity loss ranges from €287,457,124 (Egger and Olsson, 2009) to €1,895,654,656 (Remoundou et al., 2010).

Given the lack of specific quantitative estimates of the impacts of climate change on fisheries in Greece under different climate scenarios, we based our estimates on values drawn from the literature, which however can be used only for approximation. The difficulty of isolating and valuing the effects related directly to climate change must also be noted, as variations in stock abundance result from an interaction between a large number of anthropogenic and natural factors that differ considerably across water ecosystems. Primary valuation studies, taking into account the country's geographic and topographic diversity, are thus needed for a more accurate estimate of the cost impact of climate change on fishermen and Greek society as a whole.

Despite the inability —due to limited available data— to measure the full range of possible climate change impacts on fisheries and aquaculture in Greece, our study shows that climate change is expected to negatively affect the ability of fishery resources to provide goods and services of value to man. This clearly entails a loss of social welfare, a large part of which is associated with the loss of non-use values (including the value of the natural resource's existence, the value of being able to bequest these resources to future generations, and the value of conserving the biodiversity and stability of the specific ecosystems). This loss of social welfare needs to be taken into account when elaborating mitigation or adaptation policies to address climate change impacts.

2.3.8 Conclusions

- We analysed fish catch production data from a large statistical sample of 2,244,304 tonnes, collected by the Hellenic Statistical Authority (ELSTAT) for the period 1990-2009, as well as annual fish catch volumes, adjusting for the downward trend of the fishing fleet, estimated at 1.34% per year. The rise in SST over the 20-year period was estimated to have been of 0.7ºC.
- As we were able to show from the examined sample, for every 1ºC rise in SST benthic fish catches would decrease by 724 tonnes (1.1% of the mean) and mesopelagic fish catches would decrease by 160 tonnes (1.3%), while large and small pelagic fish catches would increase by 12 tonnes each, i.e. by 0.5% and 0.04%, respectively. Total catches would thus decrease by 859 tonnes or 0.8%.
- An increase of 3.3ºC in SST by 2100 (according to the climate model simulations, Chapter 1) would, based on present data, translate into decreases of benthic fish catches by roughly 3.6% and of mesopelagic fish catches by 4.2%. Large and small pelagic fish catches would increase by 1.7% and 0.13%, respectively. Total catches would fall by roughly 2.5%. It should be stressed that these rough estimates do not take account of the impacts on fisheries from factors that are difficult to quantify due to lack of data.
- Given that the rise in temperature is expected to benefit warmer-water species, total fisheries production may decrease only insignificantly, if at all. There will, however, be a redistribution of fish catches. With the rise in temperature, catches are also expected to include migrant species.
- Rainfall and river runoff into the sea typically increase an area's productivity due to the transfer of nutrients (with a lag of one or two years). Our analysis of catch trends in correlation with rainfall showed that 20% less rainfall (based on the climatic simulations of Scenario A1B) would lead to a small decrease in the production of cephalopods and malacostraca, in the order of 2%. Lower rainfall was not shown to have an impact on the production of other species.
- The present value of the income loss for commercial fisheries will range from €823,928 to €6,072,148, depending on the discount rate and on whether mean or median fish prices are used.

- The cost of biodiversity loss is estimated to range from €287 million to €1,896 million.
- In cases where coastal cages used in intensive fish farming units will need to be relocated on account of excessive pollution and changes in sea current circulation, the relocation costs are expected to be significant and still need to be accurately estimated.

2.4 Impacts of climate change on agriculture*

2.4.1 Introduction

Global concern about climate change has been mounting, in response in particular to the devastating impacts on the agriculture of developing countries (Parry et al., 2001; FAO, 2009). According to UN figures, in Africa alone 220 million suffer from a lack of drinking water due to climate change. The risks to agricultural production are associated with the loss of cultivable land, shorter growing seasons and uncertainty about what and when to plant. By 2100, it is estimated (UNFCCC, 2007) that net crop revenues in Africa could fall by 90%, millions in Asia could be at risk from hunger, while independent research efforts in Europe show that climate change will exacerbate regional economic inequalities within the EU (EEA, 2008; Stern, 2007).

The need to identify the impacts of climate change on agriculture (higher CO_2 levels, warmer temperatures, variations in precipitation, increase in weather extreme intensity and frequency, changes in the spatial distribution of crop pests and diseases; Tubiello et al., 2007) is heightened by the fact that these changes are expected to impact global food reserves, thereby leading to acute food shortages. Moreover, the increase in weather extremes can lead to a dramatic increase in food prices and to changes in the trade balance between countries (Lobell et al., 2008).

The Intergovernmental Panel on Climate Change (IPCC, 2007a) reports that a moderate temperature rise in the first half of this century is likely to increase crop yields in the temperate zone, but to reduce them in the subtropical and tropical zones. In the EU, as reported by the PESETA research project, crop production may, depending on the scenario, drop by 0-27% in Southern Europe, while increasing by as much as 40% in Central and Northern Europe. Using the HadCM3 model (Giannakopoulos et al., 2009) for Scenarios A2 and B2 (temperature rise of 2ºC, period 2031-2060) for the Northern Mediterranean, including Greece, bulb crop production is projected to decrease by 9.33% (Scenario A2), while cereal production is projected to increase by as much as 12.49% (Scenario B2). Kapetanaki and Rosenzweig (1997) have forecast a drop in maize yields in Thessaly by as much as 20%, while a study by

* Sub-chapter 2.4 was co-authored by: Andreas Karamanos, Michalis Skourtos, Demetrios Voloudakis, Areti Kontogianni and Athanasios Machleras.

the Greek Ministry of the Environment (1997) for the period 2071-2100 forecasts decreases in maize production by as much as 55% and variations in durum wheat production from -67% to +15%, depending on the scenario. According to the same study, the cotton production is expected to decrease by as much as 29% in Macedonia and Thessaly, but to increase in Thrace by as much as 21%, while viticultural crops will vary from -59% to +55% depending on the scenario and region. The impact on tree crops is expected to be negative, particularly in Southern Greece and Crete. All studies point to an increased vulnerability of crop production in the years ahead in Southern Europe and the Mediterranean region in particular, a projection of great importance to Greece.

2.4.2 Impacts of climate change on agricultural production

Methodology

Estimating the impact of climate change on plant physiology is extremely complex and involves considerable uncertainty, due to the 'futuristic' aspect of the produced estimates and to the fact that several determinants are likely to play out differently (slower or faster) than anticipated.

To estimate the impact of climate change on Greek agriculture, we drew on recent research and publications and used modelling tools that help forecast crop response to climate change (Geerts and Raes, 2009). Crop growth models integrate climatic, meteorological, soil properties, phenology and crop-physiology variables in order to limit prediction errors (Soussana et al., 2010). Such models can be divided into two main groups: statistical models (Lobell et al., 2008; Paeth et al., 2008) and crop simulation or mechanistic models (CropSyst, AquaCrop, CERES, etc.).

We chose to use the AquaCrop model (version 3.1, 2010), derived from the revised FAO report (Doorenbos and Kassam, 1979), for the following reasons: it assesses the effect of water on both plant growth and crop productivity; compared with other models, it requires fewer parameters; it is simpler to use; and, lastly, it is more accurate, with lower error probabilities (Raes et al., 2009). We drew our data from research on wheat (Karamanos et al., 2008), cotton

Table 2.28 Changes in CO_2 concentration and temperature levels per climate scenario relative to 1991-2000

Climate scenarios	A1B		A2		B2	
Time periods	2041-2050	2091-2100	2041-2050	2091-2100	2041-2050	2091-2100
CO_2 concentration	+40%	+89%	+40%	+125%	+26%	+63%
Temperature	+1.95 °C	+3.5 °C	+2 °C	+4.5 °C	+1.98 °C	+3.1 °C

Table 2.29

Assessment of possible impacts of climate change in different climate zones in Greece

Climate zones	Scenarios	A1B		A2		B2	
	Periods	2041-2050	2091-2100	2041-2050	2091-2100	2041-2050	2091-2100
Eastern Macedonia and Thrace	Cotton						
	Wheat						
	Maize						
	Nuts & fruits						
	Olives						
	Vines						
	Vegetables						
Western and Central Macedonia	Cotton						
	Wheat						
	Maize						
	Nuts & fruits						
	Olives						
	Vines						
	Vegetables						
Central and Eastern Greece	Cotton						
	Wheat						
	Maize						
	Nuts & fruits						
	Olives						
	Vines						
	Vegetables						
Western Greece	Cotton						
	Wheat						
	Maize						
	Nuts & fruits						
	Olives						
	Vines						
	Vegetables						
Ionian Sea	Cotton						
	Wheat						
	Maize						
	Nuts & fruits						
	Olives						
	Vines						
	Vegetables						
Western Peloponnese	Cotton						
	Wheat						
	Maize						
	Nuts & fruits						
	Olives						
	Vines						
	Vegetables						

Table 2.29 **Assessment of possible impacts of climate change in different climate zones in Greece *(continued)***

	Scenarios	A1B		A2		B2	
Climate zones	Periods	2041-2050	2091-2100	2041-2050	2091-2100	2041-2050	2091-2100
Eastern Peloponnese	Cotton						
	Wheat						
	Maize	roughly the same	decrease<10%	roughly the same	decrease>10%	roughly the same	roughly the same
	Nuts & fruits	roughly the same	roughly the same	roughly the same	decrease<10%	roughly the same	roughly the same
	Olives	roughly the same	decrease<10%	roughly the same	decrease<10%	roughly the same	roughly the same
	Vines	roughly the same	decrease<10%	increase<10%	decrease<10%	increase<10%	roughly the same
	Vegetables	roughly the same	decrease>10%	increase<10%	decrease>10%	increase<10%	roughly the same
Cyclades	Cotton						
	Wheat						
	Maize						
	Nuts & fruits	roughly the same	decrease<10%	roughly the same	decrease>10%	roughly the same	decrease<10%
	Olives	roughly the same	decrease<10%	roughly the same	decrease>10%	roughly the same	roughly the same
	Vines	roughly the same	decrease<10%	roughly the same	decrease>10%	roughly the same	roughly the same
	Vegetables	decrease<10%	decrease>10%	decrease<10%	decrease>10%	decrease<10%	decrease<10%
North-Eastern Aegean	Cotton						
	Wheat						
	Maize						
	Nuts & fruits	increase<10%	decrease<10%	increase<10%	increase<10%	increase<10%	increase<10%
	Olives	increase<10%	roughly the same	increase<10%	increase<10%	increase<10%	increase>10%
	Vines	increase<10%	roughly the same	increase<10%	increase<10%	increase<10%	increase>10%
	Vegetables	increase<10%	roughly the same	increase<10%	roughly the same	increase<10%	increase>10%
Dodecanese	Cotton						
	Wheat						
	Maize						
	Nuts & fruits	roughly the same	decrease<10%	roughly the same	decrease>10%	decrease<10%	increase<10%
	Olives	roughly the same	decrease<10%	roughly the same	decrease<10%	roughly the same	increase<10%
	Vines	roughly the same	decrease<10%	roughly the same	decrease<10%	roughly the same	increase<10%
	Vegetables	decrease<10%	decrease>10%	decrease<10%	decrease>10%	decrease<10%	increase<10%
Crete	Cotton						
	Wheat						
	Maize						
	Nuts & fruits	roughly the same	decrease<10%	roughly the same	decrease>10%	decrease<10%	decrease<10%
	Olives	roughly the same	decrease<10%	roughly the same	decrease<10%	roughly the same	roughly the same
	Vines	roughly the same	decrease<10%	roughly the same	decrease<10%	roughly the same	roughly the same
	Vegetables	decrease<10%	decrease>10%	decrease<10%	decrease>10%	decrease<10%	increase<10%

Key

(dark green)	increase>10%
(light green)	increase<10%
(yellow)	roughly the same
(orange)	decrease<10%
(red)	decrease>10%
(white)	not cultivated

(Kotoulas, 2010) and maize (Voloudakis et al., unpublished data). To calibrate the model's parameters to different levels of CO_2, we used data drawn from Alexandrov and Hoogenboom (2000), Li et al. (2000), Pleijel et al. (2000), Bindi et al. (2001), Kimball et al. (2002), Kimball et al. (2007) and Taub (2010). In the cases where the AquaCrop model was not used (vegetables, tree crops, etc.) we used earlier research results (Mortensen, 1994; Rosenzweig et al., 1996; Kimball and Idso, 2001; Olesen and Bindi, 2002; Chartzoulakis and Psarras, 2005; Kimball et al., 2007; Garnaut, 2008; Moriondo et al., 2008; Ventrella et al., 2008; Gutierrez et al., 2009; Moretti et al., 2010; Orduna et al., 2010).

The results obtained for Scenarios A1B, A2 and B2 for the periods 2041-2050 and 2091-2100 compared to baseline period 1991-2000 are presented in Table 2.28. The detailed climate and meteorological data used in the simulation (daily maximum and minimum temperature, daily rainfall, daily evapotranspiration) were drawn from the Research Centre for Atmospheric Physics and Climatology of the Academy of Athens (Zerefos et al., unpublished data). The assumption was made that crop management practices (sowing, harvesting, etc.), and irrigation and fertiliser use (quantity and frequency) will remain unchanged at current levels. We did not estimate the likely variation in impact on agricultural production from invasive weeds and diseases. However, the study did take into consideration the impact of desertification on crop yield. Desertification was estimated based on the data of a special study (Yasoglou and Kosmas, 2004), which made it possible to estimate the annual rate of land loss by climate zone (Kalyvas, unpublished data). In all, we estimated the impact of climatic change and desertification on the production of a number of crops. The desertification data used are linear projections of the outcomes of the above studies, since there are no scenarios forecasting the course of desertification in relation to climate change. However, in light of the anticipated decrease in rainfall and the higher intensity of extreme weather events, current forecasts may need to be revised upward, by an additional 5-10%.

To increase the accuracy of our predictions, we divided Greece into the following 11 climate zones: Eastern Macedonia-Thrace, Western-Central Macedonia, Central-Eastern Greece, Western Greece, the Ionian coast and islands, the Western Peloponnese, the Eastern Peloponnese, the Cyclades islands, the North-Eastern Aegean, the Dodecanese islands, and Crete. For practical reasons, the zones of the Northern Aegean and the Eastern Aegean were taken as one.

As shown in Table 2.29 using the AquaCrop model and research data from the Greek and international literature, of the three scenarios considered, Scenario B2 appears to be most favourable to crop production. The impacts of climate change become increasingly 'less negative to positive' the further one moves north and east: consequently, Eastern Macedonia-Thrace and Western-Central Macedonia are the zones that will benefit the most or suffer the least depending on the crop/case. The most vulnerable arable crop was shown to be wheat, while cotton production is projected to decrease the most under both Scenarios A1B and A2 in Central-

Eastern Greece. The impact of climate change on tree crop production by mid-century will range from neutral to positive but will become increasingly negative by 2100, especially in the country's southern and island regions. Vegetable crops will move northward and the growing season, longer than it is today due to milder-warmer winters, will result in increased production

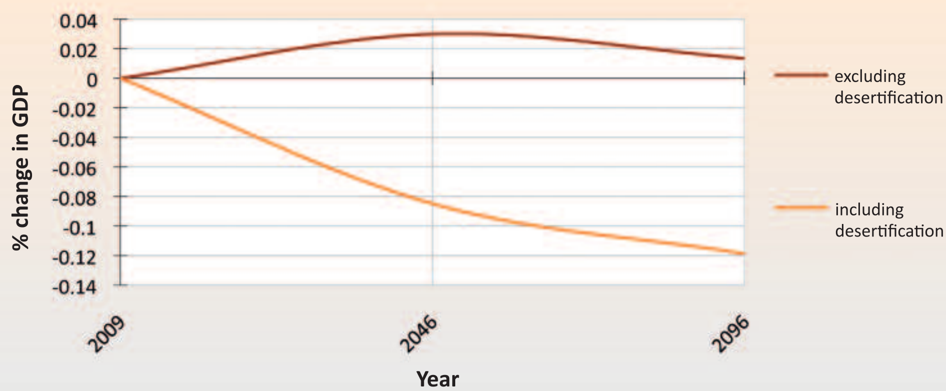
Moreover, as regards the effect of invasive pests, diseases and weeds on crop production, the prevailing view is that warmer climatic conditions will generally favour the proliferation of pests, since insect pests are able to complete a larger number of biological cycles during the course of a year. In addition, warmer winters will allow crop-threatening insects to survive the winter in places where this is not possible today, thereby giving them a 'head start' during the next growing season (Gutierrez et al., 2009). Similarly, thermophilic weed species (*Cassia, Amaranthus, Sesbania, Crotalaria, Rottboellia, Imperata, Panicum, Striga,* etc.) are also expected to expand into colder zones and higher altitudes (Karamanos, 2009).

2.4.3 Economic impacts

Despite its contraction in recent decades, agriculture remains important to the Greek economy, with agricultural production accounting for 5-6% of GDP and agricultural employment accounting for 17% of total employment (Pezaros, 2004). The agroindustry, which represents one fourth of the national industry, contributes one third of the industrial product and accounts for one third of industrial sector employment (Papanagiotou, 2005). The impact of climate change on Greek agricultural production was analysed by downscaling IPCC Scenarios A1B (3.5ºC), A2 (4.5ºC) and B2 (3.1ºC) (IPCC, 2007a) to the regional climate zone level of Greece. Due to time and data availability constraints, we focused our study on arable and tree crops, and more specifically on wheat, cotton, maize, olive and vines. The impact analysis was conducted both factoring in and excluding soil desertification.

Climate is key to agricultural production, and largely determines the type, quantity and quality of agricultural produce. The climate variables that most affect crop productivity are: temperature, precipitation, solar radiation (intensity and duration of exposure) and atmosphere composition (IPCC, 2007b; Tubiello et al., 2007; Mendelsohn and Dinar, 2009). Impacts on productivity affect farmer income and employment. A number of approaches, derived from the field of environmental economics, can be used to assess the economic impacts of climate change. Depending on the welfare measure used (price, cost or value), the methodologies developed can be classified into one of the three following categories: pricing, cost-pricing and valuating. The most suitable methodologies for valuating the impacts of climate change on the agricultural sector are market-based methods based on the change in agricultural output. If, for instance, climate change causes the cotton production to fall by 20%, then the farmer's income from cotton will fall accordingly. This change reflects the cost of inaction to climate change to be incurred by the cotton producer. If the producer resorts to using more fertiliser to make up

Figure 2.6 **Economic impact of Scenario A1B on farmer income (Percentage of GDP)**



for his production loss, he will incur higher production costs. These costs represent the cost of adaptation to climate change.

For the needs of the present study, the approach used to estimate the economic impact of climate change consisted in calculating (V), i.e. the change in agricultural production due to climate change multiplied by the market price of the agricultural product. This approach can be expressed by the formula:

$$V = \sum_{a}^{b} [(Q^b - Q^c) x P^b]$$

where:

V = the cost of climate change;

Q^b = the anticipated quantity produced in year b;[14]

Q^c = the average quantity produced during the baseline period 1990-2000; and

P^b = the expected producer price for the product in year b.

Parameter 'a' was given the values 2041 and 2091. Parameter 'b' is equal to a+x, with x given the values [0 to 9] so that estimates are produced for all the years within the decades studied, 2041-2050 and 2091-2100, respectively.

For the average quantities produced during the baseline period 1990-2000, we used the AquaCrop model estimates for wheat, cotton and maize crops. For the other crops (oil olives, table olives, table grapes, Corinthian currants, sultana raisins and grape must production), the average quantity produced was estimated from data from the Ministry of Agricultural Devel-

14 The estimates of productivity variation with the AquaCrop model use corresponding values, while 'production forecast' estimates use the average annual production level for the period 1990-2000.

Figure 2.7

Economic impact of Scenario A2 on farmer income (Percentage of GDP)

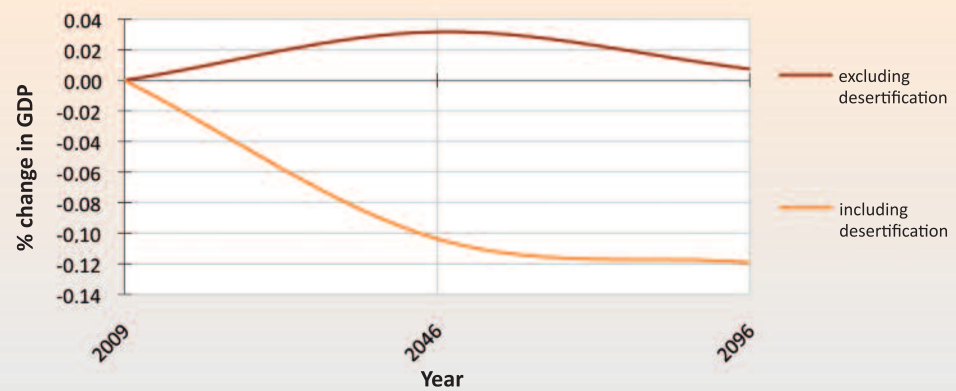
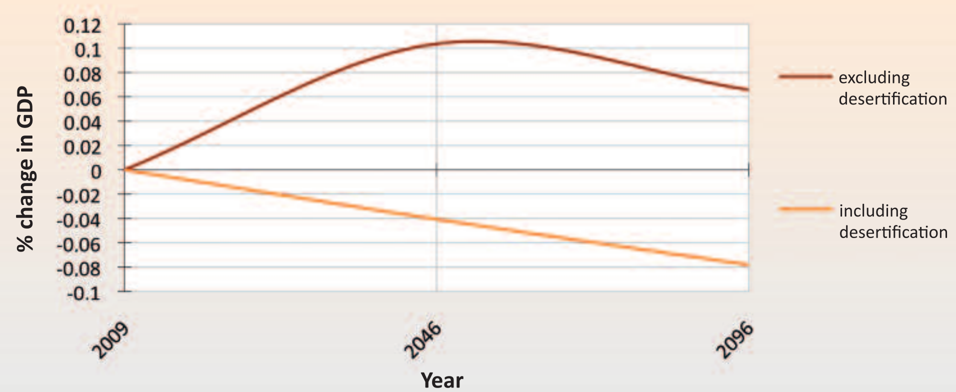


Figure 2.8

Economic impact of Scenario B2 on farmer income (Percentage of GDP)



opment and Food.[15] Finally, the expected producer prices per year and product was also estimated with data from the Ministry's website.[16]

Figures 2.6, 2.7 and 2.8 plot the impact of climate change on farmer income for each of the respective scenarios considered, assuming in one case (dark curve) that the climate will evolve smoothly till 2100 and, in a second case, taking desertification into account (orange curve).

15 http://www.minagric.gr/greek/agro_pol/3.htm
16 http://www.minagric.gr/greek/agro_pol/3.htm

The effects of climate change alone, excluding desertification, were found to have an immediate positive effect on farmer income until 2041-2050, a turning point, after which the economic impacts (for 2051-2100) worsen, relative to 2041-2050. As can be clearly seen from Table 2.30, the economic impact of all three scenarios on farmer income (excluding desertification) remains positive throughout the period 2010-2100. In contrast, the impact of climate-change induced desertification is expected to be negative. As is well-established, desertification negatively impacts agricultural production and, consequently, farmer income, due to the loss of fertile farmland and the decrease in cultivable area. The overall impact of climate change on farmer income, factoring in desertification, was found to be negative under Scenarios A1B and A2, but positive under Scenario B2. Unless measures to counter desertification are taken, climate change will thus negatively impact farmer income. Taking the impacts of the climate scenarios into account, our estimates point to the need for immediate drastic intervention to contain desertification and achieve farmer income growth.

It should be stressed that our estimates do not take into account changes in other determinants of agricultural production directly affected by climatic change, such as the impact of weeds and insect pests (including invasive species) and possible changes in pollinator efficiency. In addition, the economic estimates also involve a priori a number of uncertainties from the previous stages of analysis, as is the case with the climate data projections which were not based on future product prices, but on data from previous years, and depend on a series of uncertainties inherent in economic analysis (such as long-term variation of agricultural product prices, developments in international food markets, the discount rate used, etc.). For example, unpredictable factors concerning global production levels and agricultural trade or the possibilities of global oversupply or shortage were not taken into account. It is not inconceivable that decreases in production and expected losses of farmer income in Greece could be offset by a far greater drop in global production causing commodity prices to increase so much as to make the respective agricultural cultivations in Greece economically profitable. It should also be noted that we used a discount rate of 1% for our calculations, whereas the Stern report, for instance,

Table 2.30 **Change in farmer income due to climate change by 2100 (Percentage of GDP)**

Scenario	Impact of climate change excluding desertification	Impact of climate change including desertification	Total impact
A1B	+ 3.26	- 16.91	- 13.63
B2	+ 2.92	- 17.81	- 14.89
A2	+ 13.37	- 10.05	+ 3.31

uses a discount rate of 1.4%. Had we used Stern's discount rate, each estimated change in GDP of 0.1% for the decade 2041-2050 would have come close to 0.15% (up by 50%) and would have exceeded 0.25% (up by 250%) for the decade 2091-2100.

2.4.4 Adaptive management

'Adaptation' is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects (IPCC, 2007a). As the impacts on agricultural production are expected to be significant, the EU has launched a debate in view of adopting measures and adjusting its Common Agricultural Policy to climate change. All studies seem to concur that even a 2ºC global temperature rise would have considerable effects on agricultural production, thereby making mitigation and adaptation measures imperative (Copenhagen Diagnosis, 2009).

The overall goal (Tsiros et al., 2009) should be to achieve sustainable management of natural resources, geared toward maximising viable food production. This presupposes rational land management and the prevention and minimisation of land loss to drought, extreme weather events, flooding, etc. In the short run, emphasis would need to be placed on adjusting farming methods and practices, such as sowing densities, the timing of ploughing, sowing, harvesting, etc. (Orlardini et al., 2009). Other targets would, at the same time, include the preservation and improvement of soil productivity, more efficient water use, and the rational use of fertilisers and pesticides. In the long run, new crop varieties will have to be developed and the use of innovative technologies increased (greenhouse farming, frost protection, crop pollination).

Given that there will be differences across Greece's agroclimatic zones (with Southern Greece, Crete and the Aegean islands the most vulnerable) and because of geographic specificities within each zone (rivers, land at risk of degradation from erosion or salination, etc.), the recommended measures will also need to be tailored to the local level. Choosing the wrong course of action, such as drilling too deep for water (McKeon and Hall, 2000), could have devastating consequences for farming units (e.g. soil salination). For all these reasons, the diversity of the Greek landscape will have to be taken into account in any plan to consolidate, reorganise and restructure farming practices. Particular emphasis would need to be placed on water management and water use efficiency, soil fertility, greenhouse technology, crop selection tailored to specific agroclimatic conditions, as well as the development of new, improved/adapted crop varieties.

2.4.5 Impact mitigation

Climate change impact mitigation refers to all measures and actions to reduce the anthropogenic forcing of the climate system, including strategies to reduce greenhouse gas sources and emissions or to enhance greenhouse gas sinks (IPCC, 2007a). A major source of greenhouse gas (GHG) emissions, agriculture is also a huge 'sink' for sequestrating carbon, which could offset GHG emissions by capturing and storing carbon in agricultural soils (OECD, 2010).

According to a recent working document (EC, 2009), there is unused potential for cost-effective mitigation activities in EU agriculture. The viability of farms is a necessary basis for climate-friendly farming practices to become more widespread, while there is also a need to improve awareness and technical knowledge among farmers on climate change mitigation.

To mitigate GHG emissions, incentives need to be provided to promote organic farming and extensive livestock production systems (which help build up soil organic matter), modern animal waste processing, efficient fertiliser and pesticide use (with an aim to reducing present-day use by as much as 30%), integrated farm management plans aimed at controlling nitrate emissions, the development of small-scale renewable energy capacity (mainly biogas from animal waste) and the restoration of degraded soils.

2.4.6 Future challenges

Forecasting the impact of climate change on agriculture involves difficulties and uncertainties, stemming from a number of sources (Hansen et al., 2006). The reliability of the forecasts depends mainly on the accuracy of climate models, whether global (GCM) or regional/local (RCM). Scientific advances are constantly broadening our understanding of the complex system of interaction between natural and anthropogenic forcing that affects agricultural output. Agro-climatology has in recent years helped develop more reliable crop growth models (AquaCrop, Free Air CO_2 Enrichment (FACE) experiments), broadening available information and improving forecasting accuracy for future farming yields. Research efforts at the national level —regarding the impact of climate change on crops of national interest and the creation of a larger and more comprehensive database— need to be pursued and accelerated to allow us to correct our views if necessary.

With respect to the economic impacts of climate change on the Greek agricultural sector, the present study has attempted to produce a first estimate of a very complex issue requiring multiple data streams. Further research is required, particularly to explore adaptation actions and to determine which options would be more cost-effective at the appropriate spatial level. Timely diagnosis will enable the formulation of a more informed policy in view of climate change, and enable the Greek economy to maximise the benefits and reduce the losses attributable to climate change.

2.5 Impacts of climate change on forest ecosystems in the 21st century*

2.5.1 Introduction

Knowledge of the impacts of climate change on forest ecosystems is essential, given the economic and environmental contribution of these ecosystems to the quality of human life. Forest

* Sub-chapter 2.5 was co-authored by Anastasios Nastis, Ilias Karmiris, Eftichios Sartzetakis and Stefanos Nastis.

ecosystems occupy 65% of Greece's land surface (forests 25%, rangelands 40%). Having undergone considerable degradation as a result of centuries of disregard and improper use, their present contribution to human welfare is well below potential. Forest ecosystems provide a wide range of wood and non-wood products, including wood biomass, forage, fruits, mushrooms, honey, botanical herbs; affect water quantity and quality; enhance air quality and the sequestration of CO_2; play a valuable role in soil protection and biodiversity conservation by providing habitats and food for a host of living creatures. They also have considerable cultural and aesthetic value and provide opportunities for numerous recreational activities (hiking, camping, hunting, etc.), all essential to human wellbeing. The ability of forest ecosystems to yield products and quality services depends primarily on their stability, a function of their biodiversity, vigorousness and growth dynamic.

Forest production depends primarily on environmental factors, such as temperature, solar radiation, soil water and nutrients, but is also affected by synecological factors, such as inter- and intra- competition, interactions with animals and microorganisms, as well as wildfires (Johnsen et al., 2001). A small rise in temperature and decrease in precipitation was recorded in the course of the 20th century, a trend expected to continue in the 21st century as well (Zerefos, 2009), with precipitation projected to decrease in Greece : Scenario B2 (-35 mm), Scenario A2 (-84 mm).

It has been estimated that the overall decrease in precipitation by 2100 will not be uniform across Greece. Precipitation is expected to decrease in continental Greece (where the country's productive forests are located), but to increase in the islands of the Aegean (except Crete). Forest ecosystems will suffer from the combined effect of reduced precipitation and increased temperatures during the hot and dry period, while facing a higher risk of devastation from wildfires (Giannakopoulos et al., 2009). The question that arises is to what extent forest species will be able to adapt to the rapidly changing environment. Otherwise, forest ecosystems will be at an increased risk of destabilisation and, in extreme cases, extinction. These impacts could be considerably mitigated with the timely implementation of appropriate management strategies – such as special silvicultural treatment (FAO, 2003). Thus, the urgent need to adapt innovative forest policy and strategic management geared towards mitigating and effectively addressing the negative impacts of oncoming climate change. The purpose of the present sub-chapter is to estimate the impacts of climate change on wood and forage production and to explore management options to mitigate the adverse impacts.

2.5.2 Impacts of climate change on forest ecosystems

Assuming that today's forest management strategy remains unchanged and that no mitigation measures are taken, it is estimated that the impacts of climate change on forest ecosystems by 2100 will include (a) a spatial redistribution of the country's forests, and (b) a decrease in total canopy cover. More specifically, temperate coniferous and broadleaf evergreen forests (de Dios et al., 2007) are expected to expand by 2% (Scenario B2) to 4% (Scenario A2), while spruce, fir, beech and black pine forests will shrink by 4% (Scenario B2) to 8% (Scenario A2). Moreover, some coastal forest ecosystems are at risk of deforestation/pastoralisation and desertification (Scenario B2: 1%; A2: 2%) (Le Houérou, 1996). Spatial redistribution and the decrease in productive forest area by 160,000 ha (Scenario B2) to 320,000 ha (Scenario A2) on average would lower yearly wood biomass production by 0.5 m^3/ha or by a total of 80,000 m^3 (Scenario B2) or 160,000 m^3 (Scenario A2).

Based on the projected rise in CO_2 and temperature levels, the growing season will, depending on the scenario, be 10 to 15 days longer (Chmielewski and Rötzer, 2001), with positive repercussions on forest and rangeland production, because of the greater abundance of soil moisture for plant growth during early and late summer. The anticipated higher productivity is likely, however, to be moderated by the decrease in precipitation and the increased frequency and intensity of climate change-induced extreme weather events, such as heat waves, floods, etc. According to the BIOME3 model, it is estimated that forests' carbon assimilation rate under Scenarios B2 and A2 will decline by about 25% and 30%, respectively, by 2050, and by an additional 7% and 15% by 2100.[17] Greece's total wood production is expected to decrease on average by roughly 27% (Scenario B2) to 35% (Scenario A2) by 2100. In other words, the annual production of wood biomass is projected to decrease by an average 529,200 m^3 (Scenario B2) to 686,000 m^3 (Scenario A2) by 2100, based on the average for the last 21 years (1,960,000 m^3, Ministry of Environment, Energy and Climate Change 2010) (Sohngen and Sedjo, 2005). At the same time, rangeland production is projected to decline, mainly as a result of decreased precipitation (Papanastasis, 1982) by 10% under Scenario B2 and by as much 25% under Scenario A2. The decrease in forage production is estimated at 120 kg/ha (Scenario B2) and 300 kg/ha (Scenario A2) by 2100, meaning that Greece, with its current 5.2 million ha of rangeland, would see its total forage production decrease by 312,000 tonnes (Scenario B2) to 780,000 tonnes (Scenario A2) by 2100.

Global warming is expected to affect both the number of summer wildfires and total burned area, while the interval between two successive fires in the same area will decrease (Mouillot et al., 2002). Forests in southern continental Greece and Crete are expected to be most affected (Giannakopoulos et al., 2009; Carvalho et al., 2010). From 2000 to 2010, there were over 100,000 fire occurrences in Greece, consuming an average of 62,000 ha of arable and forest land each year (Gourbatsis, 2010). As estimated, total burned areas and total annual costs of fire fighting/suppression, damage and rehabilitation/reforestation will increase by about 10% (Scenario B2) to 20% (Scenario A2) relative to today's levels (Torn et al., 1999; Flannigan et al., 2000; Moriondo et al., 2006; Giannakopoulos et al., 2009; Carvalho et al., 2010; Schelhaas et al., 2010). The total costs of

17 http://aede.osu.edu/people/sohngen.1/forests/GTM/index.htm

fire extinction and damage, estimated today at over €400 million per year, are expected with global warming to increase by €40 million/year (Scenario B2) to €80 million/year (Scenario A2).

As a result of changes in forest structure (such as reduced canopy density) and the increased severity of weather extremes, surface runoff and erosion are expected to increase by 16% (Scenario B2) to 30% (Scenario A2), with adverse repercussions on deep infiltration and underground aquifer recharge. This, combined with the expected higher evapotranspiration, will reduce the amounts of usable water resources (Arora and Boer, 2001) by 25% (Scenario B2) to 40% (Scenario A2), i.e. by 5 billion m^3/year (Scenario B2) to 8 billion m^3/year (Scenario A2). In addition, non-use values and other environmental services are expected to fall by 5% to 10% (de Dios et al., 2007; Founda and Giannakopoulos, 2007).

Sea level rise (SLR) is predicted to accelerate relative to today, reaching 0.25 m (Scenario B2) and as much as 1 m (Scenario A2) by 2100, thereby bringing about changes in the spatial distribution of present coastal area land uses (Nicholls, 2004; Nicholls and Klein, 2005; Bindoff et al., 2007; Rahmstorf, 2007). According to Poulos (2011, personal communication), a SLR of 0.5 m by 2100 would result in the inundation of 15% of Greece's present total coastal wetland area (1,000 km^2). Such a rise is not expected to substantially impact coastal forest production, whereas total rangeland production will decline by 26,000 tonnes (Scenario B2) to 52,000 tonnes (Scenario A2). The coastal wetlands expected to face the greatest impact are the deltas of rivers Evros, Nestos, Axios, Loudias, Aliakmon and Acheloos, the lagoons of Messolonghi and Kyllini, and the Amvrakikos and Pagassitikos gulfs. The islands likely to be most strongly affected include Lemnos, Samos, Rhodes, Crete and Corfu (Nicholls and Klein, 2005).

The above changes will entail negative impacts on tourism and recreation, mainly during July and August, as the average air temperature and heat wave frequency, intensity and duration are set to increase. The earlier start of the tourist season (in May) and its prolongation into September are likely to offset such repercussions. Thus, total tourist traffic is not projected to change significantly by 2100 (Rutty, 2009). The impacts of climate change on tourism are discussed in Sub-chapter 2.7. Although the impacts on human health and the ensuing increase in healthcare and treatment costs are difficult to quantify, the degradation of forest ecosystems is expected to worsen the quality of life in large urban centres and to increase the frequency of illnesses associated with the deterioration of the urban and semi-urban environment (allergies, respiratory diseases, heart diseases, etc.).

2.5.3 Estimating the economic impacts of climate change

The average domestic production of wood products (Table 2.31) during the years 1988-2008 was 1,960,000 m^3. According to data from the 2008 report on Forest Service Activities,[18] 28%

18 http://www.ypeka.gr/Default.aspx?tabid=588&language=en-Us

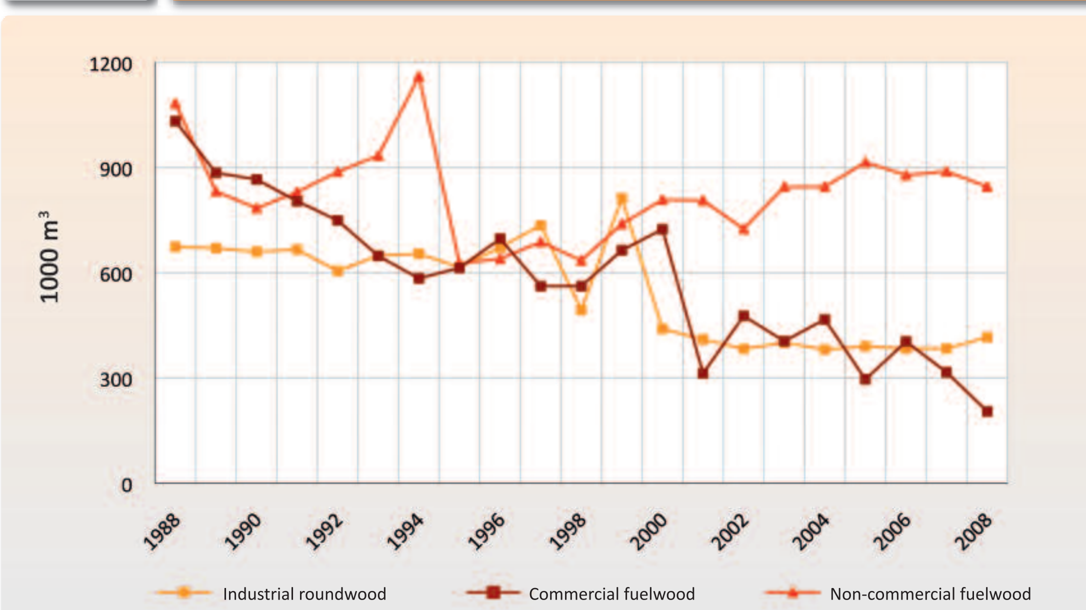
Table 2.31	Average annual timber production, 1988-2008	
Type of timber	**1000 m^3**	**% of the total**
Industrial roundwood	547.43	27.9
Commercial fuelwood	828.33	42.3
Non-commercial fuelwood	584.48	29.8
Total	1,960.24	100.0

Source: Ministry of Environment, Energy and Climate Change (2010).

of the total wood production was industrial roundwood. According to the NSSG (2007), domestic wood production covered only one-third of the national demand for industrial roundwood, but the entire demand for fuelwood.

The production of industrial roundwood (which includes sawn wood, carpentry and joinery wood, windows, doors and their frames, parquet panels, etc.) has decreased, while the production of engineered wood (particle boards, pre-laminated boards, MDF, wooden crates, etc.) has increased. Both categories (industrial roundwood and engineered woods) form part of the wood manufacturing industry. Greece's total wood production in the last 20 years has been considerably below potential, mainly on account of high production costs, cheap wood imports and

Figure 2.9 **Annual timber production, 1988-2008 (1000 m^3)**



Source: Ministry of Environment, Energy and Climate Change (2010).

forest service mismanagement. The annual production of industrial roundwood (Figure 2.9) peaked in 1999 at 812,000 m^3, which is double the present production.

The sale value of manufactured wood products came to €326 million in 2007, putting the industry on a par with the buoyant yoghurt industry, which has a turnover of €353 million (NSSG, 2007). Non-commercial fuelwood is used exclusively for heating.

Based on data available for Greece, the economic impact multiplier associated with wood manufacturing is 4.65, meaning that each initial €1 of forest wood is converted into an end-value of €4.65. This value of 4.65 is somewhere between the values of 3 and 6.5 reported in the literature for New Zealand (Griffiths, 2002; Thorpe, 1998), but higher than the value of 2.68 found for the UK (Forestry Commission, 2000) and very close to the estimated economic multipliers of 4.89 reported for the forests of California (California Economic Strategy Panel, 2002).

Estimating the economic impacts of climate change on forest ecosystems would normally require a forecasting of future prices. However, since the necessary data are lacking in Greece, we had no other option than to perform our estimates using present prices. It should be noted that until 1987 the prices paid to producers for industrial roundwood and fuelwood were determined by tender procedures by the Forest Service. Since 1987, pursuant to Presidential Decree 126/1986, agro-forest cooperatives and associations have the right to sell the timber they have harvested in public forests on the open market (Tororis, 1994). In 2010, fuelwood sold for €22.3/m^3 and beech roundwood for €60.3/m^3 (Forestry Department of the Pella Prefecture, 2010)[19]. Given that industrial roundwood accounts for 27.9% of total wood production, with fuelwood accounting for the rest, the weighted average price of wood was estimated at: (0.279 x €60.3) + (0.721 x €22.3) = €32.90/m^3. Consequently, the economic impact of forest spatial redistribution by 2050 would amount to €2.6 million/year (Scenario B2) and to €10.6 million/year (Scenario A2), while the impact of the anticipated decrease in wood production by 2100 would amount to €17.4 million (Scenario B2) and €22.6 million (Scenario A2), respectively. Using our economic multiplier of 4.65, the total economic impact by 2100 is estimated at €80.9 million/year to €105.1 million/year.

There are no official prices for forage. Considering, however, that 10 kg of forage are roughly equivalent to 1 kg of usable meat and adopting €5/kg as the present average price of meat, the economic loss from reduced rangeland production is estimated at €156 million/year (Scenario B2) to €390 million/year (Scenario A2) by 2100. Using the same assumptions, the economic loss associated with the loss of wetland area due to SLR would amount to an estimated present value of €13 million/year (Scenario B2) to €26 million/year (Scenario A2) by 2100. The impact of SLR on forest production is estimated to be insignificant.

Although it is impossible to accurately predict the increase in forest fire frequency and intensity attributable to climate change, it is safe to presume the number of wildfires and the devas-

19 Beech is one of the main forest sources of industrial roundwood in Greece (Zafeiriou et al., 2007).

tation caused by each one will increase. It is estimated that the yearly burned area of forests will increase by 10% (Scenario B2) to 20% (Scenario A2) by 2100, i.e. by an additional 20,000 ha/year to 40,000 ha/year. Considering that the average timber stock is 61 m^3/ha, the increase in fire occurrences would lead to an additional economic impact of €40 million/year (Scenario B2) to €80 million/year (Scenario A2) by 2100. Assuming that the value per m^3 of water is no less than 25% of the lowest price of irrigation water in Bulgaria (Öko Inc., 2001), i.e. €0.0026/m^3, the anticipated annual loss from the decrease in the usable water capacity of 20 billion m^3 yearly (Soulios, personal communication) would amount to between €13 million (Scenario B2) and €20.8 million (Scenario A2).

To estimate the present value of the economic impacts from climate change, it is necessary to choose a discount rate and to estimate the annual rate of economic impact variation from 2010 to 2100. Choosing the right rate for discounting the economic impact of climate change is an issue that continues to divide economists (Newell and Pizer, 2003; Stern et al., 2006; Dasgupta, 2007; Nordhaus, 2007a, b; Stern and Treasury, 2007; Stern, 2008; Weitzmann, 2007). There is still no clear consensus on which discount rate is socially more acceptable, as this essentially moral issue involves an explicit trade-off between the welfare of the present generation and that of future generations, in this case of those living in 2050 and 2100 (Varian, 2006). In the present study, we chose to use two discount rates in our economic valuation (Nordhaus, 2007a, b): 1% for a long-term horizon, i.e. more than 300 years, and 3% for the first years of climate change.

Figure 2.10 **Assessment of the economic impact of climate change (EUR millions)**

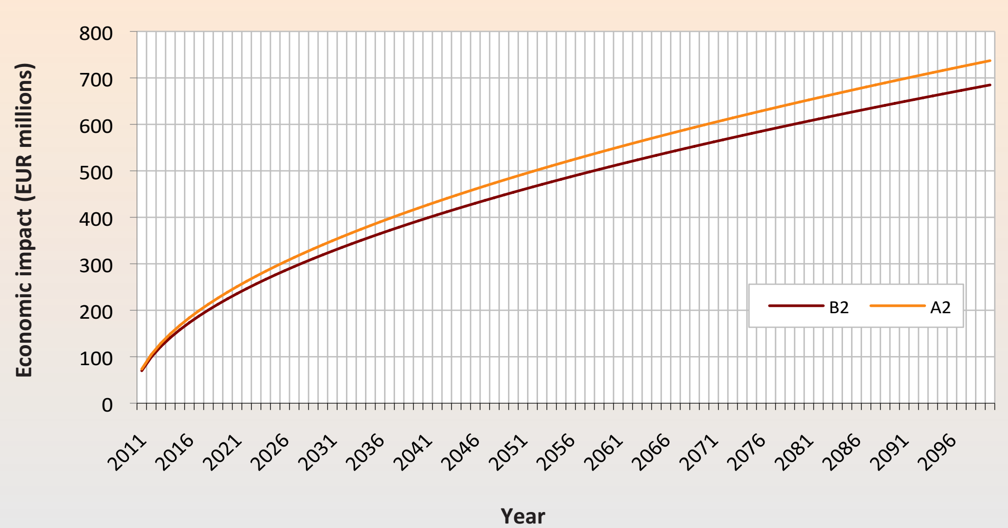


Table 2.32 **Estimated present value of the economic impact on forest ecosystems by 2100 (EUR millions)**

Discount rate	1%		3%	
	Scenario			
Present value	B2	A2	B2	A2
Redistribution of forests	46.7	94.8	14.9	30.4
Fires	721.2	1,462.1	231.0	470.9
Sea-level rise	116.8	237.4	37.4	76.2
Wood and forage biomass	3,154.2	7,300.9	1,014.0	2,320.2
Usable water	235.4	376.7	75.5	120.9
Total	***4,274.4***	***9,471.9***	***1,372.8***	***3,018.6***

The BIOME3 model, based on which the physical impacts on forest ecosystems were estimated, does not yield forecasts for each year, but only for 2050 and 2100. With the limited data available, the assumption was made in our case that biomass variation follows a simple exponential function. The best-fitting function used with Scenario B2 to estimate the annual economic impacts of climate change was $y=69.91x^{0.507121}$, where y is the biomass variation (10^3 m^3) and x are the years (x=1 for 2011, up to x=90 for 2100). The function best describing Scenario A2 was found to be $y=73{,}423x^{0.512566}$. The estimated economic impact derived from the above two functions for the next 90 years (2011-2100) are presented in Figure 2.10.

As shown in Table 2.32, the present value of the direct economic impact of climate change on forest ecosystems, for the two more likely scenarios B2 and A2 and using two different discount rates, ranges between €1.4 billion (Scenario B2; 3% discount rate) and €9.5 billion (Scenario A2; 1% discount rate). It should be noted that, due to the length of the period examined, the discount rate has a much greater impact than the two climate scenarios used. In any event, due to the score of uncertainties surrounding such forecasts and estimates, the estimated values should be taken as a lower bound of the real economic impacts. This view is also supported by the fact that the estimates are based only on the direct impacts attributable to forest ecosystems and that the indirect impacts, which may be far more important, have not been taken into account.

2.5.4 Adaptive management for impact mitigation

Mitigating adverse climate change impacts on forest ecosystems calls for the timely adoption of specific management measures. Adaptation should be focused on (a) intensifying silvicultural management interventions to reduce competition, erosion and flooding, (b) regulating the water balance through the harnessing of winter precipitation, and (c) preventing desertification of low-altitude areas. Adaptive management aimed at offsetting the adverse impacts of climate change is expected to cost 25% more under Scenario B2 than the total present cost of managing forest ecosystems, and 40% more under Scenario A2 (Bou-Zeid and El-Fadel, 2002), the total present cost having been estimated at €120 million in 2008. Erosion control will require the construction of sediment retention dams (1,000 under Scenario B2; 2,000 under Scenario A2), each costing a total of €0.5 million, including stabilisation interventions. Regulating the water supply will require the construction of (a) winter rainwater harvesting dams (500 under Scenario B2; 1,000 under Scenario A2) each with a storage capacity of 0.5 million m^3 and each costing €3.5 million, and (b) underground dams for aquifer recharge/water conservation purposes (200 under Scenario B2; 400 under Scenario A2) each costing €0.3 million. Minimising the damage caused by the greater frequency of wildfires will require an overhauling of the fire prevention and fire-fighting system, as well as the restoration of burned areas. Preventing the inundation of coastal regions of high ecological and economic value (e.g. river deltas, lagoons, etc.) will require the construction of levees or floodwalls (100 km under Scenario B2; 200 km under Scenario A2) to conserve and stabilise the ecosystems in question (Day et al., 1995). Such actions can be expected to substantially contain the adverse impacts, although the production of use and non-use values and services from silvopastural ecosystems will decrease.

In addition to the above, other necessary actions, mainly of an institutional nature, should include: setting up and up-keeping a forest cadastre, modernising the legal framework governing forest ecosystem study, overhauling the fire prevention and fire-fighting system, and reorganising state forestry services. Successful implementation of such measures would compensate for adverse climate change impacts and help increase forest and rangeland production; increase the carbon sink capacity of forests; reduce erosion and runoff; reduce the number and frequency of wildfires and the total area burned to below today's levels; minimise desertification; and contribute to the more effective protection of vulnerable and rare species populations and biotopes. There are valid indications that the immediate adoption of additional specific institutional measures, together with appropriate legislative regulations and policies, would almost totally offset the negative impacts of climate change. However, research efforts into adaptive management options aimed at preserving and enhancing sustainable ecosystem production need to be pursued and intensified. Reversing the degradation of Greece's forest ecosystems in anticipation of climate change and restoring these ecosystems back to a more productive state is a battle that must be waged and won.

In the case of forest ecosystems, the total costs of climate change adaptation until 2100 can be summarised as follows: (a) forest ecosystem management (silviculture interventions, grazing systems): €30 million/year (Scenario B2) and €50 million/year (Scenario A2); (b) improved forest-fire fighting and prevention: €40 million/year (Scenario B2) and €80 million/year (Scenario A2); (c) construction, maintenance and repair of sediment retention dams: lump-sums of €0.5 billion (Scenario B2) and €1.0 billion (Scenario A2); (d) construction and maintenance of rainwater storage dams: lump-sums of €1.75 billion (Scenario B2) and €3.5 billion (Scenario A2); and (e) construction and maintenance of levees (floodwalls) in low-lying coastal areas: lump sums of €0.1 billion (Scenario B2) and €0.2 billion (Scenario A2). Thus, the total adaptation costs amount to: €70 million/year (Scenario B2) or €130 million/year (Scenario A2), in addition to lump-sums of €2.35 billion (Scenario B2) and €4.7 billion (Scenario A2).

2.5.5 Conclusions

Climate change is, depending on the scenario (B2 or A2), expected to lead to the following:

1. Changes in the spatial distribution of forest land cover (2-4% increase in Mediterranean coniferous and evergreen broadleaf species; 1-2% forest cover loss on account of desertification; 4-8% decrease in boreal species; biodiversity loss). As a result, yearly wood biomass production will decrease by 80,000-160,000 m^3 by 2100.
2. A decrease in the carbon sink capacity of forest ecosystems of 32-45%, relative to present levels, and a decrease in total wood production of 27-35% or 529,200-686,000 m^3 by 2100.
3. A decrease in rangeland forage production of 10-25% (or 312,000-780,000 tonnes) by 2100. An additional decrease of 26,000-52,000 tonnes in rangeland production will result from the loss of coastal wetland area to SLR by 2100.
4. Additional annual costs of €40-80 million for fire extinction and damage by 2100, which highlight the need to overhaul fire prevention and fire-fighting systems, as well as the need for restoration/reforestation of burned areas.
5. A pressing need to intensify silvocultural interventions and implement grazing systems that will reduce competition and maintain productivity and biodiversity. These interventions will improve the water balance and prevent flooding and desertification.
6. A need for construction of winter precipitation retention dams in the mountainous zone and levees in the low-lying coastal zone to avoid inundation from SLR.
7. An imperative need for the immediate implementation of additional institutional measures, such as (a) setting up a forest cadastre as required by the Constitution, as a more effective way (compared to forest maps) of reducing wildfire risk and damage by 50%, and (b) modernising the legal framework governing forest ecosystem study.
8. A need to develop drought-tolerant forest species to ensure adequate production under more arid conditions.
9. Total costs from all sorts of physical impacts by 2100 from €4 billion (Scenario B2) to €9.5 billion (Scenario A2) at a 1% discount rate, and from €1.5 billion (Scenario B2) to €3.3 billion (Scenario A2) at a 3% discount rate.

10. Total adaptation costs of €70 million/year (Scenario B2) to €130 million/year (Scenario A2), plus lump-sums of €2.35 billion (Scenario B2) to €4.70 billion (Scenario A2).

2.6 Biodiversity and ecosystems*

According to the Convention on Biological Diversity (Article 2: Definitions), biodiversity refers to the variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which these organisms are part; this includes diversity within species, between species and of ecosystems.

Greece has one of the richest biodiversities in Europe and the Mediterranean on account of combined multiple factors, which include the country's climatic variety, geographical location (at the junction of three continents), complex geologic history, and great topographic diversity (pronounced relief, land discontinuity, large number of caves, gulfs and seas, and until recently only moderate human intervention), all of which have fostered the development and support of a wide variety of plants, animals, ecosystems and landscapes (Dafis et al., 1997). An important characteristic of Greek biodiversity is the high endemism observed in most animal and plant groups. Many endemic species have a very small distribution area (limited e.g. to one islet or one mountain) and are thus vulnerable to disturbance.

Climate change ranks among the top direct causes of biodiversity loss, as well as of changes in ecosystem services globally (Millennium Assessment, 2005). As regards the European environment, according to the fourth assessment by the European Environment Agency (EEA, 2007), climate change is increasingly recognised as a serious threat, particularly to coastal, alpine and arctic species and habitats.

The Intergovernmental Panel on Climate Change (IPCC) concluded in its Fourth Report (Alcamo et al., 2007) that climate change will impact considerably on several individual components of biodiversity: ecosystems, species, genetic diversity within species, as well as ecological interactions.

The effects of climate change on biodiversity are multifaceted. Biodiversity can be affected by a combination of: (a) direct impacts on organisms (e.g. the effects of temperature on survival rates, reproductive success, distribution and behavioural patterns); (b) impacts through biotic interactions (e.g. conferral of competitive advantage); and (c) impacts through changes in abiotic factors (e.g. inundation, shifts in ocean currents).

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However, climate change is not the only pressure on biodiversity and its effects are strongly dependent on interactions with other pressures, such as land-use change and habitat loss (Millennium Assessment, 2005), which reduce the abilities of organisms to adjust their distributions in response to changing climate (Campbell et al., 2009).

Southern Europe is already experiencing extremely dry weather conditions, with precipitation levels having declined by as much as 20% in the course of the 20th century (EEA, 2010). In fact, Mediterranean ecosystems rank among the most vulnerable in Europe (EEA, 2005; Schröter et al., 2005; Berry et al., 2007) and are close to reaching their environmental 'tipping point'. Greece figures among the most vulnerable regions of Europe on account of rising temperatures and lower precipitation levels in areas already facing water scarcity, and on account of rising sea levels along its long coastal zone (European Commission, 2007).

As regards the effects of climate change on species, differences in response and shifts in spatial distribution are expected for many species across Europe (Harrison et al., 2006). As part of a research project, projections of late 21st century distributions for 1,350 European plants species under seven climate change scenarios were made (Thuiller, 2005). More than half of the species studied could be vulnerable or threatened by 2080. Expected species loss, however, proved to be highly variable across scenarios and across regions. In Southern Europe, particularly in parts of the Iberian Peninsula, Italy and Greece, species abundance is expected to decrease, while species distribution/migration will depend on habitat suitability.

The plant and vertebrate species endemic to the Mediterranean region seem to be particularly vulnerable to climate change (Malcolm et al., 2006). Under the assumption of no migration, most amphibians and reptiles in SW Europe are expected to face a significant loss of their distribution range (Araújo et al., 2006).

In order to estimate climate change impacts on biodiversity, Harrison et al. (2006) used the SPECIES neural network model to simulate the possible 'climate space' of 47 species throughout Europe. An object of study in Greece was the *Sarcopoterium spinosum* shrubland and the species that use this habitat. Among these species, the red fox (*Vulpes vulpes*) shows no change in climate space under the different climate change scenarios, while two plant species, the *Genista acanthoclada* and the *Sarcopoterium spinosum*, show large increases in climate space (as high as 386% and 198% under one scenario), spreading from the SW through Central and Northern Europe, and across Western France and Spain. For the *Sarcopoterium spinosum* in particular, the simulation showed a distribution as far as in Scandinavia. One Mediterranean oak species, the *Quercus macrolepis*, displays a similar distribution shift pattern, mainly through the Balkans and France, while the woodpecker *Dendrocops medius* shows a decrease in spatial distribution in the climate space of Central European, together with a noteworthy northward expansion towards Scandinavia under one climate change scenario. Of all the olive tree species, the *Olea europea* gains the most ground, expanding west and northwest of its distribution area. The plant species *Matricaria chamomilla* and the mammal species *Sciurus anomalus* lose ground in the west and southwest, but the *Matricaria chamomilla* gains ground farther north, towards Scandinavia. In summary, three species —the *Matricaria chamomilla*, the *Sciurus anomalus* and the *Quercus macrolepis*— face a significant decrease in their forecast climate space within Greece, with losses of 88%, 98% and 56%, respectively, under one climate change scenario.

According to Schwartz et al. (2006), the largest decreases in species abundance are expected to occur in Southern Europe, in regions of the Iberian Peninsula, Italy and Greece, with many Mediterranean islands projected, under specific conditions, to lose up to 100% of their current species abundance. With respect to certain mammals in Greece, according to Levinsky et al. (2007), the spiny mouse (*Acomys minous*)[20] and the endemic Cretan white-toothed shrew (*Crocidura zimmermanni*) are predicted to become extinct under both severe and mild climatic scenarios, under the assumption of no migration. The same also holds for the mouse-tailed dormouse (*Myomimus roachi*) and the Caucasian squirrel (*Sciurus anomalus*). The endemic species, represented in the model with all of their climate locations, appear more vulnerable to climate change (based on the assumption of no migration) than other species, mainly due to their more limited distribution (Schwartz et al., 2006).

As regards flora, Kazakis et al. (2007) correlated the vascular plants of Crete's White Mountains (Lefka Ori) with climate data. Under a scenario of temperature increase, southern exposures are likely to be invaded first by thermophilous species, while northern exposures are likely to be more resistant to changes. Species distribution shifts will also depend on habitat availability. Many, already threatened, narrow-niche endemic species will be affected first.

With respect to inland water fish and according to the Red Data List of the International Union for Conservation of Nature (IUCN), 60 of the 127 species native to Greece (~47%) are threatened by climate change (Economidis, 2009). Of these 60 species, 31 are endemic and 35 —according to the IUCN criteria— have been classified in risk categories 10 (Crucially Endangered), 11 (Endangered) or 14 (Vulnerable) (Economidis, 2009).

As regards Greece's forest ecosystems, three changes could be attributed to or associated with climate change (Dafis, personal communication 2009): the dieback of the Greek fir, the invasion of conifers into deciduous broadleaved forests, and the dieback of the Scots pine. In more detail:

- The first massive dieback of Greek fir in areas of the Peloponnese, but elsewhere in Greece as well, occurred in 1989, after two dry and extremely hot summers (1987, 1988) and was initially attributed to a bark beetle epidemic. However, bark-eating beetles are known to act secondarily and to attack already weakened trees. This dieback is still ongoing, possibly at lower intensity.

20 The *Acomys minous* is no longer considered different from the North-African species *Acomys cahirinus*.

- Conifers, particularly the hybrid Greek fir (*Abies borisii regis*) and the Black pine (*Pinus nigra*), have begun to invade broadleaved forests, mostly forests of broadleaved oak (*Quercus frainetto*), Turkey oak (*Quercus cerris*), chestnut tree (*Castanea sativa*) and, to a lesser extent, beech.
- The dieback of the Scots pine in the Pieria mountain range (Thessaly) has been attributed to an attack by fungi and insects, which could however be secondary.

Turning to wetland systems, many ephemeral wetlands are expected to disappear, while other permanent ones will shrink (Alvarez Cobelas et al., 2005). Mediterranean coastal wetlands seem in many areas to be particularly at risk of decline or considerable variation in sediment deposition, as their location makes them vulnerable to rising sea levels. However, their ability to dynamically respond to such changes needs to be carefully investigated (French et al., 1995, from Nicholls and Hoozemans, 1996). According to regional models, climate change may considerably affect Mediterranean lakes in terms of water availability and quality (Dimitriou and Moussoulis, 2010). Any significant loss of wetland area is expected to affect avian migratory routes, largely determined by the suitability of wintering and resting grounds on the southbound journey. With respect to wetlands in Greece, based on unpublished data from the Greek Biotope/Wetland Centre (see Doulgeris and Papadimos, 2010) and on water balance simulations for Lakes Chimaditis and Kerkini using historical climate data and the Scenario A1B for the period 2020-2050 and Scenarios A1B and A2 for the period 2070-2100, Lake Chimaditis is expected to decrease in area by 20% to 37% and Lake Kerkini by 5% to 14%. Meanwhile, Lake Trichonis, Greece's largest, is expected to see its water level decrease and its total nitrogen concentrations increase (Dimitriou and Moussoulis, 2010).

The seagrass meadows of endemic Mediterranean marine angiosperm *Posidonia oceanica* seem to be highly vulnerable to the physical and chemical changes induced by extreme weather events (e.g. storms and floods; Orr et al., 1992; Bombace, 2001), as such events lead to the increased discharge of suspended solids and pollutants into the marine environment. Given that these meadows provide spawning and nursery sites for numerous marine species and play an important ecological role, their degradation or disappearance would have serious consequences for coastal ecosystems (Francour, 1997, from Gambaiani et al., 2009).

Marine ecosystems have been studied much less than their terrestrial counterparts and data time-series, when available, are short (Roberts and Hawkins, 1999, from Bianchi and Morri, 2000). The Mediterranean Sea is projected to see an increase in temperature and a decrease in run-off (see Joint EEA-JRC-WHO report, 2008). Changes in the biochemical and physical seawater properties resulting from global warming are likely to alter marine biodiversity and productivity, trigger trophic web mismatches, and favour disease outbreaks, toxic algal bloom and the proliferation of warmer-temperature tolerant species (see Gambaiani et al., 2009). Marine invasive alien species are a source of biodiversity loss, as they drive native species out, and can significantly alter the structure and functions of marine ecosystems, while also threatening marine industries (fishing, tourism, etc.) and human health. This is particularly the case when the species in question invade an ecosystem already vulnerable on account of other pressures (EEA, 2010). The gradual rise in sea surface temperature (SST) in the Mediterranean (Salat and Pasqual, 2002) has facilitated the entry, acclimatisation and settlement of tropical marine microalgae and other organisms (macroalgae, molluscs, fish; Occhipinti-Ambrogi, 2007). An interannual analysis based on a recent inventory showed that the number of alien species in the Greek seas has increased in recent years (Pancucci-Papadopoulou et al., 2005). The increased rate of invasions could be the result of a synergy of causes, including global warming, which favours the introduction and/or proliferation of alien species, particularly of certain thermophilic Lessepsian migrants.

Apart from the physical impacts on biodiversity and ecosystems, an effort was also made in the present study to estimate the economic impacts of climate change. As mentioned earlier, biodiversity loss entails a degradation of ecosystem services. We therefore performed a valuation of the impacts of biodiversity loss using an ecosystem service approach. A major initiative in the field of ecosystem service valuation and the development of 'toolkits' for policy makers was "*The Economics of Ecosystems and Biodiversity*" (TEEB), supported inter alia by the European Commission. This global study involved the creation of a valuation database for various ecosystem services, including provisioning services, regulating services, habitat or supporting services and cultural services.

Using TEEB data, we proceeded to estimate the economic costs of ecosystem service loss for forests and Lakes Chimaditis and Kerkini, under Scenarios A2, A1B and B2, as envisaged for Greece for the period 2011-2100. According to Brenner-Guillermo (2007), the total economic value of ecosystem services provided by forests comes to \$3,789/ha/year (base year: 2004). This value is the aggregate of the following components: water supply, genetic resource conservation, climate regulation, waste management/water purification, erosion prevention, nutrient cycling and soil fertility, pollination, biological control, 'gene pool' protection, recreation and tourism opportunities and various cultural services. At roughly the same time, Croitoru and Merlo (2005) estimated the total economic value of Mediterranean forests at \$96/ha/year. The reason why this second estimate is so much lower is that it only covers the following components: wood and non-wood forest products, grazing, recreation, hunting, watershed protection and carbon sequestration, as well as non-use values (existence values and bequest values for future generations).

Based on the methodology used, the present value (PV) of the loss of ecosystem services was calculated as follows:

$$PV = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t}$$

where C_t is the monetary cost of losing ecosystem services in time period t; T is the total number of periods examined; and r is a the discount rate that reflects the cost of capital and the relative weight between current and future benefits. The higher the discount rate, the lower the present generation's concern for future generations. Our choice of two relatively low discount rates (1% and 3%) therefore underlines the importance of ecosystem services and of their preservation for future generations.

As can be seen from Table 2.33, we calculated the present values of forest ecosystem service loss using each of the two 'total economic value' estimates mentioned above for Scenarios A2 and B2. These results can be used to assess and prioritise measures geared toward containing forest area loss. For instance, if the installation of better fire-fighting systems can reduce the expected burned areas and if the cost of such an installation is lower than the benefit that would be lost as a result of forest fire, then such an investment is cost-effective from an economic standpoint. In algebraic terms, the present value of the cost can be represented as:

$$I + \sum_{t=0}^{T} \frac{O_t}{(1+r)^t}$$

where I is the cost of installing the fire-fighting systems, and O_t is the cost of operating them in time period t.

The investment can then be considered cost-effective if:

$$I + \sum_{t=0}^{T} \frac{O_t}{(1+r)^t} < \sum_{t=0}^{T} \frac{C_t^*}{(1+r)^t}$$

where C_t^* is the cost of forest ecosystem loss due to fires in time period t, while the right-hand side of the inequality represents the benefit, in present value terms, from reduced burned areas. If the discounted benefit from preventing fires and forest area loss exceeds the cost of the fire-extinction systems, the investment can be considered worth making.

Table 2.33 **Discounted cost of forest ecosystem service loss, 2011-2100**

	Scenario A2	Scenario B2	Scenario A2	Scenario B2
Economic value of services ($/ha)	3,789		96	
Present value of cost (1%) (million $)	351,618	176,227	8,909	4,465
Present value of cost (3%) (million $)	130,790	65,614	3,314	1,663

Table 2.34 **Discounted cost of forest ecosystem service loss for lakes Chimaditis and Kerkini, 2011-2100**

	Scenario A1B	Scenario A2	Scenario A1B	Scenario A2
Economic value of services ($/ha)	3,789		96	
Lake Chimaditis				
Present value of cost (1%) (million $)	20,292	17,114	91,238	76,949
Present value of cost (3%) (million $)	8,540	6,868	38,397	30,881
Lake Kerkini				
Present value of cost (1%) (million $)	35,593	39,592	160,034	178,016
Present value of cost (3%) (million $)	13,873	15,889	62,375	71,440

Table 2.34 presents the discounted cost of ecosystem service loss associated with the physical impacts of climate change for Lakes Chimaditis and Kerkini, using two different economic values per hectare and per year for the services provided by open freshwater ecosystems: the first value (per year) is the one estimated by Brenner-Guillermo (2007) at $1,890/ha (base year: 2004), as the aggregate of two main services: water supply ($1,011/ha) and recreation/aesthetic value ($880/ha). The second value is the one calculated by Costanza et al. (1997) at $8,498/ha, comprising such services as water regulation, water supply, waste treatment, food production, and recreation.

As with forest ecosystems, estimating the present value of lake area loss and of lake ecosystem service loss can serve to assess potential mitigation or prevention measures. Measures entailing a smaller cost to implement than the potential benefits from preventing ecosystem service loss (the cost of which is estimated in the present study) are considered cost-effective and worth implementing. The cost figures obtained will obviously differ considerably depending on the assumptions and scenarios adopted, and therefore need to be interpreted with caution. In general, however, measures to limit ecosystem service loss are worth implementing when they cost less than the estimated cost of losing such services due to inaction. The present methodology and the estimates obtained for Greek forests and the two lakes chosen in the study can provide a basis for assessing different action measures to contain the impacts of climate change.

By the end of the century, climate change and its impacts may be the dominant direct drivers of biodiversity loss and the change in ecosystem service globally (MEA, 2005; Thomas et al., 2004). Currently, terrestrial and marine ecosystems play a crucial role in climate regulation, absorbing roughly half of the CO_2 emissions humanity generates. Among the measures to reduce greenhouse gas emissions are priority ‘low cost co-benefit options’ that simultaneously

Table 2.35 **Measures to address the impact of climate change at ecosystem level**

Climate impact	Ecosystem-based adaptation
Increased droughts	Use appropriate agricultural and forestry practices to increase the water retention capacity and mitigate droughts
Heat extremes	Increase green spaces in cities to improve the microclimate and air quality
River flooding	Maintain and restore wetlands and riverbeds which will act as natural buffers against floods
Increased fire risk	Cultivate diverse forests, which are more robust against pest attacks and present a lower fire risk

Source: European Commission (2009).

contribute to conservation and sustainable use of biodiversity. Some of these measures are listed in Table 2.35.

Inaction or even delayed action could result in ecosystem degradation and even loss, which would reduce the overall carbon storage and sequestration capacity of ecosystems. The climate system has 'tipping' points, beyond which the response of ecosystems can become unpredictable. Under such conditions, carbon sinks could become carbon sources.

Failure on the biodiversity targets may seriously compromise our efforts to reduce global warming, whereas stepping up our nature conservation efforts and reducing the environmental pressures on biodiversity and ecosystems helps to combat climate change and provides multiple benefits.

2.7 Economic and physical impacts of climate change on tourism*

Summary

The present study examines the impacts of climate change on Greek tourism, in physical and economic terms. It focuses on an analysis of the direct impacts and, using a modified version of Mieczkowski's Tourism Climatic Index (TCI), explores the impact of projected climate change on tourist demand. The analysis of climate projections reveals that the use of aggregate national and annual data masks significant regional and seasonal differences in climate characteristics and tourist demand. We focused our analysis on two leading destinations in Greece's tourism industry (Crete and the Dodecanese) — for which reliable economic and climate data were available — thus enabling two regional estimates of the economic impact of climate change. The results of the analysis make it particularly clear that any strategy plan for Greek

* Sub-chapter 2.7 was co-authored by: Eftichios Sartzetakis and Benjamin Karatzoglou.

tourism must necessarily: expand the tourist season, and ensure the geographic diversification of the tourism product. Achieving these objectives will crucially depend on the ability to: (a) market Greece's many, still unexploited, natural attractions; (b) develop and promote alternative eco-friendly forms of tourism; (c) attract new tourist target groups; and (d) enforce measures to reduce the industry's environmental footprint. Lastly, we were able to estimate that the operating costs of accommodation establishments would, depending on the adaptation scenario, increase by an annual 5-7%. An increase of such magnitude, combined with the forecast decrease in international arrivals during the summer peak would have serious repercussions on the net financial results of many tourism establishments, especially in tourism-intensive regions. Given the weight of the tourism industry in the Greek economy, the results of the study underscore the urgent need for a long-term strategy plan for Greek tourism, geared toward achieving the two primary objectives (i.e. extension of the tourist season; geographic diversification of the tourism product) and involving all stakeholders and drawing on collaboration between State authorities, at all levels, and the tourism industry.

2.7.1 Introduction

The aim of the present study is to provide estimates of the economic impact of climate change on Greece's tourism industry, based on projections of the physical impacts. Tourism is one of Greece's leading industries, in terms of GDP, employment, and the current account balance, considering that tourism receipts substantially reduce the current account deficit.[21] Despite its increasing weight in the Greek economy, Greek tourism faces important structural problems, such as strong seasonality, regional concentration and difficulties in coping with new trends in demand and increasing regional competition. The main characteristics and performances of the Greek tourism industry are presented in Table 2.36.[22]

Climate is a principal resource for tourism, as it co-determines the suitability of locations for a wide range of tourist activities, and, as such, makes tourism vulnerable to climate change. High temperature and other weather extremes, together with water shortages, are just some of the impacts that climate change is expected to have on the tourism industry. Two leading studies, one by Germany's Deutsche Bank (Deutsche Bank Research, 2008)[23] and another by the World Tourism Organisation (WTO, Climate change and Tourism: Responding to Global Challenges, 2008)[24] forecast a redistribution of tourist arrivals from Southern Europe to countries

21 According to the Bank of Greece, tourism receipts in 2011 reduced the current account deficit by 27%.

22 The figures of Table 2.36 were taken from the full version of the study on Greek tourism available (in Greek) from the webpage of the Climate Change Impacts Study Committee (CCISC) on the Bank of Greece website (www.bankofgreece.gr).

23 Deutsche Bank Report (2008) Climate Change and Tourism: Where will the change lead? Deutsche Bank Research, Frankfurt am Main, Germany. Available at: http://www.dbresearch.com/PROD/DBR_INTERNET_EN-PROD/PROD0000000000222943.pdf

24 World Tourism Organization, UNWTO Annual Report A year of recovery (2010), Madrid, Spain. Available at: http://dtxtq4w60xqpw.cloudfront.net/sites/all/files/pdf/final_annual_report_pdf_3.pdf

Table 2.36 **Greek tourism: Key figures and performance ranking relative to main competitors (2007)**

Key figures for Greek tourism, 2007	
Contribution to GDP	17.2% (World Travel and Tourism Council)
Contribution to employment	20.8% of total employment (World Travel and Tourism Council)
Employment (direct and indirect)	939,820 persons (World Travel and Tourism Council)
Receipts	€11.3 billion (Bank of Greece)
International tourist arrivals	15.2 million
Average spending per person	€743
Market share	1.68% (global), 3.13% (Europe)
Seasonality	47.7% of international tourist arrivals occur from July to September
Supply concentration	52% of hotel beds are concentrated in 3 regions (Hellenic Chamber of Hotels)
Hotel capacity	9,207 hotels/700,933 beds (Hellenic Chamber of Hotels)
Top 5 markets	United Kingdom (2,618,542 visitors), Germany (2,264,332), Italy (1,157,081), Netherlands (828,185), France (756,105) [NSSG]

Performance indicators for Greece and its main competitors (2007)						
Performance indicators, 2007	Greece	Spain	Cyprus	Turkey	Egypt	Croatia
Rank in international tourist arrivals	16th	2nd	below 50th	9th	22nd	24th
Rank in tourism receipts	12th	2nd	below 50th	10th	25th	26th
International tourist arrivals, 2007 (million)	15.2	58.7	2.4	22.2	10.6	9.3
% change in arrivals, 2000 - 2007	22.6	26.5	-11.1	131.3	107.8	60.3
Receipts, $ billion 2007	15.5	57.6	2.7	18.5	9.3	9.3
% change in receipts, 2000-2007	68.5	92.0	42.1	143.4	116.3	232.1
Average spending per person per trip in $	1,019.7	971.4	1,125.0	829.6	877.4	1,000.0
Market share – world arrivals (%)	1.68	6.49	0.27	2.46	1.17	1.03
Market share – world receipts (%)	1.81	6.72	0.32	2.16	1.09	1.09

Source: Own calculations based on data from multiple sources.

with lower average summer temperatures in Middle-Northern Europe (Baltic Sea region, Benelux and Scandinavia).

Both studies are solid examples of the recent and rapidly expanding literature on the impacts of climate change on the economy as a whole and tourism in particular. The main physical and economic impacts of climate change on the tourism industry, compiled from a review of the literature, are listed in Tables 2.37 and 2.38.[25]

25 See footnote 22.

Table 2.37 **Physical impacts of climate change on tourism**

Direct impacts	Indirect impacts
• Temperature increase	• Damage to coastal tourism infrastructure
• Sea-level rise • Changes in air humidity and quality	• Depreciation of tourism infrastructure due to inadequate natural conditions (e.g. lack of snow in ski resorts)
• Increased drought • Increased pollution	• Intrusion of sea water in aquifers and salinisation of drinking water
• Increase in discomfort index • Decreased rainfall and snowfall	• Decreased water availability due to decreased rainfall
• More frequent appearance of photochemical smog • Increased extreme events (storms, floods, hurricanes)	• Decrease and/or loss of ecotourism infrastructure and activities
• Increased fires and diseases	
• Destruction of sensitive ecosystems	

Source: Table compiled by the research team.

Table 2.38 **Economic impacts of climate change on tourism**

• Possible decline in the number of tourist arrivals
• Possible decline in average tourist length of stay
• Reduced seasonality
• Global fall in disposable income for tourism due to drop in GDP as a result of climate change
• Increase in average cost of services provided to tourists
• Cost of forced discontinuation of provided tourism services due to extreme natural events (opportunity cost or loss of revenue)
• Works to reduce pollution and gas emissions
• Works (incl. engineering) to address the physical impacts of climate change and extreme events (dams, water recycling systems)
• Need to develop novel bioclimatic infrastructures
• Increased maintenance cost for older infrastructures
• Works to substitute natural capital with man-made capital in order to preserve the attraction of an area (e.g. substituting a forest with a thematic park, mountain bike activities with a kart circuit, addressing the lack of snow by creating a climbing wall)
• Downgrade of cultural and historic monuments (UNESCO study, 2007) and possible destruction of archaeological monuments
• Cost of staff training and adaptation to new operations and working procedures
• Repositioning of the tourism product in the global market

Source: Table compiled by the research team.

Building on these studies and fully aware of the methodological problems and the limitations of any effort to estimate climate change impacts, we have attempted in the present study to offer the most reliable estimates possible, at a national and regional level. To the best of our knowledge, this is the first attempt to compare results using climatological estimates at the aggregate (national) and disaggregate (regional) level. It should also be stressed that the present study deals only with the cost of adaptation, and not mitigation, due to the generally small size of tourism establishments in Greece and of the country as a whole.

Tourism-supporting activities —e.g. restaurant, transport and recreational services— were not taken into account either because (a) they are addressed in other sectoral studies, (b) they are in demand by both local residents and non-residents (tourists), or (c) they have a limited economic weight.

The focus of the present study will therefore be the direct impacts of climate change on tourism establishments, distinguishing between:

- *demand-side* implications, affecting the *revenue* of tourism businesses and its annual distribution; and
- *supply-side* implications, affecting the *operating cost* structure of tourism establishments either directly (operating costs, infrastructure maintenance costs), indirectly (need for new infrastructure, higher financing costs, cost of repositioning the tourism product in the national and international markets) or potentially due to extreme climate change-related events (indemnifications, opportunity cost, higher insurance costs).

The magnitude and extent of these impacts vary in function of:

- the characteristics of the specific tourism business and the services it offers (category, type of clientele, credit policy, customer loyalty rate, dependence on tour operators);
- the specifics of each accommodation establishment (size, age, features and maintenance); and finally,
- the accommodation establishment's geographical location.

In summary, the objectives of our study are to record and present the country's natural, tourism and hotel product; to estimate and analyse the financial performance of tourism businesses; to estimate the impacts of climate change on performance; and, based on the results, to draw conclusions and formulate policy recommendations for the efficient adaptation of the Greek tourism industry to climate change.

2.7.2 Methodology and data

The present study adopts the methodology used by leading studies in the field, such as the Garnaut,[26] Metroeconomica[27] and PESETA[28] studies, making the necessary modifications to

26 Garnaut, R. (2008), Garnaut Climate Change Review: final report, Garnaut Climate Change Review.

27 Climate Change Impacts and Adaptation Cross-regional Research Programme: Project E – Quantifying the cost of impacts and adaptation, Defra Metroeconomica Ltd, UK (2005-2006).

28 Ciscar, J.C. (2009) (ed.), *Climate change impacts in Europe*, Final report of the PESETA research project, European Commission, JRC, IPTS and IES.

Table 2.39 **Attributes of study scenarios (2050)**

Attributes	SRES A2		SRES B2	
	2050	2100	2050	2100
Rise in mean global temperature (°C)	1.6	3.5	1.6	2.5
Rise in mean temperature in Greece (°C)	2.0	4.5	2.0	3.1
Global population (in billion)	11.3	15.1	9.3	10.4
Global GDP (in billion USD)	82	243	110	235
CO_2 (parts per million)	532	856	478	621
Sea-level rise (cm)	12.0-16.0	23.0-51.0	12.0-16.0	20.0-43.0
Change in rainfall in SE Europe (%)	-7	-13	-5	-7

Source: IPCC, 2007, Chapter 1 of present study and Ciscar (2009).

incorporate regional characteristics and to conform with data availability (in terms of quantity and quality). The scenarios taken into consideration in the present analysis were based initially on the IPCC study. Initial estimates using the HadCM2 climate change model under the old GCM-IS92a scenario indicated that the number of warmer days (i.e. days with an average temperature above certain critical thresholds) will increase. This increase has been found to have an important influence on the tourist index used in the present study to estimate demand for the Greek tourism product.

To analyse Greece's tourism product, it was necessary to perform simulations using regional climate models (RCMs) with a high spatial resolution. The results of these models for Greece as a whole, as well as for the 12 climate regions into which Greece was divided, were provided by the research team of the Research Centre for Atmospheric Physics and Climatology (RCAPC) of the Academy of Athens. For the purposes of the present study, the simulation results were limited to Scenarios A2 and B2 (detailed in section 1.15.2, Chapter 1), which essentially represent the two extreme estimates of anthropogenic greenhouse gas emissions in forthcoming decades. For both scenarios, the calculations were made using the average of a set of simulations of RCMs, as described in Chapter 1.

Table 2.39 presents the two scenarios' basic attributes/assumptions. Differences in climate parameters were calculated based on the baseline period 1960-1990.

2.7.3 State of play of Greece's tourism infrastructure at the national and regional level[29]

Over the last few years there has been a considerable expansion in hotel capacity at the aggregate national level, as well as an increase in higher-rated hotels (4-star and 5-star), in both

29 See footnote 22.

absolute and percentage terms. However, Greece still trails its main competitors in average number of bed spaces per establishment and in the share of upper-category (luxury) beds in total number of beds. The Greek tourism industry thus consists mostly of small, lower-category establishments, unable to provide the high-quality services needed to attract high-income tourists in large numbers.

As regards camping/caravan establishments, their contribution to the economy is very small (0.1% of total tourism receipts) and half of the demand for camping/caravanning services comes from domestic tourists. Most camping establishments are small, family-run, unincorporated businesses. They will therefore be omitted from our study, which will focus on hotel accommodation.

In terms of regional breakdown, Greece's bed capacity highly concentrated in specific regions (Crete: 21%, Dodecanese: 17%, Macedonia: 14%, Central Greece: 13%, Ionian Islands: 11%). Upper-rated hotels are also highly concentrated in a small number of regions. In addition, the capacity utilisation rate in most regions is low (except urban centres, the Dodecanese and Crete), indicating the existence of an underutilised tourism stock, as a result of overinvestment and/or insufficient advertising and regional promotion.

Another problem is high seasonality, which results in full capacity remaining idle for extensive periods each year (often for six months or more). Indicatively, the annual accommodation capacity of Greek hotels is 182 million overnight stays, while actual overnight stays in 2007 —a representative year for Greek tourism— amounted to 64 million. Greece's Research Institute for Tourism has estimated that Greece as a whole has an over-capacity of 184.2% and that the current hotel capacity could, depending on the scenario, cover future increases in demand over the next 14 to 35 years.

Finally, significant differences are observed across regions in the average length of time during which hotels remain open each year. Attica and Western Macedonia are the only two regions with high percentages of year-round accommodation capacity, whereas regions with a high accommodation capacity remain open only seasonally (Crete: 82%, Ionian Islands: 84%, the Dodecanese: 90%).

2.7.4 Economic data[30]

As mentioned in the introduction, Greek tourism makes a substantial contribution to the national economy. According to the WTO estimates for 2010, the tourism industry generated 15.5% of GDP and 10% of total employment. Tourism investment almost tripled in the period 2002-2007 and is still rising. According to ELSTAT estimates, the above figures increase twofold, when supporting tourism services, such as bars, restaurants, refreshment stands, catering

30 See footnote 22.

services, etc., are taken into account. However, neither ELSTAT nor the WTO provide a methodology for distinguishing between resident and non-resident (tourist) consumption of such services. Due to the lack of specific methodology and data for determining the industry's indirect contribution, the focus of our sectoral study will be accommodation establishments.

Changes in the number of arrivals, average length of stay and average daily spending are expected to have a significant impact on tourism receipts and the net revenue of accommodation establishments. According to available data, although tourist spending levels differ according to the country of origin, total spending per person per trip has steadily decreased over the last few years.

Accommodation establishment operating costs differ considerably in function of establishment size, category and target market, the region's physical and climate characteristics, seasonality, etc. Table 2.40 provides an indicative operating cost structure for an average-size hotel, based on various estimates, and presents primary data for various cost categories as a percentage of total turnover, collected directly from a sample of 55 hotels, as well as data from three other studies.

Finally, according to a US study, the total energy consumption of a medium-size hotel can be broken down as follows: 33% for water heating, 24% for lighting, 22% for space heating,

Table 2.40 **Indicative operating cost structure of a representative average-size hotel (in percentages)**

	Primary research (n=55)	JBR research 2002	Hotel on line USA Research	ICAP research 2009 (for B class hotels)
Turnover	100.00	100.00	100	100
Cost of goods sold and services provided	71.01	56.40		68.23
Depreciation	15.60	17.40		16.84
Salaries and contributions	32.00	39.40	43.70	33.12 (NSSG)
Gross profit	28.99	44.60		31.77
Other operating expenses (excluding financial expenses)	18.66			
Energy	5.00	3.60	6.00	
Promotion/advertisement expenses	1.00	2.80	3,00	
Maintenance expenses	3.00	2.60	3.10	
Overheads	4.00	8.00		
Financial expenses	3.84	Included in 'Other Oper. exp.'		6.18
Pre-income tax profit	4.69	26.70	27.50	-2.06
Net disposable income	2.59			

n: number of hotels in the sample.
Source: Primary research and synthesis of information from various sources.

5% for space cooling, 3% for ventilation, 3% for meal preparation, and the remaining 10% for other uses.

2.7.5 The economic impacts of climate change on tourism in Greece

As mentioned above, we consider two sources of economic impacts of climate change on tourist activity: the change in revenue and the increase in operating expenses of tourism enterprises. The economic impacts on revenue are far more important than those on operating costs. To estimate the change in revenue, at the regional and seasonal level, we used the Tourism Climatic Index (TCI, Mieczkowski, 1985).

The TCI combines different climate variables – either recorded or estimated by meteorological studies – into a single index, designed to evaluate the climatic suitability of a region to support outdoor tourism activities. The TCI has been widely used in relevant studies, and a number of authors have even suggested adding or modifying the variables and weights used in the index (see, for instance, Morgan, 2000; Amelung and Viner, 2006; de Freitas et al., 2008). Despite its drawbacks, the TCI has the advantage of being easy to calculate and easy to comprehend and thus remains widely used.

The parameters that go into the final TCI are temperature, rainfall, sunshine, and wind speed and chill. The formula used to calculate the TCI is:

$TCI = 8CID + 2CIA + 4P + 4S + 2W$,

where:

CID is the maximum daily temperature in combination with the minimum possible humidity;

CIA is the average 24-hour temperature;

P is the average rainfall (in mm/month);

S are the total hours of sunlight per day; and

W is the average wind speed (in km/h).

The values of these parameters are not incorporated into the index as such: first, the continuous variables are converted into a scale of discrete values ranging from a perfect 5 (denoting optimal conditions for tourism activity) to a minimum value of -3. In the case of Greece, none of the TCI parameters take a negative value in any of the periods examined.

The climate data used to compile the index were calculated by the research team of the RCAPC and refer to climate data by decade for the period 2010-2100, broken down by season at the national level and for each of the 12 geographical districts described in Chapter 1. These data were fed into a specially designed spreadsheet, once the available data were converted into values ranging from 5 to -3.

The calculation of the TCI for the period 2070-2100 was based on Scenarios A2 and B2. The TCI calculations for the period 2010-2070 were based on the results of Scenario A1B for

Table 2.41 Estimate of the TCI index for Greece as a whole and for the respective climate regions, on an annual basis and by season (2011-2070 for Scenario A2 and 2071-2100 for Scenarios A2 and B2)

Climate zone	Time period	TCI annual				TCI winter				TCI spring				TCI summer				TCI autumn			
		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index	
		Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2
Greece	1961-1990	61	61	0	0	44	44	0	0	58	58	0	0	89	89	0	0	61	61	0	0
	2011-2020	60		-1		44		0		58		0		89		0		66		5	
	2021-2030	60		-1		44		0		58		0		89		0		65		4	
	2031-2040	61		0		44		0		58		0		89		0		71		10	
	2041-2050	66		5		49		5		63		5		89		0		71		10	
	2051-2060	66		5		49		5		63		5		89		0		71		10	
	2061-2070	71		10		49		5		63		5		89		0		76		15	
	2071-2080	71	71	10	10	52	49	8	5	63	63	5	5	84	83	-5	-6	81	76	20	15
	2081-2090	76	71	15	10	52	49	8	5	63	63	5	5	84	83	-5	-6	83	76	22	15
	2091-2100	76	71	15	10	52	49	8	5	68	63	10	5	79	83	-10	-6	81	76	20	15

TCI rating categories and corresponding colours in the table
80≤TCI≤100 ideal,
60≤TCI≤79 excellent,
50≤TCI≤59 very good,
40≤TCI≤49 acceptable,
TCI≤39 unacceptable

Table 2.41 Estimate of the TCI index for Greece as a whole and for the respective climate regions, on an annual basis and by season (2011-2070 for Scenario A2 and 2071-2100 for Scenarios A2 and B2) *(continued)*

Climate zone	Time period	TCI annual				TCI winter				TCI spring				TCI summer				TCI autumn			
		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index	
		Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2
Western & Central Macedonia	1961-1990	55	54	0	0	41	40	0	0	,57	57	0	0	88	88	0	0	55	55	0	0
	2011-2020	53		-2		39		-2		56		-1		88		0		55		0	
	2021-2030	53		-2		39		-2		56		-1		88		0		55		0	
	2031-2040	54		-1		39		-2		56		-1		88		0		55		0	
	2041-2050	54		-1		44		3		56		-1		88		0		55		0	
	2051-2060	54		-1		45		4		58		1		88		0		55		0	
	2061-2070	59		4		44		3		58		1		88		0		60		5	
	2071-2080	60	60	5	6	46	45	5	5	57	57	0	0	83	88	-5	0	60	60	5	5
	2081-2090	60	60	5	6	46	45	5	5	59	57	2	0	80	88	-8	0	65	60	10	5
	2091-2100	65	59	10	5	46	45	5	5	64	57	7	0	75	88	-13	0	65	60	10	5
Eastern Macedonia/ Thrace	1961-1990	54	53	0	0	41	41	0	0	56	55	0	0	88	88	0	0	57	57	0	0
	2011-2020	53		-1		46		5		56		0		87		-1		56		-1	
	2021-2030	53		-1		46		5		56		0		87		-1		55		-2	
	2031-2040	53		-1		46		5		56		0		87		-1		56		-1	
	2041-2050	53		-1		46		5		56		0		87		-1		61		4	
	2051-2060	58		4		46		5		56		0		87		-1		61		4	
	2061-2070	58		4		46		5		56		0		87		-1		61		4	
	2071-2080	60	58	6	5	47	46	6	5	57	55	1	0	85	90	-3	2	67	61	10	4
	2081-2090	65	58	11	5	47	46	6	5	62	55	6	0	80	84	-8	-4	67	61	10	4
	2091-2100	70	58	16	5	47	46	6	5	62	55	6	0	75	90	-13	2	71	61	14	4

Table 2.41 **Estimate of the TCI index for Greece as a whole and for the respective climate regions, on an annual basis and by season (2011-2070 for Scenario A2 and 2071-2100 for Scenarios A2 and B2)** ***(continued)***

Climate zone	Time period	TCI annual				TCI winter				TCI spring				TCI summer				TCI autumn			
		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index	
		Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2
Northern Aegean	1961-1990	61	61	0	0	43	43	0	0	58	58	0	0	89	89	0	0	65	65	0	0
	2011-2020	60		-1		48		5		57		-1		88		-1		70		5	
	2021-2030	60		-1		48		5		57		-1		89		0		70		5	
	2031-2040	65		4		48		5		57		-1		88		-1		70		5	
	2041-2050	65		4		48		5		62		4		88		-1		75		10	
	2051-2060	70		9		48		5		62		4		88		-1		75		10	
	2061-2070	70		9		48		5		62		4		88		-1		80		15	
	2071-2080	76	71	15	10	48	48	5	5	63	63	5	5	89	89	0	0	80	80	15	15
	2081-2090	76	71	15	10	49	48	6	5	63	63	5	5	84	89	-5	0	80	80	15	15
	2091-2100	81	71	20	10	48	48	5	5	63	63	5	5	84	89	-5	0	80	80	15	15
Cyclades	1961-1990	65	65	0	0	50	50	0	0	64	64	0	0	88	88	0	0	77	77	0	0
	2011-2020	72		7		50		0		64		0		88		0		82		5	
	2021-2030	72		7		50		0		64		0		88		0		82		5	
	2031-2040	72		7		50		0		64		0		88		0		82		5	
	2041-2050	77		12		50		0		64		0		88		0		82		5	
	2051-2060	77		12		51		1		69		5		88		0		82		5	
	2061-2070	82		17		56		6		69		5		88		0		82		5	
	2071-2080	83	82	18	17	56	55	6	5	69	69	5	5	88	88	0	0	82	82	5	5
	2081-2090	83	82	18	17	56	55	6	5	69	69	5	5	88	88	0	0	82	82	5	5
	2091-2100	82	82	17	17	56	55	6	5	74	69	10	5	83	88	-5	0	82	82	5	5

Table 2.41 Estimate of the TCI index for Greece as a whole and for the respective climate regions, on an annual basis and by season (2011-2070 for Scenario A2 and 2071-2100 for Scenarios A2 and B2) *(continued)*

Climate zone	Time period	TCI annual				TCI winter				TCI spring				TCI summer				TCI autumn			
		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index	
		Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2
Eastern Aegean	1961-1990	60	60	0	0	48	48	0	0	58	58	0	0	89	89	0	0	73	73	0	0
	2011-2020	64		4		48		0		63		5		88		-1		78		5	
	2021-2030	65		5		48		0		63		5		89		0		75		2	
	2031-2040	71		11		48		0		63		5		88		-1		78		5	
	2041-2050	69		9		48		0		63		5		88		-1		83		10	
	2051-2060	70		10		48		0		63		5		88		-1		83		10	
	2061-2070	75		15		48		0		63		5		88		-1		82		9	
	2071-2080	81	76	21	16	49	48	1	0	68	63	10	5	83	82	-6	-7	83	83	10	10
	2081-2090	81	75	21	15	51	48	3	0	68	63	10	5	83	82	-6	-7	82	83	9	10
	2091-2100	81	74	21	14	51	48	3	0	73	68	15	10	78	77	-11	-12	82	82	9	9
Dodecanese	1961-1990	72	72	0	0	50	50	0	0	64	64	0	0	88	88	0	0	83	83	0	0
	2011-2020	77		5		50		0		64		0		88		0		83		0	
	2021-2030	77		5		50		0		65		1		88		0		83		0	
	2031-2040	77		5		50		0		64		0		88		0		83		0	
	2041-2050	77		5		50		0		69		5		88		0		83		0	
	2051-2060	82		10		55		5		69		5		88		0		83		0	
	2061-2070	82		10		55		5		70		6		88		0		83		0	
	2071-2080	82	82	10	10	55	55	5	5	74	69	10	5	83	84	-5	-4	83	83	0	0
	2081-2090	83	82	11	10	56	55	6	5	74	69	10	5	83	84	-5	-4	85	83	2	0
	2091-2100	82	82	10	10	62	55	12	5	79	74	15	10	78	79	-10	-9	83	83	0	0

Table 2.41 Estimate of the TCI index for Greece as a whole and for the respective climate regions, on an annual basis and by season (2011-2070 for Scenario A2 and 2071-2100 for Scenarios A2 and B2) *(continued)*

Climate zone	Time period	TCI annual				TCI winter				TCI spring				TCI summer				TCI autumn			
		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index	
		Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2
Crete	1961-1990	62	62	0	0	52	52	0	0	58	58	0	0	89	89	0	0	68	68	0	0
	2011-2020	66		4		51		-1		60		2		89		0		73		5	
	2021-2030	66		4		51		-1		65		7		89		0		73		5	
	2031-2040	68		6		51		-1		65		7		89		0		73		5	
	2041-2050	73		11		51		-1		65		7		89		0		78		10	
	2051-2060	73		11		51		-1		65		7		89		0		78		10	
	2061-2070	73		11		51		-1		65		7		89		0		83		15	
	2071-2080	79	74	17	12	52	52	0	0	70	65	12	7	84	85	-5	-4	83	83	15	15
	2081-2090	79	74	17	12	52	52	0	0	70	65	12	7	84	85	-5	-4	83	83	15	15
	2091-2100	84	77	22	15	52	52	0	0	75	65	17	7	79	83	-10	-6	83	83	15	15
Central & Eastern Greece	1961-1990	56	56	0	0	47	47	0	0	58	58	0	0	89	89	0	0	63	63	0	0
	2011-2020	61		5		47		0		58		0		89		0		63		0	
	2021-2030	61		5		47		0		58		0		89		0		63		0	
	2031-2040	61		5		47		0		58		0		89		0		63		0	
	2041-2050	61		5		47		0		58		0		89		0		63		0	
	2051-2060	61		5		47		0		58		0		89		0		68		5	
	2061-2070	66		10		47		0		63		5		84		-5		68		5	
	2071-2080	71	66	15	10	52	47	5	0	63	63	5	5	79	78	-10	-11	78	68	15	5
	2081-2090	71	66	15	10	52	47	5	0	63	63	5	5	79	78	-10	-11	78	73	15	10
	2091-2100	76	66	20	10	52	47	5	0	68	63	10	5	74	78	-15	-11	83	73	20	10

Table 2.41 Estimate of the TCI index for Greece as a whole and for the respective climate regions, on an annual basis and by season (2011-2070 for Scenario A2 and 2071-2100 for Scenarios A2 and B2) *(continued)*

Climate zone	Time period	TCI annual				TCI winter				TCI spring				TCI summer				TCI autumn			
		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index	
		Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2
Eastern Peloponnese	1961-1990	61	61	0	0	45	44	0	0	58	58	0	0	89	89	0	0	61	63	0	0
	2011-2020	61		0		44		-1		58		0		89		0		66		5	
	2021-2030	61		0		46		1		58		0		89		0		66		5	
	2031-2040	66		5		44		-1		58		0		89		0		71		10	
	2041-2050	66		5		52		7		63		5		89		0		71		10	
	2051-2060	66		5		52		7		63		5		89		0		73		12	
	2061-2070	71		10		52		7		63		5		84		-5		78		17	
	2071-2080	76	71	15	10	52	52	7	8	63	63	5	5	79	78	-10	-11	83	78	22	15
	2081-2090	77	71	16	10	52	52	7	8	68	63	10	5	74	78	-15	-11	83	78	22	15
	2091-2100	81	71	20	10	52	52	7	8	73	63	15	5	74	78	-15	-11	83	76	22	13
Western Greece	1961-1990	55	55	0	0	40	40	0	0	56	56	0	0	88	88	0	0	54	54	0	0
	2011-2020	50		-5		43		3		55		-1		88		0		53		-1	
	2021-2030	50		-5		43		3		55		-1		88		0		53		-1	
	2031-2040	51		-4		43		3		55		-1		88		0		53		-1	
	2041-2050	51		-4		43		3		55		-1		88		0		53		-1	
	2051-2060	51		-4		43		3		55		-1		88		0		58		4	
	2061-2070	56		1		43		3		55		-1		88		0		58		4	
	2071-2080	58	58	3	3	45	45	5	5	56	56	0	0	90	82	2	-6	64	59	10	5
	2081-2090	59	58	4	3	45	45	5	5	56	56	0	0	85	82	-3	-6	67	61	13	7
	2091-2100	64	58	9	3	45	45	5	5	62	56	6	0	80	82	-8	-6	71	59	17	5

Table 2.41 Estimate of the TCI index for Greece as a whole and for the respective climate regions, on an annual basis and by season (2011-2070 for Scenario A2 and 2071-2100 for Scenarios A2 and B2) *(continued)*

Climate zone	Time period	TCI annual				TCI winter				TCI spring				TCI summer				TCI autumn			
		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index	
		Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2
Ionian Sea	1961-1990	64	64	0	0	51	51	0	0	58	58	0	0	89	89	0	0	75	75	0	0
	2011-2020	69		5		50		-1		63		5		89		0		80		5	
	2021-2030	69		5		50		-1		63		5		89		0		80		5	
	2031-2040	70		6		50		-1		63		5		89		0		80		5	
	2041-2050	69		5		50		-1		63		5		89		0		80		5	
	2051-2060	75		11		50		-1		63		5		89		0		80		5	
	2061-2070	75		11		50		-1		63		5		89		0		80		5	
	2071-2080	79	74	15	10	51	51	0	0	63	63	5	5	89	83	0	-6	80	80	5	5
	2081-2090	80	75	16	11	56	51	5	0	68	63	10	5	84	83	-5	-6	80	80	5	5
	2091-2100	80	79	16	15	56	51	5	0	73	68	15	10	79	78	-10	-11	80	80	5	5
Western Peloponnese	1961-1990	55	55	0	0	44	44	0	0	56	56	0	0	89	89	0	0	60	60	0	0
	2011-2020	57		2		44		0		58		2		89		0		60		0	
	2021-2030	57		2		43		-1		58		2		89		0		60		0	
	2031-2040	59		4		44		0		58		2		89		0		60		0	
	2041-2050	59		4		46		2		58		2		89		0		65		5	
	2051-2060	60		5		46		2		58		2		89		0		66		6	
	2061-2070	65		10		46		2		58		2		89		0		70		10	
	2071-2080	71	65	16	10	51	46	7	2	63	58	7	2	84	83	-5	-6	76	71	16	11
	2081-2090	71	65	16	10	52	46	8	2	63	58	7	2	84	83	-5	-6	76	71	16	11
	2091-2100	76	65	21	10	51	51	7	7	63	63	7	7	79	83	-10	-6	81	70	21	10

rainfall, cloud cover and wind speed, and on the results of Scenario A2 for temperature. The use of results from two different scenarios is not expected to affect TCI values considerably, due to the very small differences in the results of Scenarios A1B and A2 (until 2070) and to the insignificance, in most cases, of these differences, once the continuous values are converted into the discrete values scale.

Owing to lack of data on maximum daily temperature in combination with minimum possible humidity (CID) and the average 24-hour temperature (CIA), these two temperature variables were merged into one and given a weighting coefficient of 50% in the final index. Table 2.41 presents the TCI and its variations relative to the baseline period (1961-1990) for Greece as a whole and for each of the 12 regions, by decade and by season, for 2011-2070 (Scenarios A2) and for 2071-2100 (Scenarios A2 and B2). These results are, of course, not definitive, as further research is needed to reach detailed estimates calibrated for all scenarios and all cases.

As can be observed from Table 2.41:

- At the countrywide level and on an annual basis, the TCI decreases slightly over the first two decades, but improves markedly towards the end of the century.
- At the countrywide level but on a seasonal basis, the TCI remains unchanged roughly till mid-century, but in the second half of the century improves (increases) in winter and in spring, and improves considerably in autumn. In contrast, it deteriorates (declines) considerably in summer.
- At the regional level, the overall picture drawn for Greece as a whole holds, but with important differences across regions. In other words, there are no significant changes roughly up to mid-century, but in the second half of the century the TCI in some regions improves in winter and spring, improves quite significantly in autumn and decreases considerably in summer.

It should be noted that the changes in the index by season and time period exhibit considerable differences at the regional and countrywide levels. This is because the TCI for Greece as a whole is calculated based on independent climate data of lower geographical resolution and not as a weighted average of the regional TCI values.

Impacts on arrivals, overnight stays and revenue

The assumption commonly made in the international literature is that TCI fluctuations exhibit, ceteris paribus, a linear correlation with the number of arrivals, the number of overnight stays and, by extension, regional tourism receipts Scott and Coyle, 2003; de Freitas et al., 2008) and can be used in tourist demand forecasting and management models (de Freitas et al., 2008). The authors of the present study express reservations as to whether the index at issue suffices on its own to forecast and describe a process as complex as tourist flows, without the appropriate spatial and qualitative adjustments, but share the view that it can make a positive contribution to relevant estimates.

The impact of climate change on Greek hotel revenue, used in this study as a surrogate of Greek tourism, obviously cannot be broken down at a seasonal or regional level, as this would require greater data availability. A thoroughly detailed analysis of the climate change impacts on Greek tourism could be carried out in the future, under greater time and data allowances.

Table 2.42, Panel A presents estimated arrivals, overnight stays and revenue till 2100, without taking climate change impacts into consideration. The estimates were made assuming increases of 3.5% in 2010-2020 (WTTC forecast for Greece,) and progressively decelerating increases every two decades of 3%, 2.5%, 2%, 1.5% and finally 1% in 2090-2100. We opted for partly decelerating increase rates because Greece is already a well-established tourist destination in the international market and because climate conditions in the countries feeding Greek tourism are expected to improve during the same periods. A discount rate of 1.4% (similar the one used in the Stern report) was used in order to derive present values of future streams. It should be stressed that the data in each row refer to the entire corresponding decade and not to a single year.

In Table 2.42, Panel B, we applied the annual TCI to the figures of Panel A, in order to obtain a first overall estimate of climate change impact on physical and economic figures. Panel C presents the differences in figures between Panels A and B. As was expected from the TCI estimates (Table 2.41) on an annual basis and at countrywide level, Greek tourism seems to benefit from climate change. The impacts are negative or neutral for the period 2010-2040, but turn significantly positive in the period 2061-2100. It should be emphasised that, due to space limitations, the data presented refer only to Scenario A1B.

For example, in decade 2091-2100, without taking climate changes into consideration, 41.6 million tourist arrivals are expected on average each year, a number which increases by an additional 10.2 million —or close to +25%— when taking climate changes into account. Similarly significant increases are also observed in the respective figures for overnight stays and tourism receipts.

However, the picture changes considerably when we proceed to a seasonal breakdown of the data. Table 2.42, Panel D presents estimates of the physical and economic figures once the TCI seasonal changes are taken into account. First, we converted the physical and financial figures of base year 2007 into seasonal ones, using seasonality coefficients calculated based on the monthly actual distribution of receipts in the same year. Specifically, the outcome of our computations provided the following coefficients: 4.56% for winter, 14.16% for spring, 56.11% for summer, and 25.17% for autumn. Finally, having obtained the seasonal breakdown of the physical and economic figures, we applied the respective seasonal TCIs.

As Table 2.42, Panel D clearly shows, although climate change continues to have a positive effect on all figures, the increases are much lower than the ones of Panel C. For instance, the increase in arrivals due to climate change in 2091-2100 falls on an annual basis from 25%, as

Table 2.42 **Forecast arrivals, overnight stays and revenue**
(For the whole Greek territory discounted and non-discounted to present value, on an annual basis, as well as adjustment of all forecasts taking into account the impact of TCI both on an annual and a seasonal basis)

Climate zone	Time period	Panel A. Changes assuming decelerating increases from 3.5% to 1% and i=1.4% Without taking into account TCI changes				Panel B. Taking into account TCI changes on an annual basis			
		Arrivals	Overnight stays	Receipts (in thousand euro)	Receipts discounted to present value (in thousand euro)	Arrivals	Overnight stays	Receipts (in thousand euro)	Receipts discounted to present value (in thousand euro)
Greece	2007	16,037,592	65,420,236	11,319,200	11,319,200	16,037,592	65,420,236	11,319,200	11,319,200
	2011-2020	188,143,297	767,470,509	132,789,985	121,412,900	185,058,981	754,889,025	130,613,100	119,422,525
	2021-2030	215,685,205	879,818,929	152,228,837	137,264,579	212,149,382	865,395,668	149,733,282	135,014,340
	2031-2040	247,258,916	1,008,613,802	174,513,301	155,185,855	247,258,916	1,008,613,802	174,513,301	155,185,855
	2041-2050	277,013,603	1,129,988,548	195,513,914	171,460,195	299,719,636	1,222,610,560	211,539,644	185,514,310
	2051-2060	310,348,915	1,265,969,310	219,041,702	189,441,225	335,787,351	1,369,737,286	236,995,939	204,969,195
	2061-2070	339,823,403	1,386,201,074	239,844,552	204,568,892	395,532,158	1,613,447,151	279,163,331	238,104,776
	2071-2080	372,097,146	1,517,851,501	262,623,093	220,904,565	433,096,678	1,766,679,615	305,676,059	257,118,428
	2081-2090	398,245,218	1,624,514,214	281,078,187	233,163,716	496,174,370	2,023,984,923	350,195,773	290,499,056
	2091-2100	416,652,612	1,699,601,299	294,069,973	240,572,816	519,108,172	2,117,536,044	366,382,261	299,730,065
,		Panel D. Taking into account TCI changes on a seasonal basis				Panel C. Differences between forecasts not taking/taking into account TCI changes on an annual basis			
	2007	16,037,592	65,420,236		11,319,200	0	0	0	0
	2011-2020	192,024,909	783,304,306		123,917,788	-3,084,316	-12,581,484	-2,176,885	-1,990,375
	2021-2030	219,245,072	894,340,269		139,530,120	-3,535,823	-14,423,261	-2,495,555	-2,250,239
	2031-2040	257,461,386	1,050,231,522		161,589,180	0	0	0	0
	2041-2050	293,260,731	1,196,263,518		181,516,509	22,706,033	92,622,012	16,025,731	14,054,114
	2051-2060	328,551,192	1,340,219,688		200,552,145	25,438,436	103,767,976	17,954,238	15,527,969
	2061-2070	366,765,336	1,496,102,085		220,787,555	55,708,755	227,246,078	39,318,779	33,535,884
	2071-2080	398,702,063	1,626,377,767		236,699,225	60,999,532	248,828,115	43,052,966	36,213,863
	2081-2090	430,006,223	1,754,073,094		251,759,078	97,929,152	399,470,708	69,117,587	57,335,340
	2091-2100	438,395,357	1,788,293,885		253,126,951	102,455,560	417,934,746	72,312,288	59,157,250

mentioned above, to 5.2%. Aggregation on a seasonal basis sizeably lessens the climate change impacts, which however remain positive at countrywide level.

This marked deceleration should not come as a surprise, considering the data of Table 2.41, which showed the improvement on an annual basis to be clearly the result of the index's impressive rise in autumn by 20 points or more (Scenario A2) in the period 2070-2100, and its significant rise by 5 points during winter and spring. In contrast, the index falls considerably in summer by 5 points (Scenario A2) and by as much as 10 points (Scenario B2). These seasonal differences as to the index variation are of immense importance, since the summer months contribute on average 55-60% of annual tourism receipts.

All the economic figures of Table 2.42 were calculated using a discount rate of 1.4%, as in the Stern report. For a more comprehensive analysis and to demonstrate the role of the discount rate, Table 2.42(a) gives the present value of receipts, taking into account TCI changes on an annual basis, calculated using discount rates of 0%, 1%, and 3%. To facilitate comparison, the present value of receipts calculated using the 1.4% rate discount —i.e. the data in the last column of Panel B/Table 2.42— have also been reproduced. As was expected, a higher discount rate leads to a considerable decrease in the present value of receipts.

Although the above estimates show an overall positive impact of climate change on the physical and economic fundamentals of tourism, it should be stressed that the data calculated

Table 2.42(a) **Impact of discount rate on receipts discounted to present value, taking into account TCI changes on an annual basis (EUR thousands)**

Climate zone	Time period	Discount rate i=0%	Discount rate i=1%	Discount rate i=1.4%	Discount rate i=3%
Greece	2007	11,319,200	11,319,200	11,319,200	11,319,200
	2011-2020	130,613,100	122,482,817	119,422,525	108,170,509
	2021-2030	149,733,282	139,022,597	135,014,340	120,393,559
	2031-2040	174,513,301	160,425,800	155,185,855	136,231,086
	2041-2050	211,539,644	192,537,831	185,514,310	160,325,362
	2051-2060	236,995,939	213,571,765	204,969,195	174,387,013
	2061-2070	279,163,331	249,080,615	238,104,776	199,431,787
	2071-2080	305,676,059	270,035,965	257,118,428	212,011,886
	2081-2090	350,195,773	306,301,914	290,499,056	235,815,561
	2091-2100	366,382,261	317,286,706	299,730,065	239,529,371

at the national level are for the most part misleading, at least for certain important regions. Unfortunately, as mentioned above, analysis at the regional level exceeds the scope of the present study due to the absence of available data. However, as it was deemed of great importance to at least indicate the differences emerging when ones moves to a regional breakdown, we have chosen to present the effect of climate change on a seasonal basis for two leading tourism regions, the Dodecanese islands and Crete, which account for roughly 40% of the country's total tourism output.

To point out the major differences, we focused on economic figures. We initially calculated the seasonality coefficients based on the monthly distribution of receipts for the year 2007 (NSSG data). More specifically, we used the following coefficients for Crete: 0.85% for winter, 15.96% for spring, 58.44% for summer, and 24.75% for autumn. For the Dodecanese, the corresponding coefficients were: 0.58%, 13.40%, 61.71% and 24.31%. Having aggregated the receipts on a seasonal basis we estimated the effect of TCI changes. Table 2.43 presents the results of this analysis in terms of differences.

As regards the region of Crete, quite significant reductions of receipts are observed in the summer months, a season during which more than 50% of revenues are raised, and during which the TCI falls. On an annual basis, however, and assuming full time elasticity of tourist arrivals, receipts for the region of Crete increase, mainly because of the extremely significant improvement of the TCI during autumn and spring, when approximately 40% of receipts are collected. But in the case of the region of the Dodecanese islands, the considerable decrease in receipts in the summer months is not offset by the increases in the spring and autumn months. This is due to the fact that approximately 60% of total tourism receipts are collected in the summer months.

The above analysis, despite the embedded simplifications and generalisations, proves that conclusions based on data regarding the entire territory on an annual basis can be misleading. Drawing useful conclusions requires taking into consideration both the seasonal and the regional dimensions of climate change impacts.

As there was no regional seasonality data available so for an estimation of the impacts on revenues on a seasonal basis for all regions, it was not possible to estimate the total impacts of climate change on the physical and economic figures for all of Greece. It should be recalled that, to be complete, such an effort would require data with greater geographical detail and a shorter-term basis for recording climatological variables, so as to support the design of a sound long-term tourism strategy for Greece. Still, in general terms and based on the TCI estimates of Table 2.41, climate change impacts on tourism figures are expected to be quite small and perhaps marginally negative for Greece as a whole.

Therefore, Greece would be able to benefit from climate change in economic terms so long as it can overcome the institutional factors that limit the tourist arrival period mainly to the sum-

Table 2.43	Differences in receipts between forecasts taking/not taking into account seasonal TCI

Climate zone	Time period	Winter	Spring	Summer	Autumn	Totals on an annual basis
Crete	2007	0	0	0	0	0
	2011-2020	-4,649	156,526	0	517,592	669,469
	2021-2030	-5,256	619,367	0	585,169	1,199,280
	2031-2040	-5,942	700,231	0	661,569	1,355,858
	2041-2050	-6,565	773,665	0	1,461,895	2,228,994
	2051-2060	-7,254	854,799	0	1,615,204	2,462,749
	2061-2070	-7,833	923,058	0	2,616,277	3,531,502
	2071-2080	0	1,708,746	-1,698,953	2,825,197	2,834,990
	2081-2090	0	1,803,573	-1,793,237	2,981,982	2,992,318
	2091-2100	0	2,636,252	-3,700,440	3,076,739	2,012,552
Dodecanese	2007	0	0	0	0	0
	2011-2020	0	0	0	0	0
	2021-2030	0	48,753	0	0	48,753
	2031-2040	0	0	0	0	0
	2041-2050	0	304,495	0	0	304,495
	2051-2060	18,639	336,427	0	0	355,066
	2061-2070	20,127	435,951	0	0	456,078
	2071-2080	21,735	784,606	-1,313,922	0	-507,581
	2081-2090	27,529	828,148	-1,386,838	231,697	-299,465
	2091-2100	56,808	1,281,695	-2,861,814	0	-1,523,311

mer months (school vacations, workers' holidays), and co-shape, together with the suitable climate, arrivals' figures and seasonality. This solution presupposes identifying new target tourist markets not bound by the above limitations (pensioners, weekend breaks, professional and conference tourism) and increasing the appeal of Greece's tourism product to prospective tourists and, more importantly, international tour operators.

Returning to the data of Table 2.43, we attempt to provide a sense of the magnitude of the economic impacts of climate change. It can be observed that in the last three decades of the 21st century summer receipts for Crete and the Dodecanese islands will decrease by €7 billion and €5.5 billion, respectively. Should these destinations fail to counterbalance the losses at issue by proportionally increasing arrivals in other seasons of the year during which the TCI improves, the losses entailed for tourism receipts on an annual basis will stand at roughly €240 million and €185 million, respectively. These amounts are relatively small when expressed as a percentage of the country's estimated annual tourism receipts for the base year 2007 (close to 5%). However, their level can prove to be devastating for the long-term survival and profitability of Greek hotel enterprises when expressed as a percentage of these enterprises' profits. Indicatively, for the year 2007, the turnover of all Greek hotels came to €9.93 billion, with a gross profit margin of 33.8%, a margin of earnings before interest, taxes, depreciation and amortisation (EBITDA) of 24.5%, and a net profit margin of 0.98%.[31] The translation of these percentages into figures practically means that gross annual income for the year 2008 stood at €3.35 billion, net income before interest, taxes, depreciation and amortisation at €2.43 billion, and net (distributable) profits at €973 million. Therefore, a reduction of arrivals due to climate change based on the scenarios' forecasts, and consequently a reduction of revenue by about €430 million for only two regions, would suffice to cut annual net results of hotel enterprises at national level by almost one third.

The strong negative impact of the limited reduction of receipts on annual net results stems from the fact that the hotel units' operating leverage is very high. According to the data presented above, this leverage borders on 80%, leading to a high break-even point, a limited margin of safety and strong transformation of fluctuations in tourism receipts and expenses into analogous fluctuations in annual results.

At this point it should be emphasised that the multiplier for the tourism industry is quite high, and so changes in the industry's profitability have further considerable economic impacts on other, cooperating or even —more often than not— dependent industries. Moreover, the fact that tourism is a services-providing industry translates into increased employment for a considerable number of (mostly seasonal) workers and, conversely, into a loss of a proportionately large number of jobs when tourist arrivals or average spending per visitor decrease.

These observations yield a rather optimistic view of reality, as they take no account of the parallel improvement of the same climatic parameters in the countries of origin of the tourists visiting Greece. If climate conditions in these countries change in a way that improves the local TCI, then the above estimates would probably be far more negative. For example, the final PESETA report forecasts TCI improvement in Central and Northern Europe during spring, summer and autumn, and based on these estimates concludes that there will be a shift in tourist demand from Southern to Central and Northern Europe.

31 See footnote 22.

In addition to the seasonal variation of TCI changes, equally essential is the variation across regions, which, as was demonstrated earlier, can have very serious economic impacts. It should be emphasised that the analysis carried out above for the regions of Crete and the Dodecanese was based on a seasonal breakdown of overnight stays. But it did not take into consideration the seasonality of operation of these beds, which however stands at 88.91% for the Dodecanese islands and at 81.85% for Crete. These observations highlight the huge negative economic impacts that climate change (through a deteriorating local TCI alone) can have on the revenue and profitability of Greek hotel enterprises. These impacts are masked by non-deterioration or improvement of the TCI in other seasons (during which most tourist beds remain idle) and in other regions of the country, which however account for a limited share in tourism receipts.

Cost of adaptation for tourism establishments

From the point of view of the expenses required to cope with climate change and mitigate its impacts, the economic impacts are assessed as moderate.

These impacts are limited to a possible increase in energy consumption, mainly for ventilation and cooling during the summer months. Given that energy accounts for 5% of the operating costs of accommodation establishments (Table 2.40) and only 10% thereof involves ventilation and cooling, the anticipated increase in energy costs will not exceed 0.5% of operating costs in the event that energy consumption should double.

A more serious impact will be the increase in depreciation related to the acquisition of new systems for expanding/improving existing infrastructure (renewable fuel-fired systems, innovative heat insulation materials, double-pane windows, water recycling systems, solid waste collection and recycling systems, etc.). As depreciations represent 18.6% of hotels' total operating costs, it is estimated that an organised effort to increase energy efficiency and eco-friendly operation could increase this item by 10-20%, burdening hotels' operating costs by an additional 2-4%.

Standardising these efforts by acquiring a relevant certificate (such as ISO or EMAS) or a tourism ecol-label could add an additional 0.2-0.3% to operating costs. One should also factor in the higher maintenance costs for newly acquired equipment, the costs of training personnel in the operation of such equipment and, of course, the costs of acquisition (in cases where acquisitions are made with external capital). All of the above could result in an additional increase in costs in the order of 1%.

International experience has brought to the fore the gradual increase of insurance premia paid by accommodation establishments for coverage against extraordinary events that could compromise their ability to operate at a given time. Indicatively, insurance premia for hotels in the US tripled from 2000 to 2010. Admittedly, extreme weather events such as the ones that led to such an increase (e.g. hurricanes and tornados in the southern US), have yet to occur in Greece, at least not at such severity and frequency. However, the effects of forest fires in the last few years could be taken into account in the estimations as —at least partly— a result of climate change. A potential deterioration of weather conditions and of their consequences, such as wildfires, would undoubtedly lead the Greek insurance market to rapidly adjust its rates accordingly.

Finally, one should not underestimate the cost of repositioning the Greek tourism product in the international tourism 'arena'. This is a long-term and difficult process that requires careful and comprehensive elaboration at the central (strategic) level, but tailored to the regional and climatic characteristics of each destination. The Hellenic Chamber of Hotels, the Research Institute for Tourism, and the Association of Greek Tourism Enterprises, as well as the local unions of hotel owners, should play a key role in the planning, adaptation and implementation of this effort, contributing their experience and some of their resources, but in the authors' opinion the additional economic cost per accommodation establishment would be very small.

The negative impression that the above observations may have created can be considerably counterbalanced by the following encouraging considerations:

- many of the sector's enterprises have already taken initiatives, such as the ones described above, either as part of an upgrading plan or in response to customer demand;
- many of the investments described are rapidly recouped (in 6 months to 3 years), thus allowing additional economic benefit thereafter;
- establishments in close proximity to each other can undertake such initiatives as a group and split certain costs between them (personnel training, waste collection and recycling systems, etc.); and
- under development laws, accommodation establishments can often qualify for special financing (e.g. substantial incentives are often provided under 'green tourism' initiatives in the form of grants, accelerated depreciations, labour cost subsidies, etc.).

2.7.6 Conclusions and limitations of the study

Conclusions

The present study found the potential impacts of climate change on Greek tourism to be considerable, despite the fact that we only examined the effect of the TCI on revenue, overlooking the impacts of other major factors, such as SLR, increase in extreme weather events (storms, floods, hurricanes, etc.), greater frequency of fires and diseases, and devastation of sensitive ecosystems.

Considering that climate variables, such as temperature, sunshine, wind and rainfall are known to significantly influence tourists' choice of holiday destination and vacation timing, a seasonal and regional redistribution of arrivals, and hence of revenue, is to be expected. However, although the TCI index shows Greece to benefit from climate change at the countrywide level and on an annual basis, the seasonal and regional breakdown of the TCI index points to a significant deterioration of the climatic parameters that affect tourist flows to major (thus, crucial) tourist destinations, and more precisely at the peak of the demand for Greece's tourism product.

Given these results, it is important for the tourism industry, in coordination with State authorities at all levels, to adopt a series of initiatives geared toward reducing the seasonality and enhancing the geographic diversification of Greece's tourism product. These objectives can be achieved by marketing Greece's many currently unexploited natural attractions; by developing and promoting alternative eco-friendly forms of tourism; by attracting new tourist target groups; and by taking measures to reduce the industry's environmental footprint.

The decrease in arrivals and in associated revenue, together with the increase in accommodation establishments' operating costs as a result of climate change adaptation measures, will have a profound impact on net results and the financial situation of many tourism businesses. Our analysis of the Crete and Dodecanese regions showed that the €430 million decrease in hotel revenue and the €70-90 million (5-7%) increase in hotel operating costs[32] would be enough to wipe out any annual profit in an industry that as a whole has been increasingly raking up losses since 2008, even before the negative impacts of climate change are factoring in.

The results of the study indicate that reliable detailed estimates of the economic impacts of climate change can (and should) be pursued only at the local level and on an ad hoc basis. Such estimates should apply the most reliable scenario to a small-scale area, taking all of the location's other crucial features into account (e.g. altitude, windward/leeward position). Coupling this information with an analysis of the area's tourism establishments (age, size, infrastructure, etc.) would make it possible to tailor the measures needed to mitigate and manage the physical and economic impacts of climate change to the specific location.

Limitations of the study

Future studies of climate change impacts on tourism should place greater emphasis on regional analysis and use higher resolution data. This would require more comprehensive and accurate climate data series used in the TCI. Furthermore, there is a need to replace seasonal (quarterly) data with data adjusted to the average vacation time foreign visitors spend in Greece. Similarly, data for smaller geographical areas are needed (indicatively, in the order of 15x15 km, available today), and the emphasis of the analysis should be shifted to geographical areas that already have major tourism activities or a potential to develop new sustainable and profitable activities. Empirical studies of the specific climate factors affecting international

32 Operating costs in 2007 came to €1.4 billion. See footnote 22.

tourist arrivals (and of the weighting of these factors) are needed to adjust and improve the tourism product and ensure that it meets the desired specifications. Alternative indicators of thermal discomfort, such as the ASHRAE and PET indexes, can be used in lieu of Mieczkowski's arbitrary heat scale. Finally, it would be important to take into consideration the results of similar studies on the countries of origin of foreign visitors to Greece, as well as on Greece's major competitor destinations.

2.8 Risks and impacts of climate change on the built environment*

2.8.1 Introduction and review

The them 'built environment' encompasses any construction resulting from human intervention and, in a broader sense, denotes not only the natural or artificial environment in which people live, but also the effects that human action can have on the surrounding infrastructure.

Based on the classification used in the Garnaut Climate Change Review (Garnaut, 2008), the elements of the built environment can be grouped into seven general categories:

- Buildings: for residential, commercial and industrial use;
- Supply networks: power and water processing and management infrastructure;
- Public transport: transport systems and means (roads, railways, ports, airports, urban railways, etc.);
- Telecommunications: fixed-line networks and towers for electricity and telecommunications;
- Public spaces: recreation areas, parks, and all outdoor areas that combine natural and built environments;
- World heritage properties: national heritage buildings and monuments;
- Other buildings: various types of infrastructure.

In this sectoral study, the authors present a broad review of the impacts of climate change on the built environment, before focusing on the impacts on Greece's building sector. The energy-related, economic and social implications of climate change are examined with a view to estimating the change in the energy consumption of buildings and the implications of such a change for thermal comfort and overall quality of life. In closing, the study explores and proposes policies for offsetting the climate change impacts, and estimates the cost of their implementation.

* Sub-chapter 2.8 was co-authored by: Dimosthenis Asimakopoulos, Matheos Santamouris, Andreas Papandreou, Ifigenia Farrou, Marina Laskari, Maria Saliari, George Zannis, Costas Tiggas, George Giannakidis, Theodora Antonakaki, Konstantinos Vretos, Stelios Zerefos and John Kapsomenakis.

Table 2.44 **Overview of the direct and indirect impacts of climate change on the built environment**

Climate factors	Direct impacts	Studies	Indirect impacts	Studies
Rise in mean temperature	Increase in summer energy demand (cooling) (M)	Franco and Sanstad (2008), Garnaut (2008), Miller et al. (2008), Giannakopoulos and Psiloglou (2006), Metroeconomica (2006), Hadley et al. (2006), Plessis et al. (2003), LCCP (2002)	Lower worker performance and productivity due to hotter temperatures (M)	WWF (2008)
			Excess summer demand can cause network congestion and general service disruption, resulting in general production losses (M)	Garnaut (2008), Hanemann (2008)
	Urban Heat Island (M)	Souch and Grimmond (2006), Arnfield (2003), Shimoda (2003), Livada et al.(2002), Hassid et al. (2000), Katsoulis and Theoharatos (1985), Oke (1982)		
	Decrease in winter energy demand (heating) (M)	Garnaut (2008), Metroeconomica (2006), Plessis et al. (2003), LCCP (2002)		
Increase in heat wave frequency	Increased energy demand for air-conditioning (M)	Psiloglou et al. (2009), Franco and Sanstad (2008), Miller (2008), Giannakopoulos and Psiloglou (2006), Plessis et al. (2003), LCCP (2002), Cartalis et al. (2001)	Decrease in labour productivity due to poorer health and living factors (M)	WWF (2008)
	Decreased thermal comfort in urban areas and indoors (NM)	Garnaut (2008), Younger et al. (2008), Metroeconomica (2006), Kirshen et al. (2004), Plessis et al. (2003), LCCP (2002)	General economic losses from specific service disruption (e.g. water supply, communications, power supply, etc.) due to network congestion (M)	Garnaut (2008), Franco and Sanstad (2008), Hanemann (2008), WWF (2008), Jollands et al. (2007a,b), Sailor and Pavlova (2003)
			Impacts on human health from deterioration in indoor thermal comfort (e.g. cardiovascular disease, asthma, etc.). Increase in emergency hospital admissions (M)	Garnaut (2008), Younger et al., (2008), Vandentorren (2004), LCCP (2002)
Sea-level rise	Increased damage to buildings and other infrastructure in coastal areas (M)	Hunt and Watkiss (2011), PESETA (2009), Garnaut (2008), EEA (2007), IPCC (2007), Kirshen et al. (2007), Metroeconomica (2006), Kirshen et al. (2004), LCCP (2002)	Increase in expenditure for repair and maintenance of natural capital affected by sea level rise (M)	PESETA (2009), Garnaut (2008), IPCC (2007), Metroeconomica (2006), Kirshen et al. (2004), Plessis et al. (2003), LCCP (2002)
	Increased flood events (M)	PESETA (2009), Garnaut (2008), EEA (2007), IPCC (2007), Kirshen et al. (2007), Metroeconomica (2006), Kirshen et al. (2004), LCCP (2002)		
	Increased risks to human safety (M)	Garnaut (2008), IPCC (2007)	Immigration flows due to environmental reasons (NM)	IPCC (2007)

M=Market, NM=Non-market.

Table 2.44 **Overview of the direct and indirect impacts of climate change on the built environment *(continued)***

Climate factors	Direct impacts	Studies	Indirect impacts	Studies
Increased frequency of extreme weather events	Increased damage to natural capital (M)	Garnaut (2008), IPCC (2007), Metroeconomica (2006), LCCP (2002)	Economic loss in sectors relying on urban development (e.g. tourism) (M)	Garnaut (2008)
	Increased risks to human safety (loss of human life) (M)	Garnaut (2008), IPCC (2007)	Cost of relocating affected populations, in cases where the natural capital is totally destroyed (M)	IPCC (2007)
			Increase in emergency hospital admissions due to extreme weather events (M)	Garnaut (2008), Vandentorren (2004)
	Damage to cultural heritage monuments (NM)	Metroeconomica (2006)	Economic loss in sectors relying on cultural monuments (e.g. tourism) (M)	Metroeconomica (2006)
Increased frequency of winter storms	Increase in damages to buildings and equipment (M)	Garnaut (2008), IPCC (2007), Metroeconomica (2006), Kirshen et al. (2004), Plessis et al. (2003)	Increased expenditure for building repair/restoration after flood events (M)	Garnaut (2008), Metroeconomica (2006), Kirshen et al. (2004), Plessis et al. (2003)
	Drainage system surcharge due to intense rainfall, making flood events worse	Wilby (2007), Metroeconomica (2006)		
	Increased flood events (M)	Garnaut (2008), IPCC (2007), Metroeconomica (2006), Kirshen et al. (2004), Plessis et al. (2003), LCCP (2002), Gonzalez-Rouco (2000)		
Decreased frequency of summer rainfall	Increased incidents of subsidence (M)	Garnaut (2008), Hulme et al. (2002), LCCP (2002)		
	Intense periods of summer drought leading to relative water shortage, on account of persistently high water demand (M)	IPCC (2007), Arnell (2004)	Conflicts between countries over shared water resource rights and 'climate migrants' management (NM)	IPCC (2007)
Increased frequency of summer fires	Damage to buildings and infrastructure from fires (M)	Garnaut (2008)	Decreased production due to service disruption from fire damage to power network (blackouts) (M)	Garnaut (2008)
Reduced soil moisture	Damage to natural capital due to soil subsidence (M)	Garnaut (2008), Metroeconomica (2006), Hulme et al. (2002), LCCP (2002)		
Reduced frequency of frost events	Lesser damage to buildings and road network from frost events	Garnaut (2008), Metroeconomica (2006), LCCP (2002)		

M=Market, NM=Non-market.

Sectoral studies of the impacts of climate change on the built environment tend to focus on urban centres. The reason for this is two-fold: first, the bulk of the built environment is concentrated in urban centres and, as concentration increases problems exponentially, the impacts of climate change are more pronounced in large cities;[33] and second, the majority of the global population is projected to concentrate in urban centres.[34] Similar studies have been carried out at a city level (LCCP, 2002; Kirshen et al., 2008; Jollands et al., 2007) as well as at the national level, with sectoral breakdowns (PESETA, 2009; Garnaut, 2008; Metroeconomica, 2006).

Climate change will drastically alter a number of environmental and climate factors. This change is, in turn, expected to have physical impacts on a number of parameters that affect human living conditions (e.g. damage to the built environment, additional operating costs in certain production sectors, loss of business, disruption of services, etc.). In many cases, climate change may also affect human welfare (e.g. lower thermal comfort levels, poorer health and living conditions, reduced prosperity, etc.).

Generally speaking, the impacts of climate change on the built environment can be divided into direct and indirect, as well as market and non-market impacts.[35] The direct and indirect impacts, as mentioned in the international literature, are summarised in Table 2.44. The study that follows is based on the climatological estimates of the Research Centre for Atmospheric Physics and Climatology of the Academy of Athens and focuses mainly on the temperature change-related impacts (in green in Table 2.44).

2.8.2 The building sector of Greece

Greece's building sector is responsible for roughly one third of total CO_2 emissions and around 36% of total energy consumption. Prior to the economic crisis, building sector CO_2 emissions had been growing at an annual rate of close to 4%, while the energy consumption of buildings was steadily rising.

Greek buildings are highly energy-consuming. According to Eurostat, Greek households have are the biggest energy consumers in the EU, consuming roughly 30% more energy than Spain's, almost twice as much as Portugal's and considerably more than even colder climate countries/regions, like Belgium or Scandinavia.

This has dire consequences for the country's energy balance and household budgets (low-income households, in particular), while also leading to dramatic increases in peak electrical

33 As noted in the IPCC Fourth Assessment Report (2007), the impacts of climate change will be clearly stronger in areas with rapid urbanisation and in all forms of coastal areas.

34 According to the United Nations (2008), by 2050 urban dwellers will likely account for more than two thirds —around 68%— of the global population and around 86% of the population of developed countries.

35 Alternatively, a distinction could be made between valuated and non-valuated impacts.

power loads, increasing the need for new power stations and condemning hundreds of thousands to energy poverty.

This adverse state of play of the built environment from an energy perspective has some major social and economic corollaries. Today, only 8% of low-income earners currently live in dwellings with thermal insulation and double glazing, as opposed to 70% for high-income earners. Thus, low-income earners spend roughly 120% more for heating and 95% more for air-conditioning per person and surface area than their high-income counterparts. Meanwhile, the thermal discomfort that low-income earners experience during summer can pose serious health risks.

Given that the energy demand of buildings depends directly on regional climate factors, it is evident that climate change will have significant consequences for the entire built environment. It is already well-established that the worsening thermal degradation in Greece's large urban centres, rising ambient temperature in response to local and global changes, the short-sighted empirical and/or outdated approaches to urban landscaping and building design, and the depletion of green areas in and around cities increase discomfort for urban dwellers, intensify the use of highly energy-consuming means to ensure thermal comfort, and even endanger the lives of a large part of the population with the means of coping with the emerging new climatic reality.

The present sub-chapter explores the energy-related, economic and social implications of the likely climate change for the built environment. The analysis aims, first, to calculate the increase in buildings' energy consumption as a result of climate change and the repercussions of such an increase on thermal comfort and overall quality of life, and, second, to explore and propose policies to offset the above impacts, while also calculating the cost of their implementation.

2.8.3 State of play

The insufficient protection of existing buildings from their surrounding environment, mass housing and commercial building construction with total disregard to the environment and local climatological conditions, phenomena such as the urban heat island, aging buildings, and the total lack, for nearly 40 years now, of any update in legislation on energy and environmental protection of buildings, have resulted in:

- an unsustainable widening of the country's energy deficit;
- an economic and social squeeze on the lower income brackets;
- an increase in the country's energy poverty; and
- Greece's failure to honour its international environmental commitments arising e.g. from the Kyoto Protocol or Directive 2002/91/EC of the European Parliament and of the Council on the energy performance of buildings (EPBD, 2003).

Some 65% of the country's buildings were constructed prior to 1980, with practically no thermal protection systems, such as insulation, double glazing, etc. Meanwhile, the strong increase in living space per person has also contributed to increase the energy demand per person. Finally, the high penetration of air-conditioning use in recent years has increased the absolute consumption levels of the building sector and the country's peak electrical power loads.

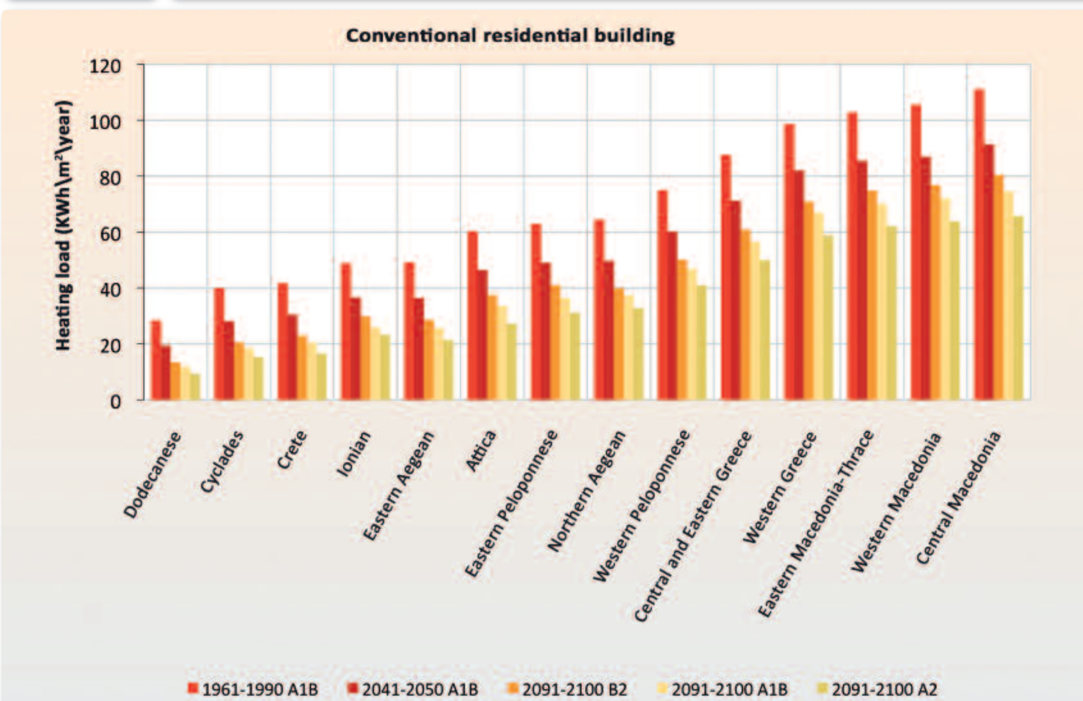
2.8.4 Physical impacts of climate change on the built environment

The likely physical impacts of climate change on the building sector involve, first, changes in the energy consumption of climate-controlled buildings and, second, changes in the indoor conditions of buildings unequipped with climate control systems.

Warmer climate conditions will obviously lead to a significant reduction in buildings' winter energy requirements. In summer, however, warmer temperatures will lead to a significant increase in energy requirements for air-conditioning, while also seriously decreasing thermal comfort in non air-conditioned buildings.

The method used to estimate the impacts of climate change on the energy consumption and indoor thermal comfort conditions of buildings consisted of the following four phases:

Figure 2.11 Estimated change in the heating load of a conventional dwelling in each climate zone under the five climate scenarios considered



Phase 1) Using the detailed simulation tool TRNSYS, we calculated the heating and cooling loads of three types of buildings, for each of the country's climate zones and under all five climate scenarios available. More specifically, we estimated the energy load requirements for residential, office and education buildings. In all cases we assumed that the indoor thermal comfort conditions are maintained year-round (at 21ºC in winter and 26ºC in summer) with recourse to auxiliary heating and air-conditioning systems.

For each type of building, we simulated three different types of constructions (of low, medium and high energy efficiency): (a) a *conventional* construction (built after the introduction of the thermal insulation requirements of 1979); (b) a *modern* construction (built in compliance with the energy technology of 2010 and the specifications of the Energy Performance of Buildings Regulation); and (c) a *passive* construction (incorporating the currently available energy-saving technology as much as possible). For each type of construction, we calculated the annual heating and cooling loads (in KWh/m2) for three time periods (1961-1990, 2041-2050 and 2090-2100) and under three emission scenarios (A1B, A2 and B2). The changes in heating and cooling loads of a conventional residential building are presented, respectively, in Figures 2.11 and 2.12.

As can be seen, the projected decrease in the heating load of buildings under the four future scenarios is particularly large relative to today. More specifically, the average decrease is

Figure 2.12 **Estimated change in the cooling load of a conventional dwelling in each climate zone under the five climate scenarios considered**

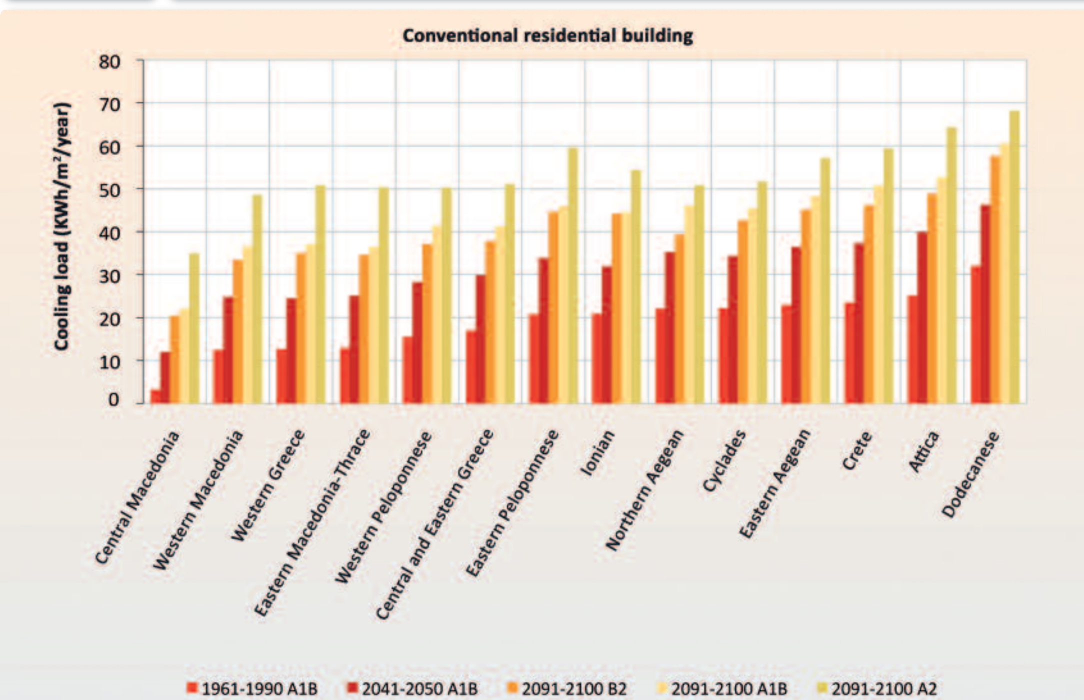


Figure 2.13

Estimated change in the heating load for three types of dwellings (conventional, modern, passive) in Attica under the five climate scenarios

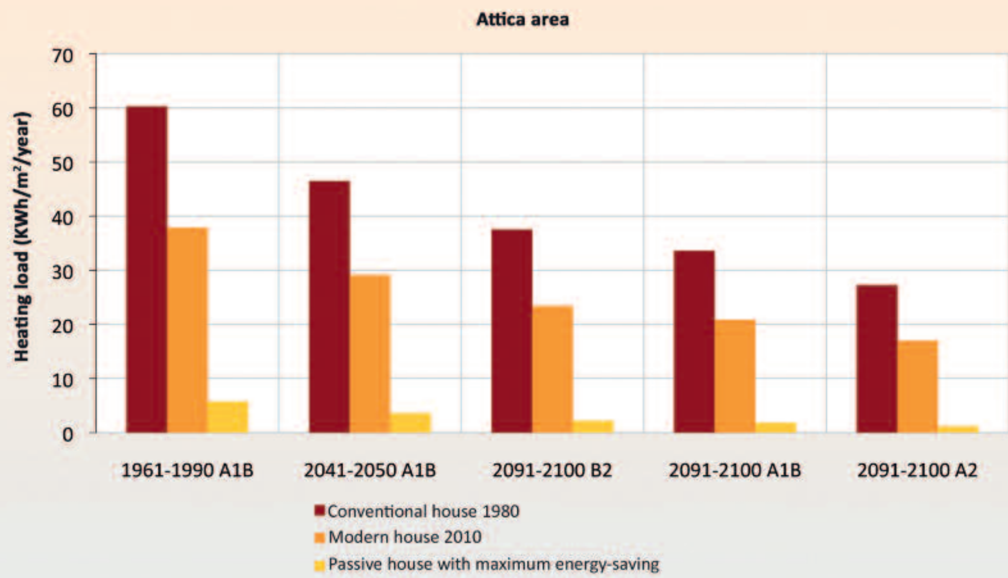
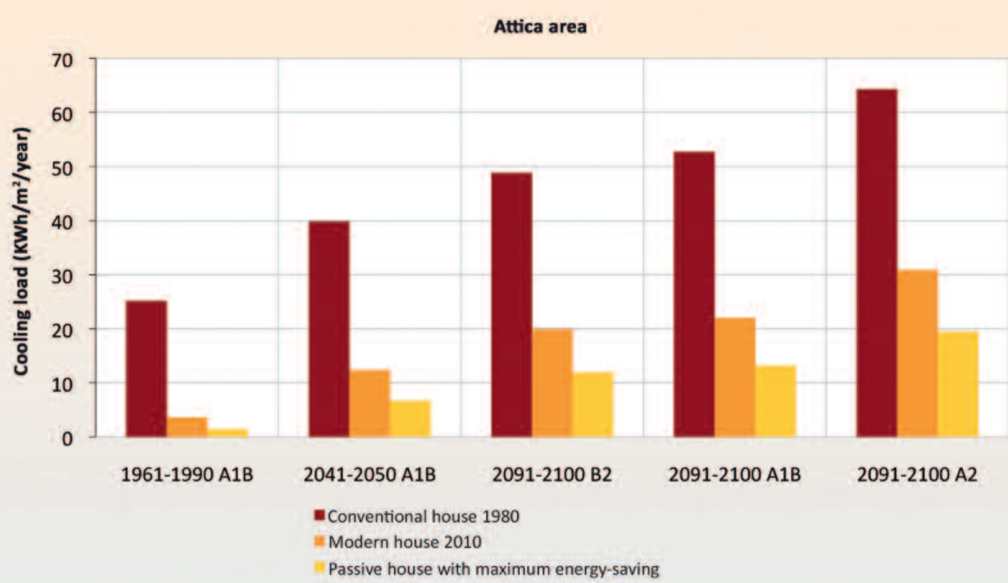


Figure 2.14

Estimated change in the cooling load for three types of dwellings (conventional, modern, passive) in Attica under the five climate scenarios



around 22.4% under Scenario A1B for 2041-2050, 50.1% under Scenario A2 for 2091-2100, 36.4% under Scenario B2 for 2091-2100 and finally 42% under Scenario A1B for 2091-2100.

Conversely, the increase in air-conditioning load relative to today is estimated at 83% under Scenario A1B for 2041-2050, while the average increase is estimated at around 248% under Scenario A2 for 2091-2100, 148% under Scenario B2 for 2091-2100 and finally 167% under Scenario A1B for 2091-2100.

The largest percentage decrease in heating load by 2050 is observed in the Dodecanese, followed by the Cyclades, while the smallest decrease is observed in Thessaly, followed by Eastern Macedonia-Thrace.

The largest increase in air-conditioning load is observed in Central Macedonia, followed by Western Macedonia, while the smallest increase is observed in the Dodecanese, followed by the Ionian.

Similar results and findings were obtained for office and education buildings.

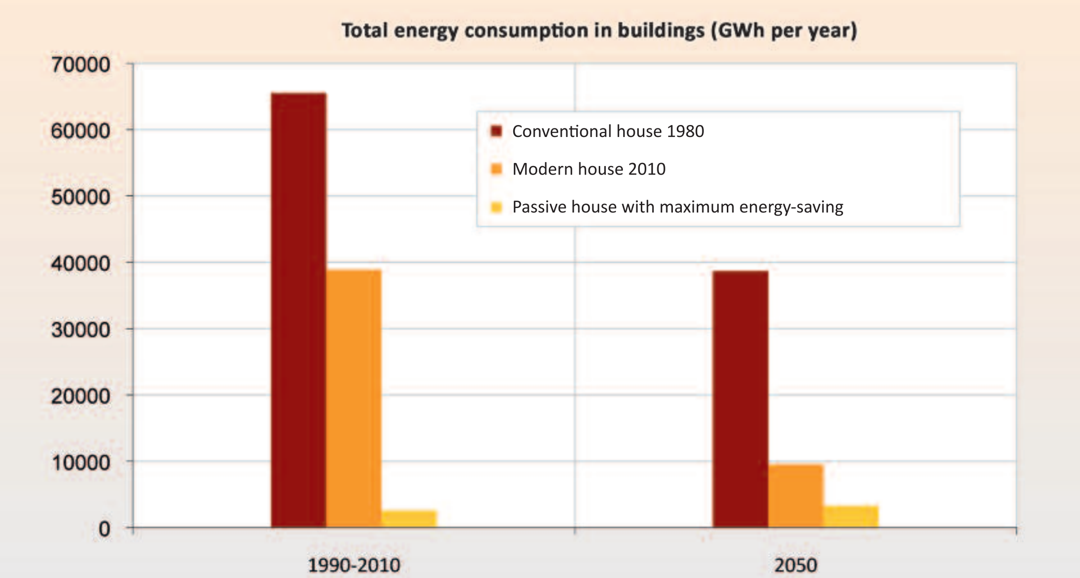
Phase 2) We studied the variation in heating and cooling loads in function of the construction standard (conventional, modern or passive). Indicatively, the variation in heating and air-conditioning loads of three types of residential buildings in Attica are presented for the five climate scenarios in Figures 2.13 and 2.14.

As regards *modern* constructions, the pace at which the heating load decreases under the four future climate scenarios relative to the current state of play is very similar to the pace observed for *conventional* constructions. In contrast, the percentage increase in the summer air-conditioning load is 4 to 6 times higher than the one observed for conventional constructions. The reason for this is that the main climatic change takes place in summer, while the improved level of construction (better shading and load management) reduces cooling loads by 50% to 70% compared with conventional constructions, and therefore increases the relative importance of the ambient temperature change, which affects buildings mainly through ventilation systems.

Finally, a *passive* construction, incorporating all the latest energy-saving technologies, has a heating load 10 to 40 times lower than that of a conventional construction, and a practically negligible air-conditioning load by today's standards. The percentage reduction in heating load attributable to climate change is roughly 50% greater than that of conventional constructions, while the respective percentage increase of air-conditioning loads is 6 to 10 times higher than that of conventional constructions and 50% to 70% greater than the respective increase in modern constructions. The higher rates of load increase or reduction are attributable, on one hand, to the drastic reduction in energy loads thanks to the incorporation of advanced energy-saving systems that contribute to the large percentage increase (increase of small figures) and, on the other hand, to the higher relative impact henceforth of ambient temperatures (via ventilation) as a result of the drastic reduction of the other loads.

Figure 2.15

Estimated total energy consumption in Greece in 1990-2010 and 2050, per type of construction



Similar results and findings were obtained for office and education buildings.

Phase 3) Based on the simulations of energy consumption by different types of construction in all the climate regions, we proceeded to calculate the total energy consumption of the entire building stock per geographic/climate region in 2010 and under the climate scenario for 2050. Databases were used to determine the type and characteristics of constructions in each region, while we also estimated the variation in the number of buildings by 2050.

The aim at this stage was to calculate total energy consumption in Greece (and not just the total load), as well as the change in total energy consumption attributable to climate change. The calculations at this stage are drastically affected by the coefficient of performance (COP) of heating and air-conditioning systems.

The buildings' characteristics were kept unchanged in both sets of simulation with regard to the climate scenarios. However, given that heating and air-conditioning systems will be much more efficient in 2050 than they are today, we altered the COP of conventional energy supply systems. More specifically, we assumed that a heat pump today has a heating COP of 3 and a cooling COP of 2. For 2050, the corresponding heating and cooling COP were set at 5 and 4, respectively.

The results obtained for the total energy consumption of the country's building stock for the three types of construction under the two climate scenarios are presented in Figure 2.15.

As can be seen, the almost certain improvement in energy production system technology in future and the better quality standards of buildings will, to a large extent, offset the effects of climate change. The following future scenarios regarding the course of buildings' energy consumption can thus be formulated.

The best-case scenario: The total energy consumption of Greece's building stock, which stands today at 90,000 GWh, could, in spite of climate change, be reduced to 5,000-10,000 GWh by 2050, if state-of-the-art energy production technology is used in all buildings, as discussed above, and if the features of the entire building stock are substantially improved to 'passive construction standards'. In addition, all new buildings constructed after 2020 would need to have nearly zero energy consumption.

The optimistic scenario: Use of high-performance energy production systems, as discussed above, in all buildings by 2050 the upgrading to 'passive construction standards' of the building stock constructed prior to 1980 and the nearly zero energy consumption of all new buildings would reduce total annual energy demand to roughly 22,000-25,000 GWh.

The realistic scenario: Use of high-performance energy production systems, as discussed above, in about 70% of buildings (with the rest remaining conventional), the upgrading to 'modern construction standards' of 60% of the building stock constructed prior to 1980 and the nearly zero energy consumption of all new buildings built after 2020 would reduce total annual energy demand to 50,000-55,000 GWh.

The worst-case scenario: Installation of high-performance energy production systems, as discussed above, in only 10% of buildings by 2050 (with the rest remaining conventional), the upgrading to 'modern construction standards' of only 20% of the building stock constructed prior to 1980 and the nearly zero energy consumption of all buildings built after 2020 would cause total annual energy demand to exceed 120,000-130,000 GWh.

Phase 4) Based on the analysis of climate change effects on the built environment, an attempt was made to quantify the impact on the quality of life as a result of the rise in indoor air temperature in low-standard buildings lacking an auxiliary energy production system.

We adopted the following methodology: having selected two typical constructions with a low-standard building envelope, we performed year-round indoor climate simulations under all the considered climate scenarios and periods: 1960-1990 (A1B), 2041-2050 (A1B) and 2091-2100 (A1B, A2, B2). The assumption was made that the buildings have no climate control, i.e. no installed air-conditioning system. The envelope attributes used were those of dwellings constructed prior to 1979 when the thermal insulation regulation first came into effect (conventional buildings).

We calculated three parameters that characterise and quantify the quality of the indoor environment:

a) maximum and minimum indoor temperatures each month;

b) the percentage of time in summer during which indoor temperature exceeds 26ºC, 28ºC, 30ºC or 32ºC; and

c) the number of degree-hours of indoor temperature higher than 26ºC.

The entire analysis was carried out for each of the country's climate regions, as defined by the Academy of Athens.

Degree-hours are defined as the sum of the differences between hourly indoor temperatures and 26ºC, or in more detail:

$$DH(26) = \Sigma\, (Tind(\iota) - 26)\, +$$

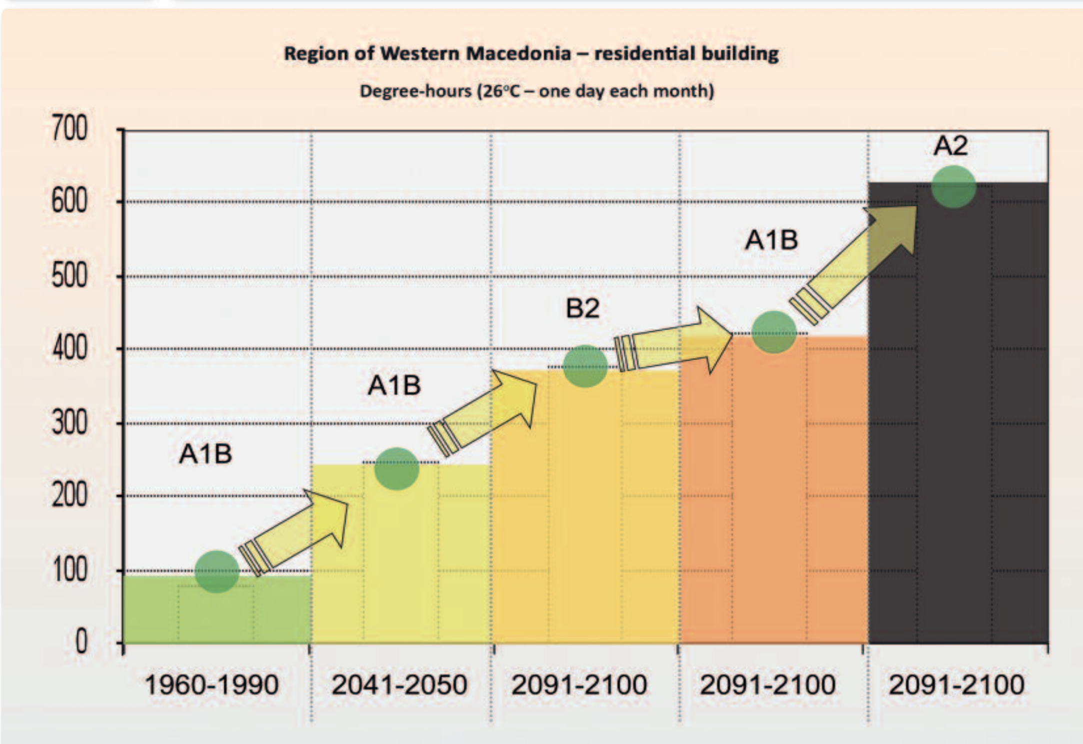
where Tind(ι) is the indoor temperature in hour (ι), while the sign (+) denotes that only positive difference values are taken into account.

Given that climate files contain one day per month, the calculations refer to all typical days of the year.

The change in air-conditioning degree-hours calculated under all climate scenarios is indicatively presented in Figure 2.16 for Western Macedonia.

The increase in cooling degree-days calculated under Scenario A1B for the years 1990 and 2050 ranges from 54% to as much as 1,000%. The largest increase is observed in Central Mace-

Figure 2.16 **Estimated change in cooling degree-hours at base temperature of 26°C for Western Macedonia under the five climate scenarios**

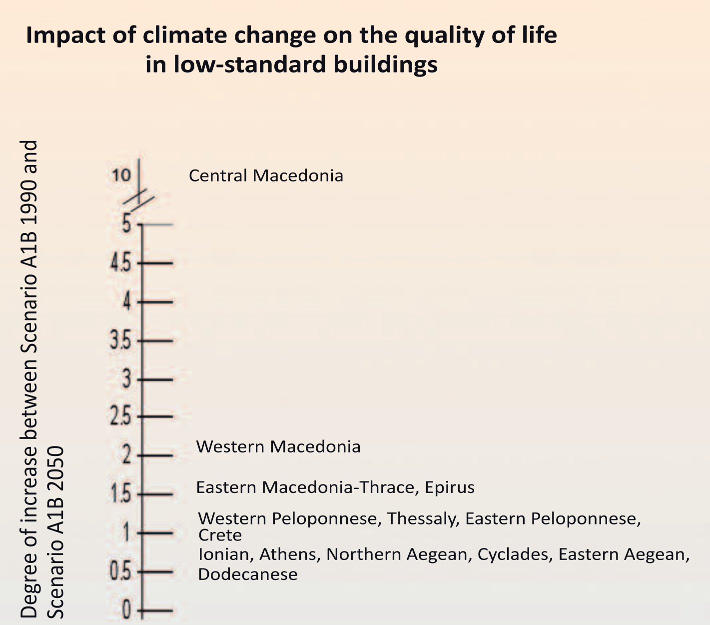


donia, followed by Western Macedonia. The smallest increase is observed in the Dodecanese. The Athens area and the other island regions present an almost uniform increase of roughly 90%. In parallel, the increase in cooling degree-days calculated between Scenario A1B for 1990 and Scenario A2 for 2100 ranges from 152% to up to 4,200%. The largest increase is observed in Central Macedonia, followed by Western Macedonia and then Eastern Macedonia-Thrace. The smallest increase is observed in the Dodecanese. The Athens area and the other island regions present an almost uniform increase in the order of 200-250%.

The increase in cooling degree-days calculated between Scenario A1B for 1990 and Scenario B2 for 2100 ranges from 100% to as much as 2,100%. The largest increase is observed in Central Macedonia, followed by Western Macedonia and then Eastern Macedonia-Thrace. The smallest increase is observed in the Dodecanese. The Athens area and the other island areas present an almost uniform increase in the order of 150%.

Finally, the increase in cooling degree-days calculated between Scenario A1B for 1990 and Scenario A1B for 2100 ranges from 115% to as much as 2,400%. The largest increase is observed in Central Macedonia, followed by Western Macedonia and Eastern Macedonia-Thrace. The smallest increase is observed in the Dodecanese. The Athens area and the other island regions present an almost uniform increase in the order of 170%.

Figure 2.17 **Estimated degree of increase in cooling degree-hours for a conventional dwelling in 2050, relative to 2010**



The rate of increase in cooling degree-days under the scenario for 2050 in all the regions studied is presented in Figure 2.17.

In parallel with the change in cooling degree-days, we also calculated, for each region and under each climate model, the maximum and minimum indoor temperatures in a typical dwelling. The results as regards the change in maximum monthly indoor temperature for a typical region, namely Western Macedonia, are presented in Figure 2.18.

The increase in maximum indoor temperature calculated between Scenario A1B for 1990 and Scenario A1B for 2050 ranges from 2.0ºC to 2.9ºC. The largest increase is observed in Western Macedonia, followed by Central Macedonia and Eastern Macedonia-Thrace. The smallest increase is observed in the Ionian. The increase in maximum indoor temperature calculated between Scenario A1B for 1990 and Scenario A2 for 2100 ranges from 4.5ºC to 7.5ºC. The largest increase is observed in Central Macedonia, followed by Eastern Macedonia-Thrace and Western Macedonia. The smallest increase is observed in the Cyclades. At the same time, the increase in maximum indoor temperature calculated between Scenario A1B for 1990 and Scenario B2 for 2100 ranges from 3.4ºC to 4.8ºC. The largest increase is observed in Central

Figure 2.18 **Estimated maximum indoor temperatures for a conventional dwelling in Western Macedonia under the five climate scenarios**

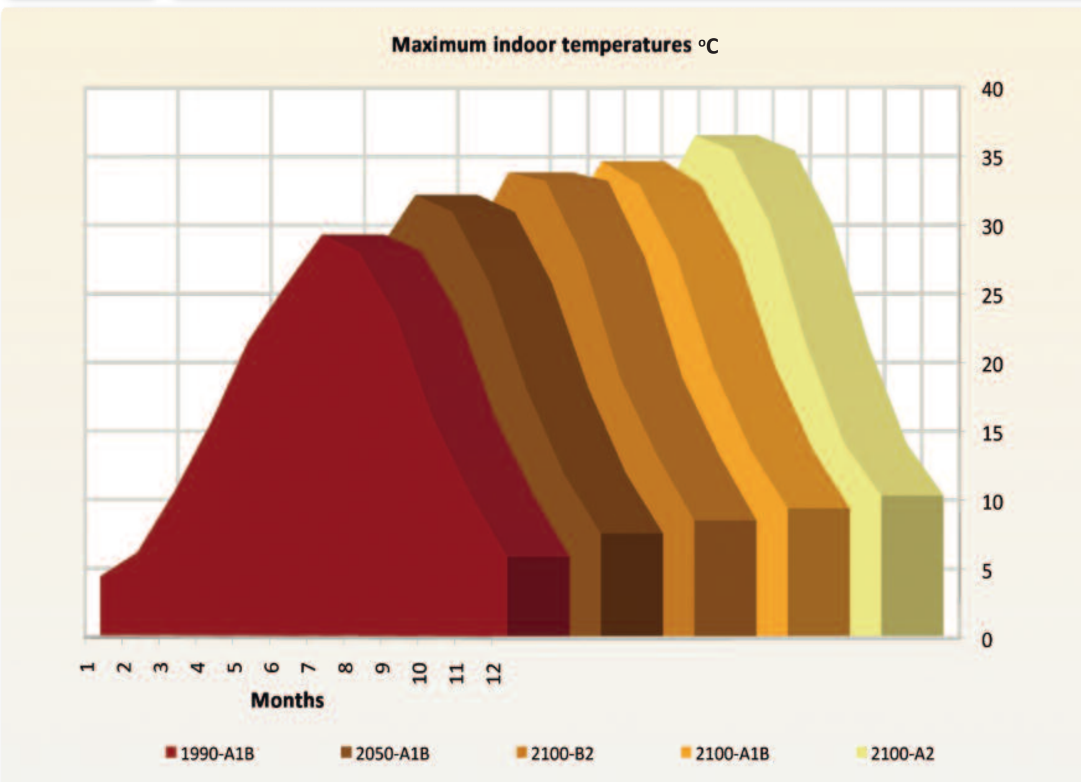
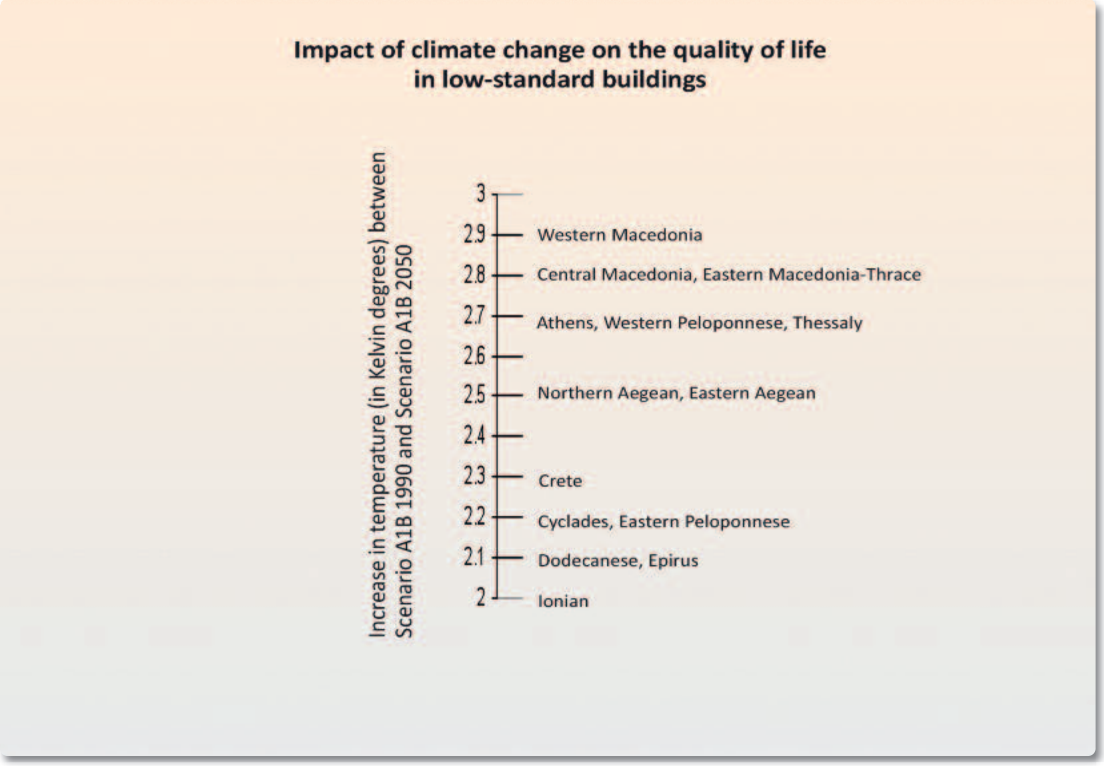


Figure 2.19

Estimated increase in maximum summer indoor temperature for a conventional dwelling in each climate zone in 2050, relative to 2010



Macedonia, followed by Eastern Macedonia-Thrace, Thessaly and Western Macedonia. The smallest increase is observed in the Cyclades. Finally, the increase in maximum indoor temperature calculated between Scenario A1B for 1990 and Scenario A1B for 2100 ranges from 3.5ºC to 5.3ºC. The largest increase is observed in Western Macedonia, followed by Central Macedonia, Eastern Macedonia-Thrace, the Western Peloponnese and Thessaly. The smallest increase is observed in the Cyclades.

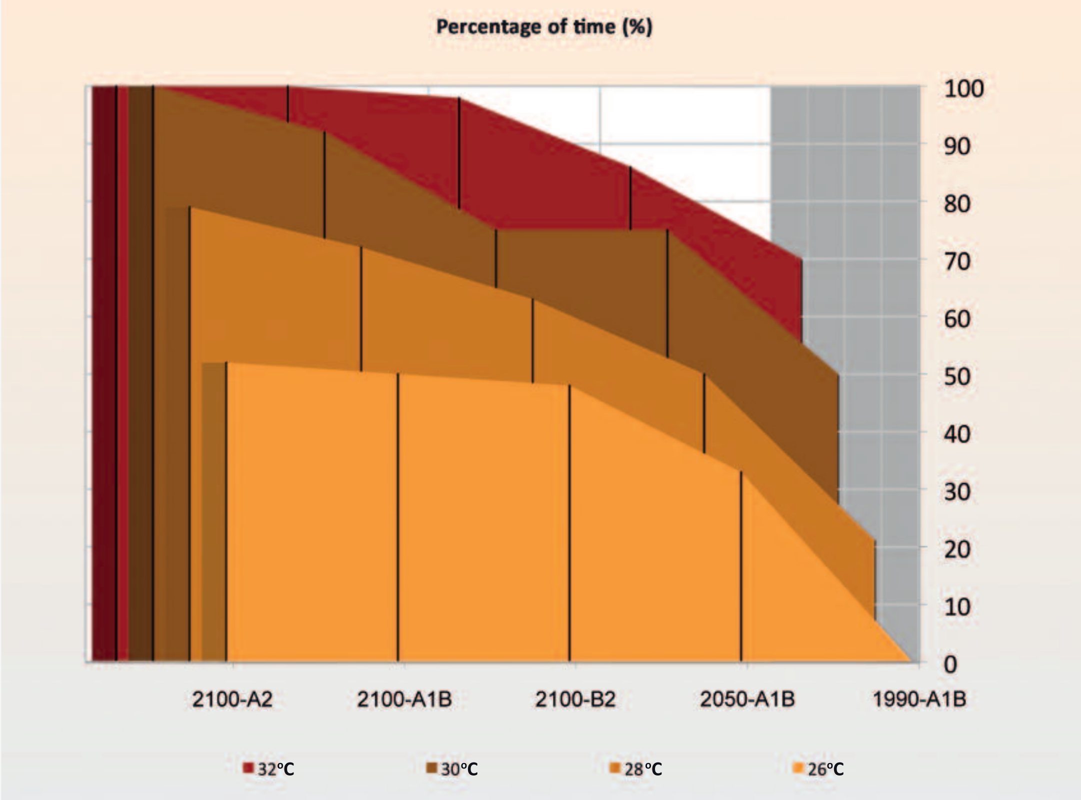
The relative increase in maximum annual indoor temperature in 2050 relative to 2010 for all of the regions is presented in Figure 2.19.

In parallel with the change in air-conditioning degree-days and the maximum and minimum indoor temperatures, we also calculated for each region and under all climate models the percentage of time in summer (in hours) during which the indoor temperature in a typical dwelling exceeds the temperature standards of 26ºC, 28ºC, 30ºC and 32ºC. The results as regards the change in maximum monthly indoor temperature in the Northern Aegean are presented in Figure 2.20.

Under Scenario A1B for the current period, the percentage of time during which the indoor temperature exceeds the standard temperature from June to September is always zero. In contrast, under Scenario B2 for 2100, this percentage increases drastically and ranges from 0% to

Figure 2.20

Percentage of time in summer (June-September) during which indoor temperature exceeds four given temperature thresholds, Northern Aegean



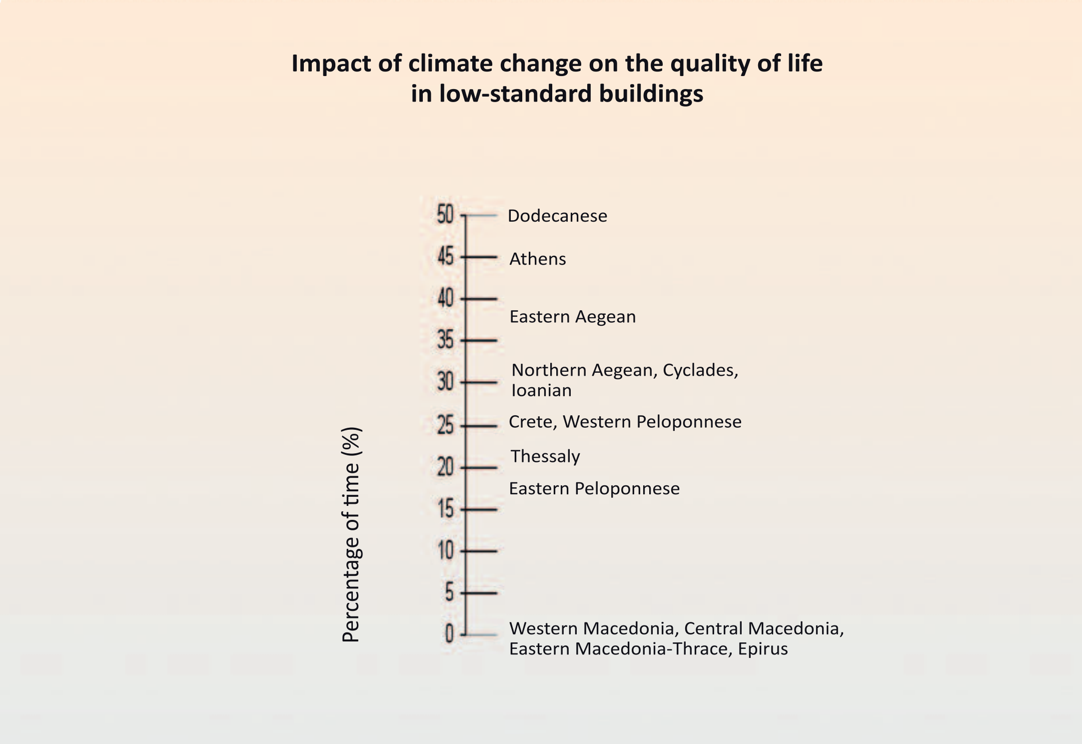
65%. The largest 'above standard temperature' value is observed in the Dodecanese, Athens and the Aegean, and the smallest in Central Macedonia. Under Scenario A1B for 2100, the percentage increases sharply, ranging from 0% to 68%. The largest 'above standard temperature' value is observed in Athens and the Dodecanese, and the smallest in Central Macedonia. Under Scenario A2 for 2100, the percentage also increases drastically, ranging from 40% to 98%. The largest 'above standard temperature' value is observed in the Dodecanese and Athens, and the smallest in Central Macedonia and Western Macedonia.

The percentage of time in summer during which indoor temperature exceeds 32ºC under Scenario A1B for 2050 for all climate regions is presented in Figure 2.21.

2.8.5 Economic impact on the built environment and potential for addressing and adapting to climate change impacts

The results of the simulations of useful cooling and heating energy demand in buildings were used to estimate the additional cost that climate change would entail for adapting build-

Figure 2.21 **Percentage of time in summer (June-September) during which indoor temperature exceeds 32°C in each climate zone under Scenario A1B 2050**



ings to the new climatic conditions. The technological adaptations required to address climate change consist, first, of equipping (or retrofitting) buildings with advanced energy-saving and alternative energy systems.

Simulations were aggregated at the regional level (total buildings per region), using estimates of the rates of change in number of buildings per use.

To estimate the cost of necessary interventions in buildings over the horizon extending to 2050, we assumed that all buildings will have advanced energy-saving and alternative energy systems, so as to have nearly zero energy consumption, as provided for by the revised EC Directive on the energy performance of buildings. More specifically, the following assumptions were made:

- All new buildings will have an insulation thickness of 15 cm.
- 60% of existing non-insulated buildings will be retrofitted with an insulation layer of 15 cm.
- The remaining 40% of existing buildings with insulation that meets current requirements will be retrofitted with 15 cm insulation.
- All glass units will be replaced with double-glazing with low emissivity and a U-value of 0.4 W/m^2-K.

Figure 2.22 **Distribution of intervention costs per technology and region**

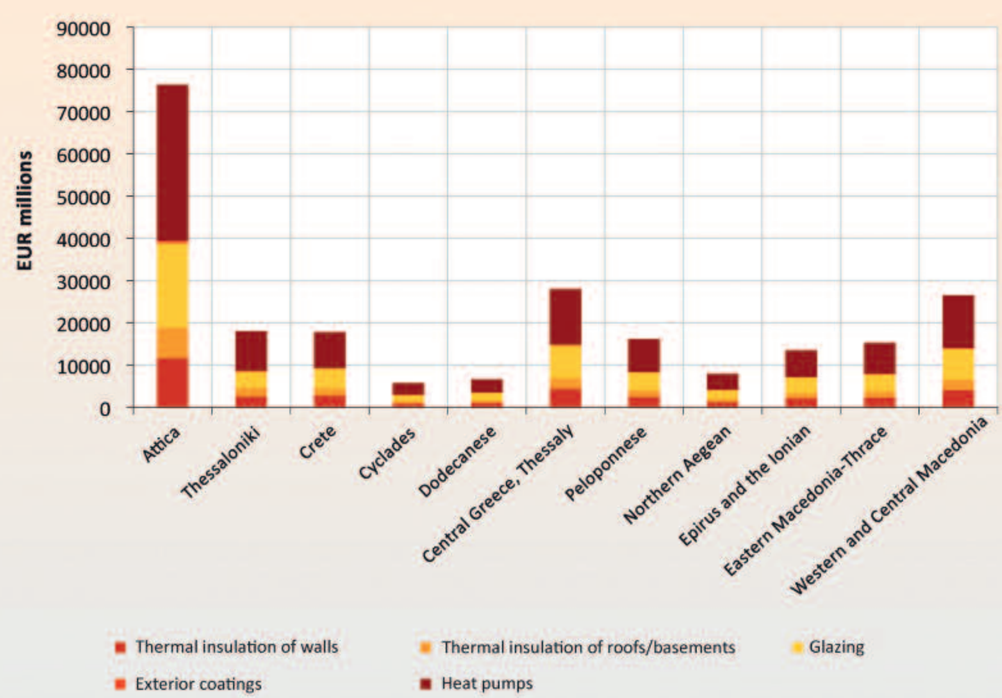
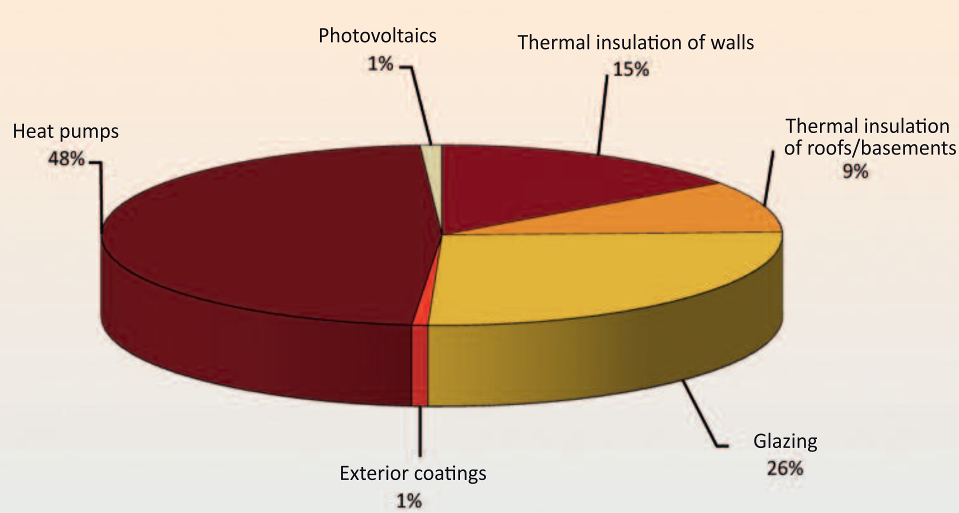


Figure 2.23 **Percentage distribution of intervention costs per technology**



- All external surfaces will be coated with highly reflective paint.
- All building heating and cooling will be achieved with electric heat pumps with a heating COP of 5 and a cooling COP of 4.
- All additional heating and cooling energy needs will be met with photovoltaic panels.
- The calculations were carried out for each climate region using comprehensive databases comprising qualitative and quantitative building attributes.
- The present analysis focused on residential, education and tertiary-sector buildings, which together represent 90% of the country's building stock.

Based on these assumptions, the examined scenario presents the cost needed for all buildings to have nearly zero energy consumption by 2050, taking climate change into account.

As can be expected, the cost is higher in the wider Attica area (Figure 2.22), where the largest share of the country's building stock is located.

The total cost of the measures needed to adapt the existing and anticipated building stock to the technological standards likely to be in effect in 2050 will amount to some €230 billion. A breakdown of these costs by technology for building envelope upgrading, heating system upgrading and photovoltaic panel installation is presented in Figure 2.23. Roughly 50% of the required cost involves building envelope upgrading. The small cost needed for additional photovoltaics to ensure zero energy consumption is a direct reflection of the extremely low energy demand for heating and cooling achieved with the thermal enhancement of building envelopes and the use of energy-saving systems.

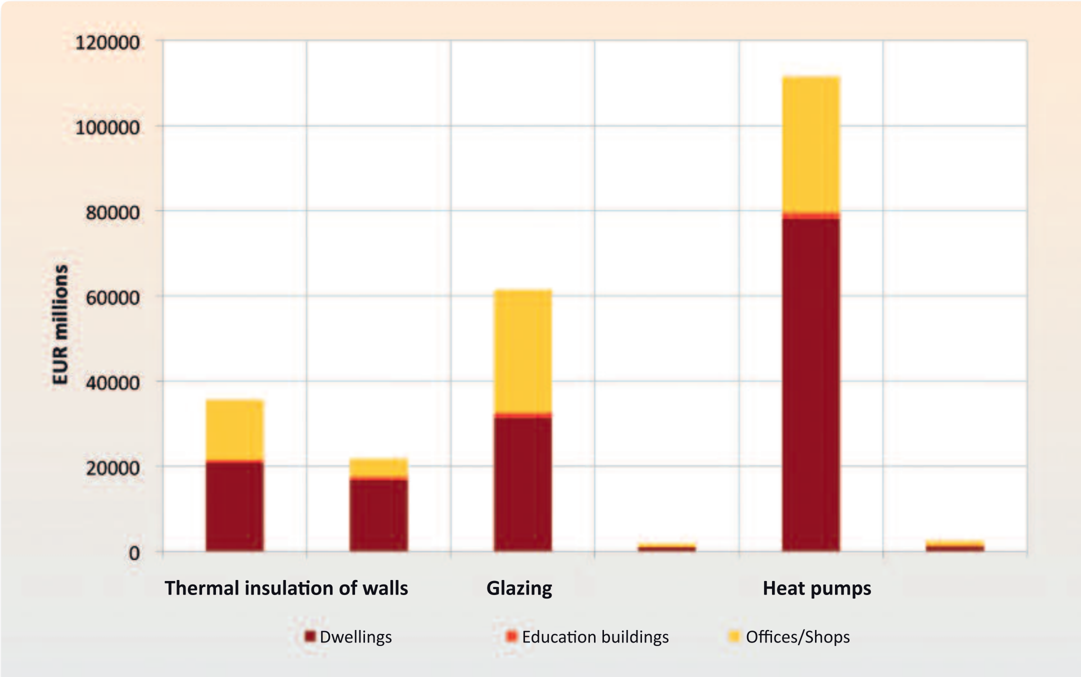
About 65% of the total cost involves residential buildings, which represent 80% of the total building stock. Absolute cost levels per building type and technology are presented in Figure 2.24.

In order to estimate the effect of climate change on these costs, we considered an alternative energy demand scenario, in which the climate parameters were assumed to remain similar to their mean values of 1960-1990. The proportion of additional costs attributable to climate change ranges from 7.6% to 10.3% of the total cost of building stock renovation, depending on the region, and averages 9% for the country as a whole. In other words, the additional expenditure for the building sector brought about by climate change by 2050 is estimated at around €20-21 billion.

2.8.6 Conclusions

The aims of the analysis were to explore the technical and cost implications of climate change on the building sector. First, calculations were made to estimate the variation in energy loads of buildings as a result of rising ambient temperatures. The average decrease in heating load was estimated at around 22.4% under Scenario A1B for 2041-2050, 50.1% under Scenario A2 for 2091-2100, 36.4% under Scenario B2 for 2091-2100, and finally 42.0% under Scenario A1B for 2091-2100. The increase in cooling load relative to today's levels

Figure 2.24 Intervention costs per type of building and technology



was estimated at 83% under Scenario A1B for 2041-2050, around 248% under Scenario A2 for 2091-2100, 148% under Scenario B2 for 2091-2100 and, finally, 167% under Scenario A1B for 2091-2100.

In addition to estimating the heating and cooling loads, the likely energy consumption of buildings was also calculated from the perspective of different technological scenarios for 2050.

The best-case scenario: Use of state-of-the-art energy production technology in all buildings by 2050 and substantial improvement in total building stock to ‘passive construction standards’ would, in spite of climate change, reduce the total annual energy consumption of today’s building stock (90,000 GWh) to 5,000-10,000 GWh.

The optimistic scenario: Use of high-performance energy production systems in all buildings by 2050 and the upgrading to ‘passive construction standards’ of the building stock constructed prior to 1980 would reduce total annual energy demand to roughly 22,000-25,000 GWh.

The realistic scenario: Use of high-performance energy production systems in about 70% of buildings (with the rest remaining conventional), and upgrading to ‘modern construction standards’ of 60% of the building stock constructed prior to 1980 would reduce total annual energy demand to 50,000-55,000 GWh.

The worst-case scenario: Installation of high-performance energy production systems in only 10% of buildings by 2050 (with the rest remaining conventional) and upgrading to ‘modern construction standards’ of only 20% of the building stock constructed prior to 1980 would cause total annual energy demand to exceed 120,000-130,000 GWh.

In addition, it was estimated that in non-air conditioned buildings the increase in cooling degree-days under Scenario A1B for 1990 and for 2050 ranges from 54% up to 1,000%. The increase in cooling degree-days between Scenario A1B for 1990 and Scenario A2 for 2100 ranges from 152% up to 4,200%. The increase in cooling degree-days between Scenario A1B for 1990 and Scenario B2 for 2100 ranges from 100% up to 2,100%. Finally, the increase in cooling degree-days between Scenario A1B for 1990 and Scenario A1B for 2100 ranges from 115% up to 2,400%.

The increase in maximum indoor temperature between Scenario A1B for 1990 and Scenario A1B for 2050 ranges from 2.0ºC to 2.9ºC, while under Scenario A2 for 2100 it ranges from 4.5ºC to 7.5ºC. The increase in maximum indoor temperature between Scenario A1B for 1990 and Scenario B2 for 2100 ranges from 3.4ºC to 4.8ºC, and under Scenario A1B for 2100 from 3.5ºC to 5.3ºC.

In parallel with the change in cooling degree-days and in maximum and minimum indoor temperatures, we also calculated the percentage increase in number of summer hours during which indoor temperatures rise above 26ºC, 28ºC, 30ºC and 32ºC. Under Scenario A1B for the current period, the percentages for the months from June to September are always zero. In contrast, they increase drastically under both Scenario B2 for 2100 (ranging from 0% to 65%) and Scenario A1B for 2100 (ranging from 0% to 68%), while under Scenario A2 for 2100, the percentage increases range from 40% to 98%.

The results of the simulations of useful cooling and heating energy demand in buildings were used to estimate the additional cost that climate change would entail for adapting buildings to the new climatic conditions. The proportion of additional costs attributable to climate change ranges from 7.6% to 10.3% of the total cost of building stock renovation, depending on the region, and averages 9% for the country as a whole. In other words, the additional expenditure for the building sector brought about by climate change by 2050 is estimated at around €20-21 billion.

2.8.7 Proposals and adaptation policies for the building sector

Climate change drastically raises the building sector’s energy consumption, particularly during summer, while also producing adverse effects on the indoor environment and indoor thermal comfort levels.

Addressing these problems calls for the planning and implementation of adaptation policies along the following two axes:

- actions to improve the thermal characteristics mainly of the urban environment; and
- actions to reduce buildings’ heating, cooling and other energy requirements.

Improving the urban environment calls for integrated action to alter the thermal balance of a given area, including landscaping and site redesign, improved air flow, increased use of cool materials, green areas, shading, ponds and fountains, etc. Such technologies are well-developed and have been shown to greatly improve urban thermal regimes.

Reducing the energy consumption of buildings or even minimising it to nearly zero can be achieved through a combined use of energy-saving technologies and renewable energy sources. Energy-saving technologies are now well-developed and have become far less costly and can reduce the energy consumption of a conventional building by as much as 90%. Meanwhile, renewable energy sources, mainly solar and geothermal, can be used to meet a large share of buildings' energy requirements. Care must be taken, however, to ensure that these combined technologies do not excessively increase the initial costs of buildings or unduly complicate the built environment.

The above adaptation techniques, apart from their beneficial impact in climatic terms, will also generate considerable economic activity, thereby contributing to the local and national economies and creating thousands of jobs.

2.9 Risks and impacts of climate change on the transport sector*

2.9.1 Introduction

Within the context of analyses regarding the transport sector, the research team – consisting of members of the *Hellenic Institute of Transport (HIT) of the Center for Research and Technology Hellas (CERTH)* – analysed the parameters of climate change in relation to the operation of the country's transport system and recorded the attributes of the phenomenon, so as to subsequently estimate and (where feasible) quantify the likely impacts.

This sectoral study analysed the 'direct' impacts on transport, and not 'indirect' ones (i.e. those that affect the sector via impacts on other systems, e.g. the economy, tourism, etc.).[36] We also analysed the 'physical' impacts on the transport sector, i.e. measurable impacts that affect physical infrastructure or installations and the system's operation.

The direct physical impacts of climate change on transport can be broken down into three main categories:

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* Sub-chapter 2.9 was co-authored by: George Giannopoulos, Eliza Gagatsi, Evangelos Mitsakis and Josep Salanova.

36 Indirect impacts also include the impacts stemming from interaction between the system's different components, such as the problematic operation or even stoppage of operation in one part of the transport network or transport sector from problems caused to another sector of the network. For instance, if part of the country's railway network is not operational due to landslides caused by heavy rainfall, this will inevitably increase the traffic on the road network serving the same connections or destinations.

1. impacts on transport infrastructure involving:
   i. reconstruction and repair of damage from natural disasters; and
   ii. proactive/preventive works to protect existing transport infrastructure;
2. impacts on transport infrastructure maintenance; and
3. impacts due to alteration to the system's operation and reliability due e.g. to delays and other changes (e.g. rerouting).

The main objective of this sectoral study was to identify the particularities and 'vulnerability' of the Greek transport system to climate change impacts, and to valuate the cost to be incurred by the transport sector as a result of these impacts under specific scenarios and parameters developed for the purposes of the overall study. In addition to valuating the cost of climate change for the country's transport system, the study takes a step further with a set of proposed management policies aimed at preventing and addressing climate change impacts.

2.9.2 Methodology and main phases of the study

Due to the complexity of the transport sector, the lack of specialised national and international literature, and the often insufficient and/or absence of specific data and measurements at national or local level, the research team developed a methodology adapted to these particularities and to Greek reality.

The adopted methodology was then applied to three distinct scenarios, based on the general scenarios of the overall study. In more detail, calculations were made under:

- *Scenario A2:* the no adaptation/no mitigation scenario (also known as the 'trend scenario' or 'business as usual');
- *Scenario A1B:* the mild adaptation/mild mitigation scenario; and
- *Scenario B1*: the strong adaptation/strong mitigation scenario.

The methodology adopted comprised the following separate phases:

Phase 1: Mapping of the key Greek transport infrastructure network and 'vulnerability' classification/assessment of operation components (infrastructure and services). The transport network's individual components were examined for four different geographic zones, established for the purposes of the present study:

- Zone I: Western Greece;
- Zone II: Central Greece;
- Zone III: Eastern Greece; and
- Zone IV: Island regions.

Phase 2: Estimating transport demand. This phase included estimating the current levels of transport demand, and forecasting future demand levels over specific time horizons.

Phase 3: Valuating the cost of climate change impacts on Greece's transport sector. For each of the three climate change scenarios developed within the general framework of the overall study, valuations were made of the cost of climate change impacts on transport infrastructure and on the provided transport services.

Phase 4: General conclusions. General conclusions and 'messages' from the analysis and application of the above methodology were drawn as to the manners in which climate change is expected to affect the Greek transport system.

Phase 5: Proposed policy guidelines. The sectoral study is concluded with the formulation of a set of proposed policies which, according to the HIT research team, should be pursued as of now and over the next 20 years or so, in order to prevent climate change and mitigate its impacts on the country's transport network as part of a broader 'Mitigation Scenario'.

2.9.3 Main results by study phase

What follows is a presentation of the main results of each of the above-mentioned study phases.

2.9.3.1 Main results of Phase 1: Mapping of the Greek transport infrastructure network and 'vulnerability' assessment

The mapping of the transport network and the vulnerability of its individual attributes to specific climate change parameters was assessed for each of the four zones into which the country was divided (see Figure 2.25).

The analysis showed that, with respect to its national transport infrastructure system, Greece can be characterised as one of Europe's most 'vulnerable' regions, mainly because it has one of the longest coastlines, with 113 m of coast for every km^2 in area (compared with a global average of only 4.5 m/km^2). Thus, several (mainly) urban regions and transport networks are located within the distance of influence from this coastline. It should be noted that 33% of the Greek population lives in coastal cities, towns or villages situated within 2 km of the sea,[37] while 12 of the country's 13 former Administrative Regions are coastal. Moreover, the Greece's largest urban centres with the highest number of movements/trips, such as Piraeus, Thessaloniki, Patras, Heraklion, Volos and Kavala, are situated in coastal zones.

Based on the above, in combination with the data from the climate change scenarios examined in the study (which project SLR to be roughly 40 cm to 50 cm), it is clear that a significant part of the country's transport infrastructure network lies at the frontline of risk from climate change impacts.

Summary data on the transport network's vulnerability are presented for each zone examined in Table 2.45. The aim of the analysis was to identify what share of the road and

37 Source: Europa, Maritime Affairs (http://ec.europa.eu/maritimeaffairs), European Commission, DG Fisheries and Maritime Affairs.

Figure 2.25 The four reference zones

railway networks and the number of airports that lie within a ‘high-risk’ zone, within 50 m of the coastline.

In addition, as emphasised earlier, the operation of most of the country’s ports is directly at risk from SLR, with direct implications for the operation of the national sea transport system, the existence and smooth operation of which are essential to the continuity and cohesion of the country’s transport network.

The sectoral study drew on the experience from previous cases of climate change effects in Greece (the 2007 Peloponnese wildfires, the January 2010 sea level rise in the Eastern Aegean,

Table 2.45 Quantitative data on transport network vulnerability, per zone

Zone I: Western Greece	Percentage of road network within 50 m of the sea	National: 1.41	Provincial: 1.93
	Percentage of railway network within 50 m of the sea	2.65	
	Number of airports at sea level	1 (State airport of Corfu "I. Kapodistrias")	
Zone II: Central Greece	Percentage of road network within 50 m of the sea	National: –	Provincial: 0.76
	Percentage of railway network within 50 m of the sea	0	
	Number of airports at sea level	0	
Zone III: Eastern Greece	Percentage of road network within 50 m of the sea	National: 1.53	Provincial: 1.92
	Percentage of railway network within 50 m of the sea	0.61	
	Number of airports at sea level	2 (Thessalonki international airport "Macedonia", Skiathos airport)	
Zone IV: Island regions	Percentage of road network within 50 m of the sea	6.64	
	Percentage of railway network within 50 m of the sea	0	
	Number of airports at sea level	1 (Heraklion international airport)	

Source: Calculations of the research team based on the digitalised road and transport network of Greece in the TRANSTOOLS model.

the 2009 floods in the Magnesia prefecture) to qualitatively describe the likely impacts of climate change on the Greek transport system, once again pointing out its 'vulnerability'.

2.9.3.2 Main results of Phase 2: Estimating transport demand

The next phase of the adopted methodology consisted in estimating the demand on Greece's existing transport network and overall transport infrastructure. The transport demand on the national road, railway, maritime and air transport networks (passengers and freight) was estimated up to 2050 using HIT data collected in the context of the *Transport Observatory* service it provides through its portal (www.hitportal.gr), and up to 2100 based on average annual rates of increase derived from existing studies and projects after a review of the international literature.

Tables 2.46 and 2.47 present the summary estimates of demand for passenger and freight transport, respectively, as derived from the HIT analysis for specific time horizons and based on the estimated rates of increase taken from existing studies, as mentioned above.

The figures point to a clear upward trend in demand for passenger and freight transport in Greece. The future levels of demand were estimated as part of the economic valuation of climate change impacts on the transport system over different time horizons, as presented in the next phase of the study.

Table 2.46	Estimated demand for passenger transport, per mode of transport

	Road transport[1] (billion vehicle-km/year)			Railway transport[2] (billion pkm/year)	Air transport (million pkm/year)[3]	Sea transport (million pkm/year)[4]
	National network	Provincial network	Total in pkm/year			
Reference year	12.9	8.7	38	1.9	38.7	86
2015	14.6	9.9	42	2.0	43.9	98
2030	16.0	10.5	46	2.3	53.0	107
2050	17.3	11.2	50	2.7	63.6	115
2100	20.0	12.9	58	3.3	85.2	132

Sources: 1 H.I.T., Transport Observatory, 2007 data.
2 European Transport Report 2007/2008, 2007 data.
3 Civil Aviation Authority, 2006 data.
4 European Commission, GD Maritime Affairs and Fisheries, 2005 data.

Table 2.47	Estimated demand for freight transport

	Road transport[1] (billion tkm/year)	Railway transport[2] (billion tkm/year)	Air transport (thousand tonnes/year)[3]	Sea transport (million tonnes/year)[4]
Reference year	25.6	0.7	130	151
2015	29.5	0.8	151.3	189
2030	37.0	1.0	190.0	240
2050	46.5	1.4	239.5	302
2100	67.5	2.0	335.0	350

Sources: 1 European Transport Report 2007/2008, 2007 data.
2 European Transport Report 2007/2008, 2007 data.
3 Civil Aviation Authority, 2006 data.
4 European Commission, GD Maritime Affairs and Fisheries, 2005 data.

2.9.3.3 Main results of Phase 3: Valuating the cost of climate change impacts on Greece's transport sector

Based on the data calculated in the previous phases (regarding transport network components, estimated network vulnerability, and existing and estimated transport demand) and on the detailed methodologies for estimating the specific aspects of climate change impacts likely to be felt in Greece (i.e. mean temperature rise, increased heat wave frequency, SLR anticipated for the wider Mediterranean basin, higher frequency and intensity of flooding incidents, and reduced snowfall), the third phase of the methodology consisted in calculating the additional costs likely to be incurred as a result of repair of infrastructure damage/deterioration, prevention, increased maintenance, and finally, the estimated delays to be expected from the average annual temperature rise under the three scenarios considered.

Table 2.48	Estimated maintenance and reconstruction costs for the Greek transport system due to different types of climate change impact (In euro)

Type of impact	Transport	Scenarios					
		2050 No adaptation	2050 Mild adaptation	2050 Strong adaptation	2100 No adaptation	2100 Mild adaptation	2100 Strong adaptation
Temperature rise	Road	150 million/year	100 million/year	50 million/year	300 million/year	200 million/year	100 million/year
	Rail	37 million/year	30 million/year	20 million/year	75 million/year	55 million/year	40 million/year
Sea-level rise	Road	3 billion one-off	3 billion one-off	3 billion one-off	-	-	-
	Rail	0.3 billion one-off	0.3 billion one-off	0.3 billion one-off	-	-	-
	Sea	0.6 billion one-off	0.6 billion one-off	0.6 billion one-off	-	-	-
Flooding	Road	200 million/year	120 million/year	60 million/year	300 million/year	200 million/year	85 million/year
	Rail	-	-	-	-	-	-
Benefits from decreased snowfall	Road	-40 million/year	-25 million/year	-15 million/year	-80 million/year	-50 million/year	-30 million/year
	Rail	-0.1 million/year	-0.07 million/year	-0.05 million/year	-0.2 million/year	-0.15 million/year	-0.1 million/year
Total		346 million/year & 4 billion one-off	225 million/year & 4 billion one-off	115 million/year & 4 billion one-off	594.8 million/year	405 million/year	195 million/year

Table 2.49	Estimated cost of delays in the transport system due to climate change (extreme weather events, overheating of transport infrastructure, etc.)

Scenarios	Road transport (EUR billions/year)	Railway transport (EUR billions/year)	Year total (EUR billions)
2050, No adaptation	9.9	0.010	9.91
2050, Mild adaptation	4.3	0.004	4.304
2050, Strong adaptation	1.4	0.001	1.401
2100, No adaptation	28	0.031	28.031
2100, Mild adaptation	9.3	0.011	9.311
2100, Strong adaptation	4.2	0.004	4.204

As can be seen from the estimated economic impacts presented in Tables 2.48 and 2.49,[38] the highest costs are expected to come from delays/cancellations (i.e. the cost of passenger

38 The detailed data and calculations in each of the cases examined can be found (in Greek) in the full text version of the transport study, posted on the webpage of the Climate Change Impacts Study Committee (CCISC) on the Bank of Greece website (www.bankofgreece.gr).

value of time – VOT) in all types of transport as a result of the different aspects of climate change, without overlooking the costs associated with the redevelopment and redesign of transport infrastructure and increased maintenance needs.

In addition to the quantitative estimates presented in Tables 2.48 and 2.49, the research team proceeded to a qualitative description of the major impacts anticipated, placing an emphasis on those that were either difficult or unfeasible to calculate and/or estimate in the context of the present study.[39]

2.9.4 Proposed management policies and measures

Further to estimating the climate change impacts, the sectoral study has also formulated a set of proposed policies and specific policy measures for coping with the impacts on the transport system as a whole and on the respective networks per mode of transport. In summary, the proposals include:

1. Cooperation between the competent authorities with a view to ranking and evaluating the country's transport infrastructure components in terms of importance, vulnerability and current state.
2. Development of monitoring systems for crucial infrastructure and use of 'smart' decision-making, risk management and disaster management systems, etc.
3. Recording of detailed data concerning the operation of the country's transport system in cases of extreme weather events; development of impact evaluation indicators.
4. Revision of the design specifications of current transport infrastructure, taking climate change parameters into account (e.g. port infrastructure design based on new weather patterns and respective data on wave size and frequency, etc.).
5. Use of new materials, more resilient to extreme weather conditions.
6. Strategic planning of land use and transport infrastructure, taking into account the forms of climate change impact in Greece's vulnerable regions.
7. Policy measures aimed at reducing transport demand, e.g. teleworking, car pooling, mobility management, school transport, etc.
8. Promotion and support of ecodriving.
9. Use of 'smart' technologies and systems with a view to improving freight transport and maximising capacity use of all means of transport (target: zero empty routes).
10. Strengthening intermodal freight transport and reducing the share of road transport in favour of sea and railway transport.
11. Promotion of the use of energy efficient (hybrid/electric) vehicles through incentive measures and the construction of necessary infrastructure (e.g. electric vehicle charging stations).

39 Table M-16 in the full text of the transport study; more details in footnote 38.

Finally, the study also included a number of policy measures that could be gradually explored and applied over a longer time horizon.[40]

2.10 Climate change and health*

2.10.1 Introduction

It is well known that climate and weather conditions are among the major factors that affect human health. This means that globally observed climate change alters parameters that in turn have an effect on the health and welfare of human populations. This is a well-established fact, often overlooked, as people tend to think that their state of health mainly depends on their own behaviour (e.g. diet, exercise, lifestyle), heredity and access/use of health services.

Recent climatic changes are believed to have already determined certain epidemiological facts on a global scale. According to the 2002 annual report of the World Health Organisation (WHO), climate change is responsible for roughly 2.4% of the world's cases of diarrhoea, as well as for 6% of the malaria cases in certain developing countries in 2000 (WHO, 2002). One problem related to the assessment of such results is that health is affected by a score of factors, thus making it difficult to measure and isolate the effect of climate change from the other factors. Despite this difficulty, and given that climate change affects several aspects of human health, the impacts of anthropogenic climate change on health have become a major issue not only for the theory of medical and environmental sciences, but above all from a practical standpoint, underlining the need for appropriate socioeconomic policy.

As pointed out in the WHO report, climate change has a profound impact on the health of European citizens. As stressed, a temperature rise of 1ºC is expected to result in a 1% to 4% increase in mortality. This means that the mortality attributable to higher temperatures could increase by 30,000 deaths per year by the 2030s, and by 50,000 to 110,000 deaths per year by the 2080s.

2.10.2 Health impacts of climate change

Climate change affects the human organism both directly and indirectly. Direct exposure is associated with changing weather conditions, such as temperature, rainfall, SLR, and increased frequency of extreme weather events. Indirect exposure stems from the lower quality of drinking water and meteorological conditions, as well as changes in ecosystems, agriculture, industry, settlements and the economy. Thus, climate change is globally associated with

40 Table M-17 in the full text of the transport study; more details in footnote 38.

* Sub-chapter 2.10 was co-authored by: John Yfantopoulos, Andreas Papandreou, Tassos Patokos, Panagiotis Nastos, Pavlos Kalabokas, Mihalis Vrekoussis, John Kapsomenakis, Demosthenes Panagiotakos, Christos Zerefos and Vilelmini Psarrianou.

existing diseases, but can also cause premature death due to increase frequency of extreme weather events.

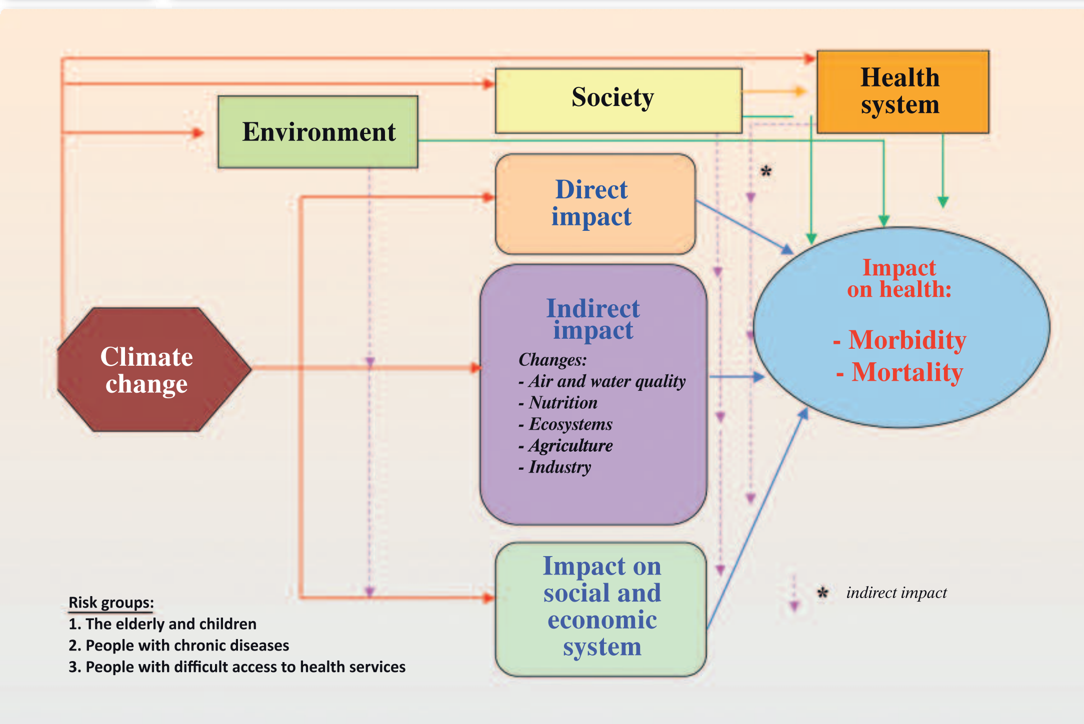
According to the WHO, climate change impacts on health can be grouped into the following three categories (WHO, 2003):

a) Direct impacts, usually caused by extreme weather events (e.g. death due to heat waves).
b) Indirect impacts, as a result of environmental changes and ecological disruptions due to climate change (e.g. higher risk of vector-borne or rodent-borne infectious diseases).
c) Other impacts on populations confronted with environmental degradation and economic problems as a result of climate change (e.g. nutritional or even psychological problems).

The link between climate change and health is schematically represented in Figure 2.26.

According to WHO forecasts, climate change and global warming are expected to have significant impacts on human health. These impacts will stem from more frequent occurrences of storms, floods, dry spells and fires, with effects on water and food availability and on overall healthcare system management. The rise in temperature will contribute to higher morbidity and mortality associated with nutrition, water and air quality. The increased frequency of heat waves is expected to lead to higher mortality due to heat stroke and heat stress.

Figure 2.26 **Climate change and health**



The core conclusion of studies on the impacts of climate change on human health on a global scale is that climate change can lead inter alia (WHO, 2003) to:

a) increased mortality due to the temperature rise and, conversely, decreased mortality in colder countries for the same reason;
b) greater frequency of infectious disease epidemics due to floods and extreme weather events;
c) substantial impacts on human health due to the relocation of populations in response to rising sea levels and the increased frequency of extreme weather events.

The US health authorities have identified 11 broad human health categories likely to be affected by climate change (CDC, 2009):

i) asthma, respiratory allergies and airway diseases;
ii) cancer;
iii) cardiovascular disease and stroke;
iv) food-borne diseases and nutrition;
v) heat-related morbidity and mortality;
vi) human developmental effects;
vii) mental health and stress-related disorders;
viii) neurological diseases and disorders;
ix) vector-borne and zoonotic diseases;
x) waterborne diseases; and
xi) weather-related morbidity and mortality (due to extreme weather events).

The populations particularly at risk from these climate change-related diseases are:

- the elderly;
- children;
- people with pre-existing chronic medical conditions;
- poor people with poor nutrition or suffering from malnutrition, living in low-income areas and with difficult access to healthcare services;
- the populations of islands and mountainous regions at risk of water and food shortages; and
- undocumented immigrants, at the fringe of society, faced with labour market, social and healthcare exclusion.

2.10.3 Climate change and health in Europe

The heat wave of 2003 and its devastating impact in several Western Europe countries served to highlight the possible impacts of climate change on health. Twelve countries with advanced healthcare systems reported a total of more than 60,000 deaths from that particularly lethal heat wave. The epidemiological data found the elderly to have been most at risk, as ageing impairs the body's ability to regulate temperature.

A source of valuable information for investigating the impact of climate change on various sectors —including health— is the PESETA project (Projection of Economic Impacts of Climate Change in Sectors of the European Union based on Bottom-Up Analysis, Watkiss et al., 2009). The methodology of the PESETA project is applied to two periods, from 2011 to 2040 and from 2071 to 2100, under IPCC climate scenarios A2 and B2. The project combines models with daily climate data and empirically established links between climate and health conditions in order to estimate the number of additional deaths (excess deaths) attributable to temperature change in Europe.

For analytical purposes, the geographical area of Europe was divided into square grids of 2,500 km^2 each, and the daily data were aggregated so as to obtain annual percentage changes in mortality for each grid. The obtained annual numbers of deaths were examined in parallel with the socioeconomic parameters per grid, as well as with data on each region's demographics and mortality rate. Comparing the annual figures obtained from running the climate change scenarios with the numbers resulting from the forecasting taking only the socioeconomic factors into account enabled an isolation of the climate change impact and the calculation of the number of cases attributable exclusively to climate change.

The findings of the PESETA project show inter alia (Watkiss et al., 2009) that:

a) By 2020, under Scenario A2, there will be a small increase in average heat-related numbers of deaths in Europe, estimated at 25,000 extra deaths per year. The number will increase significantly by 2080, reaching around 105,000 extra heat-related deaths per year.

b) Acclimatisation —i.e. the ability of the population to adapt to new climate conditions— both in practical terms (e.g. through increased recourse to air-conditioning) and in psychological/awareness terms – could considerably reduce these figures. Assuming a fixed rate of acclimatisation of 1ºC per three decades (i.e. that the population has by then engaged in actions and behaviour capable of incorporating a 1ºC higher temperature), the number of deaths caused by climate change could be reduced to 4,000 per year for the period 2011-2040, and to 20,000 per year for the period 2071-2100.

c) The number of cold-related deaths across Europe will decline slightly. Despite the great variation in the analysis, it is estimated that 50,000 to 100,000 cold-related deaths per year will be avoided due to warmer winter temperatures in 2011-2040, and 86,000 to 184,000 such deaths per year will be avoided in 2071-2100. This, in conjunction with point (a) above, means that the avoided cold-related deaths will most likely outnumber the additional heat-related deaths. However, this finding depends heavily on population acclimatisation and on the model parameters, which also involve a degree of uncertainty. Moreover, rising temperatures may make populations more sensitive to cold weather conditions. Controlling for this factor in the models entails a large decrease in the number of cold-related deaths avoided thanks to climate change.

d) The foregoing findings concern all the EU Member States in general, although (predictably) higher numbers of extra heat-related deaths are expected in the Mediterranean countries and lower ones in the north (e.g. Scandinavia). The countries of Central and Eastern Europe will see the highest increase of climate change-related deaths. For the period 2071-2100, the largest potential mortality increases from climate change were projected to occur in Italy, Bulgaria, Estonia, Greece and Spain, and the smallest potential increases in Norway, Ireland, the UK and Sweden.

e) As regards avoided cold-related deaths, the largest potential mortality benefits from climate change are expected to occur in Baltic and Scandinavian countries, while the smallest benefits are found in Ireland, Luxembourg, the UK and some Mediterranean countries.

f) A significant difference was found between Scenarios A2 and B2. Under Scenario B2, heat-related deaths per year decrease by approximately 50%, which translates into a benefit of 49,000 to 56,000 fewer deaths per year in the period 2071-2100. However, under Scenario B2 the cold-related deaths avoided thanks to climate change also decrease, by roughly 33% to 45% (which means 28,000 to 83,000 fewer avoided cold-related deaths per year compared with Scenario A2).

g) With respect to salmonella, the average annual number of cases attributable to climate change under Scenario A2 will come to roughly 20,000 in the period 2011-2040 and to roughly 40,000 in the period 2071-2100. Using Scenario B2 for the period 2071-2100, this estimate is roughly 25,000 cases per year. A number of other food-borne diseases could follow similar trends, although it should be noted that actual cases may be significantly fewer given that populations may adapt to the new conditions by adopting improved food storage and preparation practices.

h) The number of psychological stress incidents due to flooding was also estimated. Additional cases per year for the period 2071-2100 could reach as many as 5 million under Scenario A2 and 4 million under Scenario B2, although these numbers could be significantly reduced through proper acclimatisation.

i) As regards vector-borne diseases, the current incidence, in general, of these diseases in Europe is largely governed by factors other than the climate. Mosquito-borne diseases are not currently endemic in Europe; however thousands of cases of malaria occur in travellers who have been infected elsewhere in the world. Similarly, there are a few cases of travellers with Dengue fever or yellow fever. The incidence rate of these diseases increases with rising temperature, and is also affected by rainfall. In any event, the report points out that the likelihood of a reckonable threat from these diseases on account of climate change is very low, particularly as populations are expected to take the necessary healthcare precautions.

j) Rodent-borne and tick-borne diseases are uncommon in Europe. Although no precise data exist to determine the effect of climate change on the incidence of these diseases, they are not deemed a cause for concern. The same holds also for Leishmaniasis, with a few hundred cases recorded each year, mostly in immuno-compromised individuals (e.g. HIV carriers). Plague is not present in Europe and is confined to rare cases in travellers from other countries. Lyme borreliosis and tick-borne encephalitis may pose a threat, as they are already endemic in Europe. Owing to climate change, encephalitis cases are likely to also start occurring at higher altitudes and latitudes. The higher frequency of flooding due to climate change may also increase the risks of such diseases.

2.10.4 Economic impacts

As regards the economic impacts of climate change on health, the PESETA report states, inter alia, the following:

a) For the period 2011-2040, without acclimatisation, the cost of climate change will amount to €30 billion per year (based on a value of a 'statistical life' of €1.11 million) or to €13 billion per year (based on a value of a 'life year' of €59,000). Assuming that acclimatisation takes place, this cost is drastically reduced to €4.5 billion and €1.9 billion, respectively. The benefit from fewer cold-related deaths comes, respectively, to €55.8 billion and €23.7 billion (without acclimatisation) and to €21.5 billion and €9.2 billion (with acclimatisation). It should be noted that the balance is, in any event, positive, i.e. using economic costs as the sole criterion, climate change is estimated to be beneficial.

b) For the period 2071-2100, under Scenario A2 (without acclimatisation), the cost of climate change will amount to €118 billion per year based on the value of a statistical life, or €50 billion per year based on the value of a life year. Adopting Scenario B2, this cost is estimated at €56 billion and €30 billion, respectively. For this period, the economic benefit of fewer cold-related deaths is estimated at €95.8 billion (Scenario A2, without acclimatisation) based on the statistical life value, and at €40.7 billion (Scenario A2, without acclimatisation) based on the life year value. Under Scenario B2 in the absence of acclimatisation, these figures are estimated at €64.2 billion and €27.3 billion, respectively. It should be noted here that the economic benefits from fewer cold-related deaths are not always outweigh the economic loss from additional heat-related deaths.

A similar cost valuation procedure for flood-related depression estimated the relevant costs at €1 billion to €1.4 billion per year (under Scenario A2) or €0.8 to €1.1 billion per year (under Scenario B2). The PESETA report does not valuate the economic cost of increased vector-borne diseases due to climate change, but proceeds to a qualitative assessment stating that this cost is forecast to be lower than the foregoing one.

In light of all the above, the PESETA report concludes by prioritising a series of issues that need to be further explored, and underlines the need for more epidemiological studies to allow a more valid correlation of temperature with mortality, so that models can provide more reliable (and less uncertain) results. The variables incorporated in the relevant models must also be expanded to include factors related to the acclimatisation actions of populations. As regards research priorities, the report emphasises inter alia that models need to be further detailed, in order to reflect climate change impacts more accurately – e.g. taking account of factors overlooked by current models, such as atmospheric pollution, unpredictable events or diseases.

2.10.5 Natural disasters and mortality in Greece

The number of recorded natural disasters in the period 1900-2010, as well as the number of deaths and the economic impact related thereto, are presented per disaster category for all of Greece in Table 2.50.

Table 2.50 Impact of natural disasters on population mortality and the Greek economy in 1900-2010

Natural disasters	Type of event	Number of events	Deaths	Population affected	Cost (USD thousands)
Drought	Drought	1	-	-	1,000,000
	average per event		**-**	**-**	**1,000,000**
Earthquakes (seismic activity)	Earthquakes	29	951	960,398	7,099,300
	average per event		**33**	**33,117**	**244,803**
Temperature extremes	Cold waves	1	5	-	-
	average per event		**5**	**-**	**-**
	Heat waves	5	1,119	176	3,000
	average per event		**224**	**35**	**600**
Floods	Unspecified	8	66	9,730	188,000
	average per event		**8**	**1,216**	**23,500**
	General flood	12	18	6,100	1,043,359
	average per event		**2**	**508**	**86,947**
Storms	Unspecified	6	56	612	690,000
	average per event		**9**	**102**	**115,000**
	Local storm	1	22	-	-
	average per event		**22**	**-**	**-**
Volcano	Volcano eruption	1	48	-	-
	average per event		**48**	**-**	**-**
Wildfire	Forest fire	11	94	8,559	1,750,000
	average per event		**9**	**778**	**159,091**
	Scrub/grassland fire	2	14	500	675,000
	average per event		**7**	**250**	**337,500**

Source: EM-DAT, The OFDA/CRED International Disaster Database, www.emdat.be, Université catholique de Louvain, Brussels, Belgium.

Of all the presented categories of natural disasters with an impact on human populations, climate change is expected to affect the frequency of low and high temperature extremes, floods, storms and fires. In more detail, the results of future climate model simulations point to a sharp increase in the frequency of heat waves and forest fires and, conversely, to a decrease in the frequency of cold waves by 2100. As for heavy rainfall and flooding events, their frequency in most of the country (including Athens, where more than 50% of the total national population is concentrated) is expected to rise. The implies that the number of deaths due to climate change-related extreme weather events in the course of the 21st century will gradually increase, not only in Athens, but in other large cities as well. The following section attempts to quantify the variation in number of deaths in the Athens area due the variation in temperature extremes, which, as can be seen from Table 2.50, account for most weather extreme-related deaths.

2.10.6 Climate change and mortality in the Athens area

The epidemiological and climatological analyses in the relevant literature identified a 'U-type' relationship between daily temperature and daily mortality. An illustration of this relationship is presented in Figure 2.27, distinguishing between extreme cold-related and extreme heat-related deaths.

Figure 2.27 Relationship between daily deaths and temperature

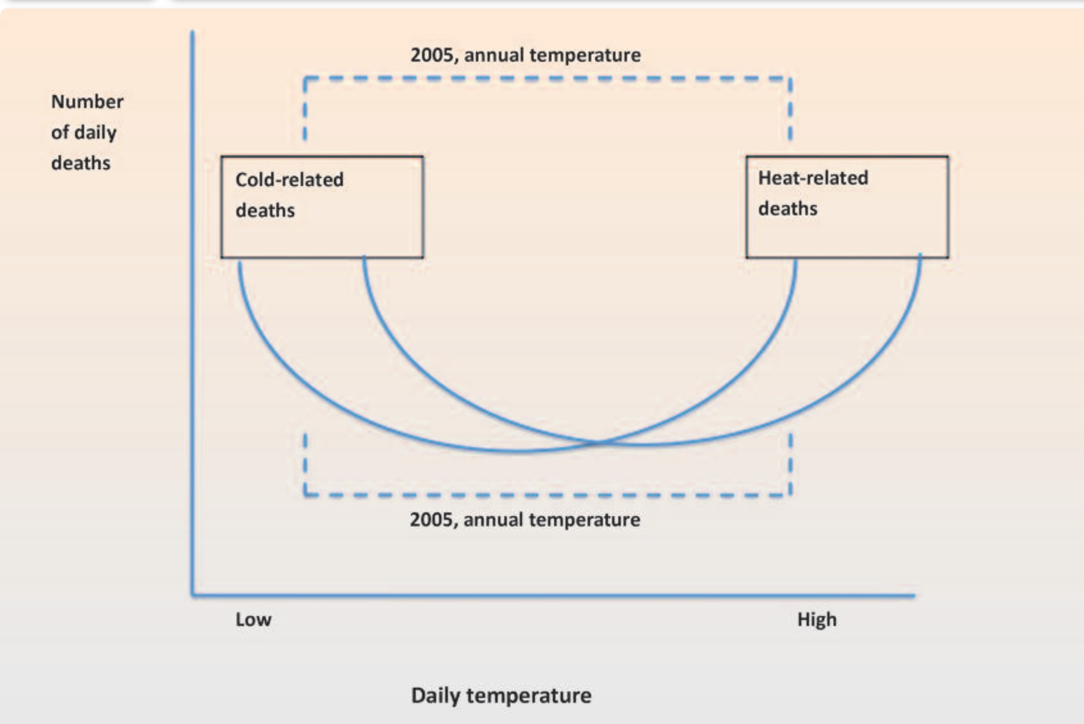
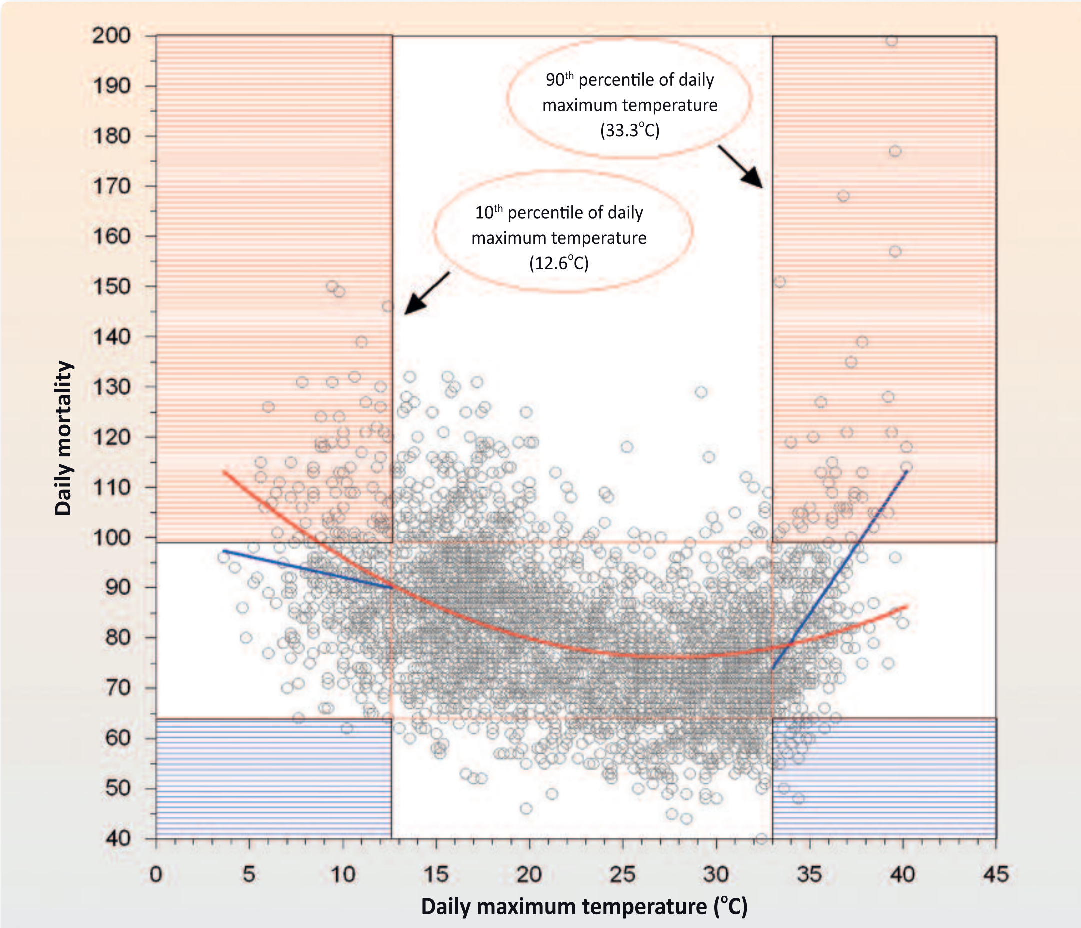


Figure 2.28 **Daily number of deaths in the Attica region in relation to daily maximum temperature (Tmax)**



In an effort to further explore this relationship for Greece in particular, we present the results of a study (Nastos et al., 2011) correlating daily mortality with maximum daily temperature in Attica (Tmax °C) and confirming the existence of a U-type relationship (Figure 2.28).

According to the research data of Nastos et al. (2011), the number of deaths (N_d) for daily temperature maximum values (Tmax) above 33°C (90th percentile of the distribution) is captured by the following equation:

$$N_d=5.451509164*Tmax-106.0651761 \quad (R^2=0.24399)$$

A test use of this equation – assuming that the mean maximum summer temperature in Attica will have risen by 2100 by about 4.4°C (Scenario A1B) – led to the provisional estimate that the number of deaths due to global warming in the Attica area may by then have increased by about 25%. Conversely, the rise in winter temperature in future will result in a lower number of deaths from exposure to extreme temperature lows. It should be noted that the decrease in number of cold-related deaths is not expected to exceed 3%. This latter estimate (Nastos et al., 2011) stems from the following equation:

$$N_d = -0.8220675372*Tmax + 100.2719899 \qquad (R^2=0.0114113)$$

which estimates the number of deaths (N_d) for daily temperature maximum values (Tmax) below 12.6°C (10th percentile of distribution), as a result of a 3.5°C higher temperature during the winter period.

Based on the above estimates, the annual additional deaths were as follows:

- In summer, the additional deaths are estimated at 21 per day (25% x 85 deaths≃21).
- In winter, the additional deaths will be 3 fewer per day (3% x 95 deaths≃3).
- In the intermediate seasons (spring and autumn), no substantial change in death numbers is expected.
- Thus, total excess deaths per year will come to 90 x (21-3) = 1,620.

Based on the above calculations, the economic impact for the Attica region will thus be in the order of €95 million per year.

The above calculations were repeated to estimate the variation in death numbers and the associated economic impact under Scenarios A2 and B2. The results of our calculations under all three scenarios are summarised in Table 2.51.

It should also be noted that these estimates do not take into account possible improvements from increased awareness and, more importantly, from prevention action taken by people at high risk (e.g. the elderly, the chronically ill) to avoid exposure to temperature extremes. A case in point is Central Europe where, in the aftermath of the deadly 2003 heat wave, the number of annual additional deaths due to hot temperature extremes has remained noticeably below 2003

Table 2.51 **The economic cost of climate change impact on health under Scenarios A2, A1B and B2**

Emission scenarios	Season	Temperature change (°C)	Change in number of deaths per year	Cost (EUR millions per year)
Scenario A2	Winter	4.2	-340	
	Summer	5.6	2,600	
	Total		**2,260**	**135**
Scenario A1B	Winter	3.5	-270	
	Summer	4.4	1,890	
	Total		**1,620**	**95**
Scenario B2	Winter	3.1	-215	
	Summer	3.8	1,760	
	Total		**1,455**	**85**

levels. This can only be attributed to raised awareness and to prevention/risk avoidance action taken by the vulnerable groups themselves. With successful awareness campaigns and proper preventive measures, the increase in heat-related deaths forecast in this study could possibly be reduced to below 10%.

2.10.7 Changes in air pollutant levels and impacts on mortality in the Athens area

Forecasting the trends in air pollutant concentrations in coming decades is important for the study of climatic changes and their impacts on human health, agricultural production and natural ecosystems. These changes, including rising temperatures and changes in meteorological parameters and different emissions, affect the levels of atmospheric pollutants.

Surface ozone (O_3), also called tropospheric ozone, belongs to the category of atmospheric pollutants that adversely impact human health. Unabated emissions of ozone-producing precursor compounds, such as nitrogen oxides (NO_x) and volatile organic compounds (VOC), in conjunction with the changes mentioned above, are expected to have a multifaceted impact on future ozone levels. It should be noted that high levels of surface ozone have already been recorded in Greece, as well as in the broader Eastern Mediterranean region, including non-urban areas, particularly in summer (Zerefos et al., 2002; Kourtidis et al., 2002; Kouvarakis et al., 2002; Lelieveld et al., 2002; Gerasopoulos et al., 2006; Kalabokas et al., 2007; Kalabokas et al., 2008).

According to the results obtained using the CTM Oslo model and based on the simulations carried out under Scenario A1 (detailed in Chapter 1), ozone levels are expected by 2100 to have fallen by 20% in Greece and by 16.5% in Athens. It should be noted that the CTM Oslo model does not take temperature changes into account.

Gryparis et al. (2004) studied the link between mortality variation and ozone levels for the Athens area and found that an increase in ozone concentration by10 $\mu g/m^3$ was associated with 0.5% higher mortality.

Assuming that (a) the population of Athens will remain broadly unchanged, (b) the total number of deaths occurring in Athens per year (30,000) will remain broadly unchanged, and (c) the percentage (0.5%) stated in the above study is linear, it is estimated that *the change in ozone levels in the Athens area by 16 $\mu g/m^3$ —corresponding to a decrease in concentration from 97.5 $\mu g/m^3$ in 2000 to 81.5 $\mu g/m^3$ by 2100— would result in 0.8% (or 245) fewer deaths per year.*

The roughly 70% decrease in NO_2 levels by 2100 forecast by the CTM Oslo model will have a positive impact (further decline in pollution-related mortality), even if specific figures cannot be advanced due to statistical uncertainties (Analitis et al., 2006; Samoli et al., 2006). Nonetheless, the results of Sections 2.10.6 and 2.10.7 taken together indicate that under Scenario A1B, particularly in Attica, the number of annual additional deaths due to higher temperature extremes in summer and lower temperatures in winter will amount to 1,620 in 2091-2100. The economic impact of temperature extremes under the same scenario (A1B) for Attica is estimated at €95 million per year. Under Scenarios A2 and B2, extreme temperature-related deaths are forecast to increase by 2,260 and 1,455 per year, respectively, while the economic costs are expected to come to €135 million (Scenario A2) and to €85 million (Scenario B2). The projected changes in air pollutants particularly harmful to human health, like ozone, are expected by the end of the 21st century to lead to a fewer number of deaths (around 10% fewer than the expected number of deaths from temperature extremes).

2.10.8 Adaptation policies in the health sector

A problem as global as climate change requires action on an international scale. According to WHO estimates (Neira et al., 2008; WHO, 2008), a significant number of deaths each year are attributed to climate change, including:

i. 800,000 deaths due to urban atmospheric pollution;
ii. 1.7 million deaths due to lack of access to clean water and sanitation;
iii. 3.5 million deaths from malnutrition; and
iv. 60,000 deaths due to extreme weather conditions and disasters.

International strategic action and policies for climate change and health have been undertaken by the European Commission, the WHO and other international organisations. In the WHO Global Conference on Health Promotion in 2008, all 193 Member States unanimously supported the adoption of preventive measures to address the impacts of climate change on health. What follows is a brief presentation of the international and national policy actions taken.

At the international level, a series of measures have been developed with a view to:

1) Developing the scientific documentation on the public health, social and economic implications of health-related climate change impacts. Research networks that study the link between climate change and health have been set up, with co-funding from international organisations and national governments. The results of their research have contributed substantially to the formulation of international action plans to address climate change impacts more effectively.
2) Raising public awareness through prevention programmes and specially-designed actions to address the public health impacts of climate change promptly and effectively. Preventive actions in the health sector generate multiple benefits for society and are assessed as highly cost-effective.
3) Promoting major infrastructure works (dams, etc.), co-financed by international organisations, to help improve health standards and prevent future disasters due to climate change.

At the national level, the governments of Europe have been developing actions to address the impacts of climate change:

1) The national health ministries have launched actions to ensure equal access to health services and social justice for all victims of climate change. This requires investment in relevant infrastructure (e.g. climate-controlled hospital rooms, operating theatres, sanitation) to prevent even partial discrimination in the provision of healthcare.
2) The national health ministries will also need to design special action plans to address the public health problems associated with climate change and/or natural disasters. The ability to treat large numbers of patients in disaster situations calls for special planning and measures, to be undertaken by experts in 'disaster management'.
3) Primary and out-hospital healthcare services must adequately designed, equipped and staffed to be able to cope with the problems caused by climate changes.
4) Hospitals will also need proper infrastructure and equipment to promptly diagnose and efficiently treat patients affected by climate change.
5) Healthcare personnel will need to receive training in environmental epidemiology and the health implications of climate change, as well as courses and training on matters of social mobilisation and sudden disaster management.

Finally, as Dr. Margaret Chan, WHO Director General, once boldly stressed (Chan, 2008) "lack of resources and too little political commitment. These are often the true 'killers'".

2.11 Climate change impacts on the mining industry*

2.11.1 Introduction

Scientific research efforts in recent years have drawn attention to the climatic changes observed worldwide as a result of both natural processes and anthropogenic activity. In some cases, these changes are expected to have dramatic economic and social impacts (IPCC, 2007). Economic activities that are linked to natural resources, due to their direct dependence on the natural environment, will soon be faced with a broad range of challenges and problems (see e.g. Ford et al., 2010; 2011; Sauchyn and Kulshreshtha, 2008).

Mining is among such activities, given that an increased intensity and frequency of climate change-induced extreme weather events —e.g. floods, wildfires, extreme temperature highs or lows— could put the viability of the mining industry at risk. In fact, recent research shows that mining activities are already suffering the effects of climate change, with considerable economic repercussions (Ford et al., 2010; 2011). The response of the global mining industry has so far been disproportionate to the magnitude of the potential impacts, although the influence of climate change on the industry is acknowledged.

* Sub-chapter 2.11 was co-authored by: Ioannis Oikonomopoulos, Dimitrios Damigos, Michail Stamatakis and Emmanuel Baltatzis.

The present sub-chapter attempts to estimate and valuate the climate change impacts on the Greek mining industry, subject to the assumptions and limitations described.

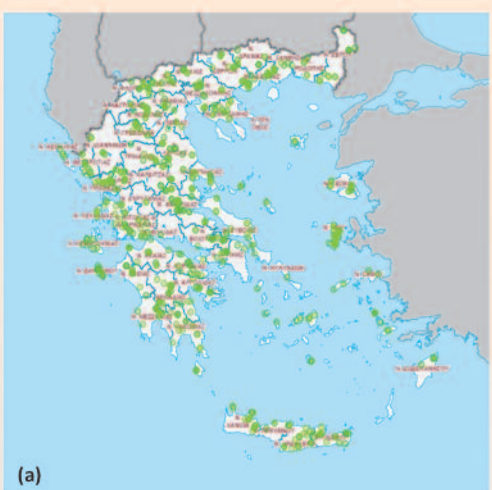
2.11.2 The Greek mining industry

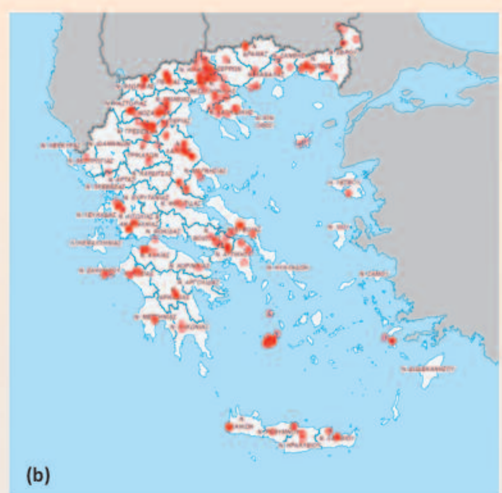
The mining industry with its strong export orientation is of high national importance, as it helps round out the trade balance, contributes to the country's energy security and self-reliance, and generates employment. Being interrelated with several other branches of the economy, it drives the development of several other activities.

The sector's contribution to national GDP has contracted considerably relative to past, levels, and currently stands at 3-5% taking the metal and mineral manufacturing sector into account (Tzeferis, 2009). Nevertheless, Greece has important mineral wealth and, despite the declining figures, still has noteworthy performance levels. More importantly, there are serious prospects of improvement, given that a large number of mineral deposits remain unexploited.

The regions either already active or presenting a potential for mining operation development, as illustrated in Figure 2.29, cover almost the entire Greek territory.

Figure 2.29 **Areas of extraction of (a) aggregates and (b) industrial minerals**





Άγιο Όρος	Mount Athos	Ν. Ευρυτανίας	Evritania P.	Ν. Κιλκίς	Kilkis P.	Ν. Πιερίας	Pieria P.
Ν. Αιτωλοακαρνανίας	Etoloakarnania P.	Ν. Ζακύνθου	Zakynthos P.	Ν. Κοζάνης	Kozani P.	Ν. Πρέβεζας	Preveza P.
Ν. Αργολίδος	Argolis P.	Ν. Ηλείας	Ilia P.	Ν. Κορινθίας	Corinthia P.	Ν. Ρεθύμνου	Rethymno P.
Ν. Αρκαδίας	Arcadia P.	Ν. Ημαθίας	Imathia P.	Ν. Κυκλάδων	Cyclades P.	Ν. Ροδόπης	Rhodope P.
Ν. Άρτας	Arta P.	Ν. Ηρακλείου	Heraklion P.	Ν. Λακωνίας	Laconia P.	Ν. Σάμου	Samos P.
Ν. Αττικής	Attica P.	Ν. Θεσπρωτίας	Thesprotia P.	Ν. Λαρίσης	Larissa P.	Ν. Σερρών	Serres P.
Ν. Αχαΐας	Achaea P.	Ν. Θεσσαλονίκης	Thessaloniki P.	Ν. Λασιθίου	Lasithi P.	Ν. Τρικάλων	Trikala P.
Ν. Βοιωτίας	Boeotia P.	Ν. Ιωαννίνων	Ioannina P.	Ν. Λέσβου	Lesbos P.	Ν. Φθιώτιδας	Phthiotis P.
Ν. Γρεβενών	Grevena P.	Ν. Καβάλας	Kavala P.	Ν. Λευκάδας	Lefkada P.	Ν. Φλώρινας	Florina P.
Ν. Δράμας	Drama P.	Ν. Καρδίτσας	Karditsa P.	Ν. Μαγνησίας	Magnesia P.	Ν. Φωκίδας	Phocis P.
Ν. Δωδεκανήσου	Dodecanese P.	Ν. Καστοριάς	Kastoria P.	Ν. Μεσσηνίας	Messenia P.	Ν. Χαλκιδικής	Chalkidiki P.
Ν. Έβρου	Evros P.	Ν. Κέρκυρας	Corfu P.	Ν. Ξάνθης	Xanthi P.	Ν. Χανίων	Chania P.
Ν. Εύβοιας	Euboea P.	Ν. Κεφαλληνίας	Cephalonia P.	Ν. Πέλλας	Pella P.	Ν. Χίου	Chios P.

Source: www.latomet.gr – access: April 2011.

Table 2.52 **Production of mineral commodities (Thousand tonnes)**

Product	2004	2005	2006	2007	2008	2009
1. Alumina hydrate	786	782	780	789	807.5	796
2. Aluminium	166	165	164.5	168	162.3	129
3. Calcium carbonate-talc-dolomite	181	200	250	350	500	600
4. Limestone aggregates	-	90,000	100,000	90,000	85,000	70,000
5. Feldspars (final products)	79	99	56	38	35.7	27.12
6. Attapulgite	4	7	7	7	25	28
7. Bauxite	2,444	2,495	2,194	2,128	2,174	1,935
8. Gypsum	912	915	900	940	900	580
9. Dead-burned magnesia	46	67	51	42	46.7	22.37
10. Kaolin	44	44	40	40	-	-
11. Caustic magnesia	86	73	69	72	70.5	57.5
12. Pumice	835	852	801	838	828	381
13. Magnesite	413	410	373	340	396.5	326.3
14. Lignite	71,900	69,064	64,100	66,100	65,000	64,000
15. Marbles, extracted products	1,738	1,500	1,790	1,690	1,500*	950*
16. Marbles, blocks	362	398	420	440	430	300*
17. Mixed sulphide ores	-	-	180	214	272	231
18. Mixed sulphide concentrates	-	-	69	144	82	60
19. Bentonite, crude	1,100	1,125	1,166	1,342	1,580	750
20. Activated bentonite	856	880	962	1,113	1,262.8	850
21. Nickel (incl. in alloys)	18	19	18	18.67	16.6	8.3
22. Nickeliferous iron ores	2,485	2,776	2,320	2,367	2,262	1,398
23. Olivine			35	40	40	33.3
24. Perlite, crude	1,067	1,075	1,049	1,100	1,000	700
25. Perlite, screened	630	600	700	650	600	450
26. Pozzolan (Santorin earth)	1,268	1,459	1,525	1,520	1,059	830
27. Refractory masses	24	26	30	31	22.6	31.6
28. Silica	93	113	110	52	52.5	38
29. Quartz – quartz products	16	15	14	15	16.2	14.3
30. Huntite – hydromagnesite	13	9	25.7	15	19.6	10

* Estimate.
Source: Greek Mining Enterprises Association (MEA), 2010.

The total annual output of mining products for the years 2004-2009, based on data collected by the Mining Enterprises Association (MEA) of Greece (MEA, 2010), is presented in Table 2.52.

2.11.3 Climate change and the Greek mining industry

2.11.3.1 Methodological approach

Estimating climate change impacts on the mining industry is a complex task involving a number of uncertainties related to climate change scenarios and the particularities of each mining operation. An additional factor hindering impact estimation and valuation is the absence of relevant research, in both the Greek and the international literature. Relevant studies (e.g. Ford et al., 2010; 2011; Pearce et al., 2011) deal mainly with a qualitative exploration of the problem through questionnaire-based surveys of mining sector businesses and staff.

We developed our methodological approach taking into consideration the availability of crucial data, the mining operations' lifespan and the weight of impact of various climate change components in total financial loss.

As regards the forecast changes in climate parameters, the results under Scenario A1B covering the period 2021-2050 were used given that the lifespan of the vast majority of known mineral deposits, including those still unexploited today (e.g. Greece's gold deposits) will have been exhausted by 2050. Although the results under Scenario A1B were available for 12 geographical regions, we carried out our analysis at an aggregate countrywide level, using a 'top-down' approach. Further reasons for this approach were the wide geographic distribution of Greece's mining operations and the difficulties posed by the present study's time constraints for the collection of data per region and mining operation. For impact estimation and, subsequently, valuation purposes, the results under Scenario A1B in terms of temperature rise, decreased precipitation, etc. were compared with the levels of the baseline period 1991-2000.

With respect to the type of impacts examined, our analysis considered both direct (e.g. increase in extreme weather events) and indirect impacts (e.g. higher cost of electricity) arising from the need to reduce greenhouse gas emissions. It was not possible in all cases to quantify and value the impacts on the industry as a whole, as some impacts depend directly on parameters specific to each mine site.

2.11.3.2 Estimated impacts

For methodological purposes, a distinction was made between the direct and indirect potential impacts of climate change on the mining industry. The direct impacts involve the cost of adaptation to climate change, while indirect impacts concern impact mitigation issues, i.e. measures to reduce greenhouse gas emissions.

2.11.3.2.1 Direct impacts

i. Infrastructure damage

Damage to mining infrastructure in Greece usually comes as the result of extreme weather events, e.g. heavy rainfall, capable of causing flooding or landslides and posing a threat to both infrastructure and personnel. Based on the results for the climate parameter variations under Scenario A1B (see Chapter 1), the chances of landslide occurrence increase as much as two-fold in the larger part of Greece, while the chances of flooding increase, almost everywhere in the country, by as much as 168%.

The exploitation of mineral wealth is closely linked with the presence and harnessing of water flows, and is consequently directly affected by precipitation levels, flood severity and the presence of aquifers. If a 'normal' inflow of water into an open-cast or underground mining site is 'manageable', i.e. capable of being pumped out, then the problem caused is essentially financial. However, a sudden massive inflow of water, resulting for instance from a flood, may not be manageable with the existing pumping facilities, may cause incalculable damage and may put the very existence of the mining site at risk (Oikonomopoulos, 1971).

Cases such as the ones listed immediately below highlight the vulnerability of mining sites to climatic factors.

- In 1897, a tremendous flood destroyed almost all of the surface lignite-mining facilities in Aliveri (Euboia), while the underground mine was inundated and rendered useless.
- Works to deepen the central shaft (total depth: 200 m) of the major lignite mine of Aliveri were interrupted in 1954 after the inflow of large volumes of water and only resumed several weeks later.
- The mining of chromite in Domokos (Central Greece, Fthiotis prefecture) was abandoned in the mid-1960s due to high mining costs caused by excessive water pumping costs (constant need to pump out large quantities of water from a depth of 200 m).
- A case worth noting was the flood in the mining region of Stratonio (Central Macedonia, Chalkidiki prefecture) on 6-10 February 2010, marked by 164 mm of rainfall within just a few hours (70 mm/h). The duration and intensity of the rainstorm caused the region's streams to swell to unusually high levels and to displace large quantities of debris. The result was the deflection of the water flow through the settlement's road network and considerable damage. Fortunately, there were no casualties, but the overall damage restoration costs were quite high.

Apart from the above cases, it is not unusual for floods to disrupt the extraction of quartz sand from river beds, mainly in Central and Northern Greece. Flooding events have a direct and potentially catastrophic effect on mining infrastructure. The ensuing disruption of the mining activity, whether temporary or permanent, entails multiple consequences.

Landslides represent another danger, particularly for open-cast mines, capable of disrupting mining operation schedules, jeopardising the mines' economic stability, and even endangering workers' lives. Landslides of different sizes have occurred during the open-cast mining of various mineral deposits in Greece. Indicatively, one could mention the landslides that have occurred at the lignite mining sites in the Ptolemais region (Kozani prefecture) and in the Vevi and Vegora (Amyntaio) regions (Florina prefecture), and well as at bauxite mining sites on Mounts Helicon, Parnassus and Giona, etc.

Despite possible underlying anthropogenic causes, all of these incidents coincided with an extreme weather event. The study of such incidents, in light of climatic changes, can thus help draw very useful conclusions. With catastrophic events having become almost twice as likely to occur, it is normal that mining operations should factor in the risks and modify their operations accordingly. Generally speaking, operating costs are projected to increase due to the need for maintenance of internal haul roads, for protection against erosion, for landslide restoration at mine pit excavations and/or waste heaps, for safer mining and smelting waste management practices, etc.

ii. Forest fires

Forest fires are directly related to fuel moisture content, which in turn is determined by rainfall, relative air humidity and temperature, and wind speed. Based on the overall analysis conducted for the entire study (Chapter 1), in the period 2021-2050 the number of extreme fire danger days is likely to increase by 20 in all of Eastern Greece, from Thrace down to the Peloponnese. Smaller increases are expected in Western Greece, mainly due to the region's wetter climate.

Fires have a negative effect on mining operations due to fact that licenses cannot be obtained for expansion into fire-stricken areas (such areas are automatically earmarked for reforestation). The pozzolanic tuff deposits on the island of Milos (Cyclades) are a typical example, where mining operations cannot be developed due the area's previous devastation by fire.

Due to the lack of detailed data on the number and size of mining units (by category of extraction) operating within or near areas characterised as forest land, it was not possible to quantify the impacts of forest fires on the mining sector.

iii. Decrease in available water resources

The decrease in available quantities of water resources, associated with climate change, results from the disruption of the hydrological cycle. Based on the projections of Scenario A1B for 2021-2050, western continental Greece will experience fewer than 10 additional days of drought, in contrast with eastern continental Greece and northern Crete where the number of additional drought days will increase by 20. The decrease in precipitation and water infiltration will be in the order of 7-8% countrywide in the period 2021-2050 (Stournaras, 2010).

The decrease in surface and groundwater reserves can have multiple impacts on the mining industry, leading in the best of cases to higher mining costs and in some cases to the curtailing or even discontinuation of mining operations.

Based on MEA (2010) data, the total net consumption of water from water networks, groundwater aquifers and surface water reservoirs came to about 17 million m^3 in 2009. In addition, roughly 5 million m^3 were consumed by recycling processes. The average aggregated net consumption of water per tonne of marketable product was estimated at 0.17 m^3, while the consumption of water for environmental restoration amounted to roughly 908,000 m^3.

Assuming for argument's sake that there is such thing as an 'average mining product' (due to the lack of data regarding the weight of water in the output function of each type of mining unit), the decrease in water availability could potentially lead to a proportionate decline in mineral product. Considering that the total output of marketable product amounted to roughly 97 million tonnes in 2009, the loss of marketable product could amount to 7.5 million tonnes. Considering that 0.31 man-hours are needed per tonne of marketable product (according to the MEA 2010 data, the number of man-hours lost on account of decreased production could amount to about 2,325,000, the equivalent of some 1,200 full-time jobs.

iv. Increased particulate matter emissions

The rate of release of particulate matter depends on the attributes of the overburden and the deposit, the mining method, the characteristics of the working area, the rate of operations, and climate conditions. To estimate the suspended dust produced, emission factors, such as the AP-42 coefficients of the US Environmental Protection Agency (USEPA), can be used, according to the following general equation:

$$E_{kpy} = [A * OH] * EF * [(1 - CE)/ 100]$$

where:

E_{kpy} = total pollutant emissions, in kg/year;

A = annual production of the mining unit;

OH = operation hours per year;

EF = pollutant emission factor, in kg/tonne; and

CE = effectiveness of pollutant control measures, as a percentage.

Indicative dust emission factors are presented in Table 2.53.

Table 2.53 **Dust emission factors**

Source	TSP	Units
Overburden excavation	1-3	kg/t
Loading in trucks	0.4-0.7	kg/t
Truck transport	1.5-3	kg/km
Primary crushing	1.5-2.5	kg/t
Screening	2.5-5	kg/t
Stockpiling	1.5-4	kg/t
Wind erosion	0.85	Mg/ha/year

Sources: Ghose (2004) and USEPA (1995).

The climate change models under Scenario A1B (see Chapter 1) forecast a decrease of 1.2% in mean relative humidity countrywide for the period 2021-2050. The decrease is expected to be greater in summer, reaching 12% in western and northern continental Greece, 6-8% in the remaining mainland, and 3-5% in the island regions. Apart from the variation in humidity, precipitation levels will decrease and the number of drought days will increase. These changes will affect the moisture content of mined material, haul road surfaces, etc.

In order to estimate PM10 dust emissions resulting from changes in critical climate conditions, we relied on the data of Table 2.53 and made the following assumptions:

- the mining industry takes no further preventive measures to control additional dust emissions;
- the total annual output of mineral products amounts to 97 million tonnes, and the total annual output of mineral waste to 546 million tonnes (MEA, 2010);
- the total area of mined land is around 15,800 hectares (MEA, 2010);
- the moisture content of the mined material decreases from 15% to 10% and the dust emission factors double; and
- the period of low humidity lasts around 4 months.

Based on the above, annual PM10 emissions are expected to increase by 180,000 tonnes on account of climate change.

It should be noted that these estimates are only approximate, given the uncertainty surrounding emission factors, the different extraction methods used in mining operations, the role of the regional microclimate in dust emissions, etc.

v. Loss of working hours due to extreme conditions

According to the climate change models for the period 2021-2050 (see Chapter 1), the number of days per year with a humidex index >38ºC will increase, with an impact on general population and worker discomfort. The Dodecanese and the coastal areas of the Ionian are expected to experience 20 additional days with humidex values >38ºC, and the low-lying mainland regions and Crete 15 additional days, whereas the mountainous regions will not experience any significant change in this parameter.

Based on the labour safety and health legislation presently in force (e.g. Circular 130427/26.6.90 issued by the Ministry of Labour), employers must ensure worker protection from heat stress and therefore provide for work breaks, depending on the (dry thermometer) temperature and relative humidity. In order to quantify the impacts of these work breaks on the mining industry, the following figures and assumptions were used:

- total man-hours worked per year: 29.9 million (MEA, 2010);
- 250 days worked per year;
- 10 days per year with conditions requiring 25% rest time to avoid heat stress for every 75% of work time;

- 3.24 tonnes of marketable product per hour worked (MEA, 2010); and
- impact on 10% of mining sites operating in (non-mountainous) regions where the humidex rises.

On this basis, the amount of mineral products lost due to the loss of working hours is about 97,000 tonnes per year.

Aside from the lost working hours they entail, warmer temperatures are also likely to accelerate or even cause spontaneous lignite combustion either in the yards of lignite-fired power plants or at lignite mining sites. This would not only result in a potential loss of fuel, but would also release gaseous pollutants (mainly CO and CO_2) into the atmosphere, which, apart from being unpleasant, could be a health concern to the local population. Due to lack of data, however, it was not feasible to quantify the impacts of this specific factor.

vi. Strengthening measures and actions for environmental protection and restoration

Climatic variations are expected to affect the environmental impact of the mining industry in various ways. Indicatively, a higher number of drought days and reduced humidity and precipitation may increase the frequency of irrigation needed at restoration sites; flood occurrences may exacerbate soil erosion; and reduced surface drainage may require further treatment of the liquid waste or water pumped out of underground mines into surface recipients, etc. (Oikonomopoulos, 1991; Menegaki and Damigos, 2009).

Quantifying such impacts (e.g. loss of x-number of tonnes of soil per year) poses considerable difficulty, as it involves extremely localised parameters. In section 2.11.3.3 below, we will nevertheless attempt a cost valuation of such impacts in relation to current expenditure for environmental protection.

2.11.3.2.2 Indirect impacts

The mining industry can be indirectly affected by (a) a broader effort to reduce CO_2 emissions (e.g. restrictions on fossil fuel exploitation for energy or mineral commodity production), and (b) increased production costs, as a result of the internalisation of external costs (CO_2 emission rights) after 2013.

The effect of such impacts is best exemplified by lignite mining operations, where the internalisation of external costs (CO_2 emission rights), the national effort to meet the European "20-20-20" target and other environmental factors are expected to lead to a steady reduction in power production from this specific resource. In line with these developments, the installed capacity of lignite-fired power plants is expected to decrease from 4,826 MW in 2010 to 3,362 MW in 2020 (down by roughly 30%) and to 2,295 MW in 2030 (down by 52.5%). Assuming that power plant availability, performance levels and other parameters affecting power production remain unchanged, lignite-fired power production is expected to be in the order of 22.2 TWh in 2020, and 15.1 TWh in 2030.

According to a recent research study (Tourkolias, 2010), a state-of-the-art lignite-fired power plant requires 1.38 tonnes of lignite to produce 1 MWh of electricity or 1.38 million tonnes per TWh. Thus, decreases of 12.7 TWh and 19.8 TWh, respectively, in power production by 2020 and 2030 would bring about decreases in lignite mining of 17.5 million tonnes and 27.3 million tonnes, respectively.

Turning to the impacts on employment, according to the same study, about 119.5 man-years are needed for each TWh of electricity produced for the fuelling of a state-of-the-art lignite-fired power plant. Decreases of 12.7 TWh and 19.8 TWh, respectively, in electricity production by 2020 and 2030 would therefore bring about decreases in employment in the order of 1,520 and 2,370 man-years.

Finally, the effort to reverse the negative impacts of anthropogenic activity on the greenhouse effect is expected to indirectly increase the operating costs of the mining industry, which, as part of the broader effort to reduce greenhouse gas emissions, will be required to replace outdated equipment and production means and adopt other measures. The international literature mainly mentions the collection of methane released from underground coal mines for subsequent use in energy production. This prospect, though interesting in theory, is of no practical relevance in the case of Greece's mining industry. At a secondary level, efforts are being made to develop lower emission equipment. However, there are no quantitative or economic estimates of their emission reduction levels and cost.

2.11.3.3 Impact valuation

The present section attempts to assess the cost of the anticipated climate change impacts on the mining industry. The fact that certain impacts depend directly on specific regional and mining-site characteristics made it impossible in some cases to provide aggregated estimates at the industry-wide level. We have nevertheless chosen to report a few typical examples as a means of underscoring the magnitude of the problem.

2.11.3.3.1 Direct impacts

i. Infrastructure damage

The cost of damage to mining property and infrastructure as a direct result of extreme weather events, e.g. heavy rainfall, can vary significantly depending on the specifics of each case. The international literature has focused extensively on disasters that have required major damage restoration. Eriksson and Adamek (2000), for instance, studied the impacts of the tailings dam wall failure at the Aznalcóllar mine in Andalucia, Spain. Total damage restoration costs amounted to some €225 million (2010). Similarly, Prommer and Skwarek (2001) estimated the total cost of damage from the failed Aurul tailings impoundment dam in Romania's Baia Mare region at €10-14 million (2010).

ii. Forest fires

As already mentioned, due to lack of data, it was not feasible to perform a valuation of the direct impacts of forest fires on the industry as a whole. Thus, no relevant cost estimates are provided.

iii. Decrease in available water resources

According to recent research (Vagiona and Mylopoulos, 2005), the price elasticity of demand for industrial water was estimated at -0.2 (other studies have produced estimates of -0.3 to -0.4). Thus, an 8% reduction in supplied water would lead to a 40% price increase. Even though the water used in mining processes is mostly taken from water wells or surface water resources, and not water networks, for our calculations we used the rate that the Athens Water Supply and Sewerage Company (EYDAP S.A.) charges its industrial consumers for consumptions exceeding 1,000 m^3 per month, i.e. €0.9866 per m^3. On this basis, the extra cost for industrial water would amount to about €0.4 per m^3, meaning that the mining industry, in order to fully cover its needs, would face additional costs in the order of €6.8 million (the industry's annual consumption of industrial water amounts to roughly 17 million m^3).

Moreover, as mentioned above, water scarcity could lead to around 1,200 lost full-time jobs. A recent research (Tourkolias et al., 2009) estimated the value of a new job (using a public expenditures approach) at €6,400 (or €4,000 to €12,000). Consequently, the annual cost to society of job loss is estimated at around €7.7 million. It should, however, be noted that the mining industry would only incur worker compensation costs.

iv. Increased particulate matter emissions

Assuming that the mining industry has taken all the necessary measures to minimise the impact of particulate matter emissions during the baseline period, the nuisance caused by increased dust emissions in proximity to the mining sites is expected to force the mining companies to take control measures (enclosed crushing plants, sealed conveyor skirts, etc.).

The cost of water-spray suppression on mine haul roads is rather insignificant, given that water-spraying frequency, currently 7-8 times per work shift, will have to be increased to 14 times per shift on dry days. However, the construction of enclosed facilities may entail significant cost for mining companies, considering that depreciation costs represent between 10% and 40% of total operating costs, whereas the construction costs, for instance, of an enclosed crushing plant using sealed conveyor skirts, water spraying systems, etc., to limit dust emissions is roughly 20% to 30% higher.

In order to approximate the cost of addressing the industry's increased emissions, we used MEA (2010) data on business turnover, financial statements of Greek mining companies, and information from personal communications.

The operating profit margin appears to range between 12% and 30%, with an average value of 20%. Operating costs therefore amount to 80%. Given that the industry's total turnover was roughly €1.8 billion in 2009, operating costs are estimated at around €1.44 billion. Assuming that depreciation costs represent 20% of operating costs and that dust prevention measures account for 5% of total investment costs and that the cost of construction of an enclosed crushing plant may be 20-30% higher (25% on average) than the cost of a non-enclosed facility, the additional cost on an annual basis is estimated at around €3.6 million.

v. Loss of working hours due to extreme conditions

According to the estimates, the loss of marketable product may amount to some 97,000 tonnes, i.e. around 0.1% of total production (MEA, 2010). Using an average aggregate estimated value per tonne of marketable product based on total turnover, this cost could amount to roughly €1.8 million per year.

vi. Strengthening measures and actions for environmental protection and restoration

In order to assess the cost implications of environmental protection and restoration, we used MEA (2010) data on expenditure for mine restoration and environmental protection. In 2009, the total expenditure for environmental purposes came to around €9.4 million, which corresponds to €0.1 per tonne of marketable product. Assuming in line with a conservative approach that a 50% increase in such expenditure would be needed to address problems of erosion, irrigation, liquid waste management, etc., the additional cost is estimated at roughly €4.7 million.

2.11.3.3.2 Indirect impacts

Our economic analysis of reduced production was limited to fossil fuels, due to lack of data on the other components of the mining industry. However, we performed an economic valuation of the indirect impacts on the industry as a whole in relation to the increase in electricity costs, based on Input-Output tables for the Greek economy.

According to estimates (Leonardos, unknown), lignite production costs come to roughly €12 per tonne and the 'selling price' (cost of fuel for lignite-fired power plants) to €16 per tonne. Thus, decreases in lignite production of 17.5 million tonnes and 27.3 million tonnes, respectively, by 2020 and 2030, would entail a loss of (gross) profits in the order of €70 million and €109.2 million respectively, on an annual basis, relative to the baseline period. Given, however, that nine lignite-fired power plants are scheduled to shut down between 2019 and 2022 (mainly due to problems with sulphur emissions), the economic impact of reducing greenhouse gas emissions is estimated at €39.2 million, which corresponds to the decrease in production between 2020 and 2030.

According to MEA data (2010), the mining industry consumes 20.16 billion MJ each year. It is not clear, however, what share of this energy concerns electricity. Therefore, in order to estimate the economic impact of higher electricity costs (estimated to increase by 25-30%) on the industry as a whole, we used the latest Input-Output table available for the Greek economy (for year 2005) published by Eurostat (2011) and comprising 59 economic sectors.

In more detail, we examined the mining industry expenditure, at base prices, for electricity purchase. As the acquisition of electricity cost the industry €113 million in 2005 and the total mining production was roughly 110 million tonnes, the average cost of electricity was in the order of €1.03 per tonne. Assuming a 30% increase in this cost (i.e. by about €0.3 per tonne) and an average annual production of 90 million tonnes, the additional cost for the entire industry would come to €27 million per year.

The cost of lost jobs due to reduced lignite mining activity is mainly a cost to society and not to the mining industry (which would only incur worker compensation costs). Based on assumptions detailed earlier, the cost of job loss is estimated at €9.8 million for 2020 and €15.2 million for 2030.

The cost to the industry of participating in the greenhouse gas mitigation effort, basically through the use of state-of-the-art equipment, has not been estimated. Although additional costs will certainly be incurred, these costs will tend to decrease with gradual improvement and adoption of new technological solutions.

2.11.3.3.3 Estimation of the total economic costs

The total economic cost of climate change impacts on the Greek mining sector for the year 2010 was calculated based on the present value of the annual additional cost for the period 2021-2050. The calculations were based on the following assumptions:

Direct impacts

i. Infrastructure damage: the present value of an accident costing €15 million. This cost was based on the assumption that one serious accident will occur during the period, as determined from similar incidents.

ii. Forest fires: not valuated.

iii. Decrease in available water resources: annual cost of €6.8 million for the purchase of water at a higher price.

iv. Increased particulate matter emissions: annual cost of €3.6 million for taking additional measures to control dust emissions.

v. Loss of working hours due to extreme conditions: annual cost of €1.8 million due to lower production.

vi. Strengthening environmental measures and actions: annual cost of €4.7 million for additional measures related to environmental protection and restoration.

Indirect impacts

Additional electricity costs: annual cost of €27 million due to higher electricity prices.

It should be noted that the calculations take no account of revenue loss due to reduced lignite production.

Table 2.54 **Estimated present value of economic impact (discount rate=1%) (In euro)**

	2021	2010
Direct impact		
i. Infrastructure damage	-15,000,000	-13,450,000
ii. Forest fires	0	0
iii. Decrease in available water resources	-170,450,000	-152,780,000
iv. Increased particulate matter emmissions	-9,030,000	-8,090,000
v. Loss of working hours due to extreme conditions	-90,240,000	-80,890,000
vi. Strengthening environmental measures and actions	-117,810,000	-105,600,000
Total direct impact	-438,620,000	-393,170,000
Indirect impact		
Higher cost of electricity	-676,780,000	-606,620,000
Total	-1,115,400,000	-999,790,000

Table 2.55 **Estimated present value of economic impact (discount rate=3%) (In euro)**

	2021	2010
Direct impact		
i. Infrastructure damage	-15,000,000	-10,840,000
ii. Forest fires	0	0
iii. Decrease in available water resources	-130,490,000	-94,270,000
iv. Increased particulate matter emmissions	-69,080,000	-49,910,000
v. Loss of working hours due to extreme conditions	-34,540,000	-24,960,000
vi. Strengthening environmental measures and actions	-90,190,000	-65,160,000
Total direct impact	-339,300,000	-245,140,000
Indirect impact		
Higher cost of electricity	-518,090,000	-374,280,000
Total	-857,390,000	-619,420,000

The net present values were calculated using two discount rates (1% and 3%) to test the sensitivity of the outcome to alternative discount rates.

The results are presented in Tables 2.54 and 2.55.

Based on the above, the present value of estimated costs comes to roughly €1 billion at a discount rate of 1%, and to roughly €620 million at a discount rate of 3%.

2.11.4 Adaptation and impact mitigation

The debate on the mining industry's adaptation to climate change has already been launched at the international level, but the results have so far been meagre. Some mining companies that have already experienced the impacts of climate change have taken short-term measures, without any far-sighted planning (Ford et al., 2010).

With regard to impact mitigation, the efforts of the mining industry have so far been almost exclusively focused on commitments and actions involving the mitigation of greenhouse gas emissions (Williamson et al., 2005; MAC, 2007; Ford et al., 2010). Such actions are often seen as a means for the industry to improve its public image, and help the mining companies implement environmental management systems that also spare them the risk of being exposed for not complying or keeping up with climate change-related legislation.

This emphasis on reducing emissions is detrimental, however, to adaptation efforts. According to Pearce et al. (2009), this stance is, to some extent, attributable to lacking awareness among mining industry practitioners and company representatives of climate change impact issues. It is also attributable to the fact that the industry's adaptation is a function of many parameters, not all of which are technological (Pearce et al., 2011).

With respect to Greek mining activity, given that the lifespan of the vast majority of known mineral deposits (including those still unexploited today) will have been exhausted by 2050, the assessment of the climate change impacts was based on Scenario A1B which covers the period 2021-2050 (see Section 2.11.3.1).

The cost of the mining industry's adaptation to climate change, as established based on the anticipated direct impacts (see Sections 2.11.3.3.1 and 2.11.3.3.3), is estimated at between €245 million (at a discount rate of 3%) and €393 million (at a discount rate of 1%).

The mitigation cost arising from the industry's contribution to greenhouse gas reduction effort (e.g. use of state-of-the-art equipment) was not estimated due to lack of data (see Section 2.11.3.2.2). However, the mitigation cost incurred indirectly by the mining industry from the rise in electricity costs (see Sections 2.11.3.3.2 and 2.11.3.3.3) was estimated at between €374 million (discount rate: 3%) and €607 million (discount rate: 1%).

Based on the above, the total cost of climate change impacts for the entire period 2021-2050, expressed in present value terms (2010), ranges from €0.6 billion (discount rate: 3%) to €1 billion (discount rate: 1%) or 0.2% to 0.4% of GDP, respectively.

Bibliography of Chapter 2, per sub-chapter

2.1 Climatic changes and impacts on Greece's water systems

COST action 620 (2004), "Vulnerability and risk mapping for the protection of the carbonate (karst) aquifers", Final Report, EUR 20912.

COST action 621 (2004), "Groundwater management of coastal karstic aquifers", Final Report, EUR 20911.

ΕΔΕΥΑ (2007), "Υλικό Οικονομικής Επιτροπής", διαθέσιμο (1/2011) στο: http://www.edeya.gr/material.php.

Erhard-Cassegrain, A. and J. Margat, "L' eau, matière première. Resources, Utilisations, Besoins et Demandes, Coût et Prix, Prelevements et Consomations, Aide-Memoire Terminologique", B.R.G.M. 78 SGN 674 HYD, Orléans.

European Commission, "Environment", Technical Report 2007/001.

European Environment Agency (2009), "Water resources across Europe – confronting water scarcity and drought", EEA Report, διαθέσιμο (1/2011): http://www.eea.europa.eu/publications/water-resources-across-europe/at_download/file.

IPCC (2007), Report on Global Climatic Changes.

Marinos, P., G. Stournaras and Z. Karotsieris (1990), "Ensembles karstiques et dispersion des écoulements souterrains en Grèce du NW. Le cas des bassins de rivières Louros et Arakhthos", Intern. Conf. Ground Water in Mountainous Regions, I.A.H., I.A.H.S., Symp. 5-8 Mémoires V. XXII Part 2, 872-82, Lausanne.

Mariotti, A., N. Zeng, J. H.Yoon, V. Artale, A. Navarra, P. Alpert and L. Z. X. Li (2008), "Mediterranean water cycle changes: transition to drier 21st century conditions in observations and CMIP3 simulations", Environment Research Letters, 3, 4.

Milly, P. C. D., K. A. Dunne and A. V. Vecchia (2005), "Global pattern of trends in streamflow and water availability in a changing climate", *Nature* 438: 347-50.

Navrud, S. and R. Ready (eds) (2007), "Environmental Value Transfer: Issues and Methods". Springer/Kluwer Publishers, Dordrect, The Netherlands.

Παπανδρέου, Α. και Μ. Σκούρτος (2000), "Βασικές Αρχές Περιβαλλοντικής Αξιολόγησης, στο: Ελληνικό Ανοικτό Πανεπιστήμιο (επιμ.), "Σχεδιασμός, Περιβαλλοντικές Επιπτώσεις και Μέθοδοι Εκτίμησής τους". Τόμος Β1, Αθήνα.

Skoullos, M. (2009), "Climate change in the Mediterranean region: Possible threats and responses in Water Management, Water Security and Climate Change Adaptation: Early Impacts and Essential Responses", C. Sadoff and M. Muller, GWP (TEC background papers) No. 14.

Stournaras, G. (1998), "Ground Water and Nitrates in Greece. An Overview", *Journal of Environmental Hydrology,* V. 6, 4.

Stournaras, G. (1999), "Correlating morphometric parameters of Greek Rhone-type deltas. Hydrogeologic and environmental aspects", *Environmental Geology*, V. 38/1, No. 1.

Stournaras, G. (2008), "Hydrogeology and vulnerability of limited extension fissured rocks islands", *Ecohydrology & Hydrobiology*, Vol. 8, No. 2-4, 391-9.

Stournaras, G. (2010), "The water in Mediterranean", in "Losing Paradise: The Water Crisis in the Mediterranean", Ashgate Publishing Ltd, UK.

Stournaras, G., D. Leonidopoulou and G. Yoxas (2007), "Geoenvironmental approach of Tinos Wetlands (Aegean Sea, Hellas)", 35th International Congress of IAH, Groundwater and Ecosystems, Lisbon, Portugal.

Stournaras, G., G. Migiros, G. Stamatis, N. Evelpidou, C. Botsialas, V. Antoniou and E. Vassilakis (2007), "The fractured rocks in Hellas", *Groundwater Hydrology*, Special Volume.

Σούλιος, Γ. (2010), "Γενική Υδρογεωλογία", τόμος 1ος, University Studio Press, Θεσσαλονίκη.

Στουρνάρας, Γ. (1998), "Η Υδρολογία της Ελλάδας", Εγκυκλοπαίδεια Πάπυρος-Larousse, Τόμος: Ελλάδα.

Στουρνάρας, Γ. (2007), "Νερό. Περιβαλλοντική Διάσταση και Διαδρομή", Εκδόσεις Τζιόλα, Θεσσαλονίκη.

ΥΠΑΝ (2003), Σχέδιο Προγράμματος Διαχείρισης Των Υδατικών Πόρων Της Χώρας, Αθήνα.

ΥΠΕΧΩΔΕ (2008), "Εφαρμογή των οικονομικών πτυχών του αρθρου 5 της Κοινοτικής Οδηγίας περί Υδάτων 2000/60/ΕΚ στην Ελλάδα", Αθήνα.

2.2 Climate change risks and impacts from sea level rise

A. In Greek

Βελεγράκης, Α. (2010), "Ερευνητική Πρόταση ΘΑΛΗΣ: Επιπτώσεις της Ανόδου Στάθμης Θάλασσας στις νησιωτικές παραλίες του Αιγαίου Πελάγους", ΕΣΠΑ 2007-2013, Πανεπιστήμιο Αιγαίου, Σχολή Περιβάλλοντος, Τμήμα Επιστημών της Θάλασσας.

Δουκάκης, Ε. (2005α), "Οι Επιπτώσεις των Κλιματικών Αλλαγών στη Χερσαία Ζώνη του Κόλπου του Ναυπλίου", 5ο Εθνικό Συνέδριο "Ολοκληρωμένη διαχείριση υδατικών πόρων με βάση τη λεκάνη απορροής", Ξάνθη.

Δουκάκης, Ε. (2005β), "Κίνδυνοι στην Παράκτια Ζώνη από τις Κλιματικές Αλλαγές και τα Τσουνάμι", Εργασίες Ημερίδας "Εκτίμηση κινδύνων στον Κορινθιακό", Δερβένι – Δήμος Ευρωστίνης.

Δουκάκης, Ε. (2007), "Φυσικές καταστροφές και παράκτια ζώνη, Πρόληψη – Διαχείριση των φυσικών καταστροφών", Ο ρόλος του Αγρονόμου Τοπογράφου Μηχανικού, ΤΕΕ, ΠΣΔΑΤΜ, ΕΜΠ, Αθήνα.

Δουκάκης, Ε. (2008), "Η προβληματική οριοθέτηση του αιγιαλού και παραλίας στη Σκάλα Ερεσού Μυτιλήνης", Conference 4MMCZ: 307-13.

Κανελλάκης, Α. και Ε. Δουκάκης (2004), "Επιπτώσεις των κλιματικών αλλαγών στις παράκτιες περιοχές της πεδιάδας της Θεσσαλονίκης", Διπλωματική εργασία, ΕΜΠ, Σχολή Αγρονόμων και Τοπογράφων Μηχανικών, Τομέας Τοπογραφίας.

Καραμπάς, Θ., Ι. Κρεστενίτης, Δ. Σακελλαρίου, Θ. Χασιώτης και Δ. Μαλιαρός (2008), "Πρόληψη και διαχείριση θαλάσσιων κινδύνων στην παράκτια ζώνη (CORI–INTERREG III B/ARCHIMED): Κίνδυνοι από τσουνάμι και πλημμύρες", 4ο Πανελλήνιο Συνέδριο: Διαχείριση και Βελτίωση Παράκτιων Ζωνών, Μυτιλήνη 23-27 Σεπτεμβρίου, 597-606.

Καρύμπαλης, Ε. και Κ. Γάκη-Παπαναστασίου (2008), "Γεωμορφολογική μελέτη των δέλτα των ποταμών Πηνειού, Καλαμά, Εύηνου και Μόρνου", Conference 4MMCZ: 85-94.

Κοντογιάννη, Α., Χ. Τουρκολιάς και Μ. Σκούρτος (2010α), "Το κόστος των Επιπτώσεων από την Άνοδο Στάθμης της Θάλασσας στην Ελληνική παράκτια Ζώνη", Τελική Έκθεση, Επιτροπή Μελέτης των Επιπτώσεων της Κλιματικής Αλλαγής (ΕΜΕΚΑ), Τράπεζα της Ελλάδος, διαθέσιμο στον ιστοχώρο www.bankofgreece.gr.

Κοντογιάννη, Α., Χ. Τουρκολιάς και Μ. Σκούρτος (2010β), "Το κόστος των Μέτρων Προσαρμογής της Ελληνικής Παράκτιας Ζώνης στην Άνοδο Στάθμης της Θάλασσας", Τελική Έκθεση, Επιτροπή Μελέτης των Επιπτώσεων της Κλιματικής Αλλαγής (ΕΜΕΚΑ), Τράπεζα της Ελλάδος, διαθέσιμο στον ιστοχώρο www.bankofgreece.gr.

Κοντογιάννη, Α. (2011), "Διερεύνηση κοινωνικής τρωτότητας και κόστος προσαρμογής από την άνοδο της στάθμης της θάλασσας στην Ελλάδα", Κείμενο Εργασίας, Πανεπιστήμιο Αιγαίου, Σχολή Περιβάλλοντος, Εργαστήριο Εφαρμοσμένων Οικονομικών του Περιβάλλοντος.

Κουρογένη, Α. και Θ. Καραμπάς (2010), "Προστασία ακτών της Λέσβου λόγω της μετεωρολογικής παλίρροιας", Διπλωματική εργασία, Πανεπιστήμιο Αιγαίου, Σχολή Περιβάλλοντος, Τμήμα Επιστημών της Θάλασσας, Πρόγραμμα Μεταπτυχιακών Σπουδών: "Διαχείριση Παράκτιων Περιοχών".

Παπαδοπούλου, Γ. και Ε. Δουκάκης (2003), "Επιπτώσεις των κλιματικών αλλαγών στον αιγιαλό και την παραλία", Διπλωματική εργασία, ΕΜΠ, Σχολή Αγρονόμων και Τοπογράφων Μηχανικών, Τομέας Τοπογραφίας.

Παπανικολάου, Δ., Μ. Παπανικολάου και Ε. Βασιλάκης (2010), "Μεταβολές Στάθμης Θάλασσας και Επιπτώσεων στις Ακτές", Τελική Έκθεση, Επιτροπή Μελέτης των Επιπτώσεων της Κλιματικής Αλλαγής (ΕΜΕΚΑ), Τράπεζα της Ελλάδος, διαθέσιμο στον ιστοχώρο www.bankofgreece.gr.

Πλιάκος, Γ. και Ε. Δουκάκης (2004), "Επιπτώσεις των κλιματικών αλλαγών στις παράκτιες περιοχές της νήσου Λήμνου", Διπλωματική εργασία, ΕΜΠ, Σχολή Αγρονόμων και Τοπογράφων Μηχανικών, Τομέας Τοπογραφίας.

Ρούσσος, Δ. και Ε. Καρύμπαλης (2009), "Παράκτια γεωμορφολογική χαρτογράφηση και εκτίμηση των επιπτώσεων στη παράκτια ζώνη από την πόλη της Ερέτριας έως και την περιοχή Μανίδες στο Νότιο Ευβοϊκό Κόλπο από μια πιθανή μελλοντική άνοδο της θαλάσσιας στάθμης", Διπλωματική εργασία, Χαροκόπειο Πανεπιστήμιο, Τμήμα Γεωγραφίας.

Σενή, Α. και Ε. Καρύμπαλης (2007), "Προσδιορισμός επικινδυνότητας παράκτιων περιοχών από την άνοδο της θαλάσσιας στάθμης με τη χρήση Συστημάτων Γεωγραφικών Πληροφοριών. Οι περιπτώσεις μελέτης του Πόρτο Χελίου και της Ερμιόνης (Πελοπόννησος)", Διπλωματική εργασία, Χαροκόπειο Πανεπιστήμιο, Τμήμα Γεωγραφίας, Πρόγραμμα Μεταπτυχιακών Σπουδών: "Εφαρμοσμένη Γεωγραφία και Διαχείριση του Χώρου".

Στεργίου, Ν. και Ε. Δουκάκης (2003), "Οι επιπτώσεις της ανόδου της στάθμης της θάλασσας στην παράκτια ζώνη των αλυκών Κίτρους Πιερίας", Διπλωματική εργασία, ΕΜΠ, Σχολή Αγρονόμων και Τοπογράφων Μηχανικών, Τομέας Τοπογραφίας.

B. In other languages

Bijlsma, L., C.N. Ehler, R.J.T. Klein, S.M. Kulshrestha, R.F. McLean, N. Mimura, R.J. Nicholls, L.A. Nurse, H. Perez Nieto, R.K. Turner and R.A. Warrick (1996), "Coastal zones and small islands", in Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses, Watson, R.T., M.C. Zinyowera and R.H. Moss (eds), (The Second Assessment Report of the Intergovernmental Panel on Climate Change, Working Group II), Cambridge University Press, Cambridge, 289-324.

Brenner, J., J. Jimenez, R. Sarda and A. Garola (2010), "An assessment of the non-market value of the ecosystem services provided by the Catalan coastal zone, Spain", *Ocean & Coastal Management,* 53, 27-38.

California Energy Commission (CEC) (2009), "The impacts of sea-level rise on the California coast – Final paper", Paper from California Climate Change Center, prepared by: Heberger, M., H. Cooley, P. Herrera, P.H. Gleick and E. Moore, Pacific Institute.

Church J.A, J.M. Gregory, P. Huybrechts, M. Kuhn, K. Lambeck, M.T. Nhuan, D. Qin and P.L. Woodworth (2001), "Changes in Sea Level", in Climate Change 2001: The Scientific Basis, Houghton, J.T. and Y. Ding, (eds), Cambridge University, Press, New York, 639-93.

Daily, G.C. (1997), "Nature's services: Societal dependence on natural ecosystems", Island Press, Washington, DC, 392.

Darwin, R. and R. Tol (2001), "Estimates of the Economic Effects of Sea Level Rise", *Environmental and Resource Economics*, 19, 113-29.

Doukakis, E. (2003), "The potential consequences of climate change on Kotychi lagoon", 8th International Conference on Environmental Science and Technology, Lemnos island.

Doukakis, E. (2004), "Accelerated sea level rise and coastal vulnerability in the Hersonissos coastal region (Crete, Greece)", *Mediterranean Marine Science,* 5, 1, 35-41.

European Commission (2005), "Impact Assessment Guidelines", SEC(2005) 791.

EUROSION (2004), "Living with coastal erosion in Europe", Final report of the project Coastal erosion − evaluation for the need for action, DG Environment, European Commission.

Folke, C., S. Carpenter, T. Elmqvist, L. Gunderson, C.S. Holling and B. Walker (2002), "Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformations", Ambio, 31, 5.

Garpe, K. (2008), "Ecosystem services provisioned by the Baltic Sea and Skagerrak", Swedish Environmental Protection Agency, Stockholm, Report 5873.

Hellenic Republic (2006), "4th National communication to the United Nations framework convention on climate change", Ministry for the Environment, Physical Planning and Public Works, Athens.

IPCC (2001), "Impacts, Adaptation, and Vulnerability, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change", McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken and K.S. White (eds), Cambridge University Press, Cambridge.

IPCC (2007), "Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change", Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds), Cambridge University Press, Cambridge.

IPCC CZMS (1990), "Strategies for Adaptation to Sea Level Rise", Report of the Coastal Zone Management Subgroup, Response Strategies Working Group of the Intergovernmental Panel on Climate Change, Ministry of Transport, Public Works and Water Management, The Hague.

Klein, R.J.T., R.J. Nicholls, S. Ragoonaden, M. Capobianco, J. Aston and E.N. Buckley (2001), "Technological options for adaptation to climate change in coastal zones", *Journal of Coastal Research,* 17, 531-43.

Koch, J. (2010), "Costs of Defending Against Rising Sea Levels and Flooding in Mid-Atlantic Metropolitan Coastal Areas: The Basic Issues", JRAP, 40, 1, 53-60.

Komar, P.D. (1998), "Beach processes and Sedimentation", 2nd edition, Prentice Hall, N.J., USA, 544.

Kontogianni, A. and M. Skourtos (2008), "Social Perception of Risk informing Integrated Coastal Zone Management on accidental oil-spill pollution: the reason you pollute matters, not numbers", in Integrated Coastal Zone Management – The Global Challenge, Krishnamurthy R., B. Glavovic, A. Kannen, D. Green, R. Alagappan, H. Zengcui, S. Tinti and T. Agardy (eds), Research Publishing, 207-25.

Kontogianni, A., G. Luck and M. Skourtos (2010a), "Valuing ecosystem services on the basis of service-providing units: A promising solution to the 'endpoint problem' in stated preference approaches", Ecological Economics, 69, 7, 1479-87.

Kontogianni, A. and Ch. Tourkolias (2010b), "Individual preferences and social values towards renewable energy technologies in Lesvos, Greece", Renewable and Sustainable Energy Reviews (submitted).

Kontogianni, A., Ch. Tourkolias, E. Ritsatakis and A. Machleras (2010c), "Local communities and wind energy. Quantitative and qualitative data exploration through social risk perception and cultural theory", Working Paper, Laboratory of Applied Emvironmental Economics, University of Aegean.

Kontogianni, A., E. Papageorgiou, B. Zannou, D. Castilla, F. Adaman, V. Melikidze, L. Salomatina, E. Papathanassiou and M. Skourtos (2011), "Assessing perceptions of marine environmental futures through Fuzzy Cognitive Mapping – A case study with Mediterranean and Black Sea stakeholders", SESAME, Final Conference, April.

Krestenitis, Y.N., Y.S. Androulidakis, Y.N. Kontos and G. Georgakopoulos (2010), "Coastal inundation in the north-eastern Mediterranean coastal zone due to storm surge events", *Journal of Coastal Conservation*, DOI 10.1007/s11852-010-0090-7.

Llasat, M.C., M. Llasat-Botija, M.A. Prat, F. Porc, C. Price, A. Mugnai, K. Lagouvardos, V. Kotroni, D. Katsanos, S. Michaelides, Y. Yair, K. Savvidou and K. Nicolaides (2010), "High-impact floods and flash floods in Mediterranean countries: the FLASH preliminary database", Adv. Geosci, 23, 1-9.

Meehl, G.A., W.M. Washington, W.D. Collins, J.M. Arblaster, A. Hu, L.E. Buja, W.G. Strand and H. Teng (2005), "How much more global warming and sea-level rise?", *Science*, 307, 1769-72.

Merlo, M. and L. Croitoru (2005), "Valuing Mediterranean Forests: Towards Total Economic Value", CABI International, Wallingford UK/Cambridge MA, 406.

Millennium Ecosystem Assessment (MEA) (2005), "Ecosystems and Human Well-Being: Synthesis", Island Press, Washington, 155.

Ministry of the Environment, Physical Planning and Public Works (2006), "Report of Greece on Coastal Zone Management", submitted to the European Commission/DG Environment, in the context of the recommendation on integrated coastal zone management (2002/413/EC).

Mississippi-Alabama Sea Grant Consortium (MASGC) (2007), "Shoreline Protection Products: Cost Estimates", supported by the National Sea Grant College Program of the U.S. Department of Commerce's National Oceanic and Atmospheric Administration under NOAA, Grant NA06OAR4170078.

Nicholls, R. (2007), *Adaptation Options For Coastal Areas And Infrastructure: An Analysis For 2030*, Report to the UNFCCC, Bonn.

Nicholls, R. (2009), "Adaptation costs for coasts and low-lying settlements", in *Assessing the Costs of Adaptation to Climate Change: A Review of the UNFCCC and Other Recent Estimates*, Parry, M., N. Arnell, P. Berry, D. Dodman, S. Fankhauser,Ch. Hope, S. Kovats, R. Nicholls, D. Satterthwaite, R. Tiffin and T. Wheeler (eds), International Institute for Environment and Development and Grantham Institute for Climate Change, London.

Nicholls, R.J., P.P. Wong, V.R. Burkett, J.O. Codignotto, J.E. Hay, R.F. McLean, S. Ragoonaden and C.D. Woodroffe (2007), "Coastal systems and low-lying areas. Climate Change 2007: Impacts, Adaptation and Vulnerability", Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds), Cambridge University Press, Cambridge, UK, 315-356.

OECD (2006), "Metrics for assessing the economic benefits of climate change policies: Sea level rise", ENV/EPOC/GSP(2006)3/FINAL, Paris.

OECD (2007), "Use of Discount Rates in the Estimation of the Costs of Inaction with Respect to Selected Environmental Concerns", ENV/EPOC/WPNEP(2006)13/FINAL.

Pattanayak, S.K., J.M. Wing, B.M. Depro, G. van Houtven, P. de Civita, D.M. Stieb and B. Hubbel (2002), "International Health Benefits Transfer Application Tool: The Use of PPP and inflation indices", prepared for Economic Analysis and Evaluation Division Health, Canada.

Poulos, S., G. Ghionis and H. Maroukian (2009), "The consequences of a future eustatic sea-level rise on the deltaic coasts of Inner Thermaikos Gulf (Aegean Sea) and Kyparissiakos Gulf (Ionian Sea), Greece", *Geomorphology*, 107, 18-24.

Poulos, S.E. and M.B. Collins (2002), "Fluviatile sediment fluxes to the Mediterranean: Aquantitative approach and the influence of dams", *Geological Society of America Bulletin,* 191, 227-45.

Richards, J. and R. Nicholls (2009), "Impacts of climate change in coastal systems in Europe", PESETA-Coastal Systems study, European Commission Joint Research Centre Institute for Prospective Technological Studies, Scientific-Technical report.

Scottish Natural Heritage (SNH) (2000), "A guide to managing coastal erosion in beach/dune systems", Report prepared by H.R. Wallingford.

Sorensen, R., R. Weisman and G. Lennon (1984), "Chapter 6 Control of Erosion, Inundation, and Salinity Intrusion Caused by Sea Level Rise", in *Greenhouse Effect and Sea Level Rise: A Challenge for This Generation,* Barth, M.C. and J.G. Titus (eds), Van Nostrand Reinhold Company, 179-214.

Sonderquist, T. and L. Hasselstroom (2008), "The economic value of ecosystem services provided by the Baltic Sea and Skagerrak. Existing information and gaps of knowledge", Swedish Environmental Protection Agency.

Tibbetts, J. (2002), "Coastal Cities: Living on the Edge", Environ Health Perspect, 110, 674-81.

Turner, R.K., I.J. Bateman and W.N. Adger (2001), "Economics of Coastal and Water Resources: Valuing Environmental Functions", Dordrech: Kluwer Academic Publishers.

Velegrakis, A.F. (2010), "Coastal systems", unpublished paper, Department of Marine Sciences, University of Aegean.

Velegrakis, A.F., M. Vousdoukas, O. Andreadis, E. Pasakalidou, G. Adamakis and R. Meligonitis (2008), "Impacts of dams on their downstream beaches: A case study from Eresos coastal basin, Island of Lesvos, Greece", *Marine Georesources and Geotechnology,* 26, 350-71.

Vött, A. (2007), "Relative sea level changes and regional tectonic evolution of seven coastal areas in NW Greece since the mid-Holocene", *Quaternary Science Reviews,* 26, 894-919.

Wigley, T.M.L. (1995), “Global-Mean Temperature and Sea Level Consequences of Greenhouse Gas Concentration Stabilization”, Geophysical Research Letters, 22, 45-8.

2.3 Fisheries and aquaculture

A. In Greek

Εθνική Στατιστική Υπηρεσία της Ελλάδος (2009), “Θαλάσσια αλιεία με μηχανοκίνητα σκάφη. Στατιστικές πρωτογενούς τομέα”, Πειραιάς.

Ελληνικό Κέντρο Βιοτόπων-Υγροτόπων, ΕΚΒΥ (2010), “Η βιοποικιλότητα της Ελλάδας: κατάσταση και τάσεις”, τελική έκθεση τομέα βιοποικιλίας, Επιτροπή μελέτης επιπτώσεων κλιματικής αλλαγής.

Παπουτσόγλου, Σ. Ε. (1981, 1990), “Το υδάτινο περιβάλλον και οι οργανισμοί του”, Εκδόσεις Καραμπερόπουλος-Σταμούλης, Αθήνα.

Παπουτσόγλου, Σ. Ε. (1997), “Εισαγωγή στις Υδατοκαλλιέργειες”, Εκδόσεις Σταμούλης, Αθήνα.

Παπουτσόγλου, Σ. Ε. (2004), “Κατασκευές Υδατοκαλλιεργειών”, Εκδόσεις Σταμούλης, Αθήνα.

Υπουργείο Αγροτικής Ανάπτυξης και Τροφίμων. Διεύθυνση Υδατοκαλλιεργειών και Εσωτερικών Υδάτων. Γενική Διεύθυνση Αλιείας. Στοιχεία Παραγωγής Υδατοκαλλιεργειών (περιόδου 1986-2005), Εσωτερικά νερά – πέστροφα, κυπρίνος, σολομός, χέλι-λοιπά είδη.

B. In other languages

Allison, E. H., A. L. Perry, M-C. Badjeck, W.N. Adger, N.L. Andrew, K. Brown, D. A. Coway, G. M. Halls Pilling, J.D. Reynolds and N.K. Dulvy (2009), “Vulnerability of National Economies to Potential Impacts of Climate Change on Fisheries”, Fish and Fisheries, Climate Change: Research to Meet the Challenges Facing Fisheries and Aquaculture, World Fish Centre, Vol. 10, 173-96.

Anagnostou, Ch., G.Chronis, A. Sioulas, A. P. Karagiorgis and Ch.Tziavos (2005), “Morphodynamics and Changes of the Coastlines of Hellas”, State of the Hellenic Marine Environment, Hellenic Centre for Marine Research, Institute of Oceanography.

Bobori, D. C. and P. S.Economidis (2006), “Freshwater Fishes of Greece: Their Biodiversity, Fisheries and Habitats”, Taylor & Francis, *Aquatic Ecosystem Health & Management* Vol. 9 (4), 407-18.

Brower, R. (2000), “Environmental value transfer: state of the art and future prospects”, *Ecological Economics*, 32,137-52.

Cochrane, K., C. De Young, D. Soto and T. Bahri (2009), “Climate Change Implications for Fisheries and Aquaculture: Overview of Current Scientific Knowledge”, FAO Fisheries and Aquaculture Technical Paper, No. 530.

Dassenakis, M., E. Krasakopoulou and B. Matzara (1994), “Chemical Characteristics of Aetoliko Lagoon, Greece, After an Ecological Shock”, Pergamon, *Marine Pollution Bulletin,* No. 7, Vol. 28, 427-33.

Daw, T., N. Adger, K. Brown and M-C. Badjeck (2009), “Climate Change and Capture Fisheries”, in Cochrane, K., C. De Young, D. Soto and Bahri (eds) *Climate Change Implications for Fisheries and Aquaculture: Overview of Current Scientific Knowledge,* FAO Fisheries and Aquaculture Technical Paper, Vol. 530, 95-135. FAO: Rome.

D´Orbcastel, E. R., J. P. Blancheton and J. Aubin (2008), “Towards Environmentally Sustainable aquaculture: Comparison between Two Trout Farming Systems Using Life Cycle Assessment”, *Aquacultural Engineering*, Elsevier, Vol. 40, 113-9.

Doukakis, E. (2004), “Accelerated Sea Level Rise and Coastal Vulnerability in the Hersonisos Coastal Region (Crete, Greece)”, *Mediterranean Marine Science*, Hellenic Centre for Marine Research, No. 1, Vol. 5, June.

Egger and Olsson (2009), “Valuing multi-attribute marine water quality”, *Marine Policy*, 33, 201-6.

ELNAIS-Ellenic Network on Aquatic Invasive Species. version (10/2010) https://services.ath.hcmr.gr

European Commission (2008), “Protecting and Harnessing the Seas”, Environment for Europeans, Magazine of the Directorate-General for the Environment, Supplement 2008, No. 32.

FAO (1995), “Code of conduct for responsible fisheries”, Rome, 41 p.

FAO (2003-2011), "Fisheries and Aquaculture topics. Ecosystems. Topics Fact Sheets", in FAO Fisheries and Aquaculture Department [on line]. Rome. Updated (cited 3 March 2011) http://www.fao.org/fishery/topic/13789/en

FAO (2008), "Report of the FAO Expert Workshop on Climate Change Implications for Fisheries and Aquaculture", Rome, Italy, 7-9 April, FAO Fisheries Report No. 870.

Flemming, N.C. and P.L. Woodworth (1988), "Monthly Mean Sea Levels in Greece During 1969-1983 Compared to Relative Vertical Land Movements Measured over Different Timescales", *Tectonophisics*, Elsevier Science Publishers B.V., Amsterdam, Vol. 148, 59-72.

Iliopoulou-Goergudaki, J., V. Kantzaris, P. Katharios, P. Kaspiris, Th. Georgiadis and B. Montesantou (2003), "An Application of Different Bioindicators for Assessing Water Quality: A Case Study in the Rivers Alfeios and Pineios (Peloponnesus, Greece)", *Ecological Indicators,* Vol. 2, 345-60.

Kagalou, I., E. Papastergiadou and I. Leonardos (2008), "Long Term Changes in the Eutrophication Process in a Shallow Mediterranean Lake Ecosystem of W. Greece: Response After the Reduction of External Load", *Journal of Environmental Management,* Vol. 87, 495-506.

Kavadas, S., G. Bazigos, K. Papaconstantinou and A. Economou (2007), "Fisheries Statistics in Hellas: Data Collection and Processing", State of the Hellenic Fisheries, Hellenic Centre for Marine Research, Institute of Marine Biological Resources.

Konstantinou, I. K., D.G. Hela and T. A. Albanis (2006), "The Status of Pesticide Pollution Surface Waters (Rivers and Lakes) of Greece. Part I. Review on Occurrence and Levels", *Environmental Pollution,* Vol. 141, 555-70.

Markou, D. A., G. K. Sylaios, V. A. Tsihrintzis, G. D. Gikas and K. Haralambidou (2007), "Water Quality of Vistonis Lagoon, Northern Greece: Seasonal Variation and Impact of Bottom Sediments", *Desalination,* Vol. 210, 83-97.

Mavrakis, A., S. Lykousis and G. Theoharatos (2004), "Delimitation of the Warm and Cold Period of the Year Based on the Variation of the Aegean Sea Surface Temperature", Mediterranean Marine Science, Hellenic Centre For Marine Research, No. 1, Vol. 5, June.

Mitraki, C., T. L. Crisman and G. Zalidis (2004), "Lake Koronia, Greece: Shift from Autotrophy to Heterotrophy with Cultural Eutrophication and Progressive Water-Level Reduction", *Limnologica,* Vol. 34, 110-6.

Navrud, S. (2006), "International benefit transfer: Methods and validity tests", *Ecological Economics,* 60, 429-34.

Navrud, S. and R. Ready (eds) (2007), "Environmental Value Transfer: Issues and Methods", Springer, The Netherlands.

Pagou, K. (2005), "Eutrophication in the Hellenic Coastal Areas", State of the Hellenic Marine Environment, Hellenic Centre for Marine Research, Institute of Oceanography.

Pancucci-Papadopoulou, M. A., K. Kevrekidis, M. Corsini-Foka and N. Simboura (2005), "Changes in Species: Invasion of Exotic Species", State of the Hellenic Marine Environment, Hellenic Centre for Marine Research, Institute of Oceanography.

Papoutsoglou, S.E. (1991), "Impact of Aquaculture on the Aquatic Environment in Relation to Applied Production Systems", European Aquaculture Society Special Publication, No. 16 (Gent, Belgium).

Papoutsoglou, S.E. and G. Tsiha (1994), "Effects of Water Pollution Caused by Organic Material on Gilthead Sea Bream (Sparus aurata) and European Sea Bass (Dicentrarchus labrax) Physiology", *Animal Science Review*, Vol. 20, 56-64.

Papoutsoglou, S. E. (1996), "Role of Management in Achievement of Aquaculture's Production Systems Aims" (Heggberg, T. G., ed.), Proceeding of World Fisheries Congress, Theme 6, 116-20.

Papoutsoglou, S. E., M. J. Costello, E. Stamou and G. Tziha (1996), "Environmental Conditions at Sea-Cages, and Ectoparasites on Farmed European Sea Bass, Dicentrarchus Labrax, and Gilt-Head Sea Bream, Sparus Aurata, at Two Farms in Greece", *Aquaculture Research*, Vol. 27, 25-34.

Ready, R. and S. Navrud (2006), "International benefit transfer: Methods and validity tests", *Ecological Economics,* 60: 429-34.

Remoundou, K., F. Adaman, P. Koundouri and P. A. L. D. Nunes (2010), "Are Stated Preferences Sensitive to Funding Sources? A Tax Reallocation Scheme to Value Marine Restoration in the Black Sea", Working Paper.

Skoulikidis, N. Th. (2009), "The Environmental State of Rivers in the Balkans – A Review within the DPSIR Framework", Science of the Total Environment, Vol. 407, 2501-16.

Vieira, S., P. Newton and ABARE (2008), "Preparing Australian Fisheries and Aquaculture to Adapt to the Potential Impacts of Climate Change", Gernaut Climate Change Review.

2.4 The impacts of climate change on agriculture

A. In Greek

Βολουδάκης, Δ., Β. Κωτούλας, Γ. Οικονόμου και Α. Καραμάνος. "Πειραματικά δεδομένα ελλειμματικής άρδευσης σε καλλιέργεια αραβοσίτου", αδημοσίευτα στοιχεία.

Γιάσογλου, Ν. και Κ. Κοσμάς (2004), "Η ερημοποίηση στην Ελλάδα", Εθνική Επιτροπή κατά της Ερημοποίησης, Υπουργείο Αγροτικής Ανάπτυξης και Τροφίμων.

Καλύβας, Δ., "Επεξεργασία δεδομένων ερημοποίησης ανά κλιματική ζώνη με τη χρήση GIS", αδημοσίευτα στοιχεία.

Κωτούλας, Β. (2010), "Μελέτη της επίδρασης της ελλειμματικής άρδευσης στην καλλιέργεια βαμβακιού Gossypium hirsutum L., cv Celia", διδακτορική διατριβή, Αθήνα, Γεωπονικό Πανεπιστήμιο.

Παπαναγιώτου, Ε. (2005), "Οικονομική Παραγωγής Γεωργικών Προϊόντων", Β΄ Έκδοση, Εκδόσεις Γράφημα, Θεσσαλονίκη.

Πέζαρος, Π. (2004), "Σύντομη Επισκόπηση της Ελληνικής Γεωργίας", Ιστοσελίδα: http://www.minagric.gr/greek/agro_pol/works.htm

ΥΠΕΧΩΔΕ (2007), "Εκτίμηση των πιθανών επιπτώσεων στην Ελλάδα από την κλιματική αλλαγή".

ΥΠΑΑΤ (2010), "Διεύθυνση Αγροτικής Πολιτικής και Τεκμηρίωσης", ιστοσελίδα: http://www.minagric.gr/greek/agro_pol/3.htm

Ζερεφός, Χ., Γ. Τσελιούδης και Κ. Δουβής, "Κλιματικά δεδομένα για τις δεκαετίες 1991-2000, 2041-2050, 2091-2100 ανά κλιματική ζώνη", Κέντρο Φυσικής της Ατμόσφαιρας, αδημοσίευτα στοιχεία για την Επιτροπή Μελέτης Επιπτώσεων Κλιματικής Αλλαγής, Τράπεζα της Ελλάδος.

B. In other languages

Alexandrov, V.A. and G. Hoogenboom (2000),"The impact of climate variability and change on crop yield in Bulgaria", *Agricultural and Forest Meteorology*, 104, 315-27.

Bindi, M., L. Fibbi, and F. Miglietta (2001), "Free Air CO_2 Enrichment (FACE) of grapevine (Vitis vinifera L.): Growth and quality of grape and wine in response to elevated CO_2 concentrations", *European Journal of Agronomy,* 14, 145-55.

Chartzoulakis, K. and G. Psarras (2005), "Global change effects on crop photosynthesis and production in Mediterranean: the case of Crete, Greece", *Agriculture, Ecosystems and Environment,* 106, 147-57.

Copenhagen Diagnosis (2009), "Updating the World on the Latest Climate Science", Allison, I., N. L. Bindoff, R.A. Bindschadler, P.M. Cox, N. de Noblet, M.H. England, J.E. Francis, N. Gruber, A.M. Haywood, D.J. Karoly, G. Kaser, C. Le Quéré, T.M. Lenton, M.E. Mann, B.I. McNeil, A.J. Pitman, S. Rahmstorf, E. Rignot, H.J. Schellnhuber, S.H. Schneider, S.C. Sherwood, R.C.J. Somerville, K.Steffen, E.J. Steig, M. Visbeck and A.J. Weaver, The University of New South Wales Climate Change Research Centre (CCRC), Sydney, Australia, 60pp.

Doorenboos, J. and A.H. Kassam (1979), "Yield response to Water", Irrigation & Drainage Paper No. 33, FAO Rome Italy, 193 pp.

European Environmental Agency (EEA) (2008), “Impacts of Europe’s Changing Climate – 2008 Indicator-based Assessment”, Joint EEAJRC-WHO report, EEA Report No. 4/2008, JRC Reference Report No. JRC47756, European Environment Agency.

European Commission (EC) (2009), “The Role of European Agriculture in Climate Change Mitigation”, SEC 1093 final Commission Staff Working Document.

Food & Agricultural Organization of the United Nations (FAO) (2009),”The State of Food Insecurity in the World: Economic Crises: Impacts & Lessons Learned”, Electronic Publishing Policy & Support Branch Communication Division, FAO.

Garnaut Climate Change Review (2008), “Viticulture, wine and climate change”, 5-12.

Geerts, S. and D. Raes (2009), “Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas”, *Agricultural Water Management,* 96, 1275-84.

Giannakopoulos, C., P. Le Sager, M. Bindi, M. Moriondo, E. Kostopoulou and C.M. Goodess (2009), “Climatic changes & associated impacts in the Mediterranean resulting from a 2 °C global warming”, *Global and Planetary Change*, 68, 209-24.

Gutierrez, A.P., L. Ponti and Q.A. Cossu (2009),”Effects of climate warming on olive and olive fly (Bactrocera oleae Gmelin) in California and Italy”, *Climatic Change*, 95, 195-217.

Hansen, J.W., A. Challinor, A.M. Ines, T. Wheeler, and V. Moron (2006), “Translating climate forecasts into agricultural terms: advances and challenges”, *Climate Research*, 33, 27-41.

Intergovernmental Panel on Climate Change (IPCC) (2007a), “Climate Change: Impacts, Adaptation & Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change”, Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC) (2007b),”Summary for Policymakers in: Climate Change 2007: The Physical Science Basis”, Cambridge University Press.

Kapetanaki, G. and C. Rosenzweig (1997),”Impact of climate change on maize yield in central and northern Greece: a simulation study with ceres-maize”, Mitigation and Adaptation Strategies for Global Change, 1, 251-71.

Karamanos, A. (2009), “Possible effects of climate change on crop-weed interactions”, 2nd International Conference on “Novel and sustainable weed management in arid and semi-arid agro-ecosystems”, Santorini, Greece, www.ewrs.org/arid/Santorini.asp

Karamanos, A., G. Economou, G. Livanos and A. Papastavrou (2008), “Evaluating Yield Responses to Water Stress and Drought Resistance Mechanisms of 20 Local Bread and Durum Wheat Landraces”, Agricultural University of Athens, 197.

Kimball, B. A., S. B. Idso, S. Johnson and M. C. Rillig (2007), “Seventeen years of carbon dioxide enrichment of sour orange trees: final results”, *Global Change Biology*, 13, 2171-83.

Kimball, B.A. and S.B. Idso (2001), “CO_2 enrichment of sour orange trees: 13 years and counting”, *Environmental and Experimental Botany*, 46, 147-53.

Kimball, B.A., K. Kobayashi and M. Bindi (2002), “Responses of agricultural crops to free-air CO_2 enrichment”, *Advances in Agronomy,* 77, 293-368.

Li, A.-G.,Y.-S. Hou, G.W. Wall, A. Trent, B.A. Kimball and P.J. Pinter Jr. (2000), “Free-air CO_2 enrichment and drought stress effects on grain filling rate and duration in spring wheat”, *Crop Science,* 40, 1263-70.

Lobell, D.B., M.B. Burke, C. Tebaldi, M.D. Mastrandrea, W.P. Falcon and R.L. Naylor (2008), “Prioritizing climate change adaptation needs for food security in 2030”, *Science*, 319, 607-10.

McKeon, G. and W. Hall (2000), “Learning from history: preventing land and pasture degradation under climate change”, Final Report to the Australian Greenhouse Office. Queensland Department of Natural Resources and Mines, Brisbane, Australia. www.longpaddock.qld.gov.au/AboutUs/Publications/ByType/Reports/LearningFromHistory

Mendelsohn, R. (2007), “Handbook of Agricultural Economics Volume 3”, Agricultural Development: Farmers, Farm Production & Farm Markets.

Mendelsohn R. and A. Dinar (2009), “Climate Change and Agriculture: An Economic Analysis of Global Impacts, Adaptation and Distributional Effects”, Edward Elgar, Cheltenham, UK.

Moretti, C.L., L.M. Mattos, A.G. Calbo and S.A. Sargent (2010), “Climate changes and potential impacts on postharvest quality of fruit and vegetable crops: A review”, *Food Research International,* 43, 1824-32.

Moriondo, M., F.M. Stefanini and M. Bindi (2008), “Reproduction of olive tree habitat suitability for global change impact assessment”, *Ecological Modelling,* 218, 95-109.

Mortensen, L.M. (1994) “Effects of elevated CO2 concentrations on growth and yield of eight vegetable species in a cool climate”, *Scientia Horticulturae,* 58, 177-85.

OECD (2010), “Climate Change and Agriculture: Impacts, Adaptation and Mitigation”, OECD publications.

Olesen, J. and M. Bindi (2002), “Consequences of climate change for European agricultural productivity, land use & policy”, European Journal of Agronomy, 16, 239–262.

Orduna, R.M. (2010), “Climate change associated effects on grape and wine quality and production”. Research International, 43, 1844–55.

Orlandini, S., M. Bindi and M. Howden (2009), “Plant biometeorology & adaptation” (K.L. Ebi et al. (eds.) Biometeorology for Adaptation to Climate Variability & Change 1, 107-29.

Paeth, H., A. Capo-Chichi and W. Endlicher, (2008), “Climate change & food security in tropical West-Africa: a dynamic-statistical modelling approach”, Erdkunde 62, 101-15.

Parry, M.L., N.W. Arnell, A.J. McMichael, R.J. Nicholls, P. Martens, R.S. Kovats, M.T.J. Livermore, C. Rosenzweig, A. Iglesias and G. Fischer (2001), “Millions at risk: defining critical climate change threats & targets”, Global Environmental Change, 11, 181–83.

Pleijel, H., J. Gelang, E. Sild, H. Danielsson, S.Younis, P.-E. Karlsson, G. Wallin, L. Skarby and G. Sellden (2000), “Effects of elevated carbon dioxide, ozone and water availability on spring wheat growth and yield”, Physiologia Plantarum 108, 61-70.

Raes, D., P. Steduto, T.C Hsiao and E. Fereres (2009) “AquaCrop-The FAO Crop Model to Simulate Yield Response to Water II: Main Algorithms & Software Description”, Agronomy Journal, 101, 438-47.

Soussana, J.S., A.I. Graux, and N.F. Tubiello (2010), “Improving the use of modeling for projections of climate change impacts on crop & pastures”, Journal of Experimental Botany 61, 2217-28.

Stern, N. (2007), “The Economics of Climate Change: The Stern Review”, Cambridge University Press, Cambridge.

Taub, D. (2010), “Effects of Rising Atmospheric Concentrations of Carbon Dioxide on Plants”. Nature Education Knowledge, 1, 21.

Tsiros, E., C. Domenikiotis, and N. Dalezios (2009), “Sustainable production zoning for agroclimatic classification using GIS and remote sensing”, Symposium on Climate Change and Variability - Agrometeorological Monitoring and Coping Strategies for Agriculture, Oscarsborg, http://www.cost734.eu/reports-and-presentations/6th-management-committee-meeting-in-oscarsborg/abstract_oscarsborg.pdf.

Tubiello, F.N., Soussana, J.F., Howden, M.,& Eaterling, W. (2007), “Fundamental advances in the understanding of crop and pasture response to climate change”. Proceed. Nat. Acad. Sciences, Accepted.

Tubiello, F.N., J.F. Soussana and M.S. Howden, (2007), “Crop and pasture response to climate change”. Proceedings of the National Academy of Sciences, USA 104, 19686–90.

United Nations Framework Convention on Climate Change (UNFCCC) (2007), “Climate Change: Impacts, Vulnerabilities & Adaptation In Developing Countries”, http://unfccc.int/resource/docs/publications/impacts.pdf.

Ventrella, D., L. Giglio, M. Rinaldi, M. Moriondo and M. Bindi (2008), “Vulnerability of some herbaceous crops to climate change in Southern Italy”. Italian Journal of Agronomy, 3, 723-724.

2.5 The impacts of climate change on forest ecosystems in the 21st century

A. In Greek

Γκουρμπάτσης, Α. (2010), "Η γεωγραφία αγροτοδασικών πυρκαγιών", (2000-2010). http://olympia.gr/2010/08/05/.

Διεύθυνση Δασών Πέλλας (2010), "Έγκριση πρακτικών δημοπρασίας απόληψης δασικών προϊόντων από τα συν/τα δάση κεδρώνας, λύκων & πατήματος", Ελληνική Δημοκρατία, Περιφέρεια Κεντρικής Μακεδονίας, Γενική Διεύθυνση Περιφέρειας, Διεύθυνση Δασών Πέλλας, Αρ. Πρωτ. 2919.

ΕΣΥΕ (2007), "Παραγωγή και πώληση βιομηχανικών προϊόντων (ετήσια έρευνα) - στατιστικές δευτερογενούς τομέα prodcom", Αθήνα.

ΕΣΥΕ (2009), "Εξωτερικό εμπόριο της Ελλάδος", τεύχος β′, Αθήνα.

Ζαφειρίου, Ε., Θ. Κουτρουμανίδης, Γ. Αραμπατζής και Σ. Σοφιός (2007), "Μηχανισμός μεταβίβασης τιμών στον τομέα του ξύλου: Μια εμπειρική προσέγγιση. Ελληνικό Στατιστικό Ινστιτούτο", Πρακτικά 20ού Πανελλήνιου Συνεδρίου Στατιστικής, 191-200.

Ζερεφός, Χ. (2009), "Αναφορά προόδου ομάδας κλίματος", Επιτροπή μελέτης επιπτώσεων κλιματικής αλλαγής, Νοέμβριος.

Παπαναστάσης, Β.Π. (1982), "Παραγωγή των ποολίβαδων σε σχέση με τη θερμοκρασία αέρος και τη βροχή στη βόρεια Ελλάδα", Διατριβή για Υφηγεσία, Θεσσαλονίκη.

Τορορής, Α. (1994), "Προεδρικό Διάταγμα 126/1986". Πρακτικά συνάντησης Ελληνικής Δασολογικής Εταιρείας, 29-43, Θεσσαλονίκη.

Υπουργείο Περιβάλλοντος, Ενέργειας και Κλιματικής Αλλαγής (2010), "Απολογισμός δραστηριοτήτων δασικών υπηρεσιών έτους 2008", Αθήνα.

B. In other languages

Arora, V.K. and G.J. Boer (2001), "Effects of simulated climate change on the hydrology of major river basins", *Journal of Geophysical Research,* 106, 3335-48.

Bindoff, N.L., J. Willebrand, V.Artale, A. Cazenave, J. Gregory, S. Gulev, K. Hanawa, C. Le Quéré, S. Levitus, Y. Nojiri, C.K. Shum, L.D. Talley and A. Unnikrishnan (2007), "Observations: Oceanic Climate Change and Sea Level", in Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds) "Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change", Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Bou-Zeid and E. M. El-Fadel (2002), "Climate change and water resources in Lebanon and the Middle East", *Journal of Water Resources Planning and Management,* 128, 343-55.

California Economic Strategy Panel (2002), "Using multipliers to measure economic impacts".

Carvalho, A., M.D. Flannigan, K.A. Logan, L.M. Gowman, A.I. Miranda and C. Borrego (2010), "The impact of spatial resolution on area burned and fire occurrence projections in Portugal under climate change", Climate Change 98, 177-97.

Chmielewski, F.-M. and T. Rötzer (2001), "Response of tree phenology to climate change across Europe", *Agricultural and Forest Meteorology,* 108, 101-12.

Dasgupta, P. (2007), "The stern review's economics of climate change", *National Institute Economic Review,* 199, 4.

Day, J.W. Jr., D. Pont, P.E. Hensel and C.Ibañez (1995), "Impacts of sea-level rise on Deltas in the Gulf of Mexico and the Mediterranean: The importance of pulsing events to sustainability", *Estuaries*, 18, 636-47.

De Dios, V. R., C. Fischer and C. Colinas (2007), "Climate change effects on Mediterranean forests and preventive measures", *New Forests*, 33, 29-40.

FAO (2003), "State of the World's Forests 2003", United Nations Food and Agricultural Organization. Rome, Italy.

Flannigan, M.D., B.J. Stocks and B.M. Wotton (2000), "Climate change and forest fires", *The Science of the Total Environment,* 262: 221-29.

Forestry Commission of Europe (2000), "English forestry contribution to rural economies".

Founda, D.and C. Giannakopoulos (2007), "The exceptionally hot summer of 2007 in Athens, Greece – A typical summer in the future climate?", *Global and Planetary Change,* 67, 227-36.

Giannakopoulos, C., M, Bindi, M. Moriondo, P. Lesager and T. Tin (2005), "Climate change impacts in the Mediterranean resulting from a 2 °C global temperature rise", WWF report, Gland Switzerland, Accessed, 1, 2006.

Giannakopoulos, C., D. Founda and C. Zerefos (2007), "Estimating present and future fire risk in Greece: Links with the destructive fires of summer 2007", National Observatory of Athens, Athens, Greece.

Giannakopoulos, C., P. Le Sager, M. Bindi, M. Moriondo, E. Kostopoulou and C. M. Goodes (2009), "Climatic changes and associated impacts in the Mediterranean resulting from a 2 °C global warming", *Global and Planetary change* (in press), doi:10.1016/j.gloplacha.2009.06.001

Griffiths, A. (2002), "Indigenous forestry on private land: Present trends and future potential. MAF", Technical Paper No 01/6, Prepared for the Indigenous Forestry Unit, Ministry of Agriculture and Forestry, New Zealand.

Johnsen, K., L. Samuelson, R. Teskey, S. MvNulty and T. Fox (2001), "Process models as tools in forestry research and management", *Forest Science*, 47, 2-8.

Le Houérou H.L. 1996. "Climate change, drought and desertification", *Journal of Arid Environments,* 34, 133-85.

Moriondo, M., P. Good, R. Durao, M. Bindi, C. Gianakopoulos and J. Corte-Real (2006), "Potential impact of climate change on fire risk in the Mediterranean area", *Climate Research,* 31, 85-95.

Mouillot, F., S. Rambal and R. Joffre (2002), "Simulating climate change impacts on fire frequency and vegetation dynamics in a Mediterranean-type ecosystem", Global Change Biology, 8, 423-37.

Newell, R.G. and W.A. Pizer (2003), "Discounting the distant future: How much do uncertain rates increase valuations?", *Journal of Environmental Economics and Management*, 46, 52-71.

Nicholls, R. (2004), "Coastal flooding and wetland loss in the 21st century: Changes under the stress climate and socio-economic scenarios", *Global Environmental Change,* 14, 69-86.

Nicholls, R., F. Hoozemans and M. Marchand (1999), "Increasing flood risk and wetland losses due to global sea-level rise: Regional and global analyses", *Global Environmental Change*, 9, S69-S87.

Nicholls, R.J. and R.J.T. Klein (2005), "Climate change and coastal management on Europe's coast", in Vermaat J.E. et al. (eds) *Managing European coasts: Past, present and Future*, Springer-Verlag Berlin, 199-225.

Nordhaus, W. (2007a), "Economics: Critical assumptions in the Stern review on climate change", *Science*, 317, 5835: 201.

Nordhaus, W. (2007b), "A review of the Stern review on the economics of climate change", *Journal of Economic Literature*, 45, 686-702.

öKo Inc. (2001), "Agricultural Water Management Policies in Bulgaria, Hungary, Romania and Slovakia", Final Report, oKo Inc., Budapest, in Easter K. and Yang Liu (eds) *Cost Recovery and Water Pricing for Irrigation and Drainage Projects, Agriculture and Rural Development* Discussion Paper 26 (2005), The International Bank for Reconstruction and Development/The World Bank, Washington, DC.

Rahmstorf, S. (2007), "Sea-Level Rise: A semi-Empirical Approach to Projecting Future", *Science,* 315, 368–70.

Rutty, M.K. (2009), "Will the Mediterranean become "too hot" for tourists? A reassessment", Ph.D. Thesis, University of Waterloo, Ontario, Canada.

Schelhaas, M.J., G. Hengeveld, M. Moriondo, G.J. Reinds, Z.W. Kundzewicz, H. ter Maat and M. Bindi (2010), "Assessing risk and adaptation options to fires and windstorms in European forestry" (in press), doi: 10.1007/s11027-010-9243-0.

Sohngen, B. and R. Sedjo (2005), "Impacts of climate change on forest product markets: Implications for North American producers", *Forestry Chronicle,* 81, 669-74.

Stern, N. (2008), "The economics of climate change", *American Economic Review,* 98, 1-37.

Stern, N., S. Peters, V. Bakhshi, A. Bowen, C. Cameron, S. Catovsky and D. Crane (2006), "Stern review: The economics of climate change".

Stern, N. and G. Treasury (2007), "The economics of climate change: The Stern review", Cambridge Univ. Pr.

Thorpe, T. (1998), "Investment in indigenous forestry", *New Zealand Journal of Forestry*, 43, No 2.

Torn, M.S., E. Mills and J.S. Fried (1999), "Will climate change spark more wildfire damages", California: Lawrence Berkeley National Laboratory.

Varian, H. (2006), "Recalculating the costs of global climate change", The New York Times.

Weitzman, M. (2007), "A review of the Stern review on the economics of climate change", *Journal of Economic Literature,* 45, 703-24.

2.6 Biodiversity and ecosystems

A. In Greek

Δουλγέρης, Χ. και Δ. Παπαδήμος (2010), "Επιδράσεις της κλιματικής αλλαγής σε υγροτόπους της Ελλάδας", Ελληνικό Κέντρο Βιοτόπων-Υγροτόπων, αδημοσίευτα δεδομένα.

Ελληνικό Κέντρο Βιοτόπων-Υγροτόπων (ΕΚΒΥ) (2010), "Η βιοποικιλότητα της Ελλάδας: κατάσταση και τάσεις".

Ευρωπαϊκή Επιτροπή (2007), "Η προσαρμογή της Ευρώπης στην αλλαγή του κλίματος – επιλογές δράσης για την ΕΕ", Πράσινη Βίβλος που υποβάλλεται από την Επιτροπή προς το Συμβούλιο, το Ευρωπαϊκό Κοινοβούλιο, την Ευρωπαϊκή Οικονομική και Κοινωνική Επιτροπή και την Επιτροπή των Περιφερειών, COM (2007) 354 τελικό.

Ντάφης, Σ., Ε. Παπαστεργιάδου, Κ. Γεωργίου, Δ. Μπαμπαλώνας, Θ. Γεωργιάδης, Μ. Παπαγεωργίου, Θ. Λαζαρίδου και Β. Τσιαούση (1997), "Οδηγία 92/43/ΕΟΚ. Το Έργο Οικοτόπων στην Ελλάδα: Δίκτυο ΦΥΣΗ 2000", Συμβόλαιο αριθμός B4-3200/94/756, Γεν. Διεύθυνση XI, Επιτροπή Ευρωπαϊκών Κοινοτήτων, Μουσείο Γουλανδρή Φυσικής Ιστορίας – Ελληνικό Κέντρο Βιοτόπων-Υγροτόπων.

Οικονομίδης, Π.Σ. (2009), "Ψάρια Εσωτερικών Υδάτων", στο Λεγάκις, Α. και Π. Μαραγκού (επιμ.), *Το Κόκκινο Βιβλίο των Απειλούμενων Ζώων της Ελλάδας*, Ελληνική Ζωολογική Εταιρεία, Αθήνα.

B. In other languages

Alcamo, J., J.M. Moreno, B. Nováky, M. Bindi, R. Corobov, R.J.N. Devoy, C. Giannakopoulos, E. Martin, J.E. Olesen and A. Shvidenko (2007), "Europe. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change", in Parry M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds), Cambridge University Press, Cambridge, UK, 541-80.

Alvarez Cobelas, M., J. Catalán and D. García de Jalon (2005), "Impactos sobre los ecosistemas acuáticos continentales. Evaluación Preliminer des los impactos en España por Efecto del Cambio Climático", in Moreno, J. M. (ed.), Ministerio de Medio Ambiente, Madrid, 113-46.

Araújo, M.B., W. Thuiller and R.G. Pearson (2006), "Climate warming and the decline of amphibians and reptiles in Europe", *Journal of Biogeography* 33, 1712-28.

Berry, P.M., A.P. Jones, R.J. Nicholls and C.C. Vos (eds) (2007), "Assessment of the vulnerability of terrestrial and coastal habitats and species in Europe to climate change, Annex 2 of Planning for biodiversity in a changing climate – BRANCH project Final Report", Natural England, UK.

Bianchi, C.N. and C. Morri (2000), “Marine Biodiversity of the Mediterranean Sea: Situation, Problems and Prospects for Future Research”, *Marine Pollution Bulletin,* 40, 5, 367-76.

Bombace, G. (2001), “Influence of climatic changes on stocks, fish species and marine ecosystems in the Mediterranean Sea”, *Archives of Oceanography and Limnology,* 22, 67-72.

Brenner-Guillermo, J. (2007), “Valuation of ecosystem services in the Catalan coastal zone”, Marine Sciences, Polytechnic University of Catalonia.

Campbell, A., V. Kapos, J. P.W. Scharlemann, P. Bubb, A. Chenery, L. Coad, B. Dickson, N. Doswald, M. S. I. Khan, F. Kershaw and M. Rashid (2009), “Review of the Literature on the Links between Biodiversity and Climate Change: Impacts, Adaptation and Mitigation”, Secretariat of the Convention on Biological Diversity, Montreal, Technical Series No. 42.

Costanza, R., R. d’Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O’Neill, J. Paruel, R.G. Raskin, P. Sutton and M. van den Belt (1997), “The value of the world’s ecosystem service and natural capital”, *Nature*, 387, 253-60.

Croitoru, L. and M. Merlo (2005), “Mediterranean forest values”, in M. Merlo and L. Croitorou (eds) *Mediterranean forests and people: Towards a total economic value,* CABI Publishing, Wallingford, Chapter 3, 105-22.

Dimitriou, E. and E. Moussoulis (2010), “Hydrological and nitrogen distributed catchment modeling to assess the impact of future climate change at Trichonis Lake, western Greece”, *Hydrogeology Journal,* 18, 441-54.

European Commission (2009), “Nature and Biodiversity, Nature’s role in climate change”.

European Environment Agency, Joint Research Centre EC and World Health Organization Europe, EEA-JRC-WHO (2008), “Impacts of Europe’s changing climate – 2008 indicator-based assessment”, EEA No. 4/2008, Copenhagen, Denmark.

European Environment Agency (EEA) (2005), “Vulnerability and Adaptation to Climate Change in Europe”, EEA Technical Report No. 7/2005, European Environment Agency, Copenhagen.

European Environment Agency (2007), “Europe’s Environment – The Fourth Assessment”, State of the Environment Report No. 1/2007, Copenhagen.

European Environment Agency (EEA) (2010), “10 messages for 2010. Climate Change and Biodiversity”, Copenhagen.

European Environment Agency (EEA) (2010), “10 messages for 2010. Marine Ecosystems”, Copenhagen.

Francour, P. (1997), “Fish assemblages of Posidonia oceanica beds at Port-Cros (France, NW Mediterranean): assessment of composition and long-term fluctuations by visual census”, *Marine Ecology*, 18, 157-73.

French, J.R., T. Spencer and D.J. Reed (eds) (1995), “Geomorphic response to sea-level rise”, *Earth Surface Processes and Landforms,* 20, 1-103.

Gambaiani, D.D., P. Mayol, S.J. Isaac and M.P. Simmonds (2009), “Potential impacts of climate change and greenhouse gas emissions on Mediterranean marine ecosystems and cetaceans”, *Journal of the Marine Biological Association of the United Kingdom*, 89, 1, 179-201.

Harrison, P.A., P.M. Berry, N. Butt and M. New (2006), “Modelling climate change impacts on species’ distributions at the European scale: implications for conservation policy”, *Environmental Science and Policy,* 9, 116-28.

Kazakis, Z D., Z I. N. Ghosn, Z V. P. Vogiatzakis and V. Papanastasis (2007), “Vascular plant diversity and climate change in the alpine zone of the Lefka Ori, Crete”, *Biodiversity and Conservation*, 16, 1603-15.

Levinsky, I., F. Skov, J. C. Svenning and C. Rahbek (2007), “Potential impacts of climate change on the distributions and diversity patterns of European mammals”, *Biodiversity and Conservation,* 16, 3803-16.

Malcolm, J.R., C. Liu, R.P. Neilson, L. Hansen and L. Hannah (2006), “Global warming and extinctions of endemic species from biodiversity hotspots”, *Conservation Biology,* 20, 538-48.

Millennium Ecosystem Assessment (MEA) (2005), “Ecosystems and Human Well-Being: Biodiversity Synthesis”, World Resource Institute, Washington, DC, USA.

Nicholls, R.J. and F.M.J. Hoozemans (1996), “The Mediterranean: vulnerability to coastal implications of climate change”, *Ocean & Coastal Management,* 31, 2-3, 105-32.

Occhipinti-Ambrogi, A. (2007), “Global change and marine communities: alien species and climate change”, *Mar. Pollut. Bull.*, 55, 342-52.

Orr, J.C., E. Maier-Reimer, U. Mikolajewicz, P. Monfray, G.C. Ray, B.P. Hayden, A.J. Bulger and M.G. McCormick-Ray (1992), “Effects of global warming on the biodiversity of coastal-marine zones”, in Peters, R.L. and T.E. Lovejoy (eds) *Global warming and biological diversity*, New Haven, CT, Yale University Press.

Pancucci-Papadopoulou, M.A., A. Zenetos, M. Corsini-Foka and C.Y. Politou (2005), “Update of marine aliens in Hellenic waters”, *Mediterranean Marine Science,* 6, 147-58.

Roberts, C.M. and J.P. Hawkins (1999), “Extinction risk in the sea”, *Trends in Ecology and Evolution,* 14, 6, 241-45.

Salat, J. and J. Pasqual (2002), “The oceanographic and meteorological station at L’ Estartit (NW Mediterranean)”, in Briand F. (ed.) *Tracking long-term hydrological change in the Mediterranean Sea,* CIESM Workshop Monograph No. 16, Monaco.

Schröter, D., W. Cramer, R. Leemans, I. C. Prentice, M. B. Araújo, N. W. Arnell, A. Bondeau, H. Bugmann, T. R. Carter, C. A. Gracia, ACdl Vega-Leinert, M. Erhard, F. Ewert, M. Glendining, J. I. House, S. Kankaanpää, R. J. T. Klein, S. Lavorel, M. Lindner, M. J. Metzger, J. Meyer, T. D. Mitchell, I. Reginster, M. Rounsevell, S. Sabaté, S. Sitch, B. Smith, J. Smith, P. Smith, M. T. Sykes, K. Thonicke, W. Thuiller, G. Tuck, S. Zaehle and B. Zierl (2005), “Ecosystem Service Supply and Vulnerability to Global Change in Europe”, *Science*, 310, 1333-37.

Schwartz, M.W., L.R. Iverson, A.M. Prasad, S.N. Matthews and RJ. O’Connor (2006), “Predicting extinctions as a result of climate change”, *Ecology*, 87, 1611–15.

Thomas, C., D. Alison, A. Cameron, R. E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, B.F.N. Erasmus, M. Ferreira de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A. S. van Jaarsbeld, G. F. Midgley, L. Miles, M. Ortega-Huerta, A. T. Peterson, O. L. Phillips and S. E. Williams (2004), “Extinction risk from climate change”, Letters to Nature, *Nature*, 427, 145-8.

Thuiller, W., S. Lavorel, M.B. Araújo, M.T. Sykes and I.C. Prentice (2005), “Climate change threats to plant diversity in Europe”, PNAS 102, 23.

2.7 Economic and physical impacts of climate change on tourism

Amelung, B. and A. Moreno. (2009), PESETA – Tourism study: Impacts of climate change in tourism in Europe. EUR Number: 24114, προσβάσιμο στο http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=2919 [12/09]

Amelung, B. and D. Viner (2006), “Mediterranean tourism: exploring the future with the tourism climate index”, *Journal of Sustainable Tourism*, 14(4): 349-66.

Bigano, A., J.M. Hamilton and R.S.J. Tol (2006), “The impact of climate on holiday destination choice”, Clim Change 76(3-4), 389-406.

Ciscar, J.C. (ed.) (2009), Climate change impacts in Europe. Final report of the PESETA research project. European Commission, JRC, IPTS and IES.

(de) Freitas, C. R. et al. (2004), “A New Generation Climate Index for Tourism and Recreation”, in A. Matzarakis et al. (eds), *Advances in Tourism Climatology*, Berichte des Meteorologischen Institutes der Universität Freiburg, Freiburg, 19–27, προσβ. στο www.mif.uni-freiburg.de/isb/ws2/report/defreitasscottmcboyle.pdf [11/2010]

(de) Freitas C. R., D. Scott and G. Coyle. (2008), “A second generation climate index for tourism (CIT): specification and verification”. Int J Biometeorol 52, 399-407, doi 10.1007/s00484-007-0134-3.

Ehmer, P. and E. Heymann (2008), "Climate change and tourism: Where will the journey lead?", Deutsche Bank Research, Frankfurt am Main, Germany, Available on http://www.dbresearch.com/PROD/DBR_INTERNET_EN-PROD/PROD0000000000222943.pdf

Hamilton, J. M., D. J.Maddison, and R. S. J. Tol. (2008), "Effects of climate change on international tourism", CAB Abstracts.

PKF Study Finds Premiums Doubled Since 1999" (2005), available at http://www.pkfc.com/ [1/2010]

IPCC (2007a), Climate Change 2007: "Impacts, Adaptation and Vulnerability, Working Group II Contribution to the Fourth Assessment", Report of the Intergovernmental Panel on Climate Change, "Chapter 17: Assessment of Adaptation Practices, Options, Constraints and Capacity", Cambridge University Press, Cambridge, UK.

IPCC (2007b), Appendix I, Parry M.L. et al. (eds), "Climate Change 2007: Impacts, Adaptation and Vulnerability", Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, επίσης προσβάσιμο στο http://www1.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-chapter2.pdf [11/09]

ICAP (2009), Κλαδική Μελέτη: Ξενοδοχειακές Επιχειρήσεις, Αθήνα.

ΙΤΕΠ (2008), "Η Εικόνα του Ξενοδοχειακού Δυναμικού της Ελλάδας. Ανάγκη Αλλαγής της Πολιτικής των Επενδυτικών Κινήτρων."

Matzarakis, A. (2002), "Examples of climate and tourism research for tourism demands", 15th Conference on Biometeorology and Aerobiology. 27 October-1 November 2002, Kansas City, Missouri, 391-2, προσβάσιμο στο http://www.mif.uni-freiburg.de/matzarakis/publication.htm [11/10]

Ματζαράκης, Α. και Β. Κατσούλης (2005), "Διάρκεια των ωρών ηλιοφάνειας στον ελληνικό χώρο", (εκδ.) Σ. Μιχαηλίδης, στο 7ο Πανελλήνιο (Διεθνές) Συνέδριο Μετεωρολογίας, Κλιματολογίας και Φυσικής της Ατμόσφαιρας, Πρακτικά, Τόμοι Α′ και Β′, Μετεωρολογικός Σύνδεσμος Κύπρου.

Mieczkoswki, Z. (1985), "The Tourism Climatic Index: A method of evaluating world climates for tourism," *Canadian Geographer*, 29, 220-33.

Nordhaus, W. (2007), "The Stern Review on the Economics of Climate Change", *Journal of Economic Literature*, American Economic Association, Vol. 45(3), 686-702.

Payet, A.P. (2007), "Impact of Climate Change on Tourism in Seychelles and Comoros", A Final Report Submitted to Assessments of Impacts and Adaptations to Climate Change (AIACC), Project No. SIS90, published by The International START Secretariat, Washington, DC, USA, www.start.org [11/2010].

Scott, D. and G. Coyle (2001), "Using a 'tourism climate index' to examine the implications of climate change for climate as a tourism resource", in Matzarakis, A. and C.R. de Freitas (eds), Proc 1st Int Workshop Climate, Tourism and Recreation, Porto Carras, Neos Marmaras, Halkidiki, Greece, 5 to 10 October 2001, International Society of Biometeorology (available at: www.mif.uni-freiburg.de/isb/ws/report.htm)

(The) PESETA research project (Final report) (2009), Juan-Carlos Ciscar (ed.), "Climate change impacts in Europe", Spain, προσβάσιμο στο http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=2879 [1/2010]

Viner, D. and M. Agnew (1999), Climate Change and Its Impacts on Tourism: Report Prepared for WWF-UK, CRU (Climatic Research Unit), University of East Anglia, Norwich, UK NR4 7TJ.

World Tourism Organization, UNWTO: Annual Report A year of recovery 2010,Madrid, Spain. Available on http://dtxtq4w60xqpw.cloudfront.net/sites/all/files/pdf/final_annual_report_pdf_3.pdf

WTTC (2006) "Ελλάδα: Ο αντίκτυπος του Τουρισμού στην Απασχόληση και την Οικονομία", London, UK, προσβάσιμο στο www.wttc.org [12/2010]

2.8 Risks and impacts of climate change on the built environment

Arnell, N. (2004), "Climate change and global water resources: SRES emissions and socio-economic scenarios", *Global Environmental Change*, 14, 31-52.

Arnfield, J. (2003), "Two Decades of Urban Climate Research: A review of turbulence, exchanges of energy and water, and the urban heat island", *International Journal of Climatology*, 23, 1-26.

Bartuska, T., G. Young and W. McClure (2007), "The Built Environment: A Collaborative Inquiry Into Design and Planning", New Jersey: John Wiley and Sons.

Cartalis, C. et al. (2001), "Modifications in Energy Demand in Urban Areas as a Result of Climate Changes: An assessment for the Southeast Mediterranean", *Energy Conversion and Management*, 42: 1647-56.

Du Plessis, C., D. Irurah and R. Scholes (2003), "The Built Environment and Climate Change in South Africa", *Building Research and Information*, 31, 240-56.

EEA (2007), Climate Change: The cost of inaction and the cost of adaptation, European Environmental Agency Report, No. 13/2007.

EUROSTAT, "Regional Population projection EUROPOP2008" διαθέσιμο στην ιστοσελίδα http://epp.eurostat.ec.europa.eu/portal/page/portal/product_details/publication?p_product_code=KS-SF-10-001

Franco, G. and A. Sanstad (2008), "Climate Change and Electricity Demand in California", *Climatic Change*, 87: S139-S151.

Garnaut, R. (2008), The Garnaut Climate Change Review, Cambridge: Cambridge University Press.

Giannakopoulos, C. and B.E. Psiloglou (2006), "Trends in Energy Load Demand for Athens, Greece: Weather and non-weather related factors", *Climate Research*, 31, 97-108.

Gonzalez-Rouco, J.F. et al. (2000), "Agreement between Observed Rainfall Trends and Climate Change Simulations in the Southwest of Europe", *Journal of Climate*, 13, 3057-65.

Hadley, S. et al. (2006), "Responses of energy use to climate change: A climate modelling study", *Geophysical Research Letters*, 33, L17703.

Hanemann, M. (2008), "What is the Economic Cost of Climate Change?", CUDARE Working Paper No. 1071, Department of Agricultural and Resource Economics, UC Berkeley, retrieved from: http://www.escholarship.org/uc/item/9g11z5cc

Hassid, S. et al. (2000), "The effect of the Athens heat island on air conditioning load", *Energy and Buildings*, 32, 131-41.

Hulme, M., et al. (2002), Climate Change Scenarios for the UK: The UKCIP02 Scientific Report, Norwich: Tyndall Centre for Climate Change Research.

Hunt, A. and P. Watkiss (2011), "Climate Change impacts and Adaptation in Cities: A Review of the Literature", *Climatic Change*, 104(1), 13-49.

IPCC (2007), Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report to the Intergovernmental Panel of Climate Change, Cambridge: Cambridge University Press.

Jollands, N., M. Ruth, C. Bernier and N. Golubiewski (2007), "The climate's long-term impact on New Zealand infrastructure (CLINZI) project – A case study of Hamilton City, New Zealand", *Journal of Environmental Management*, 83, 460-77.

International Energy Agency (2010), "Technology Roadmap, Solar Photovoltaic Energy",

International Energy Agency, (2010), "Energy Technology Perspectives, Scenarios and Strategies for 2050".

Katsoulis, B. and G. Theoharatos (1985), "Indications of the Urban Heat Island in Athens, Greece", *Journal of Climate and Applied Meteorology*, 24, 1296-302.

Kirshen, P., W. Anderson and M. Ruth (2008), "Interdependencies of urban climate change impacts and adaptation strategies: a case study of Metropolitan Boston USA", *Climatic Change*, 86, 105-22.

Kirshen, P., W. Anderson and M. Ruth (2004), "Climate's Long-term Impacts on Metro Boston (CLIMB)", Media Summary.

Livada, I., et al. (2002), "Determination of Places in the Great Athens Area where the Heat Island is Observed", *Theoretical and Applied Climatology*, 71, 219-30.

LCCP (2002), London's Warming: London Climate Change Partnership, Final Technical Report, London: Entec UK Ltd.

Miller, N.L. (2008), "Climate, extreme heat, and electricity demand in California", Lawrence Berkeley National Laboratory, retrieved from: http://escholarship.org/uc/item/6t2922q7

Metroeconomica (2006), Costing the Impacts of Climate Change in the UK: Overview of Guidelines, UKCIP Technical Report, Oxford.

Kamal-Chaoui, L. and A. Robert (eds) (2009), "Competitive Cities and Climate Change", OECD Regional Development Working Papers No. 2.

Oke, T. (1982), "The Energetic Basis of the Urban Heat Island", *Quarterly Journal of the Royal Meteorological Society*, 108, 1-24.

PESETA (2009), "Climate change impacts in Europe: Final report of the PESETA research project", Ciscar J.C. (ed.), JRC-IPTS, European Commission.

Sailor, D., and A. Pavlova (2003), "Air conditioning market saturation and long-term response of residential cooling energy demand to climate change", *Energy*, 28, 941-51.

Souch, C. and S. Grimmond (2006), "Applied Climatology: Urban Climate", Progress in Physical Geography, 30, 270-9.

United Nations (2008), World Urbanization Prospects: The 2007 Revision, New York: United Nations.

Vandentorren, S., et al. (2004), "Mortality in 13 French Cities During the August 2003 Heat Wave", *American Journal of Public Health*, 94, 1518-20.

Wilby, R. (2007), "A Review of Climate Change Impacts in the Built Environment", *Built Environment*, 33, 31-45.

WWF Ελλάς (2008), Λύσεις για τη Κλιματική Αλλαγή: Όραμα Βιωσιμότητας για την Ελλάδα του 2050, Επιστημονική Έκθεση του WWF Ελλάς, Αθήνα, Οκτώβριος.

Younger, M., H. Morrow-Almeida, S. Vindigni and A. Dannenberg (2008), "The Built Environment, Climate Change and Health: Opportunities for Co-Benefits", *American Journal of Preventive Medicine*, 35(5), 517-26.

Founta, D. and J. Aber (2011), in press.

Ελληνική Στατιστική Αρχή (2007), "Αποτελέσματα Απογραφής Οικοδομών-Κτιρίων", Πειραιάς, διαθέσιμο από την ψηφιακή βιβλιοθήκη της ΕΛ.ΣΤΑΤ.: http://dlib.statistics.gr/portal/page/portal/ESYE/

Ελληνική Στατιστική Αρχή, "Στατιστική Οικοδομικής Δραστηριότητας", 2000-2004, 2005-2006, 2007 και 2008, διαθ. από την ψηφιακή βιβλιοθήκη της ΕΛ.ΣΤΑΤ.: http://dlib.statistics.gr/portal/page/portal/ESYE/

2.9 Risks and impacts of climate change on the transport sector

Garnaut, R. (2008), Garnaut Climate Change Review: final report, Garnaut Climate Change Review. Available at: http://apo.org.au/?q=node/3028 [Accessed September 2, 2010].

Ciscar, J.C. et al. (2009), Climate change impacts in Europe. Final report of the PESETA research project. EUR 24093 EN. JRC Scientific and Technical Reports.

Climate Change Impacts and Adaptation Cross-regional Research Programme (2005-2006): Project E – Quantifying the cost of impacts and adaptation, Defra Metroeconomica Ltd, UK.

Εθνική Λιμενική Πολιτική (2006), Υπουργείο Εμπορικής Ναυτιλίας.

European Energy and Transport, Trends to 2030 – Update 2007, European Commission, DG Energy and Transport, ISBN 978-92-79-07620-6.

Ερευνητικό Πρόγραμμα του 7ου Προγράμματος Πλαισίου (2009-2012): Weather Extremes: Assessment of Impacts on Transport Systems and Hazards for European Regions.

Potential Impacts of Climate Change on U.S. Transportation (2008), Introductory chapter, Transport Research Board Special Edition 290, National Research Council of the National Academies.

Potential Impacts of Climate Change on U.S. Transportation (2008), Chapter 3, Impacts of climate change on transportation, Transport Research Board Special Edition 290, National Research Council of the National Academies.

2.10 Climate change and health

Analitis, A., K. Katsouyanni, K. Dimakopoulou, E. Samoli, A. Nikoloulopoulos, Y. Petasakis, G. Touloumi, J. Schwartz, H.R. Anderson, K. Cambra, F. Forastiere, D. Zmirou, J. Vonk, L. Clancy, B. Kriz, J. Bobvos and J. Pekkanen (2006), "Short-Term Effects of Ambient Particles on Cardiovascular and Respiratory Mortality", *Epidemiology*, 2006, 17: 2, 230-3.

CDC (2009), "The Interagency Working Group on Climate Change and Health (IWGCCH), A Human Health Perspective on Climate Change: A report outlining the research needs on the human health effects on climate change", Environmental Health Perspectives, National Institute of Environmental Health Sciences.

Chan, M. (2008), "Climate Change and health: preparing for unprecedented challenges", WHO, Geneva.

Gerasopoulos E., G. Kouvarakis, M. Vrekoussis, C. Donoussis, N. Mihalopoulos, and M. Kanakidou (2006), "Photochemical ozone production in the Eastern Mediterranean", *Atmos. Environ*., 40, 3057-69.

Gryparis, A., B. Forsberg, K. Katsouyanni, A. Analitis, G. Touloumi, J. Schwartz, E. Samoli, S. Medina, H.R. Anderson, E.M. Niciu, H.E. Wichmann, B. Kriz, M. Kosnik, J. Skorkovsky, J.M. Vonk and Z. Dörtbudak (2004), "Acute effects of ozone on mortality from the Air Pollution and Health: A European Approach project", Am J Respir Crit Care Med. 170: 1080–7.

Kalabokas, P.D., A. Volz-Thomas, J. Brioude, V. Thouret, J.-P. Cammas and C.C. Repapis (2007), "Vertical ozone measurements in the troposphere over the Eastern Mediterranean and comparison with Central Europe", *Atmos. Chem. Phys*. 7:3783–90.

Kalabokas, P.D., N. Mihalopoulos R. Ellul, S. Kleanthous and C.C. Repapis (2008), "An investigation of the meteorological and photochemical factors influencing the background rural and marine surface ozone levels in the Central and Eastern Mediterranean", *Atmospheric Environment*, 42: 7894–906.

Katsouyanni, K., D. Trichopoulos, X. Zavitsanos and G. Touloumi (1988), "The 1987 Athens heat wave", Lancet.

Kourtidis, K., C. Zerefos, S. Rapsomanikis, V. Simeonov, D. Balis, P.E. Perros, A.M. Thomson, J. Witte, B. Calpini, W.M. Sharobiem, A. Papayannis, N. Mihalopoulos and R. Drakou (2002), "Regional levels of ozone in the troposphere over eastern Mediterranean", J. Geoph. Res., 107(D18), 8140, doi 10.1029/2000JD000140.

Kouvarakis, G., K. Tsigaridis, M. Kanakidou and N. Mihalopoulos (2000), "Temporal variations of surface regional background ozone over Crete Island in the southeast Mediterranean", J. Geoph. Res., 105(D4), 4399-4407.

Kouvarakis, G., M. Vrekoussis, N. Mihalopoulos, K. Kourtidis, B. Rappenglueck, E. Gerasopoulos and C. Zerefos (2002), "Spatial and temporal variability of tropospheric ozone in the boundary layer above the Aegean Sea (eastern Mediterranean)", J. Geoph. Res., 107(D18), 8137, doi: 10.1029/2000JD000081.

Lelieveld, J., H. Berresheim, S. Borman, et al., (2002), "Global air pollution crossroads over the Mediterranean", *Science*, 298, 794-9.

Nastos, P.T., A. Matzarakis (2011), "The effect of air temperature and physiologically equivalent temperature on mortality in Athens, Greece", Int. J. Biometeorol. (under review).

Nastos, P.T., A.G. Paliatsos, M.B. Anthracopoulos. E.S. Roma and K.N. Priftis (2010), "Outdoor particulate matter and childhood asthma admissions in Athens, Greece: a time-series study", *Environ. Health*, 9:45, doi:10.1186/1476-069X-9-45.

Neira M et al. (2008) "T Year 2008. A Breakthrough year for Health Protection from Climate Change?" *American Journal of Preventive Medicine*, 2008; 5 (5)

Samoli, E., E. Aga, G. Touloumi, K. Nisiotis, B. Forsberg, A. Lefranc, J. Pekkanen, B. Wojtyniak, C. Schindler, E. Niciu, R. Brunstein, M. Dodič Fikfak, J. Schwartz and K. Katsouyanni (2006), "Short-term effects of nitrogen dioxide on mortality: an analysis within the APHEA project", Eur Respir J 2006; 27: 1129-37), Eur Respir J. 2006 June;27(6):1129-38. Epub 2006 Mar 15.

Samoli, E., P.T. Nastos, A.G. Paliatsos, K. Katsouyanni and K.N. Priftis (2011), "Acute effects of air pollution on pediatric asthma exacerbation: evidence of association and effect modification", Environ. Res., 111, 418-424, doi:10.1016/j.envres.2011.01.014.

Watkiss, P., L. Horrocks, S. Pye, A. S. Searl, and A. A. Hunt (2009), "Impacts of Climate Change in Human Health in Europe", PESETA-Human health study, EUR 24135EN.

World Health Organization (WHO) (2002), "World Health Report 2002: Reducing risks, promoting healthy life", Geneva.

World Health Organization (WHO) (2003), "Climate Change and Human Health: Risks and Responses".

World Health Organization WHO (2008), "Protecting health from Climate change: World Health Day 2008", Geneva.

Zerefos, C., K. Kourtidis, D. Melas, D.S. Balis, P. Zanis, L. Katsaros, H. T. Mantis, C. Repapis, I. Isaksen, J. Sundet, J. Herman, P.K. Bhartia and B. Calpini (2002), "Photochemical Activity and Solar Ultraviolet Radiation (PAUR) Modulation Factors: An overview of the project", *J. Geophys. Res*., 107, D18, 8134, doi: 10.1029/2000JD000134.

2.11 Climate change impacts on the mining industry

A. In Greek

Βαγιωνά, Δ. και Γ. Μυλόπουλος (2005), "Ζήτηση του Νερού και Τιμολογιακή Πολιτική στο Βιομηχανικό Τομέα", Heleco '05, ΤΕΕ, Αθήνα, 3-6 Φεβρουαρίου, 1-9.

Λεονάρδος, Μ. (άγνωστο), "Λιγνιτωρυχεία της ΔΕΗ – Παράγοντας ενεργειακής ασφάλειας για τη χώρα και μοχλός οικονομικής ανάπτυξης στη Δυτική Μακεδονία – Προοπτικές", διαθέσιμο στη διεύθυνση: http://www.scribd.com/doc/33996525/%CE%95% CE%9B%CE%9B%CE%97%CE%9D% CE%99%CE%9A%CE%9F%CE%A3-CE% 9B%CE%99%CE%93%CE%9D%CE%99%CE%A4% CE%97%CE%A3-%CE%9B% CE%95%CE%9F%CE%9D%CE%91%CE%A1%CE%94%CE%9F% CE%A3-%CE% 9C%CE%91%CE%A1%CE%99%CE%9F%CE%A3

Οικονομόπουλος, Ι. Ν. (1971), "Τα υπόγεια ύδατα κατά την εκμετάλλευση των μεταλλείων. Αντιμετώπιση περιστατικού απειλητικής εισροής, Επιστημονική Επετηρίς SMIT, Τόμος Α′.

Οικονομόπουλος, Ι. Ν. (1971), "Εκμετάλλευση του ορυκτού πλούτου και επιπτώσεις στο περιβάλλον", Δελτίο Νο. 5/1991 Συνδέσμου γεωλόγων-μεταλλειολόγων Κύπρου.

Στουρνάρας, Γ. (2010), "Παρατηρήσεις – Κλιματικές μεταβολές", τελικό παραδοτέο, ΕΜΕΚΑ, ΤτΕ, Αθήνα.

Τζεφέρης, Π. (2009), "Η Εξορυκτική/Μεταλλουργική Δραστηριότητα στην Ελλάδα – Στατιστικά Δεδομένα 2007-2008", *Ορυκτός Πλούτος*, 153, 1-16.

Τουρκολιάς, Χ. (2010), "Ανάπτυξη μεθοδολογικού πλαισίου για την αποτίμηση περιβαλλοντικών και κοινωνικών επιπτώσεων της ηλεκτροπαραγωγής", Διδακτορική Διατριβή, Σχολή Χημικών Μηχανικών, ΕΜΠ, Αθήνα.

B. In other languages

Eriksson, N. and P. Adamek (2000), "The tailings pond failure at the Aznalcóllar mine, Spain", Sixth International Symposium in Environmental Issues and Waste Management in Energy and Mineral Production, Calgary, Alberta, Canada.

Ford, J., T. Pearce, J. Prno, F. Duerden, L. Berrang-Ford, T. Smith, and M. Beaumier (2011), "Canary in a coal mine: perceptions of climate change risks and response options among Canadian mine operations", *Climatic Change*, 1-17, doi:10.1007/s10584-011-0029-5.

Ford, J., T. Pearce, J. Prno, F. Duerden, L. Berrang-Ford, M. Beaumier and T. Smith (2010), "Perceptions of climate change risks in primary resource use industries: a survey of the Canadian mining sector", *Regional Environmental Change*, 10(1), 65-81, DOI: 10.1007/s10113-009-0094-8.

Ghose, M. (2004), "Emission factors for the quantification of dust in Indian coal mines", *Journal of Scientific and Industrial Research*, 63, 763-8.

IPCC (2007), "Climate change 2007: the physical science basis", in: Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change, Geneva.

Menegaki, M. and D. Damigos (2009), "Designing surface mining rehabilitation works: A new approach towards cost-effective solutions", Third AMIREG International Conference in Assessing the Footprint of Resource Utilization and Hazardous Waste Management, Athens, Greece, 291-6.

Mining Association of Canada (MAC) (2007), "Towards sustainable mining − progress report 2007", available from: http://www.mining.ca/www/_news/news_502.php (πρόσβαση: Απρίλιος 2011).

Moriondo, M., P. Good, R. Durao, M. Bindi, C. Giannakopoulos, and J. Corte Real (2006), "Potential impact of climate change on forest fire risk in Mediterranean area", Climate Research, Special issue 13, 31, 85-95.

Pearce, T., J. Ford, F. Duerden and J. Prno (2009), "Climate change impacts and adaptations in the Canadian mining sector", Report for the David Suzuki Foundation.

Pearce,T., J. Ford, J. Prno, F. Duerden, J. Pittman, M. Beaumier, L. Berrang-Ford, and B. Smit (2011), "Climate change and mining in Canada", *Mitigation and Adaptation Strategies for Global Change*, 16(3), 347-68 (22).

Prommer, M. and K. Skwarek (2001), "Report on the Economic and Social Impacts of the Cyanide Spill and Heavy Metal Pollution on River Tisza", Report prepared for the Center for Environmental Studies (KTK-CES) of the World Wide Fund for Nature in the year 2000.

Sauchyn, D. and S. Kulshreshtha (2008), "Prairies", in Lemmen, D.S., F.J. Warren, J. Lacroix and E. Bush (eds) *From Impacts to Adaptation: Canada in a Changing Climate 2007*, Government of Canada, Ottawa, ON, 275-328.

Tourkolias, C., S. Mirasgedis, D. Damigos and D. Diakoulaki (2009), "Employment benefits of electricity generation: A comparative assessment of lignite and natural gas power plants in Greece", *Energy Policy*, 37(10), 4155-66.

US Environmental Protection Agency – USEPA (1995), "Emissions Factors & AP 42, Compilation of Air Pollutant Emission Factors", available at: http://www.epa.gov/ttnchie1/ap42/ (πρόσβαση: Απρίλιος 2011).

Williamson, T.B, J.R. Parkins and B.L. McFarlane (2005), "Perceptions of climate risk to forest ecosystems and forest-based communities". *Forestry Chronicle*, 81(5), 710-16.