



U N  
D P

# ASSESSING THE ECONOMIC IMPACT OF CLIMATE CHANGE

Energy Demand for Space Heating and Cooling  
Mavrovo Hydropower Plant System  
Pelagonia Valley and Strezevo Irrigation Scheme

NATIONAL CASE STUDIES



# **Assessing the Economic Impact of Climate Change: National Case studies**

**Energy Demand for Space Heating and Cooling  
Mavrovo Hydropower Plant System  
Pelagonia Valley and Strezevo Irrigation Scheme**

UNDP partners with people at all levels of society to help build nations that can withstand crisis, and drive and sustain the kind of growth that improves the quality of life for everyone. On the ground in 177 countries and territories, we offer global perspective and local insight to help empower lives and build resilient nations.

**Authors:**

John M. Callaway, PhD, UNEP Risoe Centre  
Natasa Markovska, PhD, Macedonian Academy of Arts and Science  
Ordan Cukaliev, PhD, Faculty of Agricultural Sciences and Food  
Anton Causevski, PhD, Faculty of Electrical Engineering  
Dragan Gjoshevski, PhD, Faculty of Agricultural Sciences and Food  
Verica Taseska, MSc, Macedonian Academy of Arts and Science  
Sofia Nikolova, MSc, Faculty of Electrical Engineering

**Edited by:**

Seth Landau, Ecoltdgroup

The views expressed in this publications are those of the authors and do not necessarily represent those of the United Nations, including UNDP, or the UN Member States.

UNDP  
8-ma Udarna brigade -2  
1000 Skopje

December 2011

# Table of Contents

---

Abbreviations .....	6
<b>Foreword</b> .....	<b>7</b>
<b>Overview</b> .....	<b>9</b>
Key findings of the study: .....	9
Executive Summary.....	10
Energy use: economic impacts of climate change due to climate-induced changes in space heating and cooling demands (Chapter 3).....	12
Water resources and energy production: the climatic impacts on power production in 2050 and 2100 using a case study of Mavrovo hydropower plant (HPP) system (Chapter 4) .....	14
Agricultural sector: the climatic impacts on crop yields and net farm incomes, in the long-term, using a case study of Pelagonia Valley (Chapter 5).....	16
General Recommendations .....	18
<b>Chapter 1:</b>	
<b>Introduction</b> .....	<b>21</b>
<b>Chapter 2:</b>	
<b>The Economics of Climate Change</b> .....	<b>25</b>
Background about the Economics of Climate Change .....	26
Brief Overview of the Economics of Climate Change .....	27
An Introduction to Integrated Environmental-Economic Assessment Approaches .....	30
Making Preliminary Estimates of the Economic .....	33
Impacts of Climate Change: What can we learn .....	33
Analytical and Institutional Capacity to Estimate the Economic Impacts of Climate Change, a “No Regrets” Approach .....	34
<b>Chapter 3:</b>	
<b>The Economic Impacts of Climate Change on Energy Demand for Space Heating and Cooling</b> .....	<b>37</b>
Introduction: Background and Objectives .....	38
Methodology, Data and Scenarios.....	38
MARKAL: the Basic Model and Approach.....	38
Modelling Changes in Outdoor Temperatures due to Climate Change .....	39
Linking Changes in Outdoor Air Temperature to Changes in Heating and Cooling Degree Days in MARKAL to Reflect Climate Change .....	40
Other Assumptions and Data.....	41
Results.....	43
Base Case.....	43
Climate Change Damage Cases.....	45
Adaptation to Climate Change Cases .....	48
Conclusions.....	53
The Way Forward – Developing Future Capacity.....	54

**Chapter 4:**

**The Economic Impacts of Climate Change on the Hydro-Electric Sector:**

**A Case Study of the Mavrovo Hydro Plant ..... 57**

**Introduction: Background and Objectives ..... 58**

**Methods for Valuing the Economic Impacts of Climate Change on Hydro-Electric Power Generation in the country .....59**

        Rainfall-Runoff Models and Hydro-Economic Models..... 60

        Hydro-Generation and Energy Sector Models ..... 61

        Evaluating the Capacity to Estimate the Economic Losses due to Climate Change in the Hydro-electric Generation Sector ..... 62

        Capacity to Simulate the Effects of Climate Change on Runoff ..... 63

        Capacity to Simulate the Joint Hydrologic Operation of Hydro- Reservoirs and Power Production by an HPP ..... 63

        Capacity to Optimally Balance Energy Supply and Demand across the Entire Generating System..... 63

        Capacity to Estimate the Economic Value of Climate Change Damages and the Adaptation Benefits and Costs of Avoiding some of these Damages ..... 63

**The Mavrovo Case Study ..... 64**

        Models, Methods and Data ..... 66

        Base Case..... 66

        Results for Climate Change Analysis: Runoff and Electricity Generation ..... 68

        Climate Change Impacts on Runoff ..... 68

        Climate Change Impacts on Electricity Generation .....71

        Results for Climate Change Damages ..... 75

**Conclusions.....79**

        Capacity Building..... 79

**The Way Forward – Developing Future Capacity..... 80**

**Chapter 5:**

**The Economic Impacts of Climate Change on Agriculture ..... 83**

**Introduction: Background and Objectives ..... 84**

**Methods for Valuing the Economic Impacts of Climate Change in the Agriculture Sector in the country ..... 85**

        Valuing the Economic Damages of Yield Reductions in the Agricultural Sector from the Bottom-Up ..... 86

        Valuing the Economic Damages of Climate Change on Irrigation Water Availability and the Benefits and Costs of Additional Reservoir Storage for Irrigation ..... 86

        Evaluating the Capacity to Estimate the Economic Losses due to Climate Change in the Agricultural Sector ..... 87

        Capacity to Estimate the Effects of Climate Change on Crop Yields ..... 87

        Capacity to Estimate the Effects of Changes in Crop Yields on Net Farm Income..... 88

        Capacity to Estimate the Effects of Changes in Climate on Irrigation Water Supply ..... 88

        Capacity to Estimate the Benefits and Costs of Additional Irrigation Water Supplies ..... 89

<b>The Strezevo Case Study</b> .....	<b>89</b>
Methods and Data .....	90
Base Case.....	90
Climate Change Case .....	90
Adaptation Case .....	92
<b>Results</b> .....	<b>93</b>
Adaptation Cases.....	96
<b>Conclusions</b> .....	<b>100</b>
<b>The Way Forward – Developing Future Capacity</b> .....	<b>102</b>
<b>Chapter 6:</b>	
<b>Conclusions</b> .....	<b>105</b>
Major Conclusions .....	107
Major Recommendations .....	108
<b>References</b> .....	<b>110</b>
<b>Annex I:</b>	
<b>Economic Theory and Additional Data for Evaluating Impacts of Climate Change on Energy Demand for Space Heating and Cooling</b> .....	<b>115</b>
Economic Theory: Diagrammatic Exposition of How Consumers and Producers Respond to Changes in Outdoor Temperatures .....	115
Simulated Temperature Changes and Heating-Cooling Degree Day Calculations .....	123
Methodology for Linking Changes in Outdoor Air Temperature to Changes in Heating and Cooling Degree Days in MARKAL to Reflect Climate Change .....	124
<b>Annex II:</b>	
<b>Modelling Information and Base Case Data for Analysing the Economic Impacts of Climate Change on Agriculture</b> .....	<b>127</b>
Valuing the Economic Damages of Yield Reductions in the Agricultural Sector from the Bottom-Up .....	127
Agronomic Models .....	128
Agro-Economic Models.....	129
Valuing the Economic Damages of Climate Change on irrigation Water Availability and the Benefits and Costs of Additional Reservoir Storage for Irrigation .....	131
<b>Results</b> .....	<b>134</b>
The Base Case .....	134
Index of Figures.....	137
Index of Tables .....	139

## Abbreviations

<b>CDD</b>	– Cooling degree day
<b>CGE</b>	– Computable general equilibrium
<b>CHP</b>	– Combined heat and power
<b>EUR</b>	– Euros
<b>GDP</b>	– Gross Domestic Product
<b>GHG</b>	– greenhouse gas
<b>GWh</b>	– Gigawatt hour
<b>Ha</b>	– hectare
<b>HDD</b>	– Heating degree day
<b>HPP</b>	– Hydropower plant
<b>IO</b>	– Input-Output
<b>IAM</b>	– Integrated Assessment Models
<b>IEA</b>	– International Energy Agency
<b>Ktoe</b>	– Kilotonne of oil equivalent
<b>MARKAL</b>	– MARKET ALlocation Model
<b>MKD</b>	– Macedonian Denar
<b>MW</b>	– Megawatt
<b>OPTIM</b>	– OPTimization Model
<b>PP</b>	– Power plant
<b>UNFCCC</b>	– United Nations Framework Convention on Climate Change
<b>WEAP</b>	– Water Evaluation And Planning model



## Foreword

---

**W**hat we do today about climate change has consequence that will last a century or more. Prudence and care about future progress and the future generations requires that we act now. Climate change can pose a serious threat to human lives, to economic development and to the natural resources on which much of humankind's prosperity depends.

In the national context, areas such as agriculture, electricity production, energy demand, human health and forestry are all directly linked to the climate. They are therefore vulnerable to impacts from climate change.

For example, climate change is expected to make summers hotter resulting in increased energy demand to power air conditioners. Climate change can change precipitation patterns – potentially reducing hydroelectricity production which in 2009 represented some 36% of the electricity producing capacity in the country. Climate change can also reduce agricultural productivity which can negatively impact rural livelihoods and the country's food security situation. To guard against climate change, the development of the country must be carried out in such a way as to make it “climate-resilient.”

At the same time as needing to become climate-resilient, the country has already committed to moving towards a low-emission economy as a partner with the EU. It is a member of the European Energy Community and thus has committed to adopting the EU acquis related to energy. In 2007 EU leaders endorsed an integrated approach to climate and energy policy and committed to transforming Europe into a highly energy-efficient, low-emission economy. In cooperation with international partners such as the EU, the UN, the World Bank and others, the national development pathway can be green, low-emission and climate-resilient.

In order to move down the green, low-emission and climate-resilient development path, national institutions will need to further develop the analytical tools and information to support informed policy decisions. This study is part of an ongoing UNDP effort to develop the analytical and institutional capacity of countries in transition to estimate the economic impacts of climate change and identify areas where adaptation may be necessary.

This report offers preliminary estimates of the economic value of the physical impacts of climate change in three areas important for the national economy – energy demand, water resources related to electricity production, and agriculture. Having a better idea of the economic impacts will make it possible to then better assess options for becoming more climate-resilient.

The study was carried out predominantly by national experts and institutions with assistance from international experts engaged by UNDP. I would like to thank all of those involved in the development of the study.

I hope the study will serve two purposes. First, it is my hope that the process of developing the study has helped to build national capacity for improved and refined analysis in the coming period. Second, it is my hope that this publication will contribute to the national dialogue about the links between development and climate change, and serve as food for thought as the country seeks to take concrete steps to pursue a course of green, low-emission climate-resilient development.

**Deirdre Boyd,**  
**UN Resident Coordinator/UNDP Resident Representative**

# Overview

---

## Key findings of the study:

This study represents one of the first attempts within the Macedonian context to quantify the likely impacts of climate change in economic terms. It analyses how the following areas will be affected by climate change impacts – electricity consumption, water resources related to electricity production, and agriculture.

It builds upon previous work that has analysed the physical impacts of climate change. This includes work carried out during the preparation of the two National Communications to the United Nations Framework Convention on Climate Change (UNFCCC). This study also identifies areas where building analytical capacity will assist in the management of natural resources and planning. The study was mostly carried out by Macedonian experts with assistance from experts from outside the country – building local capacity via a “learning by doing” approach. The following are key points from the study.

### Electricity consumption:

The total discounted costs of the overall energy system are estimated to approximately EUR 14.87 billion over the planning horizon 2006-2030. The electricity demand for all sectors (commercial, residential, transport, industry and agriculture) in 2030 is expected to grow for 65% compared to 2006 level. **Climate change is expected to increase these costs by up to EUR 263 million** – especially due to increased demand for air conditioning during hotter summers. Efforts can be made to reduce the consumption of electricity during both winters and summers through various energy efficiency improvements.

### Electricity production:

Hydropower production is already very vulnerable to changes in annual precipitation – varying from 600 to 1650 GWh of production per year. **In general, climate change is expected to decrease precipitation and therefore hydropower production.** The planned investments in the hydropower sector are quite large and should be examined to ensure they are “climate resilient.” Additionally, energy efficiency measures can help to reduce consumption which can reduce pressure to produce more energy.

### Agriculture:

**Climate change is expected to reduce the yields of most crops.** The Second National Communication to the UNFCCC estimates annual losses of ~29 million by 2025 due to reductions on yields for winter wheat, grapes, and alfalfa if there is no irrigation. This study analyses a number of crops in the Strezevo area and shows that significant drops in crop yields can be expected without adaptation. These losses are projected to increase over time. **Without adaptation, these climate change damages may become approximately the same or bigger than current net income – jeopardizing the economic sustainability of farming in some areas.** Even for irrigated crops there are likely to be losses, though these losses are projected to be

less than for non-irrigated crops. A preliminary analysis of the Strezevo irrigation area indicates that – if water is not the limiting factor – adaptation through irrigation may be a cost-effective measure even without climate change. This must be analysed on a case-by-case basis. Additional measures such as crop-switching and changing farm management techniques can also improve performances.

### **Building analytical capacity**

**The main recommendation to improve the analytical and institutional capacity for assessing/analyzing the impact of climate change. Cross-sector collaboration to collect data as well as develop models, tools and resources would improve understanding of the economic, environmental and management aspects of these resources.**

This will be necessary to better adapt to climate change and to better manage and plan the use of today's resources. This will require the involvement of Macedonian experts and a strategic decision by the Government to support this analytical capacity-building.

**Based on these findings the study recommends policy makers to focus policies on:**

- **Improving energy efficiency**
- **Ensuring that major investments are climate and resilient, and**
- **Developing better analytical and institutional capacity to evaluate and manage natural resources.**

## **Executive Summary**

Climate change is a cross-cutting issue that impacts numerous areas of the economy and society. Changes in temperature will affect energy consumption patterns, crop yields, human health and other areas. Changes in the water cycle will affect energy production, agriculture for rain-fed crops, water availability for irrigation, the forestry industry and other areas. All of these areas are important for economic and social development. For example, within the country:

- Electricity is used widely for heating and cooling, with these two uses accounting for 69% of electricity use in the commercial sector in 2009 and 67% of electricity use in the residential sector in 2009.
- Currently, approximately 20% of all electricity produced in the country comes from hydropower.<sup>1</sup>
- Agriculture accounts for more than 9 percent of GDP in the country; agriculture plus food processing represents 12 percent of GDP, while food and beverages represent 13 percent of exports.<sup>2</sup>

Policy-makers must respond to climate change with an approach which is also cross-cutting. This means involving a number of stakeholders in different areas in a coordinated effort.

<sup>1</sup> Ministry of Economy 2010

<sup>2</sup> Ministry of Environment and Spatial Planning 2008

Policy-makers from various sectors must take climate change into account, or face the risk of the policies being ineffective in a climate change-limited world.

Policy-makers must better understand the likely limits and impacts which climate change will impose on their country. At a global level, various countries, regional, and international organizations are carrying out in-depth studies using sophisticated modelling techniques which merge projections of climate data with physical impact models and then economic models to better understand the impacts of climate change. In this country, very little economic analysis has been done related to climate change impacts. Therefore, UNDP decided to carry out this study which was mostly led by national experts with some international assistance. The building of in-country capacity should assist in improving related analyses such as the yet-to-be-completed World Bank study which involves a large scale water resource assessment of the impacts of climate change on Macedonian agriculture.

The goals of the process were:

1. To identify the data and state-of-the-art models and methods needed to estimate the economic impacts of climate change and the benefits and costs of adaptation in energy, water resources, and agriculture;
2. To assess the extent of the capacity in-country to develop and apply these data, models and methods to the country's situation;
3. To use existing data, models and methods available to make some highly preliminary estimates of the economic value of the physical impacts that were identified in the National Communications; and
4. To suggest ways to improve the existing in-country analytical and institutional capacity to estimate the economic impacts of climate change and the benefits and costs of adaptation.

In this study, the economic impacts of climate change are investigated in three major areas: energy demand, water resources related to electricity production, and agriculture. Case studies are used in each sector to indicate the trend of economic impacts of climate change. The findings are used to give recommendations for developing analytical capacity which would be “no regrets” – meaning that this capacity would help the country to manage its natural resources and economic systems regardless of the severity of climate change. It is hoped that carrying out this work has helped develop analytical and institutional capacity in the country. The process of carrying out this study has provided national experts with some of the tools needed to carry out further work on evaluating impacts of climate change in order to adapt and reduce vulnerability.

## Energy use: economic impacts of climate change due to climate-induced changes in space heating and cooling demands (Chapter 3)

This chapter examines how consumers might react to changes in climate by changing their consumption patterns for heating and cooling. Although it is just one aspect of the energy sector, there is general agreement among researchers that climate change will have a great effect in this area. These impacts could necessitate large changes for the energy infrastructure.

The key findings of the analysis were:

- Electricity demand will likely be influenced by climate change – especially related to heating and cooling.
- Electricity demand for cooling during the summer is expected to increase, though demand for heating during the winter may decrease.
- Energy efficiency measures would help to reduce the growth of demand which would be beneficial regardless of how dramatically the climate changes.

In the Base Case (irrespective of climate change), **by 2030, total electricity demand is projected to grow by around 52% – including a 72% increase in commercial electricity consumption and a 46% increase in residential electricity consumption.** This will particularly be due to a large increase in the proportion of energy used for space cooling and heating – accounting for 63.8% of the total projected increased consumption in the commercial and residential sectors.

In the Base Case scenario in which no adaptation or mitigation measures are included and which aims solely at minimizing generation costs, coal-fired power plants would increasingly dominate the electricity sector. Hydro-electric capacity would increase only slightly. However, this does not take into account GHG emissions mitigation, or increasing prices for carbon emissions.

The **total system cost for this increase in power production is estimated to be at EUR 14.87 billion** over the course of the time period **until 2030**. This includes costs for investment in new generating capacity, delivery costs, operations and maintenance and fuel supply costs.

Three scenarios were run for temperature changes with the following outcomes in terms of climate change impacts:

- For the scenario with both a **warmer summer** and **warmer winter** – which is what most Global and Regional Climate Models are predicting for the future – a 3.5% increase in power demand is expected. This would result in an estimated additional EUR 118 million in total system costs.
- For the scenario with a **colder summer** and a **colder winter**, only a 0.3% increase in power demand is expected. This would result in only an estimated additional EUR 8.8 million in total system costs.

- For the scenario with both a **warmer summer** and **colder winter**, an 8.0% increase in power demand is expected. This would result in an estimated additional EUR 263.6 million in total system costs.
- The increases in electricity demand due to warmer temperatures in the summer and/or cooler temperatures in the winter are far higher toward the end of the projection period than in the beginning – meaning that **the impacts on energy demand may be more severe in the period after 2030**.

### **Recommendations regarding adaptation and capacity building for electricity consumption**

Some analysis was carried out to estimate the net benefits of adaptation, but modelling limitations made conclusions difficult to come to. In general, efforts can be made to decrease consumption of electricity during both winters and summers through:

- **Energy efficiency measures** such as improved building stocks;
- **Improving heating and cooling devices**; and
- Implementing **differentiated metering** according to peak times (with increased peak retail consumption costs resulting in reduced consumption at peak times).

Research prepared for the National Strategy for the Improvement of Energy Efficiency shows that **energy efficiency measures are very cost-effective and cheaper in the medium-term than new generation sources**. In particular, reducing peak energy demands can have a dramatic impact on overall costs for electricity production. **A renewed focus on improving energy efficiency can be seen as a “no regrets” adaptation measure to climate change** which also results in lower net GHG emissions. This is especially true since the Base Case involves a total cost of approximately EUR 14.87 billion for electricity production until 2030 and since the Macedonian electricity system is **already** heavily reliant upon electricity imports to meet current demand.

The focal point for carrying out this recommendation would be the Ministry of Economy in conjunction with the Energy Agency and potentially ESCOs to be formed within the country. UNDP and various other international organizations have a strong track record in assisting countries to stimulate these improvements.

Recommendations for improving **analytical capacity** in this sector mostly focus on improving the existing model used. National experts used a model called MARKAL to assist in developing and evaluating long-term energy plans. This model could be improved by:

- Adding a price-sensitive demand function which would make it possible to estimate the changes in electricity demand if prices go up or down;
- Extending the planning horizon of the model beyond 2030 because large changes are expected after that date;
- Incorporating the potential impacts of climate change on the supply of electricity (e.g. due to reductions in hydropower);
- Incorporating differences in prices for production due to either the cost of GHG pollution, or due to projected decreases in the costs for renewable energy.

- Adding more “adaptation” technologies on the demand and supply sides of the model – including those that increase efficiency of production and/or consumption.
- Further examining the costs and benefits of adaptation – especially related to costs of adjustment of the power production mix.

These improvements in analytical capacity could be carried out by the Macedonian Energy Agency in conjunction with the various academic institutions already involved in this sort of analysis as well as ELEM. The Ministry of Economy’s Department of Energy should be involved by providing support and coordination where necessary.

## **Water resources and energy production: the climatic impacts on power production in 2050 and 2100 using a case study of Mavrovo hydropower plant (HPP) system (Chapter 4)**

This chapter examines how climate change might impact hydropower production in the country. Although just one aspect of energy production, hydropower makes up a significant part of the electricity production in the country. Additionally, many large investments are planned in the hydropower sector and the plants are likely to be in place for decades – meaning they will be impacted by climate change.

### **The key findings of the analysis were:**

- **Hydropower is and will be an important source of electricity for Macedonia.**
- **Power production varies widely due to variations in climate. Climate change is expected to reduce power production over the long-term.**
- **This would result in higher costs for energy production, since hydropower is a relatively inexpensive source.**
- **Reducing growth in consumption through end-use energy efficiency would be a “no regrets” measure to reduce any negative impacts.**
- **Large investments should be examined to ensure they are “climate resilient.”**

Hydropower already makes a significant contribution to national power supply (10-20% of total consumption with a capacity of around 581 MW). More plants are planned to keep up with the expected fast-growing demand for energy – a total of six plants which will more than double the hydropower plant output. However, these plans have not factored in the effects of long-term climate change on hydropower generation potential.

Already, variability from year to year can result in drastic differences in hydropower production. **Nationally, the levels of production can vary from 600 to 1650 GWh – depending on climate conditions.**<sup>3</sup> This demonstrates the current vulnerability of the power system to climate variability.



The chapter includes an in-depth analysis of the potential impacts of climate change on the electrical output of the Mavrovo hydropower plant system. The Mavrovo hydropower plant system was chosen because it is the largest in the country, has a typical hydrology and geomorphology and a simulation model of the Mavrovo system already exists.

The following are the main findings of the case study:

- By **2050** under climate change scenarios:
  - In low-precipitation years, hydropower production is expected to be 11.07 GWh lower than during low-precipitation years in the base case (averages based on data from 1946 to 2007).
  - In average-precipitation years, hydropower production is expected to be 8.94 GWh lower than during average-precipitation years in the base case.
  - In high-precipitation years, hydropower production is expected to be 3.51 GWh higher than during high-precipitation years in the base case.
- By **2100**, climate change is expected to reduce hydropower production in all cases compared to the base case – by 27.62 GWh for low-precipitation years, 30.45 GWh in average-precipitation years, and 10.85 GWh in high-precipitation years.
- The annual total system costs due to impacts from climate change on the Mavrovo system alone are expected to be up to 2.54 million by 2050 and up to 7.14 million by 2100. This takes into account adaptation efforts to maximize power output from the entire energy system while minimizing costs. However, given that power production from coal-fired power plants and natural gas are likely to be much more expensive in a carbon-limited world, this cost may be much higher.
- It is also projected that in years with low precipitation, it ***will not be possible*** to meet the peak demand for electricity – though during medium precipitation and high precipitation years it should be possible to meet and even exceed system demands.
- A reduction in production capacity and an inability to meet demand results in three options – all of which are likely to be more expensive:
  - Increase production from other, more flexible sources of power such as coal-fired, natural gas-fired, oil-fired or biomass-fired plants. Most of these sources would lead to increased GHG pollution, and natural-gas fired and oil-fired plants need imported fuel to produce power;
  - Import the electricity from another country. This leaves the country reliant on regional cooperation and vulnerable to price hikes depending on the situation; or
  - Cut off the electricity to some users at certain times. This would be an extremely unattractive option as it would limit economic activity and likely cost even more than the other two options in terms of negative consequences to the economy.

### **Recommendations regarding adaptation and capacity building related to water resources and energy production**

Similar to the options discussed for electricity consumption, **improved demand side management via end-user energy efficiency can also be a “no regrets” option to avoid damages due to losses in hydropower production.** These are actually the same measures described for adapting to increased electricity demand due to climate change. For every MWh saved at peak times through energy efficiency, there is additional spare capacity in the electricity production system. This is especially important given the current state of the national electricity system – which relies heavily on imports and relies on hydropower as a source of peak electricity.

A number of shortcomings in analytical capacity were identified. The primary shortcoming was the lack of capacity to simulate the effects of climate **variables** on runoff<sup>4</sup> in catchments. This makes it more difficult to simulate the effects of climate **change** on runoff. Improving this capacity would be a “no regrets” option as it would also assist with other water management issues.

This type of analysis is probably best carried out by the Hydrometeorological Service of Macedonia in conjunction with the Ministry of Environment and Spatial Planning. However, care should be taken that if this sort of model is developed, it can be accessed for utilization by researchers outside of the Hydrometeorological Service. It is also important to ensure that numerous potential users are capable of using the model for their planning purposes. This could include Elektrani na Makedonija, ELEM (electricity production company).

## **Agricultural sector: the climatic impacts on crop yields and net farm incomes, in the long-term, using a case study of Pelagonia Valley (Chapter 5)**

This chapter examines the potential impacts of climate change on agricultural production. Agriculture in the country employs nearly 10% of the population, although there is also high rural unemployment. Furthermore, **half the country’s food is imported, which means that any reduction in domestic production could have ramifications for food security or at least the country’s balance of payments.**

The key findings of the analysis were:

- **Without adaptation, climate change is expected to reduce crop yields due to temperature changes and water cycle changes.**
- **Without adaptation, climate change damages may grow to become approximately the same size or bigger than current net income – jeopardizing the economic sustainability of farming in some areas.**

| 16 | <sup>4</sup> Runoff is the water that flows over the ground and can be used for hydropower production.

- **In the case study developed for the Strezevo irrigation preliminary analysis indicates that – if water is not the limiting factor – adaptation through irrigation may be a cost-effective measure even without climate change. This must be analysed on a case-by-case basis.**

As in much of the Balkans, land degradation is an important issue, which may be impacted significantly by climate change. Climate change is expected to impact future crop yields and water needs due to increased temperatures and less precipitation. The chapter analysed the Strezevo irrigation project area in the Pelagonia valley as a case study to examine what impacts are to be expected from climate change in the agricultural sector. The case study examined both irrigated and rain-fed lands. The chapter also carried out a preliminary cost-benefit analysis of implementing the expansion of irrigation in the area.

- In the Strezevo case there is sufficient water to meet increased demands if the areas irrigated are expanded. This may be true of other areas where irrigation used to be widespread in the country. This is due to significant amounts of land which are not under irrigation because the system has fallen into disrepair and irrigation equipment has been stolen for sale as scrap metal.
- Without any adaptation, net income reductions (climate change damages) are expected for irrigated crops in the Strezevo irrigation area. These are projected to range between EUR 840,000 and 1.2 million per year by 2050 – depending on the severity of climate change. By 2100, these damages are expected to rise to between EUR 1.25 and 2.4 million.
- Without any adaptation, net income reductions (climate change damages) are expected for non-irrigated rain-fed crops in the Strezevo irrigation area. These are projected to range between EUR 1.37 and 2.66 million per year by 2050 – depending on the severity of climate change. By 2100, these damages are expected to rise to between EUR 3.14 and 4.41 million.
- Without adaptation, these climate change damages may grow to become approximately the same or bigger than current net income – jeopardizing the economic sustainability of farming in some areas.

### ***Recommendations regarding adaptation and capacity building for the agriculture sector***

Autonomous adaptation – adaptation measures carried out by farmers without planned interventions – will likely reduce these climate change damages. These measures could include changing crop mixes, shifting planting and harvesting times, etc. A “no regrets” option for assisting this adaptation could be improving the knowledge and capacities of the farmers and focusing on extension services to assist the most vulnerable rural agricultural producers.

An initial cost-benefit analysis in the Strezevo area also shows that – if the water is available – it may be a cost-effective measure to increase irrigation. This can be done via public investment or, preferably, via partnerships with agricultural producers. Such a programme could

be carried out by the Ministry of Agriculture. A thorough investigation of the cost-benefit of this investment is still necessary. The World Bank, the EBRD, and other international finance institutions may be interested to participate in such a study linked to a possible investment.

A number of shortcomings in analytical capacity were identified.

- First, there is limited capacity to simulate the impacts of climate change on crop yields via crop models.
- Second, there is limited capacity to simulate changes in the hydrological cycle using rainfall runoff models.
- Third, there is little sector-level modelling that has been carried out.

The adaptation of crop models is a “no regrets” option. Better understanding of the impacts on crop yields of various inputs can help benefit the sector regardless of climate change. The development of these crop models can be done through either an academic research programme or via the Hydrometeorological Service.

Improved capacity to simulate changes and better model the hydrological cycle using rainfall runoff models is a “no regrets” option. Building this capacity would assist in planning for climate change. It would *also* improve understanding of the impacts of precipitation on current water availability for various uses (including irrigation and hydropower).

Additional analysis of the sector is a “no regrets” option. This would include developing linear programming models which can be used for analysing current and future farm management and sector management options. It also includes further investigation of irrigation possibilities to see if they are actually “no regrets” adaptation options. Finally, it includes expanding the analysis to more agricultural areas in the country. This would likely involve an institution such as the Institute of Agricultural Economics of the Faculty of Agricultural Sciences and Food, of the Cyril and Methodius University linked with capacity building assistance from an international institution. Any models or data which are developed using public money should be available for use by other institutions.

## General Recommendations

In addition to specific recommendations for the sectors outlined above, the following recommendations arise from this study as **“no regrets” options for analytical capacity to evaluate the impacts of climate change** and develop adaptation measures:

1. **Macro-Economic Model.** A macro-economic model capable of providing consistent long-term price and quantity forecasts such as a computable general equilibrium (CGE) model should be developed for the country. However, it is important that the model be able to address national development issues, specifically by requiring that the “entry points” into each sector can realistically represent impacts that are related to the country’s development plans and the impacts of climate change. These models can be developed through contracts with multilateral and bilateral institutions, involving international and regional

centres of expertise in this field. This sort of model should be developed in cooperation with the Ministry of Finance.

2. **There is a need to foster cross-sector collaboration to develop models, tools and resources that will improve the understanding of the economic, environmental, and operational implications of climate change.** It is recommended that the physical impact models and related integrated environmental-economic assessment models for the country are developed over a period of five to ten years in line with the identified priorities. The models and tools should be able to address national development issues, specifically by requiring that the “entry points” into each sector can realistically represent impacts that are related to the country’s development plans and the impacts of climate change. These models can be developed through contracts with multilateral and bilateral institutions, involving international and regional centres of expertise in this field. The particular national-level institutions which must be involved are discussed above.
3. **Data collection efforts should be fostered and coordinated with models development.** The case studies revealed data deficiencies in all of the sectors. In addition, an effort to assess the impacts of climate change in forestry and health sectors failed due to a lack of reliable data. The building of new databases where old ones have collapsed is underway in many sectors, and this information is helpful for better management of these sectors regardless of climate change. It is also recommended that data collection efforts by the Government and model development efforts be coordinated. The Ministry of Environment and Physical Planning could serve in the coordination role for these efforts.
4. **Local expertise to conduct climate change economic impact assessments on its own should be built.** Developing capacity should focus on the long-run development of human capital in the country – rather than solely relying on outside expertise. One way to try to ensure that the capacity is transferred is through training for national experts and collaboration with relevant national institutions in sector-related fields with modelling centres of excellence throughout the EU backed by multilateral and bilateral funding.
5. **Results of the climate change impacts assessments should be used in updating the policy framework and getting private sector buy-in.** A large institutional gap exists between the public and private sectors in some economic sectors/industries. Where possible, the Government should incorporate climate change impact assessments into sectoral planning and management policies and engage the private sector not only to recognize the potential adverse economic consequences of climate change, but also to facilitate more efficient actions by the private sector to adapt to climate change.
6. **Climate risk management must promote resilience.** Government development policies should incorporate investment and resource management policies that are consistent with sound adaptation planning, which addresses actual or potential impacts, identifies vulnerabilities and capitalizes on the potential opportunities presented by climate change.
7. **Social dimensions of climate change economic impacts, such as employment effects, should be explored,** as well as socioeconomic impacts of implementing policies for nationally appropriate mitigation actions.



The Former Yugoslav Republic of Macedonia has completed both its First and Second National Communications to the United Nations Framework Convention on Climate Change (Macedonian Ministry of Spatial and Physical Planning, 2003 and 2008). These studies identified the potential climate change impacts in a number of sectors, as well as some options for adapting to these impacts. In some cases, these studies presented preliminary estimates of the magnitude of these impacts under several different climate scenarios for some sectors. In a few sectors, very preliminary efforts were undertaken to explain and/or estimate some of the economic ramifications of these impacts. However, these national communications lacked an in-depth discussion of how physical impacts would impact:

- The economic welfare of producers, investors and consumers in different economic sectors; or
- Overall indicators of economic activity such as gross domestic product (GDP), personal consumption expenditures, private investment and government spending.

This study is envisioned as a way of filling in these gaps in the National Communications while at the same time improving the capacity of national experts and institutions to estimate the economic impacts of climate change and the benefits and costs of adaptation. It is intended that this study will pave the way for more in-depth examinations of climate change that will be able to link the physical impacts of climate change to economic impacts and to the assessment of the benefits and costs of avoiding some of these impacts (adapting). The study aims to indicate particular areas

of vulnerability with an eye towards developing adaptation policies and programmes which would be beneficial with or without climate change – “*no regrets*” measures.

Previous experience and current practice by economists suggests that this type of assessment is difficult enough in developed countries such as the U.S. and the EU.<sup>5</sup> It is even more difficult for countries in transition that have been buffeted by several decades of sudden political changes and economic upheavals<sup>6</sup>.

After the break-up of Yugoslavia, the data and models as well as the analytical and institutional capacity to plan and manage a centrally planned economy were swept away. Sectors in which these data and models had played an important role in natural resource planning and management were “privatized”. The practical capacity of government to perform many key functions in some sectors was reduced. At the same time, the analytical capacity to develop and implement natural resource and environmental planning has not been re-developed in any systematic way. The management tools and the institutional capacity to use these results in planning and management decisions in the public and private sector have also not been re-developed.

In the past 5-10 years, partly in anticipation of joining the EU, the Government has launched a set of policy initiatives that target important sectors for economic development. These initiatives have tried to balance environmental and economic objectives. In developing these initiatives, there is a strong need for the country to redevelop the analytical and institutional capacity to manage its natural resources. Accordingly, the Government has also launched a number of initiatives in the context of its development policy to do just this.

In that general context, this study aims to accomplish four main objectives in the Macedonian context:

1. To identify the data and state-of-the-art models and methods needed to estimate the economic impacts of climate change and the benefits and costs of adaptation in energy, agriculture and water resources;
2. To assess the extent of the capacity in-country to develop and apply these data, models and methods to the country’s situation;
3. To use existing data, models and methods available to make some highly preliminary estimates of the economic value of the physical impacts that were identified in the National Communications; and
4. To suggest ways in which the existing analytical and institutional capacity to estimate the economic impacts of climate change and the benefits and costs of adaptation in the country can be improved.

It concludes with suggestions about how to improve the current capacity in the country.. It also suggests how to use this information to inform public policy decisions and private sector planning and management in natural resource-based industries.

<sup>5</sup> For the U.S., see Mendelsohn and Neumann (eds.) (1999) and for the EU, Ciscar et al. (2009)

<sup>6</sup> See, for example UNDP Croatia (2009) for Croatia and Callaway et al. (2010) for Montenegro.



This study consists of 6 chapters. After the Introduction in Chapter 1, Chapter 2 defines what is meant by “economic impacts” and gives a brief explanation of how these impacts are estimated using integrated environmental-economic assessment models and macroeconomic models. Chapter 2 also provides several justifications for making very preliminary calculations of the economic value of climate change damages using existing data and methods that are available. Finally, it describes how models and methods can be useful not only to estimate the economic impacts of climate change, but also can be useful in general as planning and management tools in natural resource sectors.

**Chapters 3 through 5 are devoted to individual sectors or impact areas.**

Chapter 3 contains a country-specific assessment of the economic impacts of climate change due to climatically induced changes in space heating and cooling demands in the country’s energy sector.

Chapter 4 contains an assessment of the economic impact of climate change on the hydro-electric sector through a case study of the Mavrovo Hydro Plant. The chapter describes the simulation results of how climate change will reduce power production in 2050 and 2100 from the Mavrovo hydropower plant (HPP) system. It includes quantitative values of these impacts in terms of the additional cost imposed on the system by having to meet the same level of energy demand despite reductions in hydropower generation capacity.

Chapter 5 contains an assessment of the economic impact of climate change on agriculture. This chapter uses a case study of Pelagonia Valley to show how climate change might impact crop yields and net farm incomes in the long-term, defined here in terms of the last half of this century. The Pelagonia Valley case is chosen as representative of the agricultural sector in the country to illustrate the potential effects of climate change.

The last chapter, Chapter 6, provides a number of conclusions focusing on the estimates of the economic impacts of climate change in the sector chapters and capacity building to improve these estimates. It ends with a number of strong recommendations drawn from the study.



# The Economics of Climate Change

## Summary of Chapter 2:

### The Economics of Climate Change

Chapter 2 explores what is meant by “economic impacts” of climate change – that climate change will likely alter the supply and demand of many goods and services. This will change prices. In many cases, climate change will decrease the welfare of either consumers, producers, or both. The chapter provides a brief explanation of how these impacts are estimated using integrated environmental-economic assessment models and macroeconomic models. These models simulate the interaction between environmental and economic goods and services on the macro and micro-economic levels.

The chapter also provides justifications for making very preliminary calculations of the economic value of climate change damages using existing data and methods that are available. These calculations are helpful in identifying the potential scale of economic impacts due to climate change as well as areas of vulnerability. Finally, the chapter describes how models and methods can be useful not only to estimate the economic impacts of climate change, but also can be useful in general as planning and management tools in natural resource sectors. The methodological tools and data used for estimating the economic impacts of climate change are often the same as those used for effective planning and management of natural resource sectors.

## Background about the Economics of Climate Change—

**D**ecision makers at all levels of government and in the private sector will need information about the economic impacts of climate change and the costs and benefits of adapting to it. Indeed they are already asking for it. It is a common misconception that estimating the economic impacts of climate change is relatively easy to do – easier than simulating the effects of increases in GHG emissions on the global and regional climates, or easier than simulating the effects of regional changes in climate on the natural and man-made environment and on animals and humans. Program managers in research fields related to environmental pollution and climate change have tended to think of economic analysis as an “add on” task that can be accomplished after all the “hard work” in the natural and physical sciences is completed. This has led to the under-utilization of the full potential of economic analysis in solving environmental problems. However, there has been a growing realization that economic analysis should take a more prominent position in the process of solving environmental problems.

The newer attitude has contributed to increased co-operation between natural and physical scientists and economists in developing models that link natural and physical processes with economic market principles. The resulting new generation of “integrated environmental-economic models” can translate the physical impacts of climate change into:

- Monetary measures of these impacts;
- Impacts on sector- and macro-level measures of economic activity, income, employment, etc.; and
- Estimates of benefits and costs of reducing the physical and economic damages of climate change through adaptation.

This chapter is about how economists define and estimate “the economic impacts of climate change”. It is also about the importance of identifying and building the capacity to simulate and estimate these impacts and how to build this capacity in a way that will benefit not only climate change policy-making, but also policy- and decision-making related to natural resources planning and management.

This chapter does five things:

1. It defines what economists mean by economic impacts.
2. It describes how climate change impacts can affect economic markets, making it possible to value some – but not all – of the physical impacts of climate change.
3. It describes how models from the natural and physical sciences can be joined with economic models to simulate the effects of climate change on markets.
4. It describes some short-cut approaches, such as those used in past studies and this

study, to make preliminary estimates of these economic impacts and suggests how these estimates can be helpful.

5. Finally, it describes a way of building analytical and institutional capacity based on the principle of “no regrets” that can be used to address gaps in the analytical capacity to plan and manage economic development in many different sectors of the economy, while at the same time being helpful for making decisions about mitigating GHG emissions and adapting to climate change.

## Brief Overview of the Economics of Climate Change —

The underlying theory for valuing the economic impacts of climate change in specific sectors is the same as for valuing the damages of almost any environmental pollutant. This underlying theory has been widely applied for many air and water pollutants in numerous settings (Adams et al. 1985; Adams et al. 1986; Smith and Desvougues 1985; Carson and Mitchell 2004). What makes climate change different, for policy purposes, from conventional air pollutants is that a ton of GHG emitted from any location will have roughly the same forcing effect on global and regional climates as from any other location. However, the global nature of the impacts created by GHG-induced climate change is only relevant for mitigating GHG-induced climate change impacts (i.e. reducing net emissions – commonly referred to as “mitigation”).

On the other hand, the impacts of GHG-induced climate change will be felt at **specific locations**. Therefore, adaptation measures to address impacts from climate change only yield benefits in those specific locations. However, to the extent that adaptation actions are contingent on climate change, their benefits and costs are influenced by successful mitigation of GHGs. If emissions are reduced more, the climate will change less, climate change impacts will be decreased, and the advantage gained by adapting versus not adapting will be decreased. If, however, emissions are not reduced, the climate will change more, climate change impacts will increase, and the advantage gained by adapting versus not adapting will be increased.

Changes in climate, no matter what the cause, have the potential to affect the goods and services provided by the natural environment within many market sectors. For example, changes in temperature and precipitation and a host of other meteorological variables influence the growth and development of commercial crops, the amount of runoff that is available for use from surface and groundwater sources by humans, animals, and industry. Changes in climate can also directly and indirectly affect the flows of environmental services that attract tourists to specific locations to engage in certain forms of recreation for their own enjoyment. You can’t ski if there is no snow and going to the beach is not much fun when the air temperature is 40°C plus and the water temperature is not far behind. You cannot enjoy hearing the birds sing if they are gone. If climate change causes sea levels to rise, beaches can be lost and valuable beachfront property inundated. These are just some of the examples of how climate change can disrupt the flow of environmental services.

Whilst the physical damages of climate change are easy to explain and understand (but often hard to measure) valuing these damages in monetary terms is less easy to understand. In

some cases, climate change can affect the **demand** for a market good: it gets hotter and crops and humans need more water to survive. In others, it can affect the **supply** of a market good: crop yields can fall, water supply can be diminished, and beach opportunities for recreation may be altered. In fact, climate change simultaneously influences both the supply and demand for a market good: when it gets hotter and drier society generally needs more water, but there is less of it available.

Climate change can impact the supply and demand of market goods, change the quantities of some market goods and services that are produced and consumed, and alter the market prices of these goods (see Figure 2-1). In many – but not all – cases, climate change impacts will result in reductions in the production of some market goods and increases in their prices. For example, a warmer, drier climate could reduce domestic crop production and increase domestic food prices (depending on the situation in import markets). In other situations, a change in climate can reduce the demand, and hence the prices of these goods or services. This could happen in the case where much hotter weather makes beach recreation uncomfortable; tourists go elsewhere; and local accommodation prices fall.

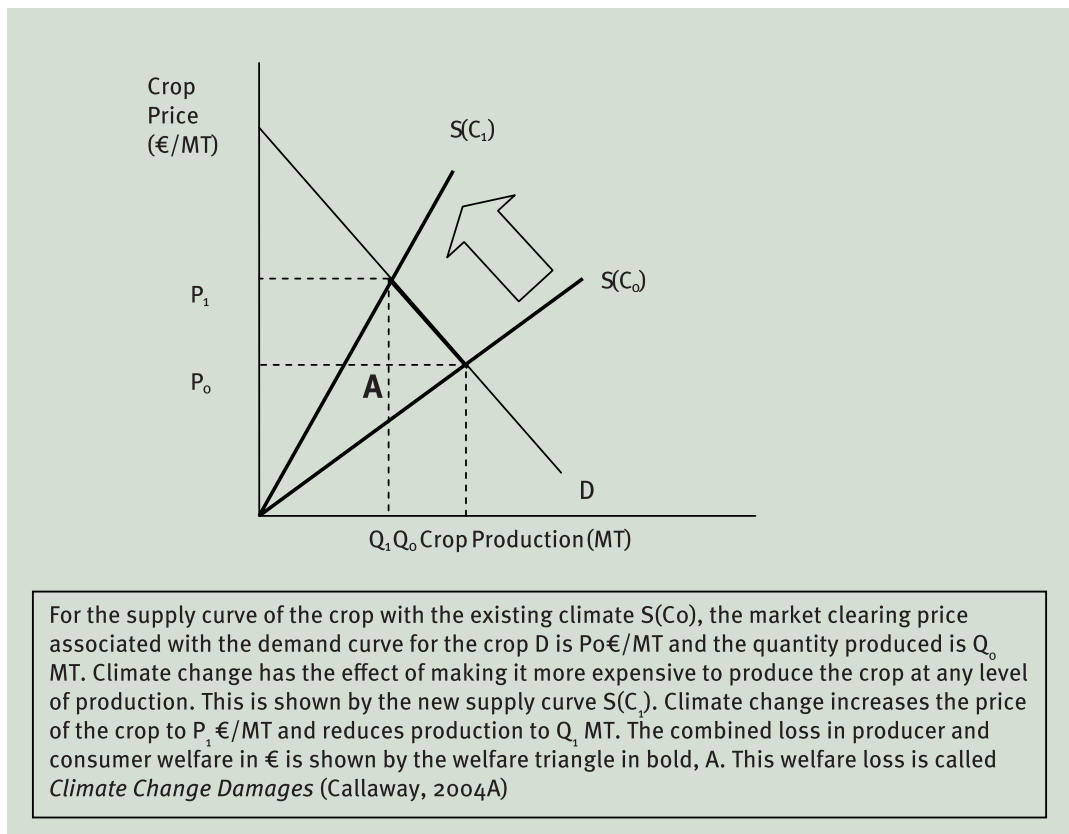


Figure 2-1: Graphic illustration and text showing how economists measure climate change damages in welfare terms

What both of these cases have in common is that when production of a market good or service falls, holding everything else constant, so do the profits of firms producing these goods and services and so does the economic welfare of consumers. When the prices of goods and services increase, this can help producers of market goods and services recover some of their lost revenues due to reduced consumption, but it will always reduce the welfare of consumers. The reduction in the economic welfare of consumers and producers of market goods due to the impacts of climate change, without taking into account additional measures to adapt to these impacts, is called “*Climate Change Damages*” (Callaway 2004a). Economists have a variety of techniques for exploiting information about these climate-induced changes in market prices, production and consumption levels to estimate climate change damages for specific sectors. The flavour of this approach is shown diagrammatically in Figure 2-1, using the example of a commercial food crop.

The same principles can be applied to valuing the benefits and costs of avoiding these damages through adaptation (Callaway 2004a, 2004b, 2008, 2009), but the diagrams to show this are quite complex. The notion is that adaptation options, while they may not eliminate – or even change – the physical impacts of climate change, can reduce some of these economic damages. That is: they reduce damages (at some cost), and the net reduction in climate change damages (the damages avoided by adaptation) are the “*Net Benefits of Adaptation*”. The part of the area A that remains after adaptation has taken place is called the “*Imposed Cost of Climate Change*”, or residual climate change damages. These are the climate change damages that can’t be avoided, either because it costs too much to do so, or else is physically impossible.

There are really two types of impacts of climate change:

- Welfare impacts – on consumers, producers and investors, and
- Impacts on indicators of economic activity.

Those impacts that are depicted in Figure 2-1 are called welfare impacts, because they are based on measures of changes in the welfare of economic agents – producers, consumers, and investors – due to market effects.

- These net changes in welfare measure the enjoyment that **consumers** lose or gain when the price of a good and/or the amount they consume changes.
- They measure the changes in net returns to **producers**: the revenue they receive from selling goods, less the cost of producing it.
- Finally, for **investors** these net welfare changes measure changes in the net returns to investors over time, less their investment costs.

The measurement of welfare impacts on all these economic groups is based on a well-developed body of economic theory that tells economists not only how to measure them, but also how to aggregate, disaggregate (and mis-aggregate) them<sup>7</sup>.

This study focuses on models and methods for measuring these welfare effects, specifically on approximating the climate change damages due to some impacts of climate change, re-

<sup>7</sup> A good textbook introduction is Just et al. 1982, *Applied Welfare Economics*, Prentice-Hall.

lated to some economic activities (and human health), in some places and/or parts of an economic sector. However, the preliminary quantitative estimates of climate change damages all fall short of being true welfare measures. This is because the models, methods and/or the data to make these calculations have either not been developed in or for the country or were not readily available in published or other, easy-to-access sources.

Impacts on indicators of economic activity are also important to measure – perhaps more important than welfare impacts in the eyes of public policy makers and elected officials. These impacts are related to changes in economic activity as measured by gross domestic product (GDP), consumer expenditures (consumption), investment and government spending, etc. Labour force participation, employment and unemployment are included in these impact measures used in national accounting systems. Typically, these impacts are measured in the macro-economy at the national level. Until approximately thirty years ago, Input-Output (IO) tables were the primary means of estimating these impacts (Miller et al. 1985). But these have given way to computable general equilibrium (CGE) models, which contain a more realistic representation of markets and their linkages (Kehoe and Kehoe 1994). In principle, both models can be used to simulate the transmission of the impacts of climate change on markets (as shown in Figure 2-1) through the inter-industry structure of the economy to other markets in other sectors.

## An Introduction to Integrated Environmental-Economic Assessment Approaches

---

Figure 2-2 is a graphic illustration of all the systems and linkages that can be (and often are) included in an integrated environmental-economic assessment. It's hard to know where to begin, since it's a matter of everything depending on everything else. However, as good a place as any is in the box labelled “National, Regional and Global Economies”. This part of the system actually needs several boxes to show the product and expenditure flows between sectors and nations. These flows of goods and money act as “conveyor belts” for economic impacts between sectors and within and between national economies.

The arrow labelled “Emissions” shows that these economies collectively produce GHG emissions that are transported into the global climate system where they mix and their net forcing effect on climate is determined by the mix of gases, the rates at which they oxidize, and how large their forcing effect is. These forcing effects are then transmitted to local climate systems, where changes in local climates interact continually with the global concentration of GHGs to influence the local environment (both natural and man-made and, directly and indirectly human health - not shown). These local impacts have the potential to shift both the supply and demand for market goods and services in (mainly, but not exclusively) natural resource sectors, such as agriculture, forestry, fisheries, tourism and recreation and water resources (which overlaps and cuts across many different sectors). These impacts are then transmitted from the natural environment to natural resource markets and sectors by changes in the flows of environmental services, some of which are priced in markets and some of which are not.



Adjustments to climate change in these sectors occur through adaptive management (and by adaptive investments) that feed back into the local environment and change the flows of environmental services back into natural resources sectors, completing the control and feedback process of adaptation to climate change. Finally, the impacts of climate change, both before and after the adaptive adjustments have taken place, are transferred to the local, national and global economies through the conveyor belt(s) of inter-industry and inter-country commodity, services and money flows. This completes the cycle.

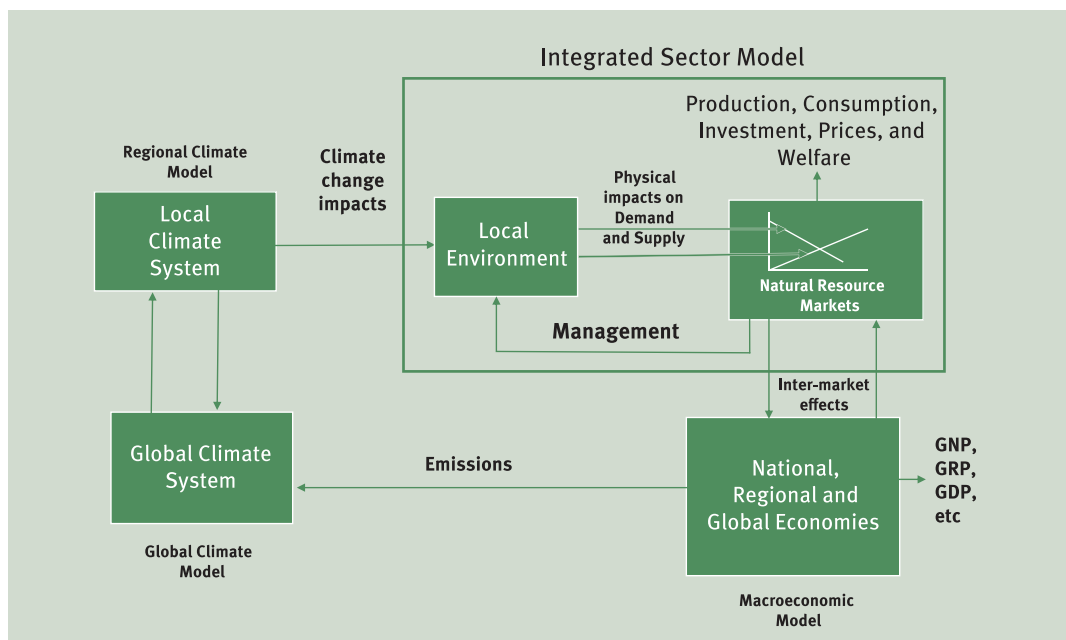


Figure 2-2: Graphic illustration of the systems and linkages, globally and locally that influence the impacts of climate change and adaptive adjustments to these impacts

Each of these systems or, in some cases groups of systems, are also represented by different types of models that can be used assess the physical and economic impacts that occur in each system. In fact, one type of model, known as Integrated Assessment Models (IAMs), captures all of the systems and inter-linkages shown in Figure 2-2. IAMs are widely used to assess the relationships between emissions policies, GHG emissions, climate change, climate change impacts and adaptation at the global and regional level<sup>8</sup>. However, the level of physical and economic detail in IAMs at the national and local level is often not adequate for assessing and valuing climate change impacts and the benefits and costs of adaptation at appropriate geographic or market scales, although there is much debate about where to draw the lines.

A number of the so-called economic sector models that are presented in this study have been used in integrated environmental-economic assessments of climate change at the local and national levels to estimate the effects of climate change on commodity markets, to value climate change damages in welfare terms and to estimate the benefits and costs of adapting to climate change. Two additional examples of this type of modelling are presented in Box 2-1

<sup>8</sup> See reviews by Wyant (1996), Kelly and Kolstad (1999) and Parson and Fisher-Vanden (1997) for a good overview of these models and their uses.

## **Box 2-1:** **Examples of economic sector models related to climate change**

Two examples of economic sector models related to climate change are two studies by Callaway et al. (2008 and 2009) in the Berg River Basin in the Western Cape of South Africa. For these studies, global climate models were used to generate information about climate change over large areas in Africa. This climate information was then downscaled to the basin level using a regional statistical climate model. A rainfall-runoff model was used to translate distributed changes in precipitation and temperature around the basin into changes in runoff, reservoir evaporation and plant water demands in irrigated agriculture for a number of different climate scenarios. A spatially disaggregated hydro-economic model developed by Callaway (2008) for the region was then used to simulate how these changes would influence long-term investment in new dams (the Berg River Dam) and the operation of the system on a monthly basis. Climate change damages were estimated for the basin without additional investments in reservoir storage capacity. The benefits and costs of the Berg River Dam to reduce these damages were also estimated, using a range of assumptions about the future growth in water demand by Cape Town and irrigated agriculture in the Berg River Basin. A key finding of this study was that changing the way in which water was allocated, rather than building a new dam, produced the largest net benefits of adaptation and was the most immune to climate risk. The finding was important because it highlighted the importance of “no regrets” adaptation options as being both more economically efficient than climate-sensitive measure and “safer” in terms of avoiding the adverse consequences of building too much or too little additional storage capacity in the face of uncertainty about future changes in climate.

The only type of model, shown in Figure 2-2, which the Berg River study did not include, was a macro-model of the larger regional and national economy. Since this is the richest agricultural region in South Africa, such a model could have been useful to project the effects of climate change and adaptation to climate change in the basin on local and national employment and on local and national income due to the export of grapes, wine and deciduous fruits, such as peaches, nectarines and plums. Adding such an analysis could also have helped to estimate the climate change damages in the region, if the demand functions for food in the model could have reflected up-market economic activity both in domestic and export markets. However, tracking the monetary exchanges through these markets from food producers to processors to food marketers and exporters and then to domestic grocery store transactions and export food demand would not have added anything to the welfare calculations because all these transactions cancel out. Nonetheless, changes in these flows would be of importance to policy makers interested in the distribution of the economic impacts of climate change. A follow-up study for a larger area in the Western Cape is underway and a macroeconomic model will be utilized to assess the impacts of climate change on various indicators of regional and national economic activity.

## Making Preliminary Estimates of the Economic Impacts of Climate Change: What can we learn

One of the objectives of this study is to try to make preliminary estimates of climate change damages in selected sectors (energy, agriculture and water resources). The estimates are preliminary because in every case the data and models, as well as the specific educational training and experience to develop and apply integrated environmental-economic models to estimate these impacts is not well developed, if developed at all. At the same time, there does not appear to be any IO- or CGE-based model for the country to estimate the economic impacts of climate change on indicators of national economic activity. Without these two types of models and related databases, comprehensive and reliable estimates of either kind of economic impact are just not possible at this time.

However, that does not mean that nothing can be done. In countries whose post- World War II experience has been dominated by political changes and economic upheavals, natural resource and social planners and managers in both the public and private sectors have made important decisions with the information and models at their disposal. To say that no estimates of the economic impacts of climate change can be made without detailed data and highly sophisticated, state-of-the-art geo-physical, biological or economic models is not correct. Such models may be able to generate more information that is more reliable and of greater help to public sector policy and private sector decisions. But preliminary estimates, however rough, still have their place in decision-making in both the private and public sectors until (or if) better information is needed.

Making these kinds of preliminary estimates can accomplish three different things:

- First, preliminary estimates can reveal the general scale of impacts that might be expected.
- Second, making these kinds of preliminary estimates of climate change damages (or impacts on indicators of economic activity) can help to locate “hot spots” and “hot sectors” where damages may be especially severe and could spill over to disrupt national economic development. For example, the agriculture and hydro-electric power sectors have been targeted for aggressive development by the Government and private sector. The results of this study, as partial as the analyses are, do tend to indicate that climate change in the future (if not already) could impose limits on this growth. Better data and models – physical impact models, sector models and macroeconomic models – are required in all of these cases to confirm this. Also, similar results of the impacts of climate change on residential and commercial electricity use indicated that will start to grow rapidly and possibly cause substantial economic losses after 2030, or so, even though this was beyond the projection period used in the analysis.
- Third, developing preliminary estimates of the economic impacts of climate change can tell us how to strengthen the national capacity to estimate the economic impacts of climate change and the benefits and costs of adapting to it. Performing preliminary

studies in co-operation with local experts and institutions can show what data and models are missing and what data and models will and won't work. This is one of those cases where "failure" can be instructive.

From the perspective of all three of these types of results, preliminary estimates of the economic impacts of climate change are worth making, despite their risks.

## Analytical and Institutional Capacity to Estimate the Economic Impacts of Climate Change, a "No Regrets" Approach

---

Another of the objectives of this study is to assess the analytical and institutional capacity to estimate the economic impacts of climate change. What is meant by analytical and institutional capacity? What are the differences between the two? What is the best way to develop these types of capacities in a country where, arguably, considerations of climate change may be secondary to considerations of economic development?

First of all analytical capacity is the capacity to develop and use various types of data bases and models discussed in this study to estimate the economic impacts of climate change. Institutional capacity refers to the ability of natural resource and social planners and managers in both the public and private sectors to use the information generated by the new data and models to make better investments and policies that will reduce climate change damages. The two do not necessarily go hand in hand and analytical capacity is probably easier to develop than institutional capacity which has to filter through public and private sector institutions before it gets adopted.

A bigger issue is why a country that is developing (or wants to develop) quickly should spend time and resources to develop analytical and institutional capacity to evaluate the economic impacts of climate change and the net benefits of adapting to it when, arguably, there are more pressing social and economic development issues. This is where the concept of "no regrets" enters the picture. A public or private sector policy or plan or law, or even a project, has "no regrets" associated with it if the benefits associated with its implementation are positive, whether or not climate change occurs, and are also positive if climate change does occur.

Take, for example, two options for coping with climate change impacts on water supplies. One option is to build more storage capacity while another option is to change the way in which water is allocated. Changing the allocation system is a "no regrets" option if it results in more efficient water use and increases the economic value of water in use whether the climate changes *or not*. In that sense, it is good for economic development and it is good for coping with climate change. Increasing water storage, however, costs a lot of money and it is important to size reservoirs correctly, as the "optimal" size of a water supply reservoir can depend a lot on climate change. So, there is always the possibility of experiencing "regrets" of building a reservoir that is either too big or too small, based on a future projection of climate change.

A reservoir that is “too big” is one that can’t be filled and its full storage capacity cannot be utilized when the climate changes. A reservoir is too small if water that could be stored, and used later, has to be released downstream before it is needed. In the first case, the “regrets” come in the form of excessive costs; while in the second case, the “regrets” come in the form of lost benefits.

A no regrets approach to capacity building is the same as planning for climate change, as shown in the above example. It involves developing the analytical and institutional capacities to plan, manage, make policies and set standards, etc. in both the private and public sectors that are generally needed to guide the economic development of a country and which are also helpful for coping with climate change. In some circles this is known as a “win-win” situation. Take the case of the water resources sector, once again. There are a variety of national development issues related to water resources and planning. The most obvious are plans to greatly increase the generation of power by hydro-electric plants. Developing hydro-economic models (see Chapter 4) would be a great aid to water resource, agriculture and energy planners, even without the issue of climate change to worry about. However, since climate change will affect both the demand for electricity, as well as the supply of water used to generate electricity, such a model is also valuable for integrating the impacts of climate change into water resources and energy planning.



# The Economic Impacts of Climate Change on Energy Demand for Space Heating and Cooling

## Summary of Chapter 3:

### The Economic Impacts of Climate Change on Energy Demand for Space Heating and Cooling

This chapter examines how consumers might react to changes in climate by changing their consumption patterns for heating and cooling. In the Base Case (irrespective of climate change), by 2030, total electricity demand is projected to grow by around 65% - including a 72% increase in commercial electricity consumption and a 46% increase in residential electricity consumption. The total discounted system cost for this increase in power production is estimated to be EUR 14.87 billion over the course of the time period until 2030. This includes investment in new generating capacity and new demand devices, delivery costs, operations and Maintenance and fuel supply costs. The chapter analyses three scenarios for temperature changes in terms of climate change impacts. Some analysis was carried out to estimate the net benefits of adaptation, but limitations made conclusions difficult to come to. Recommendations are also provided for improving the analytical capacity in this sector – including improving the capabilities of the MARKAL model which is used to project costs of changing the power production system.

## Introduction: Background and Objectives

One of the main potential areas where climate change can have an impact is on the demand for energy for space heating and cooling. If the summers get hotter, this can mean a greater demand for air conditioning – putting pressure on electricity grids. At the same time, if the winters are milder, this can mean a lower demand for heat sources – resulting in *less* pressure on electricity grids, on district heating units, or on biomass wood resources. On the other hand, if climate change results in more extreme temperature days, this can put pressure on energy resources for both heating and cooling over the course of a given year. Daily differences in climate variables already have measurable impacts on energy demand. Long-term trends of temperature changes due to climate change can have a marked impact on what energy demand requirements will be – necessitating changes in strategic decisions related to energy.

There are four purposes of this chapter, as follows:

1. To explain how the energy model, MARKAL, was used to simulate the climate change damages due to changes in outdoor temperatures due to climate change and then simulate the net benefits of adaptation;
2. To explain how the scenarios were developed that linked projected changes in temperature in the country to changes in outdoor temperatures, relevant for space heating and cooling;
3. To explain how the estimates of changes in outdoor temperature were used to estimate changes in heating and cooling degree days (HDD and CDD) and how these changes in HDD and CDD were developed to reflect climate change damages in MARKAL in order to estimate climate change damages and the net benefits of adaptation;
4. To detail other major assumptions and data inputs to MARKAL, particularly those related to the Base Case.

## Methodology, Data and Scenarios

### MARKAL: the Basic Model and Approach

The MARKAL (MARket ALlocation) Model is a dynamic optimization model developed by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA)<sup>9</sup>. It depicts both the supply and demand sides of a national or regional power market. It can be used to simulate both the short-run production and consumption of electricity, based

|38| <sup>9</sup> Seegbregts, Goldstein, and Smekens (2001)



on a given mix of electricity generation plants and distribution infrastructure, as well as investment in new generation capacity and distribution infrastructure over time.<sup>10</sup>

Unfortunately, the model currently in use by national experts does not have the capability to simulate electricity consumption along price-responsive (i.e., downward-sloping) electricity demand functions. This means it is not ideal for the long term modelling that is needed for climate change analysis. (See the functions, Do and D1 in Figure I-1 and Figure I-2 in Annex I). Additionally, instead of maximizing the sum of producer and consumer surplus in all of the demand and supply sectors of the national electricity system, it minimizes the net present value of total cost. However, MARKAL can still be used to shed light on the impacts of climate change on the supply side of Macedonian electricity sector.

For this, the methodological approach involved several steps:

1. **Step 1** was to convert the temperature projections developed by Bergant (2006) into changes in heating and cooling degree-days over the model horizon.
2. **Step 2** was to develop demand projections for the MARKAL model to reflect expected economic development under the current climate (i.e., the Base Case climate);
3. **Step 3** was to develop “climate damage” scenarios to reflect different changes in the pattern of seasonal heating and cooling degree days due to climate change;
4. **Step 4** was to run the MARKAL model for each of the climate damage scenarios, holding the generation capacities of the various generating resources fixed at levels that were determined in (and, therefore, optimal for) the current climate. This set of runs was used to estimate climate changes, assuming only partial adjustment to climate change;
5. **Step 5** was to run the MARKAL model for each of the climate damage scenarios. However, in these cases, MARKAL was allowed to determine the cost-minimizing capacity mix of generating resources to simulate supply-side adaptation through new investment in generation capacity that was optimal for the expected changes in heating degree days in each of the adaptation scenarios;
6. **Step 6** was to calculate the economic value of climate change damages as the differences in total system cost between the climate damage scenarios and the Base Case. The net benefits of adaptation were calculated as the difference in total system cost between the adaptation scenarios and the corresponding damage scenarios.

## Modelling Changes in Outdoor Temperatures due to Climate Change

Changes in daily air temperatures (min, mean and max) have been projected for the country for the years 2025, 2050, 2075 and 2100 by Bergant (2006) by season. The information on projected mean temperatures was used to forecast the monthly average temperatures.

<sup>10</sup> The MARKAL Model for the country was developed in the framework of the USAID project “Regional Energy Security and Market Development (RESMD) Strategic Planning. The model is maintained, modified, and used by the Macedonian Academy of Sciences and Arts.

The planning period in MARKAL Model is 2006 - 2030. Therefore, only the 2025- and 2050- values for the absolute changes ( $^{\circ}\text{C}$ ) in temperature (Table 3 from Bergant (2006)) were used to calculate the temperatures from 2006 to 2030. Monthly temperature projections are needed to calculate projected heating degree-days (HDD) and cooling degree-days (CDD) over the planning horizon. Since the absolute changes ( $^{\circ}\text{C}$ ) in temperature in Bergant (2006) are for 30-year periods, Bergant’s study assumed that 2025 temperature value in the Base Case and climate damage cases represented the temperature for the period 1996-2025, and 2050-value is for the period 2021-2050. Using this assumption, the average annual change in temperature was calculated for each period, and projections of the monthly temperatures were developed for each year of the planning period (the temperature projections are shown in Annex I, Figure I-3.)

## Linking Changes in Outdoor Air Temperature to Changes in Heating and Cooling Degree Days in MARKAL to Reflect Climate Change

The calculations of HDD and CDD for this study were made following the methodology used by the District heating company, “Toplifkacija” in Skopje, as described in Annex I, Table I-3. This approach has already been implemented in the Macedonian version of MARKAL and was used for the sake of consistency.

Table 3-1 provides the adjustment factors that were the basis for the climate change damage scenarios. One thing that quickly emerges is that the normalized HDD and CDD adjustments that are used in MARKAL, based on Bergant’s projections, are actually quite small. The HDD adjustments range from a reduction in HDD of about 1% to an increase of 3%, while the CDD adjustments range from a reduction of about 2.5% to an increase of around 6%. This suggests that space cooling will be more sensitive to the climate changes projected by Bergant (2006) than space heating.

Table 3-1: Adjustment factors used in MARKAL Model, 2009-2030

	2009	2012	2015	2018	2021	2024	2027	2030
AdF1(HDD)=	0.996	0.996	0.996	0.996	0.994	0.992	0.992	0.992
AdF2(HDD)=	1.007	1.007	1.007	1.007	1.005	1.003	1.003	1.003
AdF1(CDD)=	1.047	1.044	1.041	1.039	1.050	1.061	1.056	1.052
AdF2(CDD)=	0.977	0.975	0.972	0.970	0.980	0.991	0.986	0.982

The last step in the process was to create the HDD and CDD adjustment factors to reflect climate change damages. A combination of HDD and CDD adjustment factors were calculated for three alternative climate change damage scenarios using the information in Table 3-2. These scenarios are defined qualitatively as follows (the quantitative adjustments can be seen in Table 3-2):

- Damage Case 1 (DC1): Hotter in Both Winter and Summer – Decreased demand for heating and increased demand for cooling, using AdF1 for HDD and CDD;
- Damage Case 2 (DC2): Colder in Both Winter and Summer – Increased demand for heating and decreased demand for cooling, using for using AdF2 for HDD and CDD;
- Damage Case 3 (DC3): Colder in the Winter and Hotter in the Summer – Increased demand for heating and increased demand for cooling, using AdF2 for HDD and AdF1 for CDD.

## Other Assumptions and Data

The cost-minimizing version of MARKAL requires detailed information to build a Base Case. Much of this information is related to developing bottom-up estimates of electricity demand. In the absence of demand functions for electricity, MARKAL finds the cost minimizing long-run investments in generation capacity and distribution infrastructure, as well as the optimal allocation of short-run variable inputs and outputs that will meet the electricity demand estimates for various years over the planning horizon of the model.

The Base Case was developed taking into account all available reports and studies for energy development in the country. The energy resource potential of the country was analysed in detail in the “Strategy for Energy Development of the Republic of Macedonia until 2030” (Ministry of Economy, 2010) and was considered as a key document. All available national data sources (State Statistical Office, National energy balances, etc.) as well as some International databases (IEA Databases – OECD/IEA 2008) were also considered for the key input data in the MARKAL model. It is worth noting that the future temperature changes were not taken into account in the development of the Base Case.

Figure 3-1 shows the assumptions for the GDP and population growth rates, which are the key demand drivers used for energy demand projections in all energy sectors.

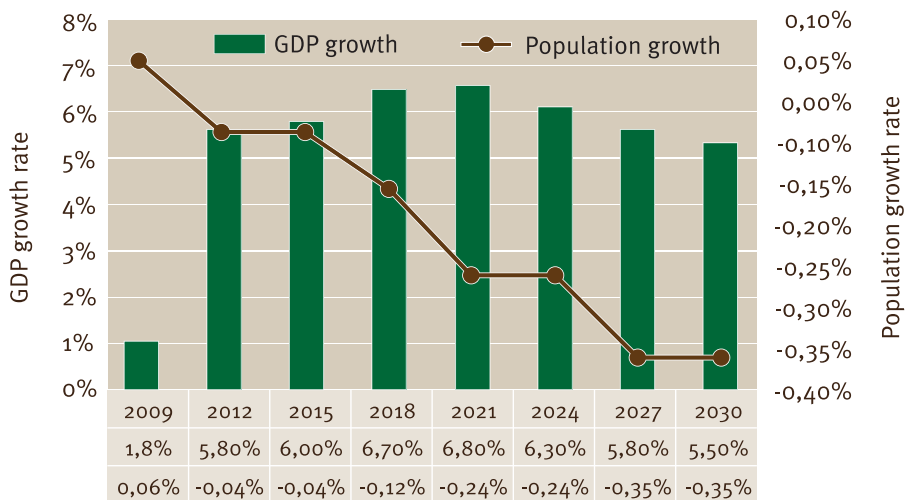


Figure 3-1: Key demand drivers - GDP and population growth rates

Figure 3-2 spells out the allocation of the future electricity demands in the commercial and residential sector by end-use services for the Base Case.

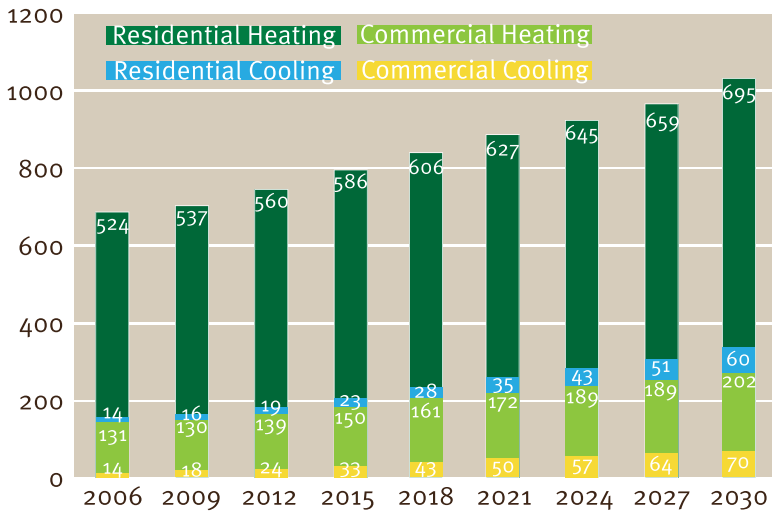


Figure 3-2: Electricity demand projection in commercial and residential sector for heating, cooling and the total under the base case (ktoe)

The average annual growth rate of electricity demand in the commercial sector is about 2.3%. This implies a roughly 72% increase in commercial electricity consumption by 2030. The average annual growth rate for the residential sector is lower, about 1.6%, leading to a 46% increase in residential electricity consumption by 2030. This compares with an average annual growth rate for commercial and residential electricity demand in the DC2 and AC2 (not shown in Figure 3-2) of about 1.75%. By 2030, total electricity demand is projected to grow by around 52%.

Figure 3-3 illustrates how the shares of end-use services change over the planning period, in both sectors for the Base Case for 2006 (inner ring) and 2030 (outer ring).

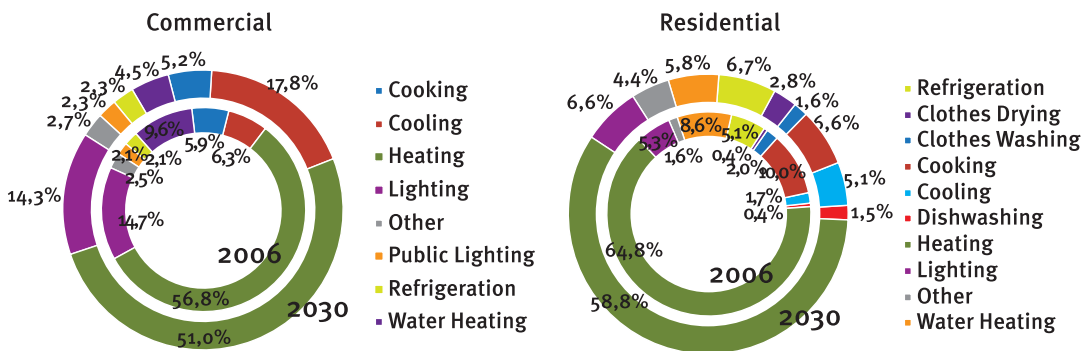


Figure 3-3: Shares of end-use services in total energy demand in 2006 and 2030, for commercial and residential sectors - Base Case

Over this period, space heating is expected to **decrease** slightly from around 57% of total electricity demand to 51% in the commercial sector, while space cooling is expected to **increase** from about 6% of total electricity demand to almost 18%. In the residential sector, space heating is also expected to fall as a share of total electricity demand from almost 65% to about 59%, while the share of space cooling is expected to increase from about 2% of the total to 5%.

## Results

---

This section presents the main results for the following three sets of scenarios:

- Base Case (BC) – baseline development scenario which gives the optimal generation capacity mix taking into account only country’s development plans (without climate change);
- Climate Change Damage Cases (DC) - scenario which introduces the climate changes by adjusting the degree days in accordance with the national climate scenarios, while the generation capacities are fixed to the optimal capacity mix from the Base Case;
- Climate Change Adaptation Cases (AC) - scenario which establishes the optimal capacity mix for adaptation to the climate change by allowing for endogenous capacity adjustments in the model. (The climate changes are the same as in DC<sub>1</sub>, but the method of adjustment to climate change is allowed to differ).

### Base Case

MARKAL calculates two important pieces of information for the analysis of the economic impacts of climate change. First, it establishes the system cost-minimizing investment levels in generation capacity and optimal generating capacity mix that will be used to constrain capacity adjustments in the climate change damage cases. Second, it establishes the total system cost for the Base Case, which serves as a reference for measuring climate change damages and the residual damages of climate change.

The optimal capacity mix for electricity generation that will satisfy the estimated future energy demand in the Base Case is given in Figure 3-4. Coal-fired power plants dominate the Base Case for the entire period, followed by the hydropower plants. Coal-fired capacity increases starting in 2021, while hydro capacity increases slowly, pretty much throughout the entire period. Oil fired generation capacity disappears after 2012 (due to retirement), while combined cycle gas and renewable generation grow throughout the period, first replacing the lost oil-fired capacity and then contributing to the general capacity growth of the system.

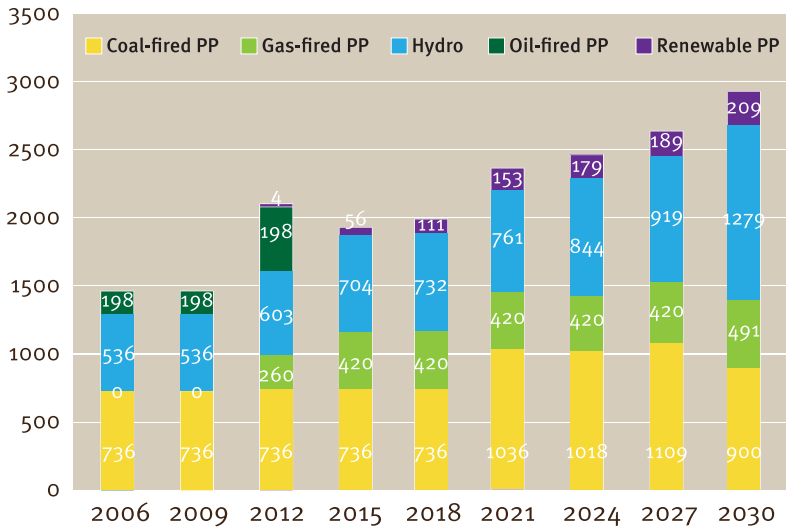


Figure 3-4: Electricity generation capacity mix - Base Case

The **total discounted system cost** for the Base Case is estimates to be **EUR 14.87 billion**. The growth in the energy system requires significant levels of new investment and payments for fuels. The annual expenditures associated with the energy system are presented in Table 3-2, where the growth in expenditure for fuel, operating power plants and devices, and the acquisition of new power plants and devices can be noticed.

Table 3-2: Annual energy system expenditure by cost type<sup>11</sup> (EUR 10<sup>^6</sup>), 2006-2030 – Base Case

	2006	2009	2012	2015	2018	2021	2024	2027	2030
Fuel Supply Costs	422	571	634	632	681	706	785	844	977
Delivery Costs (All sectors)	89	87	102	118	125	130	139	145	156
O&M* Costs (Demand devices)**	27	8	18	29	40	48	56	64	72
O&M Costs (Power plants)	161	153	160	165	172	195	184	183	169
Annualized Investment (Demand devices)	0	37	86	132	181	217	252	289	325
Annualized Investment (Power plants)	0	0	28	62	74	119	179	224	268
<b>Total</b>	<b>700</b>	<b>856</b>	<b>1027</b>	<b>1136</b>	<b>1273</b>	<b>1415</b>	<b>1595</b>	<b>1750</b>	<b>1967</b>

\* O & M = Operations and Maintenance

\*\* Demand devices are heating and cooling devices (such as air conditioning units)

11 The annualized investment costs associated with existing power plants and demand devices are not included.

## Climate Change Damage Cases

The optimal generating mix from the Base Case, as previously shown in Figure 3-4 was used to constrain the capacity adjustment in the climate change damage cases in order to simulate partial adjustment to climate change. The resulting changes in residential and commercial heating and cooling demand can be seen in Table 3-3. The percentage changes shown in this figure are relative to the Base Case. These changes in demand represent the impacts of climate change on residential and commercial energy consumers, allowing them to adjust to climate change on both the supply and demand side using only the technology, policies and know-how in the Base Case. No long-run adaptation is included. As expected the changes in demand follow the pattern of the simulated changes in heating and degree-days (Table I-3 in Annex I) and the corresponding adjustment factors introduced into MARKAL (Table 3-1).

The most interesting feature about Table 3-3 is that the cooling impacts, both positive and negative, dominate the heating impacts in relation to the Base Case. That is: a change in heating degree-days has a larger impact on the commercial sector than the residential sector. This is “as expected” due to the relative size of the two sectors in terms of their space air conditioning use and the fact that space air conditioning in the summer is expected to grow more rapidly in the commercial than the residential sector. However, note that while the percentage changes in sectoral electricity demand in one of the sectors can be quite large (as high as 40% to 50% relative to the Base Case) in many of the cases, the percentage change in the total demand by these two sectors is generally quite small, especially in the first two cases (DC1 and DC2). In DC1 energy demand never increases by more than 3.5% in both sectors and in DC1 never more than 1.1%. This is because the effects of climate change on electricity demand in these two scenarios are offsetting. Only in the third scenario (DC3) are the climate impacts reinforcing in way that increases in electricity demand in both sectors. In DC3, energy demand increases slowly, relative to the Base Case, in response to climate change, reaching a level where it is 8% higher in 2030. Finally, it is important to note that, at least in the two most likely scenarios (DC1 and DC2), the increases in electricity demand due to warmer temperatures in the summer and/or cooler temperatures in the winter are far higher toward the end of the projection period than in the beginning. This is line with the temperature projections and suggests that the MARKAL analysis needs to be extended farther into the future.

Table 3-3: Percentage change (from the Base Case) in residential and commercial and electricity demand for the three Climate Change Damage cases, 2006-2030

		2006	2009	2012	2015	2018	2021	2024	2027	2030
		<i>Hotter in the Summer and in the Winter</i>								
<b>DC1: Commercial</b>	Cooling	0.0%	4.9%	9.9%	13.9%	17.8%	23.3%	30.4%	37.0%	45.0%
	Heating	0.0%	-0.2%	0.2%	0.7%	0.4%	-1.2%	-1.1%	-2.8%	-4.6%
<b>DC1: Residential</b>	Cooling	0.0%	3.8%	8.8%	13.2%	18.0%	23.7%	30.5%	38.2%	46.3%
	Heating	0.0%	-0.2%	-0.3%	-0.2%	0.2%	0.2%	-0.4%	-0.1%	-1.8%
<b>DC1: Both</b>	<b>DC1Total</b>	0.0%	0.1%	0.3%	0.9%	1.7%	2.2%	2.7%	3.7%	3.5%

		2006	2009	2012	2015	2018	2021	2024	2027	2030
<b>DC2: Commercial</b>	<i>Colder in the Summer and in the Winter</i>									
	Cooling	0.0%	-3.3%	-5.8%	-8.2%	-10.5%	-12.3%	-13.3%	-14.4%	-16.6%
	Heating	0.0%	0.4%	0.8%	0.7%	0.8%	0.0%	0.8%	1.3%	1.1%
<b>DC2: Residential</b>	Cooling	0.0%	-2.5%	-5.0%	-7.5%	-10.6%	-12.5%	-13.3%	-14.4%	-15.9%
	Heating	0.0%	0.6%	0.9%	1.9%	2.6%	1.9%	2.2%	2.5%	3.2%
<b>DC2: Both</b>	DC2 Total	0.0%	0.4%	0.5%	1.0%	1.1%	0.2%	0.3%	0.2%	0.3%
<b>DC3: Commercial</b>	<i>Hotter in the Summer and Colder in the Winter</i>									
	Cooling	0.0%	4.9%	9.9%	13.9%	17.8%	23.3%	30.4%	36.9%	42.5%
	Heating	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
<b>DC3: Residential</b>	Cooling	0.0%	4.5%	8.8%	13.2%	18.0%	23.4%	30.3%	37.5%	46.1%
	Heating	0.0%	0.6%	0.9%	2.0%	2.8%	3.6%	3.7%	3.4%	3.6%
<b>DC3: Both</b>	DC3 Total	0.0%	0.7%	1.2%	2.4%	3.5%	4.8%	5.9%	6.8%	8.0%

Figure 3-5 shows the absolute difference in electricity demand for the two sectors in each of the three climate change damage cases. (These differences will also hold true for the adaptation cases since the HDD and CDD are the same for both sets of scenarios in which the climate changes). This figure makes it possible to see that, when hotter summers and winters are expected (DC1) – which is what most Global and Regional Climate models are predicting for the future – the impact on electricity demand will largely involve increases in space cooling demand in the commercial sector, and to a lesser extent residential sector. What is interesting about this scenario is that the reduction in space heating demand does not really set in until 2030. The DC2 scenario, which simulates colder temperatures year-round, does not fit the typical projections of Global and Regional Climate Models, nor Bergant’s data. However, it does help us to see that when these conditions occur simultaneously, for example in a single year or for several years in the context of climate variability, that the changes in heating and cooling demands will be virtually offsetting and the net impact very small. DC3, on the other hand, is more realistic in that combines the effects of warmer temperatures in the summer, with colder winters. In portions of the country winter conditions are highly variable. Also in parts of Europe, North America and Northern Asia, warmer summer temperatures have coincided with colder winter temperatures. The impacts of such a climate regime are shown in the DC3 scenario. This is a “worst” case, conceptually, in that both space heating and cooling demands will increase. Moreover, under these climatic conditions, the relative increase in demand growth is larger in the residential sector than the commercial sector by 2030.



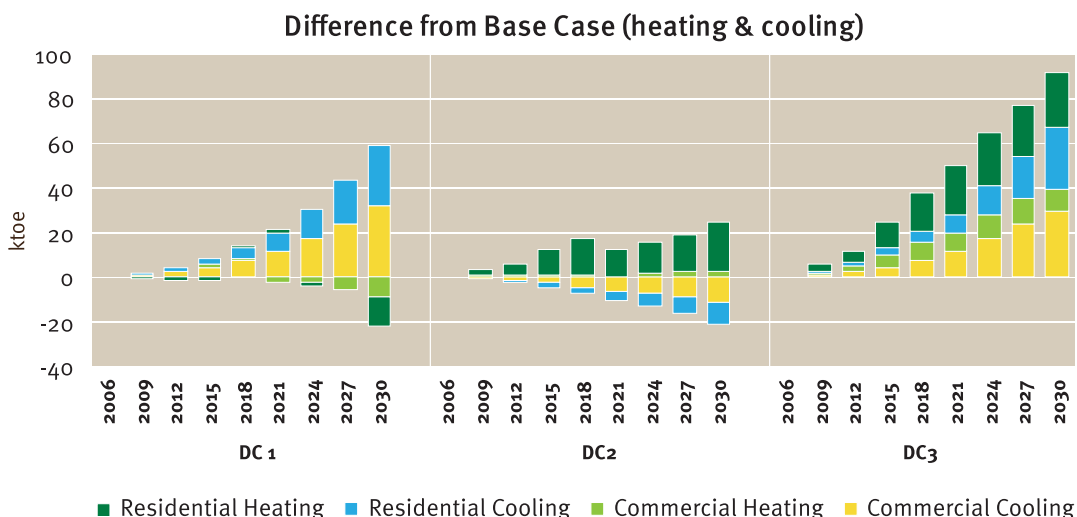


Figure 3-5: Difference in the heating and cooling demand for the residential and commercial sectors in the climate change damage cases compared to the Base Case

As previously mentioned, the version of the MARKAL Model used in this study minimizes the total fixed (investment) and variable cost of building, operating, maintaining the infrastructure in the national power system. The demand for electricity in this version of MARKAL is not simultaneously determined by the interaction between downward sloping demand curves for electricity and the short and long-run supply curves for the electricity produced by the system. It is not possible to determine how climate change impacts will affect the market-clearing price of electricity, nor is it possible to determine the consumer surplus or producer surplus welfare measures that are consistent with the price changes that occur in response to climate change. What is possible to do is to calculate the minimum electricity system cost and compare the cost with that in the Base Case. This would be an acceptable measure of climate change damages in the case of a cost minimizing industry subject to demand constraints and where the price of electricity is equal to the marginal system cost.

Table 3-4 presents the MARKAL estimates of the present value of the total system cost for the Base Case and the three climate change damages cases, which are all in the range of about EUR 14.8 – 15.1 billion. The difference between this cost in each of the scenarios and the Base Case represents an approximate estimate of climate change damages under the conditions described above. The system costs in each of the damages cases rises, relative to the Base Case. This is expected since the system was constrained in how it could adjust to climate change, by the capacity levels in the Base Case, although the mix of resources allowed to produce electricity was able to change. The increase in total system costs due to climate change that were simulated using the MARKAL Model are relatively small, as low as 0.06% and as large as 1.74% compared to the Base Case system cost. The relative magnitudes of these damages conform to the picture presented in Figure 3-5 and are directly related to how much energy has to be produced in each of the climate change damage scenarios to cope with the changes in residential and commercial electricity demand due to climate change.

Table 3-4: Present value of total system cost for the Base Case and Damage Cases (EUR 10<sup>6</sup>)

Case/Scenario	System Cost	Estimated Climate Change Damages
Base Case	14,869	--
Damage Case 1	14,987	– 118 (-0.8%)
Damage Case 2	14,877	– 8.8 (-0.06%)
Damage Case 3	15,132	– 263.6 (-1.74%)

## Adaptation to Climate Change Cases

The previous section shows the physical and economic damages due to the impact of changes in outdoor temperatures in the country on space heating and cooling demands for electricity. In estimating these physical and economic impacts, the adjustment of electricity producers was constrained by the generation capacity in the Base Case. This is the same thing as saying the electricity producers remain on their short-run supply curves, as they try to adapt to the increases in electricity demand. They can adapt partially to climate change with generating resources they have, and they can invest in any new capacity that was not in the Base Case. Additionally, efforts can be made to decrease peak consumption of electricity during both winters and summers through energy efficiency measures such as improved building stocks, improving heating and cooling devices, and implementing differentiated metering according to peak times (with increased peak retail consumption costs resulting in reduced consumption at peak times) – which can have a dramatic impact on overall costs for electricity production.

For the adaptation cases within this study, adaptation is treated generally as a process that allows industries and firms to move from their short-run supply curves to their long-run supply curves and invest in new capital and equipment that is optimal for the adjustment to climate change. This process is known as full adjustment. Rather than having to use just the generation capacity they already have at their disposal, they can adjust their generating capacity and distribution capacity so that it is optimal for climate change. As such, an important ingredient of the methodology used in this study is that MARKAL simultaneously selects the long-run cost-minimizing mix of generating plants, their capacities, and operates and maintains the new and old plants consistent with short-run cost-minimization.

The heating and cooling degree days used in the Adaptation Cases are the same ones that were used in the Climate Change Damage. However, they have been re-named as follows to avoid confusion:

- **Adaptation Case 1 (AC1):** Hotter in Both Winter and Summer - Decreased demand for heating and increased demand for cooling, using AdF1 for HDD and CDD;
- **Adaptation Case 2 (AC2):** Colder in Both Winter and Summer - Increased demand for heating and decreased demand for cooling, using AdF2 for HDD and CDD;
- **Adaptation Case 3 (AC3):** Colder in the winter and Hotter in the summer - Increased demand for heating and increased demand for cooling, using AdF2 for HDD and AdF1 for CDD.

The projected energy demands in the commercial and residential sectors for the analysed period are the same as were used in the Damage Cases (See Table 3-3), since the HDD and CDD adjustment factors (meaning the simulated climate changes) are the same in the Climate Change Damage and Adaptation scenarios.

In this case, the possibility for endogenous adjustment of the capacity mix by the model gives the new optimal generation mix (Table 3-5), which is different than the generation capacity mix used in the Base and Climate Change Damage scenarios (Figure 3-4). The differences in the capacity mix between the three adaptation capacity cases and the Base Case and Damage Case Capacity generation capacity are shown in Figure 3-6, Figure 3-7, and Figure 3-8.

Table 3-5: Optimal generation capacity mix (MW) - AC1, AC2 and AC3

		2006	2009	2012	2015	2018	2021	2024	2027	2030
<b>AC1</b>	Coal-fired PP	736	736	736	736	736	1036	1018	1109	900
	Gas-fired CHP	0	0	260	458	458	458	458	458	491
	Hydro PP	536	536	603	704	732	761	844	919	1279
	Oil-fired PP	198	198	198	0	0	0	0	0	0
	Renewable PP	0	0	4	56	111	169	178	187	211
	<b>Total</b>	<b>1470</b>	<b>1470</b>	<b>1801</b>	<b>1954</b>	<b>2038</b>	<b>2424</b>	<b>2498</b>	<b>2674</b>	<b>2881</b>
<b>AC2</b>	Coal-fired PP	736	736	736	736	736	1036	1018	1109	900
	Gas-fired CHP	0	0	260	402	402	402	402	402	486
	Hydro PP	536	536	603	704	732	761	844	919	1279
	Oil-fired PP	198	198	198	0	0	0	0	0	0
	Renewable PP	0	0	4	56	113	126	182	190	209
	<b>Total</b>	<b>1470</b>	<b>1470</b>	<b>1801</b>	<b>1898</b>	<b>1983</b>	<b>2324</b>	<b>2445</b>	<b>2621</b>	<b>2875</b>
<b>AC3</b>	Coal-fired PP	736	736	736	736	736	1036	1018	1109	900
	Gas-fired CHP	0	0	260	463	464	464	464	464	484
	Hydro PP	536	536	603	704	732	761	844	919	1279
	Oil-fired PP	198	198	198	0	0	0	0	0	0
	Renewable PP	0	0	4	56	111	172	178	187	210
	<b>Total</b>	<b>1470</b>	<b>1470</b>	<b>1801</b>	<b>1959</b>	<b>2043</b>	<b>2432</b>	<b>2504</b>	<b>2679</b>	<b>2874</b>

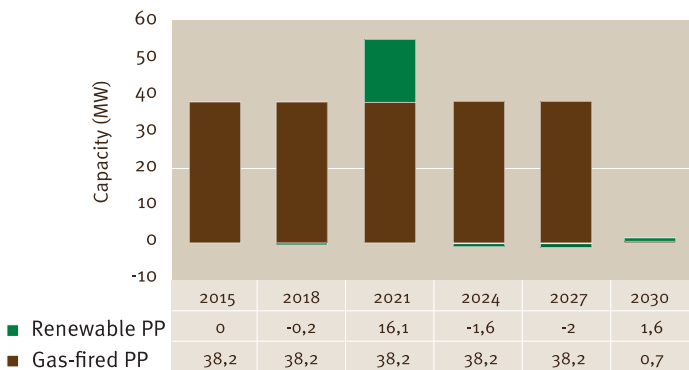
The capacity adjustments vary quite a bit in each case. In AC1, virtually no capacity is dropped – only small amounts of renewable between 2024 and 2030 – but modest amounts of combined cycle gas-fired capacity are added (around 38 MW per period) in each period between 2015 and 2030 plus about 15 MW of renewables in 2021. This suggests that, at least in the AC1 case, it will actually be more expensive to adjust capacity to adapt to climate change, relative

to the Base Case, than to do nothing. This only takes into account the adaptation options that are characterized in the supply side of the MARKAL model and not the demand side.

The results for the AC2 case confirm to expectations that adjusting to climate change along their long-run supply curves would make producers better-off (reduce their systems costs, here) than using short-run measures. However, not only is this scenario the one with the smallest climate change damages, but also the amount of capacity that is shed (mostly gas-fired) compared to the Base Case (almost 600 MW in total) is greater than the amount of gas-fired capacity added in the AC1 case!

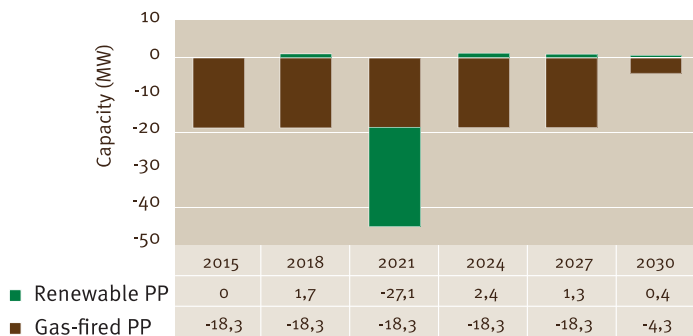
The results for the AC3 scenario, which had the largest climate change damages, look very much like the results for AC1. However, the capacity increases in each of the periods between 2015 and 2027 are around 25 MW/period greater than in the AC1 case. In both cases, more gas-fired capacity and, in 2021, more renewable capacity is added to cope with climate change, however, the added increments of gas-fired and renewable capacity are about twice as great as in AC1. This is not surprising, since the climate change damages are about twice as great in AC3 as in AC1.

**Difference in generating capacity - AC1 versus Base Case**

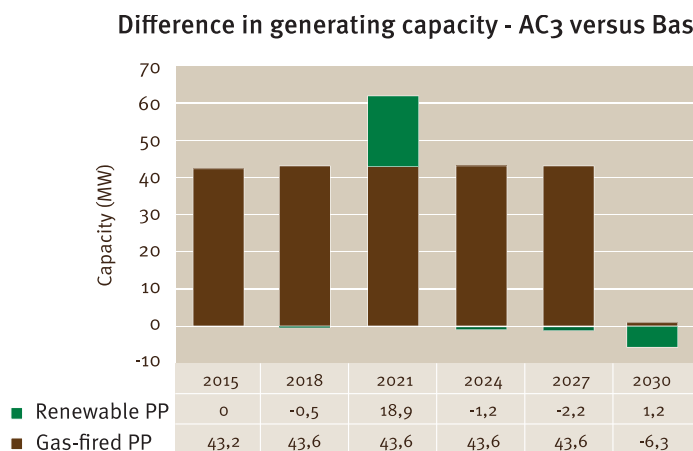


**Figure 3-6: Difference in generating capacity between the adaptation case AC1 and the Base Case**

**Difference in generating capacity - AC2 versus Base Case**



**Figure 3-7: Difference in generating capacity between the adaptation case AC2 and the Base Case**



**Figure 3-8: Difference in generating capacity between the adaptation case AC<sub>3</sub> and the Base Case**

Table 3-6 presents all of the climate change benefit and cost measures that were estimated in this study to characterize the economic welfare impacts of climate change on the residential and commercial sectors of the national electricity system in the country. The estimates of the net benefits of adaptation for the three climate change cases were contrary to our expectations for the two most economically “damaging” climate cases AC<sub>1</sub> and AC<sub>3</sub>. The largest economic losses (climate change damages) were associated with the climate case in which summer temperatures were projected to be the warmest and winter temperatures were projected to be the coldest (DC<sub>3</sub>). This much is common sense. The second largest climate change damages were associated with the climate case in which it was hotter in both winter and summer (DC<sub>1</sub>).

However, in both of these cases, MARKAL projected that electricity producers would add more capacity and shed very little to adapt to climate change and that this would be more costly. However, since the demand for electricity (for heating and cooling only) in the climate damage and the adaptation cases have changed compared to the Base Case, this reaction only added to the utility’s cost without creating any benefits. Thus, as shown in Table 3-6, the net benefits of adaptation were negative, but also very small – around one million Euros in both cases. Since the net benefits of adaptation were quite small and the climate change damages were relatively large in these two cases, the value of the residual damages that could not be avoided by climate change were also larger than climate change damages by one million Euros. Only the case in which it was projected to be colder in winter and summer (DC<sub>2</sub>, AC<sub>2</sub>) showed positive net benefits of adaptation. In this case, climate change damages were an order of magnitude smaller than the other cases (Table 3-6), but the benefits of adaptation were twice as large. In percentage terms, shedding capacity in this case along their long-run supply curves reduced climate change damages by about 22%, compared to less than 1% in the other two cases.

Table 3-6: Present value of total system cost for the Base Case and Damage Cases (EUR 10<sup>6</sup>)

Case/Scenario	System Cost Adaptation	System Cost Damage	Climate Change Damages	Net Benefits of Adaptation	Residual Damages
Climate Case 1	14,988	14,987	- 118	- 1	- 119
Climate Case 2	14,875	14,877	- 8.8	+ 2	+ 6.8
Climate Case 3	15,133	15,132	- 263.6	- 1	- 264.6

These results lead to the question: why is the projected system cost higher in two of the adaptation cost cases (AC1 and AC3) than in the corresponding climate change damage cases (DC1 and DC3), given that the climate changes were identical in each “pair” (DC1 with AC1 and DC2 with AC2) and that the system was constrained to operate with the same generating capacity in the climate change damage cases and the Base Case (but not the adaptation cases, where optimal capacity adjustments were allowed).

There are several possible reasons for this:

1. The internal cost accounting framework in MARKAL which allowed relatively large amounts of “variable capacity” to satisfy the growing demands in DC1 and DC2, but without changing the system’s capital cost, while all of the capacity changes in AC1 and AC2 did involve changes in capital costs, thus changing the system capital costs. This would lead to understating the magnitude of the climate change damages, likely raising them to the point where the avoided damages (adaptation benefits) would also be larger. This is the most likely cause.
2. The fact that the climate change damages were relatively small compared to the total system cost could mean that MARKAL is somewhat insensitive to small shocks, although if this were true, why would the cases DC2 and AC2 with the smallest demand increases turn out to have lower full adjustment costs in the adaptation case and then in the partial adjustment damage case?
3. The absence of price-sensitive electricity demand functions in MARKAL would make it possible (and even plausible) for the net adaptation benefits in AC1 and AC3 cases to be positive through the effect of increases in the price of electricity on consumer demand that would have differential effects on consumer and producer welfare.

All of these possibilities require further investigation.

## Conclusions

---

The main objective of this analysis was to use the MARKAL Model to assess the impacts of changes in outdoor temperatures due to climate change on the space heating demand for electricity in the country by residential and commercial customers. Part of this involved estimating both the economic value of climate change damages due to these changes in temperatures and the benefits and costs (or net benefits) of adaptation by changing the type and amount of generating capacity needed to cope with the changes in demand.

Since most of the climate change studies done in the country, to date, have focused on mitigation, the results of this analysis help to fill an important analytical gap. This study also sheds important new light on the physical and economic impacts of climate change on the Macedonian electricity generation sector, but it also raised a number of questions about how to use MARKAL to estimate the welfare impacts of climate change and the benefits and costs of adaptation. This was a first attempt and what was learned will be extremely important for preparing future assessments, including the Third National Communication to the UNFCCC and beyond.

The main results of this study are:

1. For the projected changes in temperature, the changes in space heating and cooling demands for electricity were relatively small in the early part of the projection period, but larger for the last ten or so years.
2. For the most likely climate change case (2) involving increases in winter and summer temperatures, the increase in summer space cooling demand dominated over the reduction in winter heating demand, and the net increase – though relatively small – grew larger over time.
3. The “worst case” in terms of climate change damages involved increases in summer temperatures and decreases winter temperatures (case 3), as would be expected.
4. Climate change damages as measured by increases in total system cost increased with the demand for electricity, over time, but were still relatively small.
5. Allowing the electricity supply system to adjust capacity “optimally” to climate change did not always reduce total system costs, which was the opposite of what was expected. In fact, in the two most relevant climate change cases, DC1/AC1 and DC3/AC3, relatively large amounts of capacity were added in the adaptation cases to cope with climate change, optimally, over time. Only in AC2 did adaptation reduce the damages in DC2, conforming to expectations.

## The Way Forward – Developing Future Capacity

This was a preliminary study, one of whose major aims was to look inside the analytical capacity of national institutions to estimate the economic impacts of climate change. The study demonstrated in a very positive manner that the tools and expertise to do this are, for the most part, already in place in terms of the expertise in the Macedonian Academy of Sciences and Arts and the MARKAL model. However, because the underlying capacity to assess the economic impacts of climate change on space heating and cooling demands does already exist, the results of this study provide national researchers with some important challenges for the future.

These future research challenges include:

1. **Adding Price-Sensitive Demand Functions to MARKAL.** The economic theory for this analysis, described in Annex I, show how changes in temperature can shift electricity demand curves and influence the market price of electricity. A full accounting of climate change damages and the benefits and costs of adaptation would include changes in both consumer and producer welfare. However, for this study, changes in electricity demands and prices were not calculated by the model to be an outcome of market processes. To do so would have required using the “Elastic” version of MARKAL, which allows the simulation of market clearing along downward sloping (price-sensitive) demand curves. This requires additional information about the demand curves for electricity in the country, which is not currently available, namely: the price elasticity of electricity demands in the different end uses and sectors in the model. To generate this information would require a competent economic statistician (“econometrician”) to collect information about electricity end uses and prices from a number of households and merge this with new survey information about the energy-using durable goods in commercial buildings. These data could then be used to estimate demand the parameters of “empirical” regression equations for individual end uses and aggregate electricity demand in both sectors. The information from this type of study would then feed into the MARKAL-ELASTIC model. However, the type of project needed to generate this type of information might take as much as 2-3 person years of full-time effort plus the expenses of a survey of 300-500 households and an equivalent number of commercial buildings. An interim alternative to this approach would be to use this version of MARKAL to conduct a sensitivity analysis of electricity consumption and production, climate change damages and the benefits and costs of adaptation to different assumptions about these price elasticities of demand, obtained from the literature. The capacity to do this currently exists in the country.
2. **Extending the MARKAL Planning Horizon Beyond 2030.** The results of this study showed that climate-driven increases in residential and commercial electricity demand will increase rapidly over time. This is consistent with the projections in Bergant (2006), which show substantially increased temperatures, especially in the summers, by 2050 and 2100. Extending the MARKAL model this far into the future involves a great deal of uncertainty with respect to the economic drivers of electricity demand and the state-of-the art in both generating and demand-side conservation technology. However, the fact that some forms of generation capacity, particularly hydro-electric plants, take a long time to build and



will operate far into the future will require some kind of advance warning built into the planning process if electricity demands increase very rapidly. A first-look approach to this problem would be to use the model in a “what-if” framework to evaluate future 30-year periods, for example 2030-2060 and/or 2060-2090, etc.), assuming a range of economic growth scenarios, but holding technological engineering parameters of the various generating technologies constant at today’s state-of-art. This would provide somewhat of an upper bound on climate change damages and a lower bound on the net benefits of adaptation and would be a useful to place to start investigating the potential for judging just how much capacity might be needed in the “distant” future to avoid developing too much or too little capacity in the near “future”. The capacity to do this type of analysis currently exists in the country.

3. **Make the Analysis “Comprehensive”.** This would involve adding two additional elements to the study. First, since renewable resources (hydro-electric, biomass-fired, and wind and solar electricity generating plants) are all likely to be influenced by climate change, these supply-side impacts should be included in the MARKAL Model analysis. Of these resources, hydro and biomass are, perhaps, the most important; hydro – because of the influence of climate change on runoff that provides the pressure to run the turbines that generate electricity and biomass because climate influences the net primary productivity (growth rates) of forests that will provide some of this biomass. At the current time, the capability to estimate the effects of climate change on runoff in catchments in the country using rainfall-runoff models does not exist. The capacity to estimate the impacts of climate change on the growth rates of different forest species and forests types exists for the Balkans, but the problem is that such studies are very long-term in nature and the results are highly sensitive to a number of factors, making it generally difficult to forecast changes in forest growth rates due to climate change alone. In fact, existing studies using state of the art vegetation models suggest that forests almost everywhere in Europe and North America are expected to benefit from the fertilizing effect of elevated CO<sub>2</sub> concentrations for the next 20 to 30 years before the drying effect of higher temperatures sets in (IPCC 2007). Second, since the country is embarking on an aggressive policy to mitigate GHG emissions, the impacts of these mitigation policies need to be factored into future climate damage and mitigation assessments. This would be done by adding annual or decadal GHG mitigation targets to the MARKAL model and allowing the model to achieve the optimal capacity mix and electricity output that maximizes the welfare of producers and consumers on the electricity sector and meets the mitigation targets. The capacity to do this currently exists.
4. **Adding Additional Adaptation Technologies on the Demand and Supply Sides of MARKAL.** MARKAL is a bottom-up model. This means that the supply-side and end-use technologies in the model are represented as activities which have input-output efficiencies, capacity limits, performance parameters and both fixed and variable costs both for generating and consuming electricity and for generating GHG. Adding more of these activities – the ones that are relevant to the country – increases the amount of potential adaptation and mitigation that can be simulated by the model; however, the activities that the model chooses as optimal for coping with climate change and/or meeting specific GHG targets are selected based on satisfying economic conditions.

- 5. Looking further into the Partial- and Full- Adjustment that was encountered in the Current Study.** In this study, allowing electricity producers to adjust their generating capacity to adapt to climate change, as opposed to holding this capacity fixed at Base Case levels, increased total system costs and this came as somewhat of a surprise. Some of the possible reasons have been listed and the finding out which is correct and explaining and/or fixing this phenomenon is well within the current capacity of national researchers, given additional investigations with the current version of the model.

On balance, then, extending the time horizon of the analysis (2), making it more comprehensive by including mitigation targets (3), adding additional supply- and demand-side adaptation and mitigation technologies, (4) dealing with the adaptation issue that appeared in this study, and perhaps adding electricity demand functions based on existing information about the general range of price-sensitivities of commercial and residential electricity demands, as reported in the literature, (1) are the main improvements that could be made to this analysis for the Third National Communication.

# The Economic Impacts of Climate Change on the Hydro-Electric Sector: A Case Study of the Mavrovo Hydro Plant

## Summary of Chapter 4:

### The Economic Impacts of Climate Change on the Hydro-Electric Sector: A Case Study of the Mavrovo Hydro Plant

This chapter examines the potential impacts of climate change on Macedonian hydropower production. Climate change is expected to have impacts on hydropower production due to a change in the quantity and distribution of rainfall and snow melt. The chapter examines the Mavrovo Hydro Plant system as a case study to examine possible impacts from climate change. Already, variability from year to year can result in drastic differences in hydropower production. Nationally, the levels of production can vary from 600 to 1650 GWh – depending on climate conditions. In the Mavrovo Hydro Plant system alone, the annual total system costs due to impacts from climate change are expected to be up to 2.54 million by 2050 and up to 7.14 million by 2100. This takes into account adaptation efforts to maximize power output from the entire energy system while minimizing costs. A number of shortcomings in analytical capacity were identified. The primary shortcoming was the lack of capacity to simulate the effects of climate variables – and subsequently climate change – on runoff in catchments. Improving this capacity would be a “no regrets” option as it would also assist in other water management issues.

## Introduction: Background and Objectives ---

**U**nderstanding the expected impact of climate change on water resources and subsequently hydropower resources is important for such country with a large hydropower sector. The treatment of the impacts of climate change on water resources in both the First and Second National Communications to the UNFCCC (2003 and 2008) is limited to a brief discussion of recent historical trends. This chapter includes additional analysis of the potential impacts of climate change on water resources as they relate to hydropower production.

The main objectives of this chapter are therefore:

1. To simulate how climate change will reduce power production in 2050 and 2100 from the Mavrovo hydropower plant (HPP) system; and
2. To try to value these impacts in terms of the additional cost imposed on the system by having to meet the same level of energy demand despite reductions in hydropower generation capacity.

The hydropower sector was targeted for investigation because hydro-electric generation already makes a significant contribution to the national power supply and more plants are scheduled to be built to keep up with the fast-growing demand in the future. In addition, there were good models, data and analytical capacity to simulate the hydrologic operation and power generation aspects of the Macedonian hydro system and other power plants in the larger Macedonian energy supply system.

## Methods for Valuing the Economic Impacts of Climate Change on Hydro-Electric Power Generation in the country<sup>12</sup>

In this study, there are at least four important linkages and sets of relationships that have to be characterized in order to simulate the economic impacts of climate change on hydro-electric power generation. These include:

1. The relationship between changes in temperature and precipitation on runoff into the hydropower reservoirs;
2. The relationship between changes in runoff and reservoir storage (water elevation);
3. The relationship between changes in storage (water elevation) and power generation; and
4. The relationship between changes in hydro-electric power generation and the cost and supply of additional power from other generating units in the system.

Items 1-3 are explored in Box 4-1.

### Box 4-1: Important characteristics of hydropower related to climate, runoff and water availability

Before delving into the analysis of climate change's impact on hydropower, it is useful to point out a few important characteristics of hydropower related to climate, runoff and water availability, as described below:

**Changes in temperature and the amount, type and timing of precipitation will affect runoff into a hydro reservoir.** A reduction in precipitation and an increase in temperature (as projected in this case) will reduce runoff, as will a reduction in precipitation (unless the loss in precipitation is offset by a reduction in evaporation through cooler temperatures).

**A change in the type of precipitation (rain vs. snow) will affect the timing of the peak runoff season.** Water stored as snow takes longer to melt and become runoff, than precipitation does.

**Storage reservoirs act as a dynamic filter for runoff.** The amount of storage increases as runoff increases, but at some point the maximum capacity of the reservoir is reached and the operators will have to release water. Alternatively, reservoir operators in the country must release water (or let runoff pass through the reservoir) to maintain storage for flood flows.

<sup>12</sup> This section is based on information gathered for a previous study by Callaway, et al. (2010), dealing with the economic impacts of climate change in Montenegro.

**Multi-purpose reservoirs, where the timing of water supply and demand is also attenuated further, complicate the operational problem.** This is because storage for these uses can compete with storage for hydro-electric generation.

**In general, operators have specific preferences for water elevations given different circumstances.** They will want the water in the dam to be at relatively high water elevations (to provide more kinetic energy to drive turbines) when electricity is in high demand and lower water elevations when there is less demand.

**Finally, one must account for the economic “balancing” of the system, either (or both) in the short-run and/or the long-run:** In the short-run, the capacity of the generating and distribution system is fixed, so that decisions about how to make up for power losses are based on short-run marginal costs. In the long-run, investment in new capacity and distribution is variable and the balancing is based on equating long-run marginal costs with expected economic benefits. It is from these economic calculations that estimates of climate change damages can be computed.

What kind of models and data are needed to characterize these relationships and estimate the economic damages of climate change due to the impacts of climate change on runoff into hydro reservoirs? And what are the possibilities for using these approaches in the country, given the current capacity of national experts and institutions to estimate the economic losses due to climate change?

The following types of models would need to be used to conduct a complete analysis to estimate the economic impacts of climate change on the hydro-electric sector due to climate change:

- A rainfall-runoff model to convert changes in temperature and precipitation into runoff into system reservoirs;
- A reservoir operation model in the form of a so called “hydro economic model” or more traditional, systems simulation model to determine when and how much water to release through the hydro turbines to generate electricity; and
- An energy sector model to simulate electricity production from all units in the country and imports to local and export demands.

## Rainfall-Runoff Models and Hydro-Economic Models

**Rainfall-runoff models** simulate the effects of weather and climate on river discharges over an entire catchment or larger river basin. To calibrate these models to a single catchment requires observed data on discharges at gauging stations, recorded precipitation and temperature at weather stations and other information on the morphological and geophysical characteristics in a catchment or a larger basin. This information makes it possible to set certain parameters of physically-based relationships needed to simulate the effects of weather and climate on runoff for a specific reservoir.

**Hydro-economic models** take this information about runoff and other information about the impacts of climate change on reservoir storage and on the demand for water and simulate the operation of the reservoir and conveyance system in the basin over time and space. The models can then use this information to maximize the net economic returns due to water use under alternative allocation systems. The number and type of water uses in the model can vary depending on the situation.

These two types of models are discussed in greater detail in Annex II.

Hydro-electric generating plants are easily encompassed in this framework. The amount of power that can be generated from a given plant over a given period of time is based on the initial storage at the start of the period, on the change in storage over the period and on the capacity and other operating parameters of the plant.

Hydro-economic models are always built from the bottom-up, using a unique approach for every basin and they require a fairly good knowledge of optimization modelling techniques to build them. However, in recent years, several new modelling systems have been developed to do physical basin modelling for policy purposes that are much easier to build due to very user-friendly geo-referenced interfaces.

One of these is the **Water Evaluation And Planning model (WEAP)**.<sup>13</sup> It would be relatively easy to set up WEAP to model all of the individual hydro-plants and reservoirs in the country in order to estimate the economic impacts of changes in runoff due to climate change. It would also be possible to estimate climate change damages and the costs and benefits of some type of adaptation options, under somewhat restrictive economic assumptions about electricity demand. An advantage of WEAP is that it is easy to modify the characteristics and location of hydro plants and demand levels, as well as a number of other parameters. It is also very easy to play “what if” games to test various assumptions. Accordingly, it is being more and more widely used in climate change studies and is currently being used by the World Bank to conduct a large scale water resource assessment of the impacts of climate change on the country agriculture.<sup>14</sup>

## Hydro-Generation and Energy Sector Models

Both hydro-economic models and WEAP-like models could be developed and used to simulate the effects of climate change on investment and operation of hydropower plants in the country. However, neither of these types of models could be used to determine how this would affect investment and operation of other power plants in the country. To do this would require an energy model of the national power system as a whole.

There are basically two kinds of models that can be used for this purpose: short-run and long-run models. The difference is that short-run electricity system models simulate the operation of the system over hourly, daily or monthly periods with its generating capacity and distribu-

<sup>13</sup> <http://www.weap21.org/index.asp?doc=04>

<sup>14</sup> See Strzepek 2011

tion system fixed. Whilst long-run models can do this (usually at a larger time step) and they can also simulate investment in new capacity and distribution.

The country has both kinds of models. The short-run model, **OPTimization Model (OPTIM)** (Causevski and Bosevski, 2003 and 2004), is very interesting because it simulates the operation of all hydro-reservoirs and associated hydropower plants and run-of-river hydropower plants in the country on variable time steps, as short as an hour over a period of one year. It also simulates the operation of all other types of power plants (thermal, fossil fuel). In the model, the hourly and daily loads over the year are fixed and the model decides which plants satisfy the load based on available and expected generating capacity and minimum total cost. The model is somewhat unique in that it includes, jointly, the hydrologic operation of the reservoir, along with power production from all generating resources. It should be noted, however, that while it is possible to adjust basin runoff into the various hydropower reservoirs in the system, the OPTIM model cannot simulate the climatic and hydrologic processes that govern runoff itself.

The long-run model available to national experts is the MARKAL model, which was used in the previous chapter covering the economic impacts of climate change due to changes in the climate-driven demand for space heating and cooling. MARKAL is a multi-year model that runs on a monthly time step. It can be used to determine the retirement of existing plants, the distribution infrastructure and the long-run cost-minimizing mix of generation and distribution resources that will replace the older units to meet future electricity demands. MARKAL also simulates monthly power production by each of the generating units that are available. While it does contain a hydro-electric generating sub-sector, the available maximum capacity of the hydro plants in each month of the planning period must be based on information obtained from OPTIM.

## Evaluating the Capacity to Estimate the Economic Losses due to Climate Change in the Hydro-electric Generation Sector

The capacity of experts and institutions to estimate the economic losses due to climate change in the energy sector, with a special focus on providing additional water for power generation to adapt to climate change, can be broken down into the following parts:

- Capacity to simulate the effects of climate change on runoff;
- Capacity to simulate the joint hydrologic operation of the reservoir and power production by a hydro-electric power plant (HPP);
- Capacity to optimally “balance” energy supply and demand across the entire generating system; and
- Capacity to estimate the value of the climate change damages due to changes in runoff and the benefits and costs of adaptation measures to avoid some of these damages.



## **Capacity to Simulate the Effects of Climate Change on Runoff**

MIKE SHE is an advanced integrated hydrological modelling system that simulates water flow in the entire land-based phase of the hydrological cycle from rainfall to river flow, via various flow processes such as, overland flow, infiltration into soils, evapotranspiration from vegetation, and groundwater flow. According to various actors, some initial capacity was built to calibrate and use the MIKE SHE model in the country. However, this initial capacity appears to have been lost.

Therefore, there is no systematic way to relate changes in temperature and precipitation at any time step or scale to runoff. Several local experts attributed the failure to use the MIKE SHE model to the poor quality of the climate and discharge data needed to calibrate the model and to the fact that the hydrology of many catchments areas (high elevation with steep slopes and very high energy discharges) made it difficult to calibrate the model. These issues need to be further investigated.

## **Capacity to Simulate the Joint Hydrologic Operation of Hydro-Reservoirs and Power Production by an HPP**

This capacity exists in the form of OPTIM, which is currently maintained and used by various faculty members of the Macedonian Academy of Sciences and Arts. The model has been undergoing a series of refinements that have been published and was recently used in the Second National Communication to the UNFCCC to investigate how the country could reduce GHG emissions by increasing the capacity of renewable resources, including hydro-electric plants, to displace fossil fuel plants.

## **Capacity to Optimally Balance Energy Supply and Demand across the Entire Generating System**

This capacity also exists in the form of OPTIM, which is a short-run model of the Macedonian electricity generating system, and MARKAL, which can function as either a short- or long-run model, depending on how investments in new generating and distribution capacity are treated. The OPTIM model can be used to supply information about the capacity of the hydro system (based on hydrologic conditions) to the MARKAL model. Both models are maintained at, and used extensively by, members of the Faculty of Electrical Engineering & Information Technology in Skopje and of the Macedonian Academy of Sciences and Arts.

## **Capacity to Estimate the Economic Value of Climate Change Damages and the Adaptation Benefits and Costs of Avoiding some of these Damages**

Both the OPTIM and the MARKAL models are least-cost optimization models with exogenous prices. Neither model incorporates the downward sloping demand functions of consumers

for energy service, or for energy (the demand which is derived from the demand for energy services). However, both models can provide estimates of these metrics consistent with the assumption of a cost minimizing producer. In the case study that follows, measures of replacement cost and the change in total system cost were used to approximate climate change damages and were compared. This is not exactly correct, but more theoretically correct measures of changes in short-run profits were hard to develop from the model output data bases. This, hopefully, can be remedied in the near-future.

## The Mavrovo Case Study

---

Existing hydropower plants in the country, with a capacity of around 581 MW, currently supply from 10 to 20 per cent of annual average energy consumption in the country, depending on energy demand and hydrologic conditions. Of the existing HPPs, roughly 94 per cent of the generating capacity comes from seven large hydropower plants, while the remaining 6 per cent comes from 10 small hydropower plants. With an expected average annual growth rate in energy demand of about 2.5 per cent, the country has plans to add six new large HPPs with a total installed capacity of 690 MW. However, these plans have not factored in the effects of long-term climate change on hydropower generation potential of existing and new plants due to future reductions in the magnitude and seasonal distribution of runoff due both to reduced precipitation and higher temperatures, especially in the second half of the century (Bergant 2006).

In that context the purpose of this study was to try to analyse the impact of future changes in precipitation on runoff and the resulting impact on power generation. Presumably, decreases in precipitation and higher temperatures will reduce runoff available to the HPPs and this, in turn, will result in reduced water storage and pressure head to drive the generating turbines, resulting in reduced capacity to produce electricity. In this case, the lost generation will have to be replaced by either imported electricity or electricity generated by other types of power plants, principally coal- and oil- or natural gas-fired plants.

To look at this set of issues, it was decided to focus the investigation on the hydro system. Mavrovo, and apply what was learned in this analysis to help improve the capacity of national experts to do more thorough studies in the sector.

The Mavrovo energy system was selected for this exploratory study for several reasons:

- The system is the largest in the country, consisting of three HPPs and a large storage reservoir.
- The hydrology and geomorphology of the Mavrovo basin is fairly typical of existing and potential hydro sites.
- A simulation model of the Mavrovo system is available for use by the project.

The Mavrovo hydro system (See Box 4-2) is composed of three HPPs (Vrutok, Raven and Vrben), which together have an installed generating capacity of around 200 MW, representing about 35 per cent of the country's total hydro-electric generating capacity. The total contribution of the Mavrovo hydro energy system to average annual electricity production in the country is around 488 GWh, or almost 34 per cent of the whole hydro generation.

### Box 4-2: The Mavrovo System

Figure 4-1 is a schematic diagram of the Mavrovo system, which was originally constructed in the 1950s. As shown, the Mavrovo complex is a cascade system. The first plant in line is HPP Vrben, which is rated at 12.8 MW. After passing through the Vrben powerhouse, runoff is discharged into Mavrovo Reservoir. This is a large, multi-year, storage reservoir with an average annual capacity of 270 million m<sup>3</sup>. It receives most of its runoff from catchments in the Shara Mountain region. Water that is released from the Mavrovo reservoir then travels by gravity to HPP Vrutok (150 MW) and from there to HPP Raven (19.2 MW). The discharge from the Raven power house flows into the River Vardar that flows through Skopje. The system is interconnected through power lines to the national power grid.

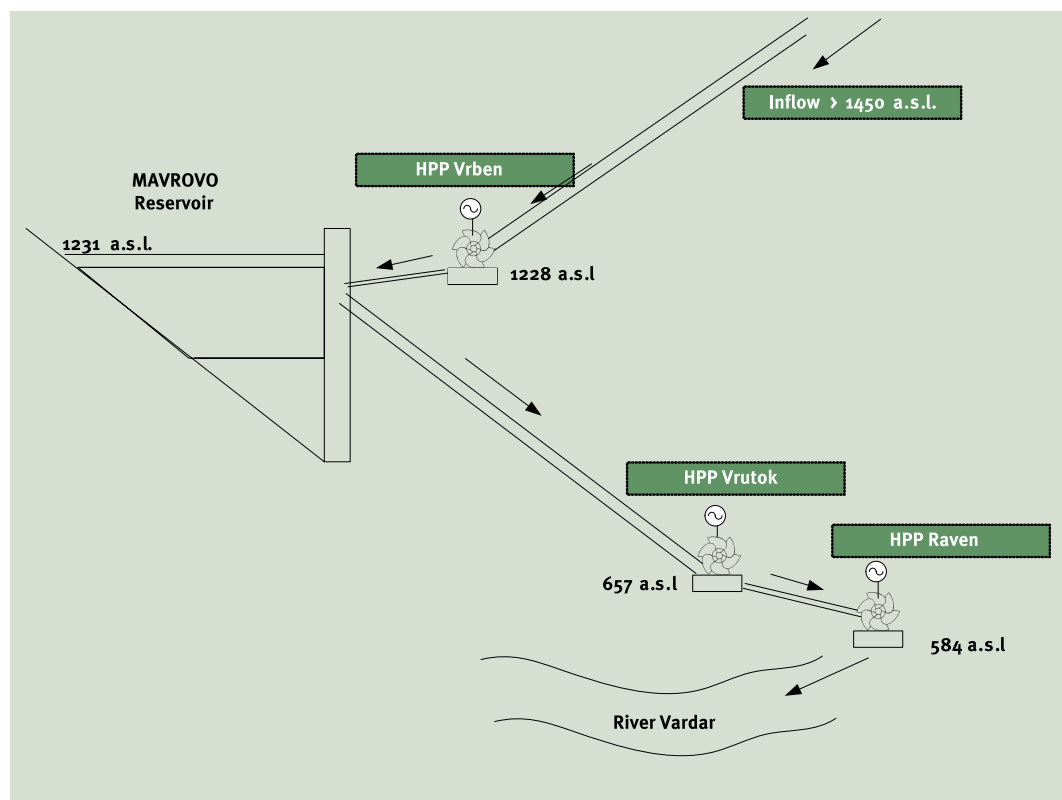


Figure 4-1: Schematic Diagram of Mavrovo Hydroelectric Generating System

## Models, Methods and Data

The model used in this exploratory study case – OPTIM – was originally developed by Bosevski and Causevski (1996) and has undergone a number of new developments over the years, as documented in Janíček et al. (2008). It is a dynamic optimization model of a complex electric power system, including hydro-electric generation and all other generating resources. The objective of the model is to manage the hydro system such that least-cost energy is used to meet the hourly electricity demand, taking into account the operating conditions of the power generating stations. The model includes energy balancing, the power balancing in each time interval, as well as water balancing for the hydropower plants.

The Methodology for this study consisted of three parts:

- Developing Base Case data;
- Introducing climate change in the analysis; and
- Estimating the economic value of climate change damages.

## Base Case

The purpose of the Base Case analysis was to establish a reference for runoff and power generation that coincided with current climatic conditions and to establish the electrical loads that the system would have to meet in the present and the future. For this analysis, climate change impacts on electricity supply, as presented in Chapter 3, were not taken into account. The load profile for electricity demand in the country is based on historical consumption patterns obtained by using the database for historical consumption (see Figure 4-2).

### **Box 4-3:** **Load Profile for electricity demand in the country**

The load profile for electricity demand in the country is based on historical consumption patterns obtained by using the database for historical consumption. The base year is 2010 where the annual electricity needs are 9500 GWh and peak load (in December) is 1700 MW. The projected electricity needs for the period until 2100 can be divided into 3 scenarios depending on growth rate: low, medium and high growth. The growth rate and annual electricity demand for three scenarios are shown in Figure 4-2. The growth rates used in these projections are larger until 2030 (1.5, 2.0 and 2.5%) and after that the growth rates are smaller until 2100 (1.0, 1.5 and 2.0%). These predictions are made based on economic development studies for the country and on the national energy strategy of 2010.

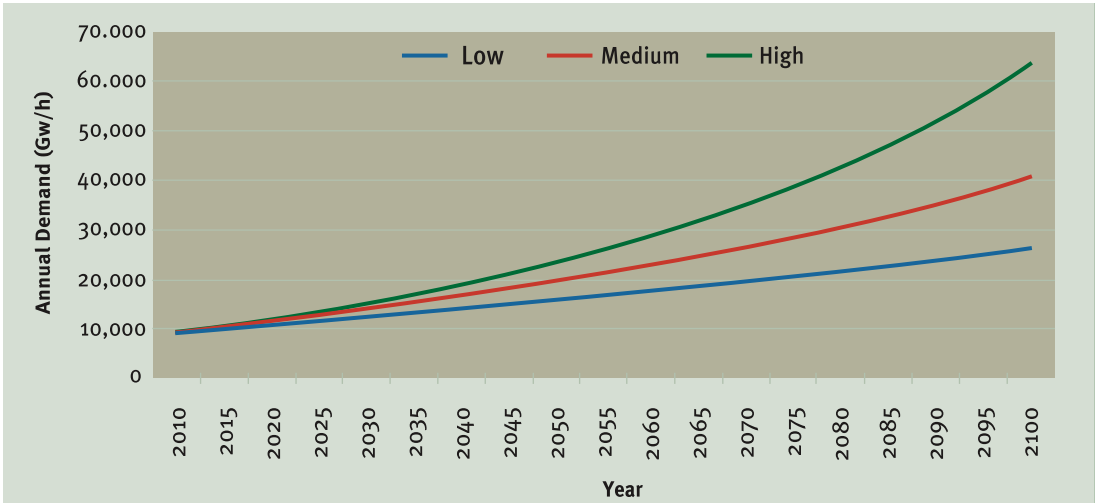


Figure 4-2: Projections of Annual Electricity Demand for 2050 and 2100

The Base Case climate was assumed to remain constant over all periods (current, 2050 and 2100). The calculation of the electricity generation of each HPP is based on water inflow (run-off) and other parameters. The databases of all HPPs consist of average monthly inflow for the period from 1946 until 2007. Based on the water inflow of around 60 years, the inflows are divided into 3 hydrology representatives:

- Representative of dry hydrology (low runoff) with 14 % of the driest years;
- Representative of average hydrology (average/medium runoff) with 74 % of the average years; and
- Representative of wet hydrology (high runoff) with 12 % of the wettest years.

The representative of the dry, average and wet hydrology years is made with the water monthly database of each HPP sorted by ascending order of the average yearly inflow. Figure 4-3 gives the representatives for the minimum, medium and high runoff for the entire system.

**Base Case Runoff for Mavrovo Reservoir for High, Medium and Low Precipitation Conditions**

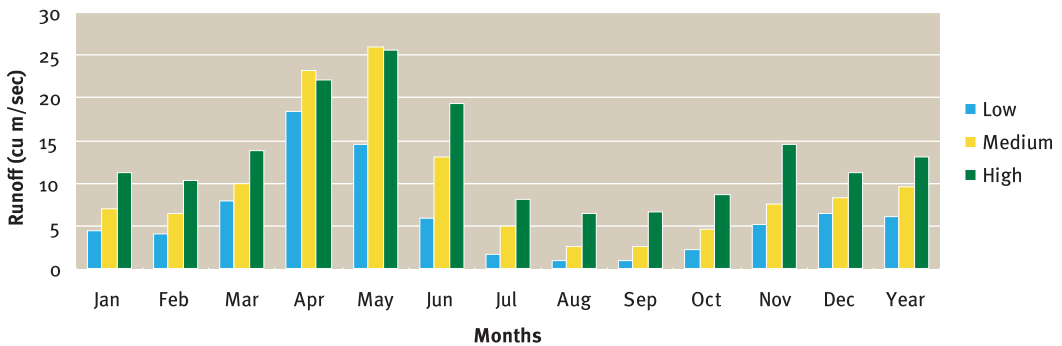


Figure 4-3: Monthly runoff for the Base Case (Current Climate) for low, average (medium) and high precipitation Conditions

## Results for Climate Change Analysis: Runoff and Electricity Generation

To introduce climate change into the analysis, it is necessary to change the runoff available to the Mavrovo part of the electricity supply system in the model. To project the runoff for the Mavrovo hydro system one must take into account the fact that the Mavrovo hydro system is located on north-western part of mountain region where the main water comes from melting snow of Shara Mountain. This means that the runoff season for the Mavrovo reservoir in the spring (April, May and June) is due largely to snow melt, while runoff in winter period (from December until March) is mainly from snow precipitation as precipitation and not snow melt. The runoff for other periods of the year is mainly from rainfall.

Following Bergant (2006), the closest meteorological station to the Shara Mountain watersheds is the Popova Sapka weather station, located in a sub-alpine climate. The projected runoff values for 2050 and 2100 for the low, average/medium, and high precipitation conditions were determined by normalizing the changes in precipitation at this site (as projected by Bergant) and applying these percentage changes to runoff<sup>15</sup>.

### Climate Change Impacts on Runoff

The runoff projections for the three sets of precipitation conditions share three things in common. First, runoff in March, April and May is projected to increase (or at least not decrease) in 2050 and 2100 relative to the Base Case. Since the amount of runoff that occurs during this period is larger than for any other 3-month period during the year, this increase will have a substantial positive impact on both inter- and intra-annual reservoir storage. Second, projected runoff in all of the remaining months is reduced by climate change in 2050 and 2100 relative to the Base Case. Finally, the net effects of these changes in runoff on average monthly and annual runoff are most severe under low precipitation conditions and least severe under high precipitation conditions. In fact, the projected change in average monthly and annual runoff is actually positive for 2050 under high precipitation conditions. This makes sense, because the dryer the soil, the lower the percentage of precipitation that becomes runoff and the higher the percentages that infiltrate the soil and are evaporated or percolate to groundwater.

#### **Box 4-4:** **Results for the Climate Change Analysis: Runoff**

The projected runoff changes for 2050 and 2100 are shown below for the low runoff scenario (Figure 4-4), the average/medium runoff scenario (Figure 4-5), and the high runoff scenario (Figure 4-6). The Base Case values are shown in each of the projections for the case of comparison.

<sup>15</sup> The preferred method would have been to use a rainfall runoff model as discussed previously in this chapter. But no such model available was available to the study and the local capability to calibrate such a model is extremely limited.

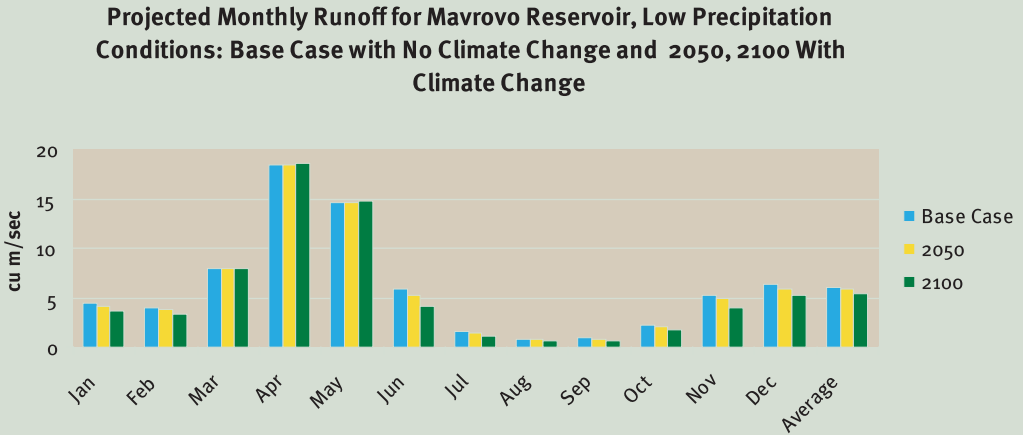


Figure 4-4: Monthly Runoff for Mavrovo Reservoir for Low Precipitation Conditions in 2050 and 2010 (With Climate Change) Compared to the Base Case (Without Climate Change)

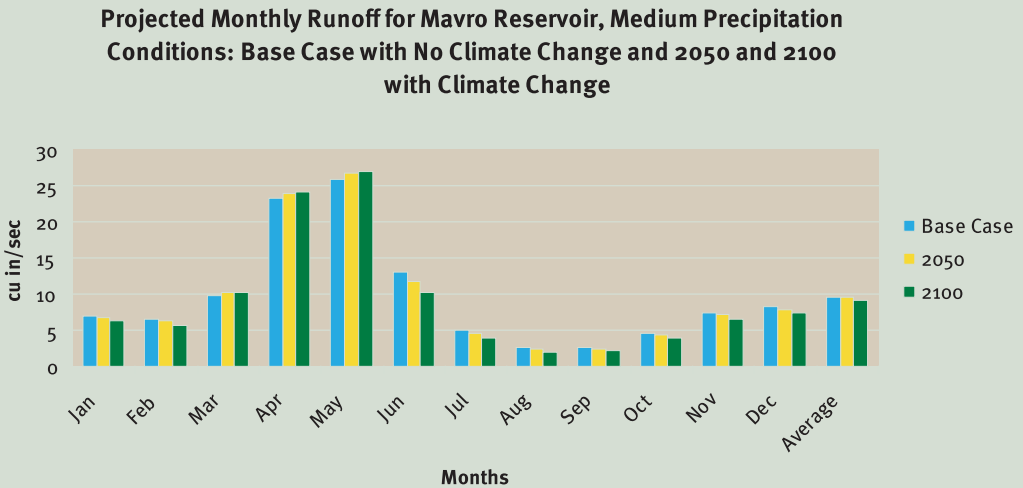


Figure 4-5: Monthly Runoff for Mavrovo Reservoir for Medium Precipitation Conditions in 2050 and 2010 (With Climate Change) Compared to the Base Case (Without Climate Change) (m<sup>3</sup>/sec)

**Projected Monthly Runoff for Mavrovo Reservoir, High Precipitation Conditions: Base Case with No Climate Change and 2050 and 2100 with Climate Change**

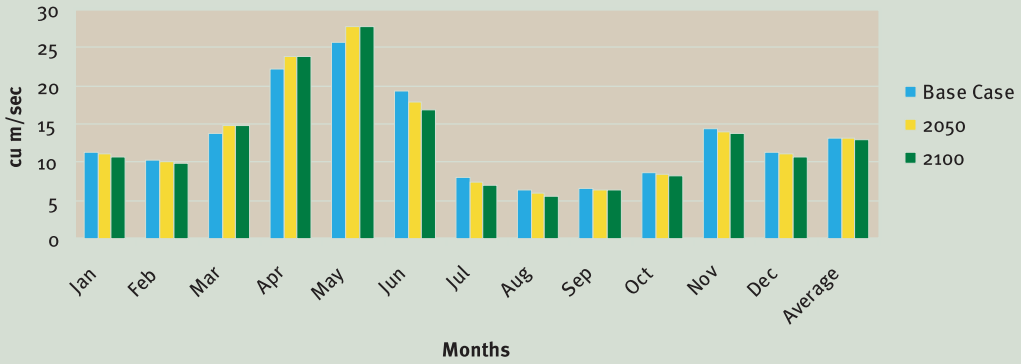


Figure 4-6: Monthly Runoff for Mavrovo Reservoir for High Precipitation Conditions in 2050 and 2100 (With Climate Change) Compared to the Base Case (Without Climate Change)

Table 4-1: Projected Runoff for Low, Medium and High Precipitation Conditions for the Base Case (No Climate Change) and 2050 and 2100 (With Climate Change)

Case	Monthly Average Runoff (m <sup>3</sup> /sec)	% Change
<b>Low</b>		
Base	6.03	--
2050	5.81	-3.53%
2100	5.45	-9.58%
<b>Medium</b>		
Base	9.66	--
2050	9.51	-1.52%
2100	9.12	-5.56%
<b>High</b>		
Base	13.15	--
2050	13.24	0.63%
2100	12.96	-1.45%



## Climate Change Impacts on Electricity Generation

Box 4-5 shows the results of expected changes to power generation due to climate change under various precipitation scenarios. Within each precipitation condition scenario, the results for power generation fairly closely mirror the pattern of runoff changes for the medium and high precipitation conditions. That is: there is either no decrease or a small increase in power generation during the March-May period in 2050 and 2100, relative to the Base Case, and small reductions in the remaining months. This is due to the fact that the main impacts of climate change in these two scenarios are to change the seasonal distribution of runoff and reservoir operators are able to change reservoir operation sufficiently to accommodate for these changes. However, under low precipitation conditions, there are decreases in power generation in all of the months in 2050 and 2100 relative to the Base case. Furthermore, under low precipitation conditions, the ability of the hydro system to meet the April and May peaks in all periods is less than for the other two sets of precipitation conditions. Under climate change, this gap is exacerbated for low precipitation conditions. However, under medium precipitation condition, the system does not have to reduce power generation in 2050 or 2100 relative to the Base Case and under high precipitation conditions; the system can actually increase power generation under the projected climate changes in 2050 and 2100.

### Box 4-5: Results for the Climate Change Analysis: Power Generation

The projected changes in hydro-electric power generation for 2050 and 2100 are shown below for low precipitation conditions (Figure 4-7), average/medium precipitation conditions (Figure 4-8), and for high precipitation scenario (Figure 4-9). These results are tabulated and the changes in electricity generation are shown in Table 4-2. The Base Case values are shown in each of the projections for the case of comparison.

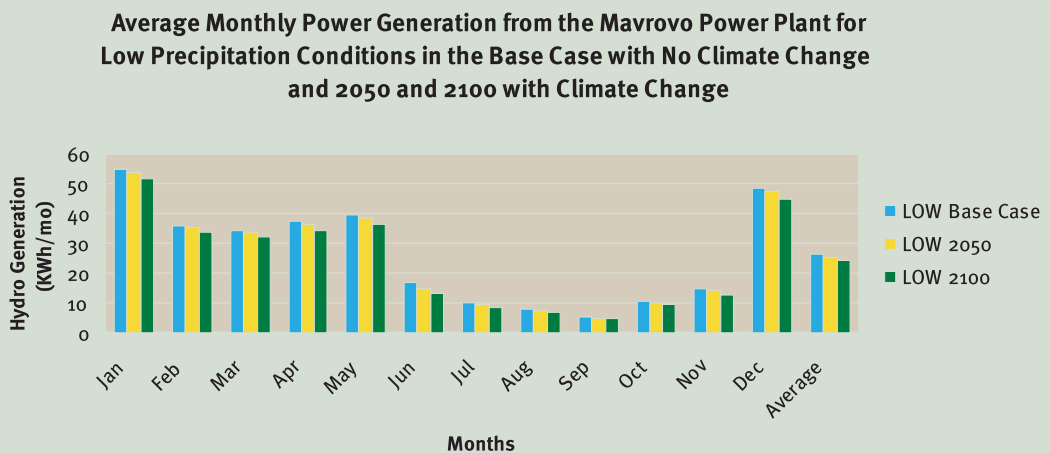


Figure 4-7: Monthly Hydro-electric Power Generation for Mavrovo for Low Precipitation Conditions in 2050 and 2010 (with Climate Change) Compared to the Base Case (without Climate Change) (GWh/month)

**Average Monthly Power Generation from the Mavrovo Power Plant for Medium Precipitation Conditions in the Base Case with No Climate Change and 2050 and 2100 with Climate Change**

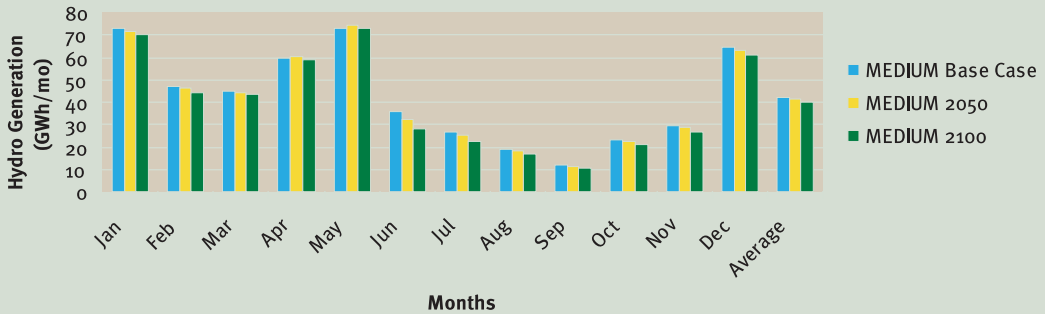


Figure 4-8: Monthly Hydro-electric Power Generation for Mavrovo for Medium Precipitation Conditions in 2050 and 2100 (with Climate Change) Compared to the Base Case (without Climate Change)

**Average Monthly Power Generation from the Mavrovo Power Plant for High Precipitation Conditions in the Base Case with No Climate Change and 2050 and 2100 with Climate Change**

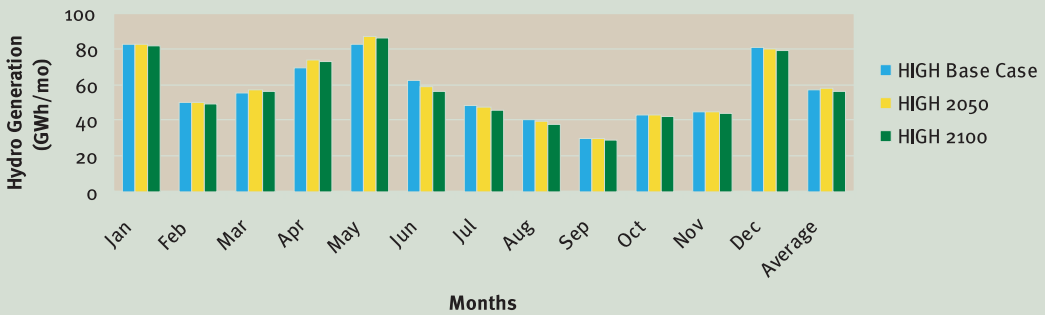


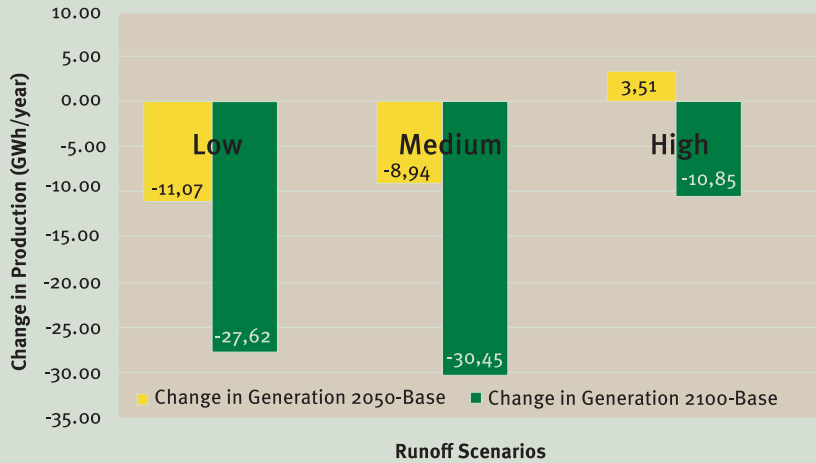
Figure 4-9: Monthly Hydro-Electric Power Generation for Mavrovo for High Precipitation Conditions in 2050 and 2100 (with Climate Change) Compared to the Base Case (without Climate Change)

Table 4-2: Projected Hydropower Generation for Low, Medium and High Precipitation Conditions for the Base Case (With No Climate Change) and 2050 and 2100 (With Climate Change)

Case	Monthly Average Power Generation GWh	Annual Average Power Generation GWh	% Change
<b>Low</b>			
Base	26.28	315.32	--
2050	25.35	304.25	-3.51%
2100	23.98	287.70	-8.76%
<b>Medium</b>			
Base	42.22	506.62	--
2050	41.47	497.69	-1.76%
2100	39.68	476.18	-6.01%
<b>High</b>			
Base	57.37	688.39	--
2050	57.66	691.91	0.51%
2100	56.46	677.54	-1.58%

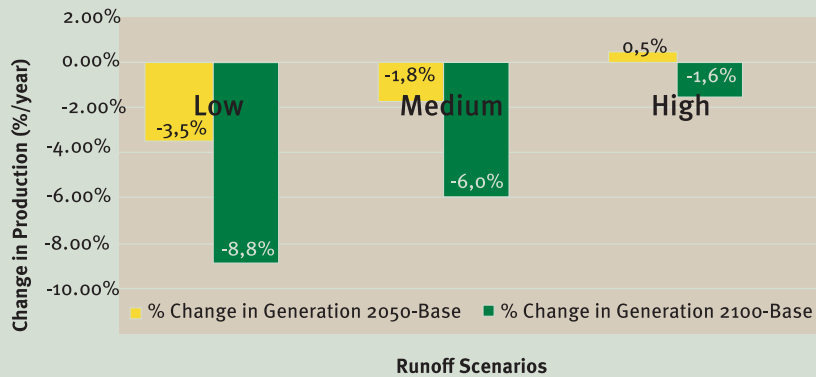
The projected changes in average annual hydro-electric generation by Mavrovo for 2050 and 2100, under climate change, compared to the Base Case, are shown in Figure 4-10 and in Figure 4-11 (derived from the results in Table 4-2). The first figure – Figure 4-10 – shows the changes in power production in GWh, relative to the Base Case, and the second one – Figure 4-11 – shows the relative changes in percentage (%) compared with base case scenario.

**Change in Annual Electricity Generation from Mavrovo Power Plants for the High, Medium and Low Climate Projections in 2050 and 2100 Compared with Base Case with no Climate Change**



**Figure 4-10: Change in Annual Hydro-Electric Power Generation for Mavrovo for Low, Medium and High Precipitation Conditions in 2050 and 2100 (with Climate Change) Compared to the Base Case (without Climate Change) in GWh**

**Change in Annual Electricity Generation from Mavrovo Power Plants for the High, Medium and Low Climate Projections in 2050 and 2100 Compared with Base Case with no Climate Changes (%)**



**Figure 4-11: Change in Annual Hydro-Electric Power Generation for Mavrovo for Low, Medium and High Precipitation Conditions in 2050 and 2010 (with Climate Change) Compared to the Base Case (without Climate Change) in percentage (%)**

## Results for Climate Change Damages

Two approaches were used to value the climate change damages due to runoff reductions at the Mavrovo hydro-electric power system. The first approach was simply to calculate the cost of replacing the hydropower production that was lost in 2050 and 2100 relative to the Base Case, using the cost of replacing this power from different types of power plants. This was done using the annualized life-cycle cost data for different types of electricity generation plants.

### *Results for Climate Change Damages Analysis*

Two approaches were used to value the climate change damages due to runoff reductions at the Mavrovo hydro-electric power system. The first approach was simply to calculate the cost of replacing the hydropower production that was lost in 2050 and 2100 relative to the Base Case, using the cost of replacing this power from different types of power plants. This was done using the annualized life-cycle cost data in Table 4-3 for different types of electricity generation plants.

Table 4-3: Annualized Life-Cycle Generation and Total Cost Estimates for Different Types of Power Plants in FYR Macedonia in 2010

Plant Type	Generation Cost (EUR/kWh)	Total Cost (EUR/kWh)
Coal-Fired	0.04	0.100
Gas-Fired	0.058	0.118
Nuclear	0.053	0.115
Import	>0.055	>0.115
Wind Power	0.089	0.152
PV Systems	0.260	0.350

Source: National Energy Plan, 2009

It must be mentioned that the prices for renewable (both wind and PV in the last rows) reflect feed-in tariffs (beneficial prices) which are much higher than the regular commercial price – though this commercial price is expected to rise dramatically in the coming decade as current commercial prices do not reflect the economic price. Two estimates were used to bound the cost of replacing the power that is lost as a result of reduced runoff due to climate change, generation and total cost. The Generation Cost includes investment, fuel and operating and maintenance costs. Total cost includes the generation cost plus the transmission and distribution cost. The replacement cost results are presented in the text.

The OPTIM was used to simulate reservoir management and power production at Mavrovo and at all of the other HPP sites and for all of the other fossil fuel-fired plants in the country in the Base Case and 2050 and 2010 with and without climate change (changes in runoff). In

general, the reductions in power generation by the Mavrovo system were surprisingly small in comparison to the Base Case (No climate change), but were largest in relative terms for the dry precipitation conditions when there were both changes in the type and seasonality of precipitation and also sharp reductions in precipitation and runoff in the runoff season.

The relative changes in power production by the Mavrovo system depended on the nature of the precipitation conditions for which the reductions in runoff were projected. Under the driest conditions, the projected reductions in average monthly power production were about 3.5 per cent in 2050 and about 8.8 per cent for 2100, compared to the Base Case, whereas the comparable projected changes in power production at Mavrovo under high precipitation conditions were an increase of about 0.5 per cent for 2050 and a reduction of about 1.6 per cent for 2100.

Two different approaches were used to value the annualized climate change damages in 2050 and 2100 associated with these reductions:

The first approach was to assume that the reductions in power, relative to the Base Case, were replaced 1 for 1 with production from either coal- or gas-fired, or nuclear plants – then again by replacing the production with that from renewable energy sources. For this approach, the projected annualized value of climate change damages for 2050 ranged from a benefit of about EUR 140,000 per year to a cost of about EUR 1.3 million per year, depending on the type of power plant and precipitation conditions. For 2100 these projections ranged from a cost of EUR 575,000 per year to about EUR 3.6 million per year. For the replacement with renewables, the same amount of reduced electricity can reach a cost of nearly EUR 10 million. The replacement cost from renewable is much higher comparing with the same ones from base load conventional power plants, mainly because of relatively higher production and feed-in tariffs for renewables.

The estimated climate change damages for replacing lost production with traditional sources of power are shown in Table 4-4. The estimated climate change damages for replacing lost production with renewable energy sources are shown in Table 4-5.

Table 4-4: Annualized Cost (10<sup>6</sup> EUR/year) of Replacing Lost Hydropower Production due to Climate Change with Coal, Gas and Nuclear Alternatives

Precipitation Condition	2050		2100	
	Generation	Total	Generation	Total
<b>Coal</b>				
Low	-0.443	-1.107	-1.100	-2.751
Medium	-0.358	-0.894	-1.218	-3.045
High	0.141	0.352	-0.434	-1.084

Precipitation Condition	2050		2100	
	Generation	Total	Generation	Total
<b>Gas</b>				
Low	-0.642	-1.306	-1.596	-3.246
Medium	-0.519	-1.055	-1.766	-3.593
High	0.204	0.415	-0.629	-1.279
<b>Nuclear</b>				
Low	-0.587	-1.273	-0.575	-3.164
Medium	-0.474	-1.028	-1.614	-3.502
High	0.187	0.405	-0.575	-1.247

Table 4-5: Annualized Cost ( $10^6$  EUR/year) of Replacing Lost Hydropower Production due to Climate Change with Renewable Energy Alternatives

Precipitation Condition	2050		2100	
	Generation	Total	Generation	Total
<b>Wind Power</b>				
Low	-0.985	-1.683	-2.458	-4.198
Medium	-0.796	-1.360	-2.710	-4.629
High	0.312	0.534	-0.965	-1.649
<b>PV systems</b>				
Low	-2.879	-3.875	-7.180	-9.666
Medium	-2.326	-3.131	-7.918	-10.659
High	0.913	1.229	-2.820	-3.797

The second approach was to calculate the change in total system cost, as estimated by OPTIM, associated with the changes in generation in 2050 and 2100 relative to the Base Case. For the total system cost approach to estimating climate change damages, the projected annualized climate change damages for 2050 were losses of about EUR 1.2 to 2.5 million per year and EUR 4 to 7.1 million per year for 2100. The systems cost estimate is probably preferable, since it captures all of the disaggregated power substitutions, such as in base and peak-load that are covered up by the more aggregate replacement power cost approach. The results are shown in Table 4-6.

Table 4-6: Projected Increase in Annualized Total System Cost in 2050 and 2100 due to Reductions In Runoff from Climate Change for Mavrovo Hydro System Under Low, Medium and High Precipitation Conditions

Precipitation Conditions	2050-Base (10 <sup>6</sup> EUR)	2100-Base (10 <sup>6</sup> EUR)
Low	2.540	7.140
Medium	1.210	4.010
High	2.070	5.380

The estimated value of the climate change damages shown for the system cost approach is roughly twice as high as the total replacement power cost calculations. To understand this discrepancy, one has to think about what happens when climate change reduces the generation of electricity by hydropower plants and replaces it with electricity generated by coal- and gas-fired plants or imports. The replacement cost approach assumes that the only cost of closing this gap is the increase in the cost of alternative fuels. This assumes no change in the cost of hydropower production and that all of the substitutions (kWh from a fossil fuel plant for a kWh from a hydro plant) are all made at the same cost. Neither of these assumptions is necessarily correct and the results are telling us that these assumptions are indeed *not* correct, at least insofar as the system is modelled.

One example of this is the substitution of base load plants for peaking load plants. In the country, the least cost solution is to use fossil fuel plants to provide most of the base load and for hydro plants to provide most of the peak power. When climate change reduces this possibility in 2050 and 2100 relative to the Base Case, then it costs more both to run the hydro plants as base load plants and to run the fossil fuel plants as peak load plants. Thus, the costs of using both types of generating resources rise. This is reflected in the total systems cost estimate of climate change damages, but not in the replacement cost estimates. In other words, the replacement cost measure of climate change damages only reveals part of the picture and excludes the cost of not using hydro-electric plants optimally as well as costs related to meeting peak loads with base load plants.

Finally, it should be pointed out that, while this study did not estimate the benefits and costs of any adaptation measures, this does not mean that simulated adaptation was not captured by this approach. The fact that the analysis was conducted with a model that captured both changes in reservoir and power system operation in a least-cost optimization framework indicates that a great deal of adaptation was included in the analysis. In reality, the estimates of climate change damages that were developed in this study are actually estimates of residual damages – that is the value of climate change damages that cannot be avoided by adaptation. The problem with estimating the net value of the climate damages that can be avoided and those that cannot is three fold:

1. There is no single theory to suggest which adaptations should be included in the estimate of climate change damages and which should not. However, assuming that no autonomous adaptation will take place in response to climate is simply wrong.



2. The costs of adaptation are more difficult to calculate than most non-economists imagine because these costs include both changes in technology and behaviour.
3. There is a real lack of studies that estimate the basic engineering costs associated with adaptation technologies. This is not the kind of dirty work that economists like to do and engineers have different approaches to measuring costs than do economists.

Despite these problems, an approach for trying to separate out short-run from long-run adaptation will be discussed in the last section of this chapter, covering improvements to this study.

## Conclusions

---

Overall, this chapter had two main objectives. The first was to assess the capacity of national experts and institutions to estimate the economic value of climate change damages associated with reductions in runoff that reduce the capacity of hydro-electric plants to generate electricity and the benefits and costs of adaptation measures to avoid some of these damages. The second was to undertake an exploratory case study of the Mavrovo hydro-electric system, to see how far one can go with these methods and find out what additional work has to be done to go farther. Following the conclusion, the chapter will address the question of how to fill these capacity gaps in the short and longer term.

## Capacity Building

The national capacity to estimate these economic impacts was assessed in four different areas:

- Capacity to simulate the effects of climate change on runoff;
- Capacity to simulate the joint hydrologic operation of the reservoir and power production by an HPP;
- Capacity to optimally “balance” energy supply and demand across the entire generating system; and
- Capacity to estimate the value of the climate change damages due to changes in runoff and the benefits and costs of adaptation measures to avoid some of these damages.

**The capacity to calibrate a rainfall runoff model in catchments and to use the calibrated model to simulate the effects of climate change on runoff does not exist (although it may have existed at one time).** This is a fundamentally important limitation to overcome, not just for climate change analyses – as the impact on runoff is perhaps the most crucial physical impact of climate change in water resources – but perhaps even more importantly this shortcoming limits water resource planning and management activity related more generally to climate variability and economic development, where the tangible costs and benefits of various development projects are far more apparent than in climate change studies.

**The capacity to simulate the joint hydrologic operation of the reservoir and power production by an HPP currently exists in the form of OPTIM, a power systems model that also includes reservoir operation for power production by HPPs.** The capacity to optimally “balance” energy supply and demand across the entire generating system is present in the form of OPTIM for short-run assessments and is satisfied for both short- and long-run assessments by the MARKAL model (which must be used in tandem with OPTIM). In both cases, these models are widely used and updated by staff members of the Macedonian Academy of Arts and Sciences. However, until now, these models have not been used in studies to estimate the economic impacts of climate change.

**Finally, the capacity to estimate the value of the climate change damages due to changes in runoff and the benefits and costs of adaptation measures to avoid some of these damages really did not exist prior to this study, although the models did.** This was the first time OPTIM had been used for that purpose (just as this was the first time that MARKAL had been used to assess the impacts of changes in heating and cooling degree days due to climate change). In the course of the case study a number of issues emerged about the best way to use both models to estimate climate change damages and the benefits and costs of adaptation. Recommendations from this study should be helpful in accomplishing this objective.

As in the studies for energy and agriculture, the case study of the impacts of projected reductions in runoff due to climate change was a very worthwhile exercise for investigating the strengths and limitations of the local capacity to estimate climate change damages. While the benefits and costs of alternative adaptations were not specifically investigated in this study, the Mavrovo study was helpful in educating local experts how this could be done with existing models and data (for the most part). As with the other two studies, the analysis contained in this chapter was performed entirely with existing models and data and most of the hard analytical work was done by local experts under the guidance of a single international expert.

## The Way Forward – Developing Future Capacity

Like all of the studies in this study, the Mavrovo study is preliminary and designed to test the local capacity (expertise, models and data) to estimate climate change damages and the benefits and costs of adaptation and to reveal problems with and improvements to the methodology. At the same time, this study revealed the importance of including climate change into future hydropower development plans and doing so in a power systems framework for the entire country. This study also reveals a clear way forward to develop the local capacity to improve upon this study.

These improvements include:

- 1. Take Steps to Improve the Local Capacity to Simulate the Effects of Climate Change on Runoff in Catchments.** The methodology used in this study to project the effects of changes in temperature and precipitation and other meteorological variables on runoff at appropriate time steps and spatial scales were flawed compared to the current state-of-

the-art. Local water resource experts need to become familiar with how to calibrate and implement one or more rainfall runoff models that are suitable for Macedonian hydrologic and climatic conditions. The acquisition, training and use of the model also needs to be set in a larger context, involving both a thorough investigation of the data needs of various rainfall runoff models and the availability of this data in the country as well as a plan to expand and improve the quality of hydrologic and meteorological data gathering networks and systems.

2. **Improve the Methodology in this Study to Dispense with the Projection of Runoff Based on Wet, Average and Dry Precipitation Conditions.** Simulating the physical impacts of climate change in this study was hindered by the fact that there was no way to tell how, for example, average precipitation conditions in the Base Case became wetter or drier relative to the other precipitation conditions in the climate change cases. In other words, it was not easily possible to show how climate change affected the distribution of precipitation conditions. This problem appears to be due to the reliance of OPTIM and local experts on historical runoff data. This situation will change if the first recommendation is followed, as the ability to use rainfall-runoff models to project future conditions breaks the need to be wholly dependent on historical data.
3. **Improve the Methodology in this Study to Disentangle the Effects of Climate Change and Economic Development on Climate Change Damages.** The question is how large is a share of the damages due to climate change and how much of the benefits of avoiding these damages are due to climate change and how much is due to economic development? The usual approach is to hold one of the two constant and “partial” out the contribution of the other effect. However, there is a limitation to this approach in that it does not include the interaction between climate change and economic development on benefit and cost measures. In fact, when both climate and economic development are changing at the same time, the benefits and costs that are estimated for this interaction must, by definition, have something to say about the vulnerability of what we do (or don’t do) to adapt to climate change. Decomposing climate change damages and the net benefits of climate change into the partial effects of climate, economic development and the interaction between the two should be possible with the models used in this study. However, the experimental design of the scenarios is very important in order to isolate these effects.
4. **Link the OPTIM and MARKAL Models in order to Better Simulate Long-Run Physical Impacts and Adaptation.** The MARKAL model was not used in this analysis. However, the models have been used together in a previous study to assess the costs of reducing GHG emissions. The benefit of integrating the models is that OPTIM can be used to provide information about the technology and operating parameters of existing and future HPPs that is used in MARKAL. In addition, OPTIM can provide this information for different climate scenarios that will also be used in the multi-year analysis conducted using MARKAL. In theory, the models should interact simultaneously, but this is perhaps too much to ask. However, for the Third National Communication efforts should be undertaken to develop a methodology to look at multiple climate impacts over a number of years in the entire energy sector, using both models.
5. **Better Develop the Methodology to Decompose Residual Damages into Climate Change Damages and the Net Benefits (Benefits minus Costs) of Adaptation.** One way to do this proposed by Callaway (2004A) is to use capital investment in new plants and distribution

systems as the demarcation point for estimating the benefits and costs of adaptation. This approach, which was used in this study to estimate the economic impacts of changes in heating and cooling degree-days, involves allowing all short-run adaptation modelled in OPTIM on an annual basis to be included in the estimation of climate change damages. Estimates of the benefits and costs of adaptation are then based on the long-run adjustments as simulated in MARKAL. This approach allows a systematic, and not altogether arbitrary, approach for modelling damages from and adaptation to climate change, while at the same time allowing for the correct accounting of short-run and long-run benefits and costs. Such an approach could be implemented in the Third National Communication to the UNFCCC consistent with a similar recommendation made in the energy chapter.

# The Economic Impacts of Climate Change on Agriculture

## Summary of Chapter 5:

### The Economic Impacts of Climate Change on Agriculture

This chapter examines the potential impacts of climate change on Macedonian agricultural production. Climate change is expected to impact crop yields and water needs due to increased temperatures and less precipitation in the future. The chapter examines agricultural production associated with the Strezevo irrigation project in order to evaluate the potential levels of impacts of climate change on crop yields and farm incomes. In the rain-fed part of the region, without adaptation the climate change damages for the most severe climate change scenario roughly equal the net income in the Base Case by 2050. In the irrigated part of the agricultural sector in this region, the magnitude of climate change damages reaches the level of net income in the Base Case by 2100 under medium climate change conditions – and far surpasses the Base Case net income levels under the high climate change scenario. However, this does not account for adaptation by farmers such as changing crop rotations, changing farm management techniques, etc. The chapter also carries out an initial cost-benefit analysis of implementing the expansion of irrigation in the area. The initial cost-benefit analysis in the Strezevo area shows that – if the water is available – it may be a cost-effective measure to increase irrigation. A number of shortcomings in analytical capacity were identified. This includes a lack of capacity to estimate the impacts of input variables (including climate change) on crop yields via crop models. It also includes a lack of capacity to model hydrological cycles – which limits projections of climate change impacts and also impacts the ability to manage water needs given current climate variability.

## Introduction: Background and Objectives

---

The collapse of Yugoslavia and the overnight “privatization” of the agricultural sector in FYR Macedonia have created a number of challenges for the invigoration and future development of the sector. According to the National Agricultural and Rural Development Strategy (Ministry of Agriculture, Forestry and Water Economy 2007), the major weaknesses of the agricultural sector include the small size and fragmentation of farms, low physical productivity, high production costs, lack of credit for production loans, difficulties in attracting direct foreign investment, declining land prices, and unstable market conditions in many subsectors. For these reasons, the country imports over half of its food; there is high rural unemployment; and extensive rural-urban migration. The response of the Government has been to subsidize the production of key crops, and while this has led to increased production of subsidized crops; it has not solved the underlying problems in the sector.

The problems faced by the country are not at all unique in the Balkans and they are all inter-related. The small size of farms, low productivity, high production costs, unstable commodity prices and low net farm incomes are all related to the fact that farmers lack the economic incentives to expand and consolidate farm holdings. These incentives can only be created by stronger domestic and international markets for local agricultural commodities and by the creation of modern, private sector market institutions, both in the finance and agricultural sector.

Based on future projections of temperature and precipitation for the country (Bergant 2006), the most likely long-term effects of climate change will be reductions in the net primary productivity (i.e., yields) of most crops. This will be accompanied by reductions in runoff, which will reduce the potential supply of irrigation water. Both irrigated and rain-fed crops will have higher water requirements due to increased crop water demands, driven by higher temperatures, and reduced soil moisture availability due to less precipitation and runoff. Conversion of rain-fed crop areas to irrigation will be further aggravated by reduced runoff that will shrink the amount of potential reservoir storage available to irrigate crops, not to mention adding substantially to production costs as a result of new reservoir construction.

Given the current situation of the agricultural sector in the country and the potential effects of climate change, the major objective of this chapter of the study is to use a case study to show how climate change might impact crop yields and net farm incomes in the long-term - defined here in terms of the last half of this century. Before doing this, it is important to take a quick look at the data and models that can be used to do this and compare them with the data and models currently available in the country. Finally, by putting the conclusions of the case study together with the knowledge gained about the capacity of Macedonian institutions to estimate the economic impacts of climate change, recommendations will be presented for making future improvements to this capacity.

## Methods for Valuing the Economic Impacts of Climate Change in the Agriculture Sector in the country<sup>16</sup>

---

For this study and perhaps more generally, there are two broad types of welfare impacts to consider. Reductions in crop yields can result in losses in the welfare of farmers as measured by net farm income and a reduction in the welfare of consumers in cases where climate change leads to increases in commodity prices<sup>17</sup>. Losses in producer welfare occur because, as average yields – measured in kg per hectare – fall, revenues from the sale of the product fall while production costs per kg of output rise (even if costs per ha remain constant). This results in a reduction of net farm income (revenues – cost). A rise in marginal production costs, which causes an increase in the price of the product, has the effect of reducing the welfare of consumers (but not necessarily producers).

The other impact that is important to consider is the need for additional water supply, both for existing irrigated agricultural land and for rain-fed areas that are converted to irrigation. This impact cuts both ways. In general, reducing the supply of water will increase its scarcity value and, if the policy of the government is to price water at its economic value, this will raise the cost that farmers must pay for water, reducing their net income. If new reservoirs have to be built to supply water, then this will create additional costs that farmers might have to pay depending on government policy. However, increasing irrigation water supply is also an adaptation measure that has the potential to offset some of the economic losses caused by climate change. As long as the benefits of developing these additional supplies is greater than their cost, the economic losses due to climate change will be reduced, creating positive net adaptation benefits.

So, what kind of models and data are needed to estimate these economic impacts – both the economic damages of climate change due to long-term yield reductions and the benefits and costs of additional irrigation water supplies? And what are the possibilities for using these approaches in the country, given the current capacity of national experts and institutions to estimate the economic losses due to climate change in the country?

---

<sup>16</sup> This section is based on information gathered for a previous study by Callaway, et al. (2010), dealing with the economic impacts of climate change in Montenegro.

<sup>17</sup> How this effect occurs is shown graphically in Figure 2-1. For a more detailed exposition of the economics, see Callaway 2004A.

## Valuing the Economic Damages of Yield Reductions in the Agricultural Sector from the Bottom-Up

Bottom-up approaches for valuing the economic losses associated with yield reductions start with the effects of climate on crop yields and then work up to farm level production and further to market and sector level production. This is in contrast to top-down methods which generally rely on the observed variation in net farm incomes or land prices over space and then use this variation to project how a change in climate at any given location will affect net farm income. As such, for this type of approach it is necessary to know how yields will change in order to estimate the economic losses due to climate change<sup>18</sup>.

There are at least two distinct approaches that have been used to value the impacts of climate change in agriculture and many other sectors/impact categories, as well:

- **Agronomic.** This approach relies on the observed response of crop yields to different soils, climates, and management regimes to simulate changes in average annual crop yields. Independent projections of crop prices and crop areas are used to convert these yield changes into economic values.
- **Agro-economic.** This approach combines the agronomic approach to determine the impacts of climate change on crop yields with agricultural market models to determine crop production, prices and economic gains and losses due to climate change. These methods are often “normative” (optimization-based) in that the results are consistent with both agronomically “optimal” and economically efficient management.

Detailed elaboration of these approaches is provided in Annex II.

## Valuing the Economic Damages of Climate Change on Irrigation Water Availability and the Benefits and Costs of Additional Reservoir Storage for Irrigation

For this type of study, under ideal circumstances, two additional types of models could be used to value the economic losses due to climate change:

- **A rainfall-runoff model.** This type of model is used to determine how changes in temperature and precipitation, derived from global and regional climate models will affect runoff from one or more catchments into water supply reservoirs for irrigated agricultural crops.
- **A hydro-economic model.** This type of model, mentioned in the previous chapter, is used to simulate the flow of water from runoff to reservoirs and points of water demand and to simulate the operation of the reservoirs over time in the system so as to allocate the reservoir releases to the demand points according to economic criteria.

<sup>18</sup> The top-down approach in agriculture is best represented by the Ricardian approach, pioneered in Mendelsohn et al. (1994) and has been used to estimate the economic losses due to climate change in Africa by Kurukulasuriya et al. 2008 and Seo and Mendelsohn 2008A, in Sri Lanka (Seo, et al. 2005) and in South America (Seo and Mendelsohn 2008b), and China (Wang et al. 2009).



Hydro-economic models are often linked to, or contain, agro-economic (sector) models to simulate the demand for water from irrigated areas.

Both of these types of models are discussed in greater detail in Annex II.

## Evaluating the Capacity to Estimate the Economic Losses due to Climate Change in the Agricultural Sector

The capacity of experts and institutions to estimate the economic losses due to climate change in the agricultural sector, with a special focus on providing additional irrigation water to adapt to climate change, can be broken down into the following parts:

- Capacity to estimate the effects of climate change on crop yields;
- Capacity to estimate the effects of changes in crop yields on net farm income;
- Capacity to estimate the effects of changes in climate on irrigation water supply; and
- Capacity to estimate the benefits and costs of additional irrigation water supplies.

In general, it is clear that in almost all of these categories, the models and data to estimate the physical and economic impacts of climate change are limited. However, we also found that, even though so little is currently known about the physical and economic impacts of climate change in the country, at least for now it is possible to get around, and minimize the level of hindrance caused by, these limitations.

In the conclusions to this chapter, as in the previous and coming sector chapters, a “way forward” is mapped out to try to overcome these limitations. There is great awareness in the country by local experts about the current level of analytical capacity in these areas. There also exists a great deal of local ingenuity to get around some of these problems and make do with what currently exists to arrive at some important and suggestive results about what may be important to look at in the future.

## Capacity to Estimate the Effects of Climate Change on Crop Yields

At the time of this study, there was no evidence that there are any mathematical models that relate changes in climatic, soils, and management variables to crop yields (crop yield models). This includes an absence of both empirical models and process models. There are estimates of current crop yields for different areas, given identified inputs, in the framework of crop budgets. However, these crop budgets do not allow for varying production inputs - such as fertilizer. They also do not allow for changing or climate variables - such as growing season temperatures and precipitation - and estimate the impacts of these changes on specific crop yields. There also do not appear to be fine-grid-scale soils budgets such as are available in the EU for calibrating crop models.

## Capacity to Estimate the Effects of Changes in Crop Yields on Net Farm Income

Currently, no agricultural sector (agro-economic) models for the country exist. There are also no studies and hardly any organized data that would make it possible to estimate economic demand functions for domestic consumers. What do exist for some regions are the crop budgets and bottom-up engineering cost estimates for irrigation building projects and region-level farm models for both irrigated and non-irrigated farms. These are exactly the right kind of tools for estimating the economic impacts of climate-driven yield changes on farmer behaviour and net farm income.

The limited availability of resources for the current scoping study did not make it possible to fully realize this opportunity. However, some preliminary work with a small scale model (farm level optimization model) did yield some interesting results regarding how a profit-maximizing farmer would alter their crop mix to adapt to climate change. In addition, the crop budgets for both irrigated and non-irrigated crops were used extensively in the case study to estimate the economic value of climate change damages and the benefits and costs of avoiding these damages by irrigation.

It is worth noting that the fact that the country imports so much of its food from international markets at fixed prices, combined with the relatively small size of Macedonian farms (on the order of a few hectares) and the volatility of local markets for many products means that the consumption of domestic consumers in many cases does not have that great an impact on food prices.

## Capacity to Estimate the Effects of Changes in Climate on Irrigation Water Supply

FYR Macedonia has previously invested in developing the capacity to calibrate the MIKE-SHE rainfall-runoff model and implement it in water resources planning and management assessments. However, there are some problems with fully utilizing it. One reason cited for this is that Macedonian hydrologic conditions are, for many basins, so unique (especially mountain catchments with steep gradients and high energy flows) that either the model was very hard to calibrate and/or the results from these calibration exercises did not fit the observed data very well. Another reason is that the stream flow records for many catchments are not homogeneous or are unreliable for other reasons. It is hard to verify these reasons without extensive knowledge and information about the gauging network, stations and data collection methods. However, the inability to translate changes in precipitations and temperature into changes in runoff, at least on a monthly time scale, represents a serious shortcoming.

## Capacity to Estimate the Benefits and Costs of Additional Irrigation Water Supplies

For this study, it was possible to use the crop budget information to estimate the benefits and costs of additional irrigation water supplies for both fully irrigated and supplementally irrigated crops. However, the optimal level of irrigation water applications and the associated crop yields were based not on yield models per se, but on a very simple model of crop water use. This model simulates the effects of temperature on plant evapotranspiration and precipitation. These two factors influence the soil water budget for each crop. The change in yield due to a change in temperature was assumed to be proportional to the ratio of actual water use by the crop (as measured by evapotranspiration) to the maximum water use by the crop<sup>19</sup>. Given the likely importance that deficit irrigation practices could have under extremely dry and hot conditions, this assumption of proportionality does not make a lot of sense. Furthermore, very high, sustained daytime temperatures due to climate change could limit many important crop functions. These limitations due to temperature would probably have a profound effect on irrigation efficiency. This further underscores the need to have better crop yield models available in the country for studying climate change impacts.

## The Strezevo Case Study

---

The Strezevo irrigation project is a multi-purpose water project. It was originally designed to provide water storage for municipal and industrial use, irrigation, waste treatment, small hydropower generation and flood control. It is located in the southern part of Pelagonia Valley in the Bitola municipality. The useful storage capacity of the reservoir is around 110 million cubic meters.

The maximum irrigated area for which the project was designed was roughly 20,200 ha. Over time, however, following the breakup of Yugoslavia, the amount of land that is fully irrigated has fallen to a current level of 5208 ha and the system has fallen into disrepair due to lack of use and the stealing of irrigation equipment, such as metal pipes and valves, for sale as scrap metal.

The project area was selected for this case study for several reasons:

- It has a hot, dry climate which is typical of much of the country's agricultural regions and which is likely to be most severely impacted by climate change in the long-run;
- The national experts who worked on this study are familiar with the area and the agronomic and economic data that are available to conduct such studies;
- The system is in need of refurbishment, which is not at all atypical of socialist-era agricultural and water projects – making this a representative example for other, similar projects. This issue poses both important problems for future agricultural development and water resource development; and

---

<sup>19</sup> This relationship is included in the CROPWAT model, to be discussed later.

- The system’s capacity is under-utilized, which makes it difficult to value the economic damages of climate change and the benefits and costs of avoiding these damages. This is because in practical terms, there is a lot of water available, but not much land that can be irrigated because the infrastructure has been scavenged.

## Methods and Data

The Methodology for this study consisted of three parts:

- Developing the Base Case,
- Developing the Climate Change Case, and
- Developing the Adaptation/Adjustment Case.

## Base Case

The purpose of the Base Case analysis was to establish a reference for crop and irrigation water use, crop yields, and net income by both irrigated and non-irrigated (rain-fed) crops in the area. The model was used to calculate the soil water deficit in the area for the various irrigated crops under the climatic conditions of the Base Case. This took into account the effect of temperature on crop water demand. It also took into account the availability of soil moisture carry-over from previous periods as well as inputs of water from precipitation. The amount of irrigation water required to bring each crop to maximum yield was determined through a simple empirical formula – the same for all crops -- developed by Stewart et al. (1977)<sup>20</sup> that is a part of CROPWAT. Given the estimated yields and water use, information about average product prices and crop budgets for the area were used to calculate net revenues for each crop. These values were totalled for all crops (twenty-five irrigated and seven non-irrigated) using the observed crop mix in the region. The same approach was used to calculate the yields and net income for crops in the Base Case. However, the crop water requirement for these crops was limited by the amount of precipitation that could effectively reach the root zone of the crops. These detailed data are shown in Annex II, Table II-1.

## Climate Change Case

The purpose of the climate change case was to show how high, medium and low changes in temperature and precipitation, as projected by Bergant (2006) for 2050 and 2100, would affect crop yields and the net income from irrigated and rain-fed crop production in the region. The detailed temperature and precipitation projections for the climate change cases are shown in Table 5-1. CROPWAT was used to calculate the effects of reduced rainfall and higher temperatures on the soil water balance, crop water demands, and crop yields. Irrigation quantities on irrigated lands were held constant and no additional water was applied to the rain-fed crops in

<sup>20</sup> Stewart, et al. (1977) represents an interesting and straightforward presentation of how CROPWAT can be used in deficit irrigation studies.

order to estimate the physical damages of climate change without any corresponding adjustments by farmers<sup>21</sup>.

### Box 5-1: Projected monthly precipitation and temperature values for the “Medium” climate change scenarios for the area in 2050 and 2100.

Table 5-1 presents the projected monthly precipitation and temperature values for the “Medium” climate change scenarios for the area in the years 2050 and 2100. The projections for this scenario show consistent increases in temperature and consistent decreases in precipitation across all months of the year. From a crop perspective, this means that plant water demands will increase due to higher temperatures and that the existing amount of soil water that contribute to plant growth will decrease due to reduced rainfall. Thus, without additional irrigation water, one can expect that crop yields will fall on irrigated lands, unless irrigation quantities are increased, and that crop yields on rain-fed land will also fall and probably require supplemental irrigation water to replace the lost precipitation.

Table 5-1: Base Case and Climate Projections for Average Monthly Temperature and Precipitation for the “Medium” Climate Change Scenarios

Case	Average Monthly Temperature in Degrees C by Month												Year	% change
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Base	-0.8	2.1	6.2	10.9	15.7	20.1	21.9	21.3	17.1	11.4	5.6	1	11	-
CC2050	1.9	4.8	8.5	13.2	18	22.8	24.6	24	19.2	13.5	7.7	3.7	13.5	22.24
CC2100	4.7	7.6	11	15.7	20.5	25.8	27.6	27	21.6	15.9	10.1	6.5	16.2	46.49
Average Monthly Precipitation in mm by Month														
Base	47	53	47	50	56	37	39	37	41	64	75	65	611	0
CC2050	47	52	44	47	52	33	34	33	39	61	71	64	576	-5.72
CC2100	46	51	40	43	48	29	30	29	35	54	64	63	533	-12.8

For irrigated crops, the fact that much of the land in the Strezevo project has been abandoned means that there is sufficient irrigation water to meet the higher demand for irrigation water due to climate change. However, this is not the case for rain-fed (dry land) agriculture for which yields are limited by effective rainfall. To measure the physical damage from climate change, the amount of water available for irrigation was held constant at Base Case values. Since higher temperatures, due to climate change, increase a crop’s need for water compared to the Base Case, the result is that crop yields will fall if more water is not supplied compared to the Base Case.

The following steps were carried out to evaluate damages in the Climate Change Case:

<sup>21</sup> The CROPWAT calculations are not shown, but can be obtained from the authors.

- For rain-fed crops, soil water availability was determined by projected precipitation, whereas for irrigated crops, this was determined by the availability of irrigation water and rainfall.
- Crop yields for both types of crops were calculated for the Climate Change Case using the empirical formula in CROPWAT and FAO Irrigation and Drainage Paper 33.
- The net income from the production of irrigated and rain-fed crops was calculated using the yield information from CROPWAT and the budget data.
- The yields and net income estimates were compared to the Base Case values to determine the extent of the yields reductions and net income losses (climate change damages) due to climate change.

## Adaptation Case

This study is not a comprehensive assessment of the costs and benefits of a wide variety of adaptation options, but is intended to be an illustrative analysis to show how these benefits and costs can be measured and estimated in applied analysis. It is clear from the observed responses of farmers to climate variability that there are number of ways to soften the blows of fluctuating temperatures and precipitation. The most prominent of these is adjustments in crop mixes, deficit irrigation practices, input substitution and changing the timing of management activities to offset adverse climate variability. These types of actions will probably occur without any planned government action, simply because it is in the economic interest of farmers to undertake them to avoid some of the damages of climate variability and climate change. Adaptation actions which take place without a planned intervention are often referred to as “autonomous adaptation”.

In this analysis, we looked instead at how the existing water available for irrigation could be used to avoid the climate change damages by three means:

- Supplying the existing irrigated area with enough water to restore the Base Case yields;
- Supplying the agriculture area with supplemental irrigation water for their crops; and/or
- Expanding and refurbishing the irrigated area to the maximum available area, subject to the availability of water supply from the reservoir.

The following steps were carried out to evaluate damages in the Adaptation Case:

- The CROPWAT model was used to determine the full and supplemental irrigation water requirements of all crops, consistent with achieving the Base Case yields.
- Crop yields were not optimized in economic terms, but this can be done with a bit more time and data manipulation.
- Available water supply was calculated for each of the climate scenarios (high, medium and low for 2050 and 2010) by reducing the existing irrigation capacity of the system by the per cent reduction in precipitation in each scenario.

- Estimates of adaptation benefits and costs were calculated taking into account refurbishment and additional water costs as well as the improvement in yields due to the adaptation. These were estimated to show the net reduction in climate change damages that could be achieved through each of the measures.

## Results

Figure 5-1 shows the aggregated results for the per cent yield reductions (in relation to the Base Case) simulated by CROPWAT using the climate change projections for 2050 and 2100. Simulated crop yield losses become greater as the projected climate changes become more severe (low-medium-high) and over time. Moreover, the rain-fed yield reductions are observably (20 to 25 per cent) greater than the yield losses for irrigated agriculture, where irrigation quantities were held constant at Base Case values.

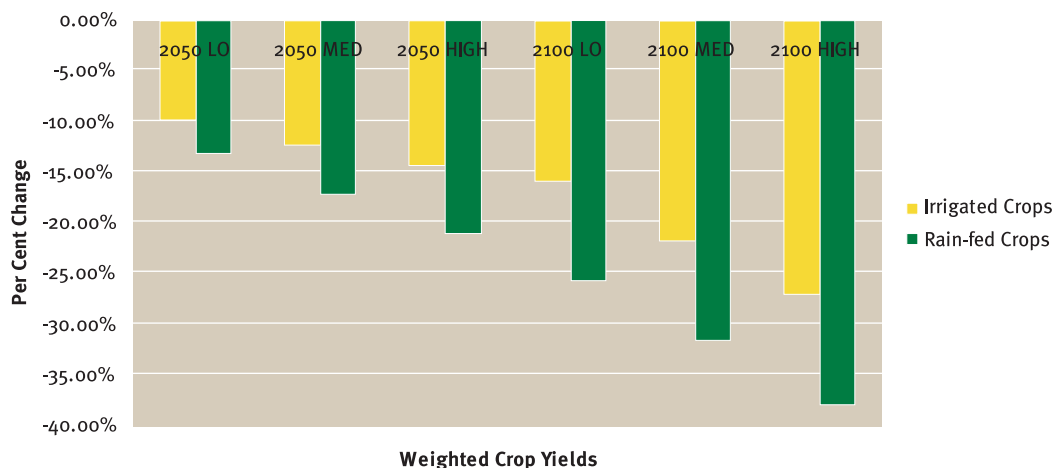


Figure 5-1: Per Cent Reduction in Area-Weighted Crop Yields due to Low, Medium and High Climate Change Projections for 2050 and 2100

The results shown in Figure 5-1 hide the fact that there is a great deal of disparity in the yield losses of different crops. In fact, the five irrigated crops that currently share the largest planted area (See Annex II, Table II-1) are among the least valuable in terms of their net income per ha, but among the most sensitive to climate change, while the five most valuable crops in terms of their net returns have very small planted areas but are among the least sensitive to climate change. This suggests that changing cropping patterns to substantially increase the planted area of high-value, less climate-sensitive crops would be one way for farmers to reduce their yield and - as we will see, shortly - their net income losses. However, the effectiveness of this

type of adaptive response will depend very much on market conditions for these high-valued crops. If prices are unstable and the markets are thin, or if local farmers cannot compete effectively in these high-valued product markets, income losses could actually increase because of declining revenues and high production costs.

These factors related to the relative economic viability of certain crops underscore two things. First, they show how important it is to model the physical impacts of and adaptation to climate change in an economic and not just a physical, bottom-up, framework. Second, they also demonstrate the important role that markets and marketing and the industrial structure of the agricultural sector play in determining the profitability of farmers. This is in contrast to the view-point that tends to see agricultural development issues almost strictly from a production efficiency viewpoint.

Figure 5-2 shows the aggregated results for the per cent reductions in net income per ha (in relation to the Base Case) due to the projected yield losses. Not surprisingly, these reductions show the same general patterns as for crop yield losses across time, the severity of the climate scenarios in each year, and land uses (irrigated and rain-fed) in agricultural sector. However, the per cent losses are much larger. There are at least three reasons for this:

- First, both the yield and net income losses are calculated without any type of adaptation taking place. As such, losses of this magnitude will probably not be observed, except in cases where the adaptation options are extremely limited, as may be the case in some rain-fed areas that will have to be abandoned if access to irrigation water is, or is expected to become, much more limited.
- Second, the adjustments that farmers can make on their own to climate change – through autonomous adaptation – will be observable and will almost certainly be undertaken in a profit-maximizing (or loss-reduction) framework. This may make it possible to reduce net income losses substantially by changing crop mixes and to a lesser extent through some forms of input substitution.
- Finally, these large net income losses are partly explainable by the fact that they are due entirely to reductions in revenues from the sale of food commodities without any concomitant reduction in production costs. This is especially “painful” in economic terms to the rain-fed sector, since their net income margins are on average substantially smaller than for irrigated farmers.



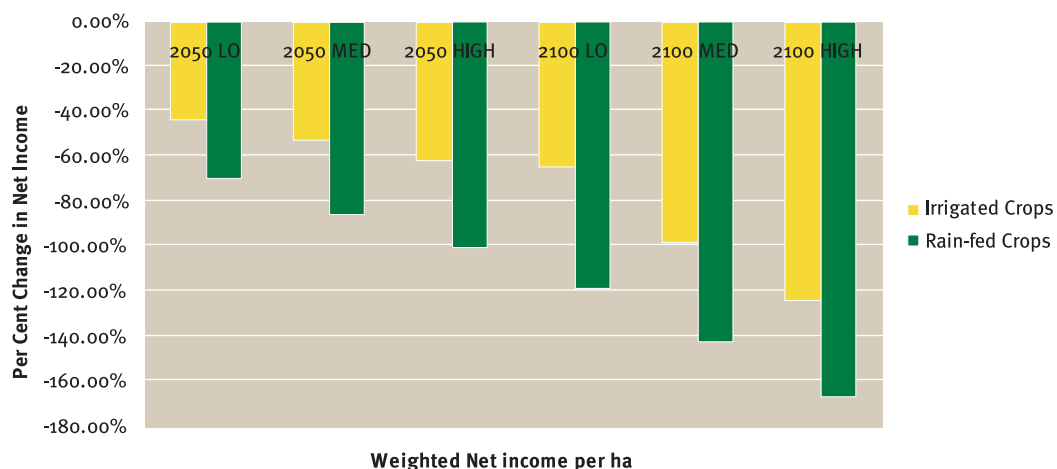


Figure 5-2: Per Cent Reduction in Area-Weighted Net Income/ha from Crop Production due to Low, Medium and High Climate Change Projections for 2050 and 2100

Figure 5-3 presents estimates of climate change damages.<sup>22</sup> In relative terms, it should look very much like Figure 5-2 since the per cent change in the area weighted average of the net income losses is equal to the per cent change in climate change damages. This is simply because climate change damages, as defined here, are equal to the total losses in net income due to climate change.

It is noteworthy that by 2050, the climate change damages in the rain-fed part of the region for the most severe climate change scenario roughly equal the net income in the Base Case (presented in Annex II, Table II-1 and Table II-2). For the irrigated part of the agricultural sector in this region, the magnitude of climate change damages reaches the level of net income in the Base Case by 2100 under the medium climate change scenario – and far surpasses the Base Case net income levels under the high climate change scenario.

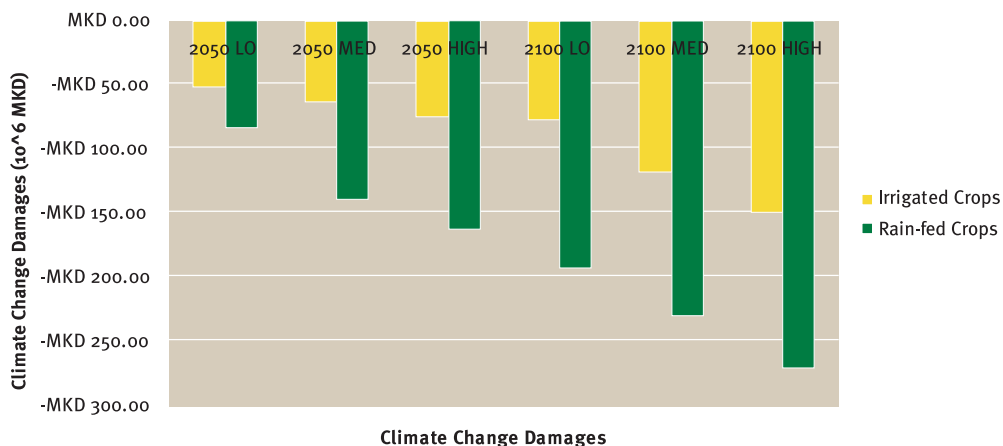


Figure 5-3: Climate Change Damages due to Low, Medium and High Climate Change Projections for 2050 and 2100

<sup>22</sup> All economic values in this chapter are undiscounted and given in terms of today's price equivalency.

## Adaptation Cases

The objectives of the adaptation assessment was to determine how much of the climate change damages could be reversed using the available water supply to restore the Base Case yields on irrigated and rain-fed agricultural lands and how this would affect water use in relation to water availability.

For existing irrigated agricultural land (5208 ha) and existing rain-fed agricultural land (14,992 ha), the costs of adaptation included the additional cost of water, while the benefits of adaptation are estimated as the additional revenue that is created by irrigating the crop to achieve the Base Case yields on both types of land use – fully irrigated for irrigated land and supplemental irrigation for rain-fed land.

This part of the analysis is summarized in Table 5-2. This table includes the estimates of the economic values of:

- Climate change damages, as shown in Figure 5-3;
- The net benefits of adaptation (which are the benefits of adaptation minus the costs); and
- The residual damages - which represent the damages that cannot be avoided by adaptation.

First of all, the fact that the net adaptation benefits are positive in all cases shows that the economic benefits of these measures is greater than their costs. Second, the net values of the avoided climate change damages (i.e., the net adaptation benefits) are relatively large in proportion to the climate change damages. For irrigated agriculture the net benefits of adaptation range from about 70 to 80 per cent of the value of climate change damages, leaving 20 to 30 per cent of the damages that cannot be avoided.

For rain-fed agriculture (now supplementally irrigated in the adaptation case), the net benefits of adaptation, while large in absolute terms, are relatively smaller than for irrigated agriculture when compared to climate change damages. For the area that is supplementally irrigated, increasing rain-fed yields by partial irrigation only reduces about 27 to 36 per cent of the climate change damages, leaving roughly 64 to 73 per cent of the original damages that cannot be avoided by this form of adaptation.

Table 5-2: Economic Values for Climate Change Damages, Net Benefits of Adaptation and Residual Damages Associated with Low, Medium and High Climate Change Projections for 2050 and 2100 for Restoring Full Yields to Irrigated Land and Supplemental Irrigation of Rain-fed Lands

Cases	Irrigated Crops			Rain-fed Crops		
	Climate Change Damages (10 <sup>6</sup> MKD)	Net Benefits of Adaptation (10 <sup>6</sup> MKD)	Residual Damages (10 <sup>6</sup> MKD)	Climate Change Damages (10 <sup>6</sup> MKD)	Net Benefits of Adaptation (10 <sup>6</sup> MKD)	Residual Damages (10 <sup>6</sup> MKD)
2050 LO	-51.69	39.13	-12.56	-84.74	28.90	-55.84
2050 MED	-63.35	48.60	-14.75	-140.21	38.26	-101.95
2050 HIGH	-74.12	55.29	-18.83	-164.47	48.30	-116.17
2100 LO	-77.18	62.50	-14.68	-194.07	60.79	-133.28
2100 MED	-117.80	85.82	-31.98	-231.83	78.81	-153.02
2100 HIGH	-148.38	105.61	-42.77	-272.38	98.48	-173.90

This last conclusion suggests that converting the entire area to irrigated agriculture might be a better option in economic terms, as long as there is sufficient water available to do this. To look at this option, the first piece of information that is needed is the cost of refurbishing a hectare of project land so that it can be fully irrigated. Lacking other data, the refurbishment cost was estimated to be MKD 61,500 per ha (~EUR 995), based on a combination of expert judgment and other refurbishment projects in the country. Given a discount rate of 5% and a 20 year amortization period, the annualized value of the refurbishment cost is MKD 7275 per ha (~EUR 118).

The second piece of information needed is the delivery capacity of the system under the different climate scenarios. The average annual delivery capacity of the irrigation for each of the climate scenarios is shown below in Table 5-3. Lacking a rainfall runoff model, these estimates were obtained by reducing the Base Case capacity by the same per cent reduction as the change in precipitation for each climate change case.

Table 5-4 presents a preliminary benefit-cost analysis of refurbishing the remaining 14,992 ha in the irrigation project, so that all of the area is fully irrigated. The effects of climate change on effective rainfall and crop water demand are estimated using the CROPWAT model, as in all of the previous cases. The net returns to land in column (1) include both the net revenue from crop production (holding the crop mix constant), including delivering additional water on each hectare to meet the elevated crop water demand and the annualized refurbishment cost. The

water required per hectare to fully irrigate the crops on each hectare was determined in the climate change analysis. The available irrigation water is simply the irrigation water in Table 5-3 less the amount required to irrigate the existing 5208 ha. The information in these first two columns is used to calculate the amount of additional land that can be fully refurbished and irrigated with the available water supply. The net benefits for the refurbishment project, not including the original 5208 ha that were already irrigated, under the six climate scenarios ranges from MKD 194 million (~EUR 3.13 million) in the 2050 Low climate change case to MKD 65 million (~EUR 1.05 million) in the 2100 High climate change case.

Table 5-3: Estimated Water Availability for Strezevo Reservoir

Climate Change Case	Water available for irrigation ( $10^6 \text{ m}^3$ )
Base Case	95.00
2050 LO	92.72
2050 MED	89.57
2050 HIGH	87.71
2100 LO	89.45
2100 MED	82.84
2100 HIGH	75.51

Table 5-4: Preliminary Annual Results for a Benefit-Cost Assessment of Refurbishing and Fully Irrigating the Remaining 14,992 ha in the Project

CASE	Net returns/ha for refurbished land (MKD/ha)	Water required per ha to refurbish irrigated land ( $\text{m}^3/\text{ha}$ )	Available water after irrigating 5208 ha ( $10^6 \text{ m}^3$ )	Additional area that can be refurbished with available water (ha)*	Net returns of refurbishing additional area to full irrigation ( $10^6 \text{ MKD}$ )
2050 LO	13,417	4,504	69,249	14,492	194
2050 MED	12,996	4,575	65,729	14,368	187
2050 HIGH	12,213	4,669	63,196	13,535	165
2100 LO	13,010	4,765	64,624	13,562	176
2100 MED	9,688	5,126	56,133	10,951	106
2100 HIGH	7,616	5,472	46,999	8,589	65

\* Land is the constraining factor. There is sufficient water to irrigate an additional 883 ha

The results in Table 5-4 are from a partial<sup>23</sup> benefit-cost analysis without estimating the net benefits of adaptation. The next step is to put the refurbishment option together with the additional water supplied to the existing 5208 ha and compare this option with the two different adaptation options in Table 5-2.

This is shown in Table 5-5 in which the original options on irrigated and rain-fed lands are combined in the left half of the table and the refurbishment and full irrigation options are combined in the right half of the table. The climate change damages for the two options are identical and are the same as in Table 5-2 (when added together). However, the net benefits of adaptation and the residual damages are much larger for the option that involves converting the entire area to irrigated area and fully irrigating it than for the original two options depicted in Table 5-2. In fact the net adaptation benefits are around 28 to 85 per cent higher for this set of options than the original two. At the same, the residual damages (those that could not be avoided by the full irrigation + refurbishment option) are roughly cut in half in all of the climate scenarios. Of course these results will probably be very sensitive to the assumptions regarding refurbishment costs and water availability made in this analysis. Autonomous adaptation by farmers will, as previously indicated, also increase total net adaptation benefits by further avoiding climate change damages due to market incentives.

Table 5-5: Economic Values for Climate Change Damages, Net Benefits of Adaptation and Residual Damages Associated with Low, Medium and High Climate Change Projections for 2050 and 2100 Comparing Full Irrigation + Refurbishment on All Lands with Full Irrigation on Irrigated Land + Supplemental Irrigation on Rain-fed Lands

Cases	Restore water to irrigated land + supplemental irrigation for rain-fed land			Restore water to irrigated land + refurbish rest of area for full irrigation*		
	Climate Change Damages (10 <sup>6</sup> MKD)	Net Benefits of Adaptation (10 <sup>6</sup> MKD)	Residual Damages (10 <sup>6</sup> MKD)	Climate Change Damages (10 <sup>6</sup> MKD)	Net Benefits of Adaptation (10 <sup>6</sup> MKD)	Residual Damages (10 <sup>6</sup> MKD)
2050 LO	-136.43	68.03	-68.4	-136.43	87.44	-48.99
2050 MED	-203.56	86.86	-116.7	-203.56	156.33	-47.23
2050 HIGH	-238.59	103.59	-135	-238.59	176.63	-61.96
2100 LO	-271.25	123.29	-147.96	-271.25	227.63	-43.62
2100 MED	-349.63	164.63	-185	-349.63	258.99	-90.64
2100 HIGH	-420.76	204.09	-216.67	-420.76	309.23	-111.53

\* The refurbishment costs have been annualized and both the costs and benefits for 2050 and 2100 are expressed in terms annual future values. This should not be mistaken for a benefit-cost analysis.

<sup>23</sup> Based on future values for just 2 years, where refurbishment costs have been annualized and included with the other annual future value costs and benefits from crop production.

## Conclusions

---

This chapter has two main objectives. The first is to assess the capacity of national experts and institutions to estimate the economic value of climate change damages and the benefits and costs of adaptation measures. The second is to undertake an exploratory case study both to see how far one can go with these methods and to look at how the gaps in the analytical capacity affect the estimates of these economic impacts. Following the conclusion, the chapter will address how to fill these capacity gaps in the short and longer term.

The national capacity to estimate these economic impacts was assessed in four different areas:

- Capacity to estimate the effects of climate change on crop yields;
- Capacity to estimate the effects of changes in crop yields on net farm income;
- Capacity to estimate the effects of changes in climate on irrigation water supply; and
- Capacity to estimate the benefits and costs of additional irrigation water supplies.

The first three areas focus on the national capacity to project the physical impacts of climate change that are important in the agricultural sector. These inputs are not only important for bottom-up economic analyses, but also there is often a great deal of overlap between physical impacts and how farmers and natural resource planners and managers adjust to these physical through autonomous adaptation. In modelling physical impacts, it is therefore important to do so in a way which makes it possible to take into account the economically-motivated behaviour of these actors.

**The capacity to simulate the impacts of climate change on crop yields is quite limited in the country.** Except for the extensive use of models, like CROPWAT, which look at the effects of climate on soil water supply and demand in a fairly primitive water balance framework, we could find no empirical or process-oriented models to simulate climate change on crop yields. Such models and the capacity to use them in the country do exist. A complication to using these models in country is that they are poorly supported by local databases, their crop coverage is limited, and they assume more “optimal” agricultural management than is actually practiced in – or perhaps is not applicable to – local conditions.

**The capacity to estimate reductions in crop yields on resource allocation and net income at the farm level exists, but is not focused on climate change analysis.** The capacity to survey farmers regarding their resource use and management practices, the preparation of crop budgets, and the development and implementation of farm-level linear programming models is also fairly well-developed in the country. A next step is to integrate their use into climate change and adaptation assessments and to blow up the scale of these models from the typical farm to the regional and national levels.

**The capacity to simulate how climate change will affect the hydrologic cycle in catchments is not well developed.** An effort to develop this capacity with the introduction of the MIKE-SHE

model seems to have been lost. Without models like this, it is virtually impossible to simulate how runoff into irrigation water supply reservoirs will be affected.

**On the other hand, the capacity to simulate how climate change will affect the soil water balance for crops is adequate enough for the time-being,** as demonstrated by the use of CROPWAT in this study. However, this capability is better integrated into simulation models that look at the whole plant response to climate, linking together major plant development processes (which CROPWAT does not do that well).

**The capacity to estimate the benefits and costs of additional irrigation water supplies from the bottom-up is well developed, but the capacity to do this, conceptually, in a climate change framework, is quite limited.** Part of this is due to the need for more interaction between physical scientists and economists and part due to the intervention of outside experts who often circumvent and undervalue local capacity.

The case study of the impacts of potential long term impacts of climate change on the Strezevo irrigation area proved to be a useful framework for testing the strengths and limitations of the local capacity to estimate the economic value of climate change damages and the benefits and costs of a limited set of adaptation options. The study was done entirely with existing models and data. It used a bottom-up approach to project the local impacts of climate change in 2050 and 2100 on the use of water by irrigated and rain-fed crops and crop yields using the CROPWAT model. This included a very simple crop yield algorithm that is embedded in the model. Crop budgets were used to estimate the various components of net farm income from each crop as yields and water use changed due to climate change and to adaptive management. Estimates of long-term climate change damages were large. Yields were reduced on the order of 10 to 25 per cent for irrigated agriculture (holding water use constant at Base Case values) and around 15 to 40 per cent for rain-fed crops. The future value of the climate change damages associated with these yield losses, ranged from MDK 50 to around MDK 150 million per year for irrigated agricultural lands in the region and MDK 80 to almost MDK 250 million for rain-fed agriculture.

Lacking detailed crop simulation models, and because there was not time to develop a linear programming model of resource use and production for the country, the study examined the adaptation costs and benefits of providing additional irrigation water for supplemental irrigation of rain-fed crops in the region and for a refurbishment of the irrigation system and extending full irrigation back to the entire project area. Both types of adaptation measure substantially reduced long-term climate change damages. Refurbishing the project is estimated to create net adaptation benefits equal to 65-85% of climate change damages.

The study revealed the importance of estimating both climate change damages and the benefits and costs of adaptation using a linear programming approach that better captured how farmers would adjust autonomously to climate change and to any planned adaptations, such as project refurbishment and/or enlargement. It could have benefitted substantially from better crop yield models that took into account the non-linearity between crop response, climate and resource use. Finally, the study was limited by the lack of a model to simulate the effects of climate change on irrigation water supplies. This is a particularly important limitation in

view of the large projected changes in crop yields in the second-half of this century, which almost certainly will place pressure on the development of new irrigation projects to replace rain-fed agriculture.

## The Way Forward – Developing Future Capacity ———

Like all of the studies in this document, the Strezevo study is preliminary and designed to test the local capacity (expertise, models and data) to estimate climate change damages and the benefits and costs of adaptation. The bottom-up nature of the methodology was dictated by capacity limitations, as already discussed. At the same time, this study reveals a clear way forward to develop the local capacity to improve upon this study.

These improvements include:

1. **Take Steps to Improve the Local Capacity to Simulate the Response of Crops to Climate Change and Management.** CROPWAT is an “old” model that has been greatly surpassed by newer crop simulation models like CERES and EPIC. Models like these have recently been used in the country to assess the physical and economic impacts of climate change in the agricultural sector and adaptation options to avoid these impacts (Industrial Economics Incorporated 2011). However, local experts and institutions have no knowledge of these models, their strengths and weaknesses. This puts domestic agricultural planners and resource managers at a distinct disadvantage for the future when it comes to adjusting investment and management plans and actions in the country to adapt to climate change. This type of capacity improvement will benefit not only climate change assessments, but also a much wider range of planning and management activities within the country.
2. **Take Steps to Improve the Local Capacity to Simulate the Effects of Climate Change on the Hydrologic Cycle.** For this study we were unable to find any estimates of the average annual yield of the Strezevo reservoir. More importantly, national experts and institutions lack the capacity to simulate the effects of climate change on the hydrologic cycle, using rainfall runoff models. This is an important short-coming when it comes to modelling water resource availability for expanding irrigation. The need for this capacity extends well beyond the needs of the climate change community and extends to all levels of water management in multiple sectors.
3. **Develop Linear Programming Models for Evaluating Climate Change Damages and the Benefits and Costs of Adaptation.** In the case study, the crop mix was held constant in the Base Case, climate change and adaptation cases. However, it is likely that farmers would autonomously adapt to climate change and to planned adaptation options by changing their crop mixes and use of resources to maximize their profits. These types of substitutions could have been examined by linking the CROPWAT model to a linear programming model of the irrigated and rain-fed farms in the area. The capacity both to gather the data for these models and develop the models themselves already ex-



ists in the country. However, it needs to be focused on developing sub-regional and national models of agricultural production in the context of the sector as a whole in any given area. These can be used for a wide range of planning and resource management purposes, including climate change. For the time being, at least, it will not be necessary to incorporate domestic food demand into these models, as the country is a “price-taker” in many agricultural commodity markets. Every effort should be made to develop these models for use in the Third National Communication to the UNFCCC. A very important aspect of these models is that they allow bottom-up integration of numerous adaptation options, both autonomous and planned, with top-down, rational economic behaviour.

4. **Extend the Number of Regions to be Investigated.** For the Third National Communication to the UNFCCC, it is recommended that this study be extended to a larger number of regions with the general objective of covering the entire country with a series of sub-regional or single, national linear programming-based agricultural sector model. For the time being, the yield-water response in the sector model can be generated by the CROPWAT model. But a better, longer term, goal is to develop the capability to simulate the effects of climate change on crop yields using a model like CERES or EPIC. As in almost all of the previous recommendations, the development of and implementation of agricultural sector models at the sub-regional and national levels for National Communications to the UNFCCC represents a “no-regrets” capacity building option with very broad planning and resource management benefits.

## Chapter 6 | Conclusions

Chapters 3 through 5 all contain a concluding section that presents the main findings with respect to the status of the capacity to estimate the economic impacts of climate change and use this information to make public policy recommendations how to address these “capacity gaps” in the short- and long-term. This section combines these findings and recommendations with major conclusions that flow from the case studies into a shorter list that highlights the most important results of this study.

The study on the residential and commercial parts of the energy – particularly electricity – sector demonstrated in a very positive manner that the tools and expertise required to estimate the climate change damages and the benefits and costs of adaptation are, for the most part, already in place in terms of the expertise in the Macedonian Academy of Sciences and Arts and the MARKAL model. However, while the underlying capacity to assess the economic impacts of climate change on space heating and cooling demands does exist, the results of this study also show that more experience is needed to correctly implement the energy sector model used in this analysis and integrate all production sectors into the analysis in a long-run framework to guide future energy investments. As such, this study provides national researchers with some important challenges for the future.

When it comes to the tools and expertise for carrying out the economic impacts assessments of climate change on the hydro-electric sector, the situation is slightly different. The capacity to simulate the impacts of climate and climate change on basin runoff, using rainfall-runoff models, does not exist (although it may have existed at one time). Also, the capacity to estimate the value of the climate change damages due to changes in runoff and the benefits and costs of adaptation measures to avoid some of these damages really did not exist prior to this study, although the models did. On the positive note, the capacity to simulate the joint hydrologic operation of the reservoir and power production by a Hydropower Plant (HPP) currently exists in the form of OPTIM, a power systems model that also includes reservoir operation for power production by HPPs. Also, the capacity to optimally “balance” energy supply and demand across the entire generating system is present in the form of OPTIM for short-run assessments and is satisfied for both short- and long-run assessments by the MARKAL model (which must be used in tandem with OPTIM). In both cases, these models are widely used and updated by staff members of the Macedonian Academy of Arts and Sciences although, until now, these models have not been used in studies to estimate the economic impacts of climate change. Analytical capacity in this area could be greatly improved in the future by developing a long-run hydro-economic model to look at the benefits and costs of investment in new capacity.

The case study on agriculture is interesting for two reasons. It not only illustrated some important model and data limitations, but it also showed how local capacity – experts, model and data – could still come up with some important, although preliminary, findings. First of all, the country lacks the capacity to simulate the effects of climate and changes in climate on crop yields, using state-of-the art crop yield models. However, use of the CROPWAT model (which is considerably outdated) still made it possible to obtain preliminary estimates of the impacts of climate change on crop yields. Also, as previously mentioned, the capacity to simulate how climate change will affect the hydrological cycle in catchments is not well developed. On the other hand, the capacity to estimate reductions in crop yields on resource allocation and net income at the farm level exists, but needs to be more focused on climate change analysis. The same applies to the capacity to survey farmers regarding their resource use and management practices, the preparation of crop budgets, and the development and implementation of farm-level linear programming models which is also fairly well-developed in the country. A next step is to integrate farm models into climate change and adaptation assessments and to blow up the scale of these models from the typical farm to the regional and national levels.

Finally, it should be noted that all of the recommendations about capacity improvements are not aimed specifically at estimating the economic impacts of climate change and the benefits and costs of adaptation. All of the missing models and data that are identified in the study have much wider applications than to climate change policy. They can also be used to investigate the benefits and costs of a much wider range of investment and resource management policies both by the private and public sectors. Policies which aim at improving economic efficiency in all of the economic sectors that are impacted by climate change can probably do as much or more to reduce climate change damages than policies targeted to reduce climate change impacts of these sectors as they are currently structured. Thus, the capacity development recommendations in this study are, effectively, “no regrets” options to help in the development of a more climate-resilient economy.

## Major Conclusions

---

1. **Need for Macroeconomic Model.** An important analytical gap that was found to be especially limiting in the case studies was the apparent lack of a macroeconomic model for the country, both in-country and in the larger institutional modelling community.
2. **Value of Preliminary Estimates of Climate Change Damages.** This study has demonstrated that, even in the absence of more sophisticated data and better models, preliminary estimates of climate change damages – as in the Case Studies – can provide useful information about the economic impacts of climate change to guide decisions both about development policy and building the capacity to improve the analytical capacity about economic development and options for coping with climate change.
3. **Need for Better Models and Data.** This study set out the state-of-the-art in modelling climate change damages in all of the case study sectors. There are significant gaps in both models and data in every sector we examined in both simulating the physical impacts of climate change and translating these impacts into measures of climate change damages using integrated environmental-economic sector models.
4. **Priorities for Capacity Building.** Based on the results of the case studies and the development plans of the country, the priorities for developing these type of models would appear to be as follows:
  - a. **Highest priority:**
    - i. Extending the time horizon of the analysis with MARKAL beyond **2010**, making it more comprehensive by including mitigation targets and adding additional supply- and demand-side adaptation and mitigation technologies and electricity demand functions based on existing information about the general range of price-sensitivities of commercial and residential electricity demand.
    - ii. Improve the capacity to simulate the effects of climate change on the hydrologic cycle, using rainfall runoff models.
    - iii. Develop hydro-economic models for basins targeted for future hydro-electric development.
    - iv. Introduce newer crop simulation models like CERES and EPIC.
  - b. **Lower priority**
    - i. Adding price sensitive demand functions to MARKAL and including the impacts of climate change on renewable generating resources.
    - ii. Developing sub-regional and national models of agricultural production in the context of the sector as a whole in any given area.

- iii. Stand management models (and support data) for forests that include growth models to simulate the impacts of climate change and forest disturbances on the growth of managed forest types.
- iv. A dynamic, two sector model of the agriculture and forest sector, for example through integration with EUFASOM.

## Major Recommendations

---

1. **Macro-Economic Model.** A macro model capable of providing consistent long-term price and quantity forecasts such as a computable general equilibrium (CGE) model should be developed for the country. However, it is important that the model be able to address national development issues, specifically by requiring that the “entry points” into each sector can realistically represent impacts that are related to the country’s development plans and the impacts of climate change. These models can be developed through contracts with multi- and bi-lateral institutions, involving international and regional centres of expertise in this field.
2. **Foster cross sector collaboration to develop models, tools and resources that will improve the understanding of the economic, environmental, and operational implications of climate change.** It is recommended that the physical impact models and related integrated environmental-economic assessment models for the country are developed over a period of five to ten years in line with the identified priorities. The models and tools should be able to address national development issues, specifically by requiring that the “entry points” into each sector can realistically represent impacts that are related to the country’s development plans and the impacts of climate change. These models can be developed through contracts with multi- and bi-lateral institutions, involving international and regional centres of expertise in this field
3. **Data collection efforts should be fostered and coordinated with models development.** The case studies revealed data deficiencies in all of the sectors. In addition, an effort to assess the impacts of climate change in forestry and health sectors failed due to a lack of reliable data. The building of new data bases where old ones have collapsed is going on in many sectors, and this information is also helpful for better management of these sectors regardless of climate change. It is also recommended that data collection efforts by the government and model development efforts be coordinated.
4. **Local expertise to conduct climate change economic impact assessments on its own should be built in the future.** Developing the capacity to build and implement models that can be useful for planning and managing natural resources and estimating the physical and economic impacts of climate change should focus on the long-run development of human capital in the country. One way to try to ensure that the capacity is transferred is through training for national experts and collaboration with relevant national institutions in sector-related fields with modelling centres of excellence throughout the EU backed by multi- and bilateral funding.

5. **Results of the climate change impacts assessments should be used in updating the policy framework and getting private sector buy-in.** A large institutional gap exists between the public and private sectors in some economic sectors/industries. The government should where possible incorporate climate change impact assessments into sectoral planning and management policies and engage the private sector not only to recognize the potential adverse economic consequences of climate change, but also to facilitate more efficient actions by the private sector to adapt to climate change.
6. **Climate risk management must promote resilience.** Government development policies should incorporate investment and resource management policies that are consistent with sound adaptation planning, which addresses actual or potential impacts, identifies vulnerabilities and capitalizes on the potential opportunities presented by climate change.
7. **Social dimensions of climate change economic impacts, such as employment effects, should be explored,** as well as socioeconomic impacts of implementing policies for nationally appropriate mitigation actions.

## References

- Adams, R.M. and McCarl, B.A. 1985. “Assessing the benefits of alternative ozone standards on agriculture: The role of response information,” *Journal of Environmental Economics and Management* 12(3): 264-276.
- Adams, R.M., Callaway J.M. and McCarl, B.A. 1986. “Pollution, Agriculture and Social Welfare: The Case of Acid Deposition,” *Canadian Journal of Agricultural Economics*, 34(1): 3-19.
- Adams, R.M. and McCarl, B.A. 1999. “The Economic Effects of Climate Change on Agriculture,” Chapter 2 in R. Mendelsohn and J. Neumann (eds.) *Effects of Climate Change on the US Economy*, Cambridge University Press, NY, US.
- Alig, R.J., Adams, D.M. and McCarl, B.A. 2002. “Projecting impacts of global climate change on the US forest and agriculture sectors and carbon budgets,” *Forest Ecol. Manag.* 169: 3-14.
- Bergant, K. 2006. *Climate Change Scenarios for Macedonia - Review of methodology and Results*. University of Nova Gorica, Slovenia, September 2006.
- Booker, J.F. and Young, R.A. 1991. *Economic Impact of Alternative Water Allocations in the Colorado Basin: Colorado Water Resources Research Institute Completion Report No. 161*. Ft. Collins, CO, Colorado State University.
- Callaway, J.M. 2004A. “The Benefits and Costs of Adapting to Climate Variability and Climate Change”, Chapter 4 in *The Benefits of Climate Policy*. OECD, Paris France.
- Callaway, J.M. 2004B. “Adaptation Benefits and Costs: are they Important in the Global Policy Picture and How can we Estimate them?” *Global Environmental Change* 14: 273-282.
- Callaway, J.M., Louw, D., Hellmuth, M., Nkomo, J. and Sparks, D. 2008. “Benefits and costs of adapting water planning and management to climate change and water demand growth in the Western Cape of South Africa”, Chapter 3 in N. Leary, C. Conde, J. Kulkarni, A. Nyong and J. Pulhin (eds.). *Climate Change and Vulnerability and Adaptation*, Earthscan Books, London UK, pp. 53-70.
- Callaway, J.M. Louw, D.B. and Hellmuth, M. 2009. “Chapter 14: Benefits and Costs of Measures for Coping with Water and Climate Change: Berg River Basin, South Africa”, In Ludwig, F., Kabat, P., van Schaik, H. and van der Valk, M. (eds.). *Climate Change Adaptation in the Water Sector*. Earthscan Books, London, UK, pp. 191-212.
- Callaway, J.M., Kaščelan, S. and Marković, M. 2010. *The Economic Impacts of Climate Change in Montenegro: A First Look*. UNDP, Montenegro, Podgorica.

- Carson, R.T. and Mitchell, R.C. 2004. *Valuing Oil Spill Prevention: A Case Study of California's Central Coast*. Kluwer. Dordrecht, NE.
- Causevski, A. and Bosevski, T. 2003. "Improved model for electricity generation planning in the small economic autonomous power system", ETRAN 2003, Herceg Novi, 8-13 June 2003, *Zbornik radova, Sveska I*, pp. 341-343.
- Causevski, A. and Bosevski, T. 2004. *Model for Generation Planning in an Electric Power System*, XXXIX International Scientific Conference on Information, Communication and Energy Systems and Technologies, ICEST 2004, 16-19 June 2004, Bitola, Macedonia.
- Ciscar J.C., et al. 2009. *Climate Change Impacts in Europe. Final Report of the PESETA Research Project*. Joint Research Centre, Seville, SP. [<http://ftp.jrc.es/EURdoc/JRC55391.pdf>] Accessed 3 November 2011.
- Hurd, B.H., Callaway J.M., Smith, J.B. and Kirshen, P. 1999. "Economic Effects of Climate Change on U.S. Water Resources", in *The Impact of Climate Change on the United States Economy*, R. Mendelsohn and J.E. Neumann (eds.). Cambridge University Press, Cambridge, UK. pp. 133-177.
- Industrial Economics Incorporated. 2011. *Reducing the Vulnerability of FYR Macedonia's Agricultural Systems to Climate Change Preliminary Impact Assessment and Adaptation Options*. Draft Report: March 2011.
- IPCC. 2007. *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.
- Just, R., Schmitz, A. and Hueth, D. 1982. *Applied Welfare Analysis*. Prentice-Hall, NY, US.
- Kehoe, P.J. and Kehoe, T.J. 1994. "A Primer on Static Applied General Equilibrium Models." *Federal Reserve Bank of Minneapolis Quarterly Review*, 18(1) [<http://www.minneapolisfed.org/research/QR/QR1821.pdf>] Accessed 3 November 2011.
- Kelly, D.L., and Kolstad, C.D. 1999. "Integrated Assessment Models for Climate Change Control" in Folmer H. and Tietenberg T. (eds.). *International Yearbook of Environmental and Resource Economics 1999/2000: A Survey of Current Issues* Edward Elgar Cheltenham, UK.
- "A Ricardian analysis of the impact of climate change on African cropland." *AfJARE* 2(1): 1-23.
- Lettenmaier, D.P. and Wood, E. 1994. *Implementation of the VIC-2L Land and Surface Scheme to Model the Hydrology of Large Scale Continental Rivers*. Palo Alto, CA. Report Prepared for the Electric Power Institute.



Mendelsohn, R., Nordhaus, W. and Shaw, D. 1994. “Measuring the Impact of Global Warming on Agriculture,” *American Economic Review* 84: 753-771.

*The Impact of Climate Change on the United States Economy*. Cambridge University Press. New York, US.

Miller, R.E. and Blair, P.D. 1985. *Input-Output Analysis: Foundations and Extensions*. Prentice Hall, NY, US.

Ministry of Agriculture, Forestry and Water Economy, 2007. *National Agricultural and Rural Development Strategy (NARDS) for the Period 2007-2013. Final Draft*. Skopje, June 2007.

Ministry of Economy, 2010. *Strategy for Energy Development of the Republic of Macedonia by 2030*. Skopje.

Ministry of Environment and Spatial Planning, 2003. *Macedonia’s First National Communication*. Skopje, ME.

Ministry of Environment and Spatial Planning, 2008. *Second National Communication*. Skopje, ME.

Nijssen, B., Lettenmaier, D.P., Liang, X., Wetzel, S.W., and Wood, E.F. 1997. Stream flow simulation for continental-scale river basins. *Water Resour. Res.* 33, 711-724.

OECD/IEA. 2008. *IEA Online Database: Energy Balances of Non-OECD and OECD Countries and Energy Statistics of Non-OECD and OECD Countries*.

Parson, E.A. and Fisher-Vanden, K. 1997. “Integrated Assessment Models of Global Climate Change.” *Annual Review of Energy and the Environment* 22: 589-628.

Schneider, U. A., J. Balkovic, S. D. Cara, O. Franklin, S. Fritz, P. Havlik, I. Huck, K. Jantke, A. M. I. Kallio, F. Kraxner, A. Moiseyev, M. Obersteiner, C. I. Ramos, C. Schlepner, E. Schmid, D. Schwab and R. Skalsky. 2008. The European Forest and Agricultural Sector Optimization Model - EUFASOM. Research Unit Sustainability and Global Change, Working Paper FNU-156, Hamburg, Germany. [[http://www.fnu.zmaw.de/fileadmin/fnu-files/publication/workingpapers/wp156\\_eufasom.pdf](http://www.fnu.zmaw.de/fileadmin/fnu-files/publication/workingpapers/wp156_eufasom.pdf)] Accessed 7 November 2011.

Seegbregts, A.J., Goldstein, G.A., and Smekens, K. 2001. Energy/Environmental Modelling with the MARKAL Family of Models. ETSAP Energy Technology Systems Analysis Program. [<ftp://ftp.ecn.nl/pub/www/library/report/2001/rx01039.pdf>] Accessed 3 November 2011.

Seo, S.N., Mendelsohn, R. & Munasinghe, M. 2005. “Climate change impacts on agriculture in Sri Lanka,” *Environment and Development Economics* 10, 581–96.

- Husbandry in Africa,” *AfJARE* 2: 65-82.
- Seo, S.N. and Mendelsohn, R. 2008B. “A Ricardian Analysis of the Impact of Climate Change on South American Farms,” *Chilean Journal Of Agricultural Research* 68(1): 69-79.
- Smith, V.K. and Desvousges, W.H. 1985. “The Generalized Travel Cost Model and Water Quality Benefits: A Reconsideration,” *Southern Economic Journal* 52(2): 371-381.
- Smithers, J.C. and Schulze, R.E. 1995. *ACRU Agrohydrological Modelling System*. User Manual: Version 3.0. Water Research Commission, Pretoria, RSA Report TT70/95.
- Stewart, J.I., Cuenca, R.H., Pruitt, W.O., Hagan, R.M. and Tosso, J. 1977. *Determination and utilization of water production functions for principal California crops*. W-67 California Contributing Project Report. Davis, United States of America, University of California. [<http://www.fao.org/docrep/004/y3655e/y3655e01.htm#TopOfPage>] Accessed 27 Oct 2011.
- Stöckle, C., Martin, S., and Cambell, G. 1992. “A model to assess environmental impact of cropping systems” *Amer. Soc. of Agr. Eng.*, 92(2041):321-331.
- Strzepek, K. 2011. *Responding to Climate Change in Macedonia’s Agricultural Sector: Water Resources Impact Assessment – Presentation*. [[http://siteresources.worldbank.org/ECAEXT/Resources/258598-1277305872360/7190152-1303416376314/7889046-1303751700019/7893844-1303752022697/Macedonia-Water-Impacts\\_v2.pdf](http://siteresources.worldbank.org/ECAEXT/Resources/258598-1277305872360/7190152-1303416376314/7889046-1303751700019/7893844-1303752022697/Macedonia-Water-Impacts_v2.pdf)] Accessed 3 November 2011.
- Supit, I., Hooijer, A.A. and van Diepen, C.Z. 1994. *System Description of the WOFOST 6.0 Crop Simulation Model Implemented in CGMS, Volume 1: Theory and Algorithms*. EUR 15956 EN, Joint Research Centre, Commission of the European Communities, Luxembourg.
- UNDP Croatia. 2009. *A Climate for Change: Climate Change and its Impacts on Society and Economy in Croatia*. Zagreb, Croatia.
- Vaux, H.J. and Howitt, R.E. 1984. “Managing Water Scarcity: An Evaluation of Interregional Transfers” *Water Resources Research* 20: 785-92.
- Vucetic, V. 2006. *Modelling of the Maize Production and the Impact of Climate Change on Maize Yields in Croatia. Final Report*. Meteorological and Hydrological Service of Republic of Croatia, Meteorological Research Division, Research and Atmospheric Modelling Department, Numerical Modelling Unit, Zagreb Croatia.
- Ward, F.A., Hurd, B. H., Rahmani, T., & Gollehon, N. 2006. “Economic impacts of federal policy responses to drought in the Rio Grande Basin,” *Water Resources Research* 42(3): 41-53.

Weyant J. 1995. “Integrated Assessment of Climate Change: An Overview and Comparison of Approaches and Results,” in J. P. Bruce (ed.), *Climate Change 1995: Economic and Social Dimensions of Climate Change*. Cambridge University Press, Cambridge, UK.

Yates, D. 1994. *WATBAL – An Integrated Water Balance Model for Climate Impact Assessment of River Basin Runoff*. IIASA Working Paper: WP-94-64, Laxenburg, Austria.

# Economic Theory and Additional Data for Evaluating Impacts of Climate Change on Energy Demand for Space Heating and Cooling

## Economic Theory: Diagrammatic Exposition of How Consumers and Producers Respond to Changes in Outdoor Temperatures

---

**T**he economic impacts of climate change, including the economic value of climate change damages and the costs and benefits of adaptation can be simulated using models of individual consumer behaviour and the supply and electricity market supply and demand. The economic theory that underlies this type of valuation is presented in Figure I-1 and Figure I-2. Figure I-1 provides the basis for understanding the valuation of climate change damages (or benefits) when outdoor temperatures during the heating and/or cooling season are influenced by climate change. Figure I-2 looks at how energy producers react to the resulting changes in demand, both in the short-run and long-run.

The top panel of Figure I-1 presents two “comfort curves”,  $C_0$  and  $C_1$ , which show the relationship between how comfortable an individual feels inside a residential or commercial building and electricity use, under two different outdoor temperature regimes. Each of these curves shows that, holding the climate constant, increasing energy use makes the individual more comfortable as indoor temperature is increased in the heating season and decreased in the cooling season. But at some point, as the building becomes too hot in the heating season or too cold in the cooling season, individual comfort starts to decline as energy use increases past the point of maximum comfort, where the indoor temperature is ideal. The curve on the left,  $C_0$ , shows this relationship for a climate that is warmer in the heating season and colder in the cooling season than the curve to the right,  $C_1$ .

The lower panel of Figure I-1 shows the demand for electricity that can be derived from the information in the top panel in conjunction with a model of comfort-maximizing consumer behaviour. Each demand curve traces out the electricity consumer’s marginal willingness-to-pay for electricity under a given climate regime. The demand curve,  $D_0$ , is associated with the comfort curve,  $C_0$ , while the demand curve,  $D_1$ , is connected to the comfort curve,  $C_1$ .  $D_1$  is flatter than  $D_0$ . This must be the case since every point on  $C_1$  lies to the right of  $C_0$ . Why this is important will be illustrated shortly.

The individual consumer in Figure I-1: Illustration of how changes in outdoor temperature influence the space heating and cooling demands of residential and commercial electricity customers is a “price taker” in the market for electricity. This means that their consumption of electricity cannot influence the price of electricity. The “initial” price of electricity is shown as  $P_0$ . At that price, the consumer whose demand curve is  $D_0$  will use  $Q_0$  kWh of electricity at the price,  $P_0$ . It can be shown that one way to approximate the welfare of a consumer in a market is by cumulating the marginal willingness-to-pay increments under the demand curve for the good and then subtracting the expenditures of the consumer for the good. That calculation for the electricity demand curve,  $D_0$ , is equivalent to the sum of geometric areas in Figure I-1, labelled B and D, or B+D.

Now, what happens when it becomes colder outdoors during the heating season and/or warmer during the cooling season? The answer is that it requires more electricity to achieve the ideal indoor temperature and the comfort curve shifts from  $C_0$  to  $C_1$ . At the market price,  $P_0$ , the consumer increases electricity consumption from  $Q_0$  to  $Q_1$  kWh.

However, as the upper panel of Figure I-1 indicates, the comfort level associated with  $Q_1$  along the comfort curve  $C_1$  falls slightly in relation to the original comfort level along  $C_0$ .

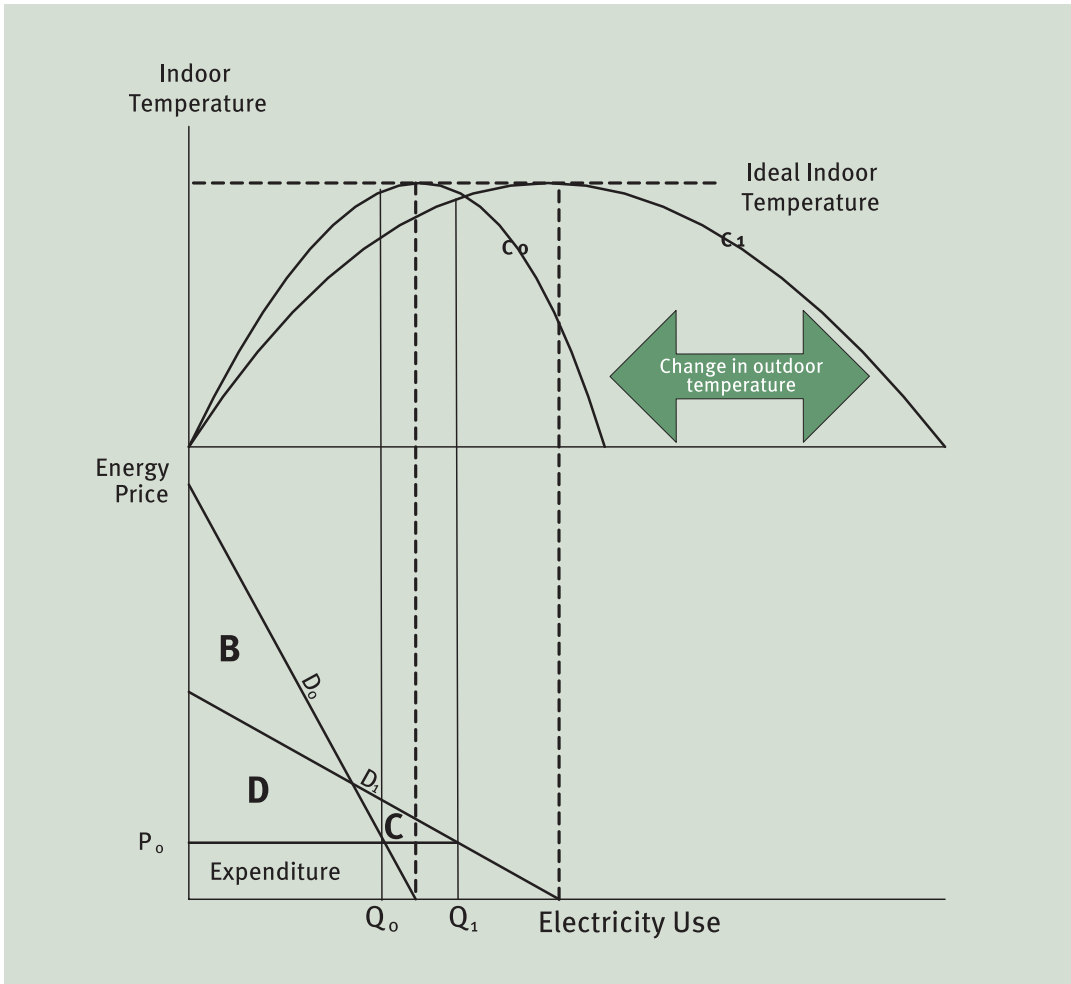


Figure I-1: Illustration of how changes in outdoor temperature influence the space heating and cooling demands of residential and commercial electricity customers

What are the welfare consequences of the change in the climate regime? Since the marginal willingness-to-pay for electricity along the new demand curve,  $D_1$ , associated with the change in climate lies below the marginal willingness-to-pay for electricity along part of the old demand curve,  $D_0$ , the consumer loses an amount of welfare equal to the geometric area **B**, but gains back a small amount of welfare where  $D_1$  lies above  $D_0$ , equal to the area **C**. Thus the climate change has created an approximate net loss of what is conventionally known as a change in “consumer surplus” due to the change in climate, as described above (assuming there is no adjustment of the electricity price in the market) equal to the area  $C-B < 0$ .

The situation is reversed when the initial climate is described by the comfort curve  $C_1$  and it becomes warmer outdoors during the heating season and/or colder during the cooling season. In this case, initial electricity consumption is  $Q_1$  kWh along the demand curve  $D_1$ . The net

level of consumer welfare associated with this level of consumption is equal to the sum of the geometric areas,  $D+C$ . When the climate changes, the comfort function shifts to the left and electricity falls along the new demand curve,  $D_0$ , to  $Q_0$  kWh. As a result, there is an increase in welfare (i.e., consumer surplus) equal to the net amount  $B-C > 0$ . Thus, when it gets warmer during the heating season and/or colder during the cooling season, residential and commercial customers may benefit from climate change.

Figure I-1 only considers the change in welfare of an individual electricity consumer, whose consumption cannot influence the price of electricity. However, to view the total welfare picture and to correctly measure the value of climate change damages and the benefits and costs of adaptation one must look at how electricity markets will respond to climate changes, both on the demand and supply side of the electricity market. This is shown in Figure I-2.

Figure I-2 shows the aggregate demand curves for electricity at the national level,  $D_0$  and  $D_1$ . These curves are derived by summing up all of the demand curves of individual electricity users, horizontally. The supply curve picture for electricity in Figure I-2 is a bit more complex, because it is made of a long-run supply curve,  $S_{LR}$ , and part of the short-run supply curve,  $S_0$ . The long-run supply curve,  $S_{LR}$ , traces out the minimum marginal cost on the vertical axis of producing  $Q$  kWh of electricity on the horizontal axis, when all of the inputs to the production of electricity, including power plants and distribution infrastructure and all of the supply-side adaptation options that require new investment are variable. The portion of the short-run supply curve,  $S_0$ , shows how much it will cost at the margin to produce more electricity (than  $Q_0$  kWh) if no new generation and distribution capacity is added. By implication this supply curve also includes whatever short-run adaptation options that are needed to increase electricity production above the initial long-run level of  $Q_0$ , without new investment to deal with existing climate variability

If the price of electricity is initially  $P_0$ , then the resulting equilibrium along the long-run supply curve occurs at the point where the initial demand curve,  $D_0$ , intersects  $S_{LR}$ . At this point, the market price is  $P_0$ , electricity production in the market is equal to  $Q_0$  kWh. The corresponding level of long-run welfare of producers and consumers is equal to the sum of the geometric areas  $A+B$ , which is the area below the relevant market demand curve,  $D_0$ , and above the relevant market supply curve,  $S_{LR}$ , to the left of  $Q_0$ . This area represents the sum of all of the consumer surpluses plus all of the short- and long-run profits of producers, depicted in this diagram.

This was the situation described in Figure I-1 for the individual consumer, blown up to the market level. Now, what happens when all residential and commercial consumers face a shift to the right of their comfort functions is that the market demand curve for electricity also shifts in the same general way as it did for the individual consumer from  $D_0$  to  $D_1$ . What happens to the market price of electricity and, ultimately, to the welfare of consumers and producers in the market depends on how producers react to this increased demand for electricity. If producers do nothing and hold  $Q_0$  fixed then the market price of electricity would rise to  $P_{max}$ , and at this price, electricity consumers would have to turn down their thermostats. This might occur in the very-short-run, if producers regarded the change in climate as purely “transient”. But it can probably be assumed that there exists some flexibility for producers to adjust to these situations using the existing adaptive capacity of the electricity supply system to cope with

climate variability. In that case, producers would supply electricity along the short-run supply curve,  $S_o$ , from  $Q_o$  up to  $Q_{SR}$ , at a market price of  $P_{SR}$ , which is less than  $P_{max}$ . At this equilibrium, the sum of consumer surplus and the short- and long-run profit of producers would be reduced the sum of the geometric areas,  $A + C_1$ . Since the initial level of welfare was equal to the sum of the areas  $A + B$ , the change in welfare after the partial adjustment must equal  $A + C_1 - A - B = C_1 - B < 0$ .  $-B$  is the aggregate consumer surplus loss due to the change in climate and  $C_1$  is an increase in both consumer and producers surplus due to both the way in which the demand curve for electricity responds to climate change and the short-run, partial adjustment to the change in temperature.

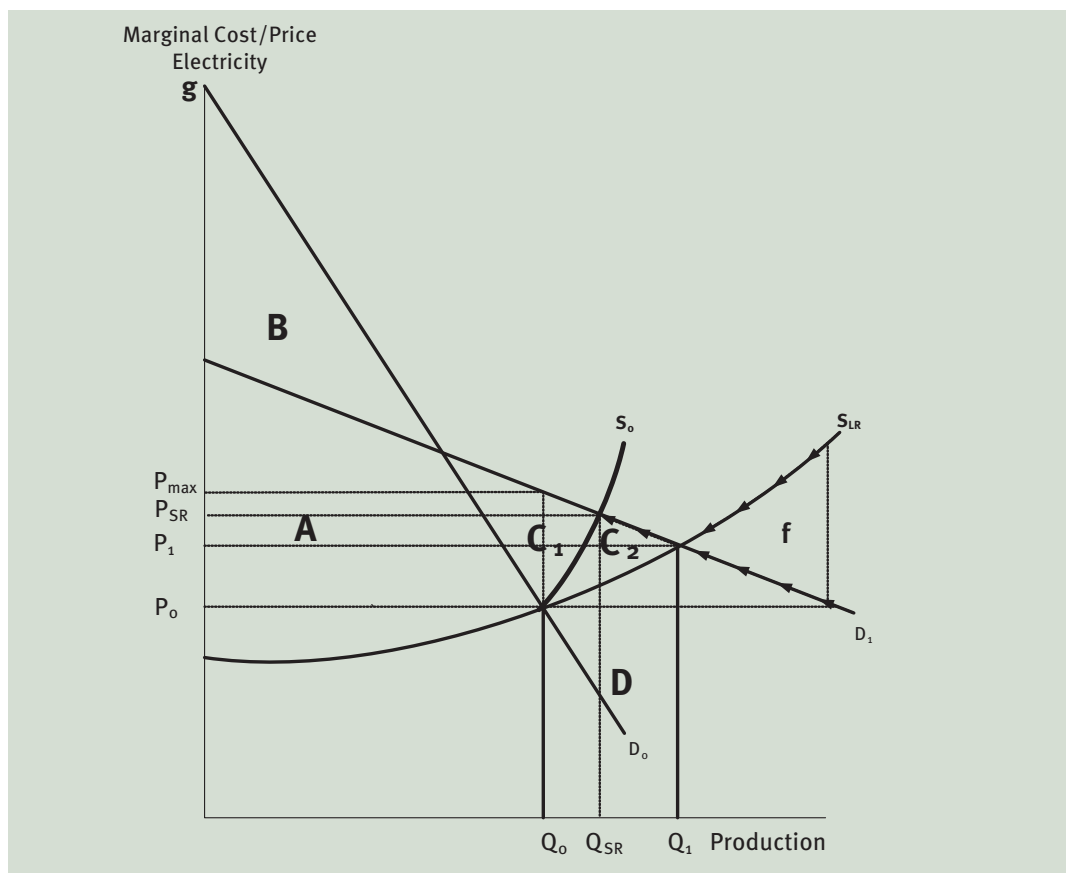


Figure I-2: Illustration of electricity market adjustments to changes in the effect of outdoor temperatures on residential and commercial electricity customers

If the operant definition of climate change damages in a sector, following Fankhauser (1997) and Callaway (2004A), is the reduction in welfare due to climate change, taking into account only short-run adaptation through a process of partial adjustment, then the area,  $C_1 - B$  would be the corresponding measure of climate change damages for the decrease in outdoor temperature during the heating season and/or the increase in outdoor temperature during the cooling season.



The short-run, partial adjustment by producers, just shown, is only one possible response. It can be expected to occur either when the climate change is not regarded as permanent (i.e., it is transient) and/or the cost of adjusting capacity and other infrastructure to adapt to climate change is considered to be too expensive based on the expected benefits. Obviously, if the damages of climate change are uncertain, then the expected benefits of avoiding these damages will also be uncertain, while the costs will be better known.

However, assuming both that producers now expect the climate change to be permanent and that the investment costs of adapting to climate change in the long-run are warranted based on the expected benefits, then another adjustment would occur. In that case, producers would adapt/invest along their long-run supply curve up to the long-run equilibrium level of production  $Q_1$ , where the market price of electricity is  $P_1$ . At this long-run, full adjustment equilibrium, the net welfare of producers and consumers would be equal to  $A + C_1 + C_2$ . If we compare this to the welfare level associated with short-run, partial adjustment  $A + C_1$ , the net benefit of the long-run, full adjustment, compared to the partial adjustment response is  $A + C_1 + C_2 - A - C_1 = C_2$ . In other words,  $C_2$  represents the net long-run benefits of adaptation that are *in addition* to the short-run, partial adjustment benefits,  $C_1$ . Correspondingly, the residual damages – the climate change damages that are not avoided equal  $A + C_1 + C_2 - A - B = -B + C_1 + C_2$ .

The economic welfare calculations and benefit-cost measures described in Figure I-2 are summarized in Table I-1 and Table I-2, respectively. Table I-1 shows the total welfare in Figure I-2 associated with the following market equilibria:

- Upper Left: The intersection of the demand curve,  $D_0$ , with the supply curve,  $S_0$ ,
- Upper Right: The intersection of the demand curve,  $D_1$ , with the supply curve,  $S_0$ ,
- Lower Right: The intersection of the demand curve,  $D_1$ , with the supply curve,  $S_{LR}$
- Lower Left: The intersection of the demand curve,  $D_0$ , with the supply curve,  $S_{LR}$

Table I-2 shows the welfare calculations for the various benefit and cost measures associated with climate change. All of the benefit and cost measures except the last two in Table I-2 have already been explained. The Cost of Caution is the cost of not planning for a climate change that actually occurs (when there are just two climates under consideration) or the cost of planning for a less damaging climate than that which actually occurs (when there are multiple climate states to consider). This cost is simply the reverse of the net benefits of adaptation. In other words, you lose what you would have gained by full adjustment to climate change.

Table I-1: Total Net Welfare of Consumers and Producers for Increases in the Demand for Space Heating and Cooling as Illustrated in Figure I-

Supply Curve	Climate ( $D_0$ )	Climate ( $D_1$ )
$S_0$	$A + B$	$A + C_1$
$S_{LR}$	$A + B - D$	$A + C_1 + C_2$

The Cost of Precaution is a bit more complicated to explain. It is the cost of planning for a climate change that doesn't occur (when there are just two climates under consideration) or the cost of planning for a climate change that is more damaging than that which actually occurs. So, in this case it is assumed that producers planned for the demand curve  $D_1$  and adjusted their production capacity along the long-run supply curve, until they could produce  $Q_1$  kWh at a price of  $P_1$ , but in fact the demand curve  $D_0$  did not shift to  $D_1$  after the investment in additional capacity was made. As a result, the net welfare level of  $B+A$  must be reduced by the cost of the investment in the un-needed (or stranded) generation capacity. This is equal to the area under the long-run supply curve between  $Q_0$  and  $Q_1$ , as measured by the area  $-D$ . Thus, total welfare (Table I-1) under this case is  $A + B - D$  and the Cost of Precaution is equal to  $A + B - D - A - B = -D$ .

Table I-2: Benefit-Cost Measures Defined in Figure I-2

Climate	Climate ( $D_1$ )
Climate Change Damages	$A + C_1 - A - B = C_1 - B$
Net Benefits of Adaptation	$A + C_1 + C_2 - A - C_1 = C_2$
Residual Damages	$A + C_1 + C_2 - A - B = C_1 + C_2 - B$
Cost of Caution	$A + C_1 - A - C_1 - C_2 = -C_2$
Cost of Precaution	$A + B - D - A - B = -D$

Table 1 -1 and Table I-2 summarize the welfare adjustments when the heating season gets colder and the cooling season gets warmer. But what about the changes in welfare when the situation is reversed: when it gets warmer in the cooling season and colder in the cooling season? From Figure I-2, it would first appear that when climate changes in this way, the result must be that total welfare increases, since the total welfare where  $D_0$  intersects  $S_0$ , namely  $A+B$  is greater than the welfare where  $D_1$  intersects either  $S_0$  ( $A + C_1$ ) or  $S_{LR}$  ( $A+C_1+C_2$ ). However, in this particular climate case, the benefits and costs of market adjustments depend on whether the electricity system in the current period is on its short-run or long- run supply curve. If the industry is initially in long-run adjustment to the demand curve  $D_1$ , producing  $Q_1$  kWh at a price of  $P_1$ , and the climate changes to the demand curve to  $D_0$ , then the optimal equilibrium point to which producers should adjust, is for them to generate  $Q_0$  kWh at a price of  $P_0$ . In other words, the welfare change in terms of Table I-1 could at first be construed to involve an adjustment from the lower right cell of Table I-1 (where net welfare is equal to  $A + C_1 + C_2$ ) to the upper left cell (where net welfare equals  $(A+B)$ ). This may seem at first to be intuitively obvious, since it is the value of the residual damages (Table I-2) of shifting from  $D_0$  to  $D_1$  along  $S_{LR}$ , but with the reverse sign. Unfortunately, however, this is not the end of the calculation, because while the variable cost of generation can be avoided, the fixed cost cannot. In this case, the fixed cost of generation is equal to the area under the long-run supply curve between  $Q_0$  and  $Q_1$ , as shown by the geometric area,  $D$ .

The fact that the fixed cost of additional generating capacity once made, cannot be avoided, makes it difficult to use all of the benefit cost definitions in Table I-2 to characterize the adjustments to climate change in this case. What can be said is that, if the industry is initially

producing  $Q_1$  kWh along the long-run supply curve at a price of  $P_1$ , the net benefits (or cost) of adjusting to climate change will be  $A+B - A - C_1 - C_2 - D = B - C_1 - C_2 - D$ . On the other hand, if the industry is initially on the short-run supply curve  $S_0$  and producing  $Q_{SR}$  kWh at a price of  $P_{SR}$ , the net benefit (or cost) of adjusting to climate change will be  $A+B - A - C_1 = B - C_1$ . One cannot say for certain whether the net change in welfare along either path will be positive or negative. However, it should hold that  $B - C_1$  will be greater than  $B - C_1 - C_2 - D$ . This would be the case because the investment cost  $D$  is not incurred and the adaptation benefit from the previous climate case,  $C_1$ , is not lost.

Perhaps two final comments are in order, regarding the measurement of adaptation benefits. The first issue has to do with including short-run adaptation as a part of the impacts of climate change. The justification for doing this is partly based on theoretical and partly on practical grounds. On the theoretical side, first, economists generally allow some sort of substitution to occur when they measure damages. For example, when the price of a good or service increases, economic theory demands that, in measuring the welfare loss to consumers, consumers are allowed to adjust their consumption of all goods to the change in the price of any single good. On the practical side, it is very difficult to observe how the short-run adaptive capacity developed to deal with existing climate variation can be separated from the short-run adaptive capacity to deal with climate change. However, it is possible to observe investment and the distinction between adjusting to climate in the short-run and adjusting to climate in the long-run is not only easier to observe, but is also evidence that economic agents are adapting to climate change, because they are willing to accept the economic costs of making these investments. Therefore, the distinction seems useful. Finally, it should be noted that the relative magnitude of the net benefits of short-run adaptation vs. long-run adaptation, where it is even possible to measure the short-run benefits, is an empirical and not a theoretical issue.

## Simulated Temperature Changes and Heating-Cooling Degree Day Calculations

The temperature changes used in the analysis to reflect climate change are shown below in Figure I-3.

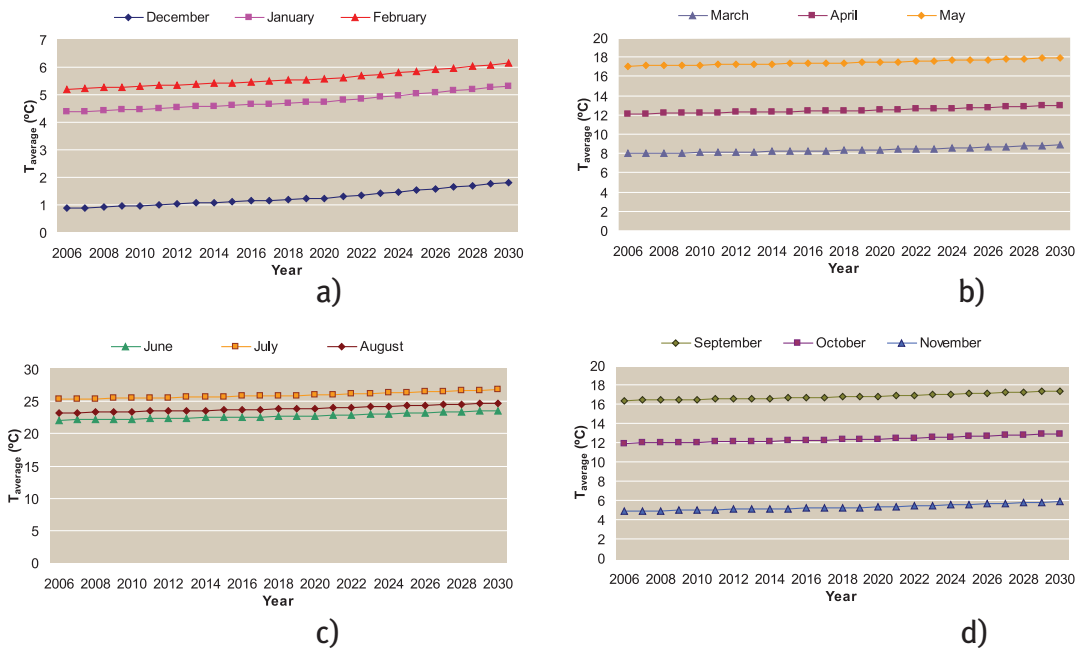


Figure I-3: Projections for the monthly average temperatures

## Methodology for Linking Changes in Outdoor Air Temperature to Changes in Heating and Cooling Degree Days in MARKAL to Reflect Climate Change

The calculations of HDD and CDD for this study were made following the methodology used by the District heating company, “Toplifkacija” in Skopje, the capital of the country. This approach has already been implemented in the Macedonian version of MARKAL. According to this methodology, HDD the value for given outdoor temperature is calculated as:

$$HDD = D_{(HS)} \cdot (T_{Base} - T_{Av(HS)}), \quad (1)$$

where:  $D_{(HS)}$  is the number of days in the heating season,  
 $T_{Base}$  is the base temperature of the space that is heated, which is 20°C,  
 $T_{Av(HS)}$  is the average temperature during the heating season

Using the same approach, CDD values are calculated as:

$$CDD = D_{(CS)} \cdot (T_{Av(CS)} - T_{Base}), \quad (2)$$

where:  $D_{(CS)}$  is the number of days in the cooling season,  
 $T_{Base}$  is the base temperature of the space that is cooled, which is 20°C,  
 $T_{Av(CS)}$  is the average temperature during the cooling season

The calculation of the HDD and CDD were made under following assumptions:

- Average duration of heating season – 180 days (from beginning of October till end of March, next year<sup>24</sup>)
- Average duration of the cooling season – 120 days (from beginning of June till the end of September)

The projected vales for the HDD and CDD for the average heating and cooling season are given in Table I-3, rows HDD1 and CDD1, respectively. In addition, the HDD and CDD were calculated for the heating season duration of 182 days and 112 days for cooling season. The projected values of the HDD and CDD for the two different season lengths are also shown in Table I-3, rows HDD2 and CDD2, respectively. The values for HDD1 reflect the shorter heating season and are thus always higher than HDD2 projection, while HDD (average) is the mean value. For CDD values presented in Table I-3, CDD1 is always higher than CDD2 and the average CDD is the mean value.

<sup>24</sup> In reality the heating season is from 15th of October until 15th of April, but for the purpose of this analysis this period was shifted 15 days earlier to include whole months, with intention to use the projected monthly values for the temperature (Figure 2).

Table I-3: Projections for HDD and CDD in the country

Year	2007	2008	2009	2010	2011	2012	2013	2014
HDD1	2538	2533	2528	2523	2518	2513	2508	2503
HDD(average)	2548	2543	2538	2533	2528	2523	2518	2513
HDD2	2566	2561	2556	2551	2546	2541	2536	2531
CDD1	216	221	226	231	236	241	246	251
CDD(average)	206	211	216	221	226	231	236	241
CDD2	201	206	211	216	220	225	230	235
Year	2015	2016	2017	2018	2019	2020	2021	2022
HDD1	2498	2493	2488	2483	2478	2473	2463	2453
HDD(average)	2508	2503	2498	2493	2488	2483	2478	2471
HDD2	2525	2520	2515	2510	2505	2500	2490	2480
CDD1	257	262	267	272	277	282	291	300
CDD(average)	246	251	257	262	267	272	277	283
CDD2	239	244	249	254	258	263	272	280
Year	2023	2024	2025	2026	2027	2028	2029	2030
HDD1	2443	2433	2423	2413	2403	2393	2383	2373
HDD(average)	2463	2453	2443	2433	2423	2413	2403	2393
HDD2	2470	2460	2450	2440	2429	2419	2409	2399
CDD1	310	319	328	337	346	356	365	374
CDD(average)	291	300	310	319	328	337	346	356
CDD2	289	298	306	315	323	332	341	349

The next step was to normalize the HDD and CDD adjustments for use in MARKAL. The normalization for HDD1 and CDD1 for 2009 to compute the adjustment factors AdF1 for HDD and CDD is:

$$\text{AdF1(HDD)}_{(2009)} = \text{HDD}(1)_{(2009)} / \text{HDD(average)}_{(2009)} = 2528 / 2538 = 0.996, \text{ and}$$

$$\text{AdF1(CDD)}_{(2009)} = \text{CDD}(1)_{(2009)} / \text{CDD(average)}_{(2009)} = 226 / 216 = 1.047.$$

The AdF2 (HDD) and AdF2 (CDD) adjustment factors are calculated in the same way, using HDD2 and CDD2, respectively. The Base Case normalization, by definition, is 1.000. Therefore, if the adjustment factors are less 1.0 there is a decrease in HDD or CDD and if the adjustment factors are greater than 1.0, there is an increase in HDD or CDD.

Table I-4: Energy demand projection in commercial and residential sector by end-use services

Base Case (ktoe)											
Sector	End-use service	2006	2009	2012	2015	2018	2021	2024	2027	2030	Avg. growth rate
Commercial	Cooking	13.6	13.6	14.3	15.1	16.2	17.5	18.5	19.5	20.5	1.70%
	Cooling	14.4	18.2	24.2	32.6	42.8	50	57.2	63.9	70.3	6.80%
	Heating	130.5	129.9	139.4	149.8	161.2	171.8	179.9	189.1	201.7	1.80%
	Lighting	33.7	33.8	36.8	40.5	45	49.2	52.4	54.5	56.6	2.20%
	Other	5.8	5.9	6.5	7.2	8.2	9	9.7	10.2	10.7	2.60%
	Public Lighting	4.8	4.9	5.4	6	6.8	7.5	8.1	8.5	9	2.60%
	Refrigeration	4.8	4.9	5.4	6	6.8	7.5	8.1	8.5	9	2.60%
	Water Heating	22.1	23.3	22.7	21.8	21	21.6	21	20	17.8	-0.90%
	<b>Total</b>	<b>229.8</b>	<b>234.5</b>	<b>254.8</b>	<b>279.1</b>	<b>307.9</b>	<b>334.1</b>	<b>355</b>	<b>374.4</b>	<b>395.6</b>	<b>2.30%</b>
Residential	Refrigeration	41.6	41.1	43.9	47.3	51.8	58.3	65	71.7	78.7	2.70%
	Clothes Drying	3.2	4.8	6.9	9.6	12.9	17.1	21.9	27.3	33.4	10.30%
	Clothes Washing	16	15.8	16	16.2	16.5	17.2	18	18.6	19.3	0.80%
	Cooking	80.5	80.2	79.6	76.9	77.5	77.5	78.7	78.5	78.4	-0.10%
	Cooling	13.6	15.7	18.9	23.1	28.3	35.1	42.7	50.9	60	6.40%
	Dishwashing	3.5	4.2	5.2	6.5	8.1	10.2	12.6	15.3	18.3	7.10%
	Heating	524.4	536.5	560.1	585.7	605.9	626.6	644.7	659.4	694.9	1.20%
	Lighting	43.2	42.1	44.5	48.7	54	59.9	65.9	71.7	77.6	2.50%
	Other	12.8	12.9	15.1	18.1	22.3	28.3	35.3	43.2	52.5	6.10%
	Water Heating	69.9	66.7	64.3	67.3	68.1	71.3	73.6	78.3	68.6	-0.10%
<b>Total</b>	<b>808.6</b>	<b>819.8</b>	<b>854.6</b>	<b>899.4</b>	<b>945.5</b>	<b>1001.5</b>	<b>1058.3</b>	<b>1115</b>	<b>1181.6</b>	<b>1.60%</b>	

# Modelling Information and Base Case Data for Analysing the Economic Impacts of Climate Change on Agriculture

## Valuing the Economic Damages of Yield Reductions in the Agricultural Sector from the Bottom-Up

- ***Agronomic.*** This approach relies on the observed response of crop yields to different soils, climates, and management regimes to simulate changes in average annual crop yields. Independent projections of crop prices and crop areas are used to convert these yield changes into economic values.
- ***Agro-economic.*** This approach combines the agronomic approach to determine the impacts of climate change on crop yields with agricultural market models to determine crop production, prices and economic gains and losses due to climate change. These methods are often “normative” (optimization-based) in that the results are consistent with both agronomically “optimal” and economically efficient management.



## Agronomic Models

An agronomic model is based on a model for simulating the effects of changes in climate at various time and spatial scales on crop yields, under different geo-physical conditions and management regimes. Such a model can take the form of a simple, single equation, regression model or a numerical simulation model. The state-of-the-art in agronomic modelling consists of simulation models, like those developed under the names of CERES (Tubiello et al. 2002), EPIC (Stöckle et al. 1992) and WOFOST-DSSAT (Supit et al. 1994), all of which support a number of row crops, with more under development. These models are readily available off the shelf, but must be calibrated to local geo-physical and climatic conditions by trained agronomists, agricultural engineers and agro meteorologists. In most cases, this applied work is supported by crop-specific plot level agronomic research and by larger field studies at the farm research level to look more closely, for example, at disease and pest management issues.

These models simulate the effects of daily weather on the growth and yield of individual row crops. As such, they need daily observations on a number of meteorological variables, as well as information about the physical environment in which the crop is grown related to soils, drainage, water uptake, etc., and “management”. These types of models can also be used to simulate a number of different types of management practices related to the type, timing and quantity of inputs (water, fertilizer, harrowing, ploughing, etc.) applied. The relevant output of these models is the physical yield of the crop that can be harvested in weight units.

Calibrating these models is very data intensive and many countries and specific sites do not have complete data sets to do this. In that case, these types of models are generally calibrated from plot data at a few locations and then the calibrated model is used in a representative fashion to simulate yields over a number of other locations with the same geo-physical and climatic characteristics as the plot locations. In cases, where the data problems are more extreme, it is possible to use a limited number of input values in combination with the results of “experiments” conducted with these models to generate “pseudo data” and then fit regression models to these data. The regression models can then be used to simulate the effects of climate changes on yields changes at locations for which there are very limited soils and management data (for example)<sup>25</sup>. This method was successfully used in the PESETA study of the economic impacts of climate change in the EU (Ciscar et al. 2010).

An illustration of how such a model can be used to estimate the economic impacts of climate change appears in the recent Human Development for Croatia, A Climate for Change (UNDP 2009). This study was based on research by Vucetic (2006) who used the CERES- MAIZE model to estimate the impacts of different IPCC climate scenarios on maize production in Croatia. The simulated reductions in yield ranged from 3-8% for the year 2050 and from 8-15% for the year 2100. The authors of the UNDP study evaluated these reductions using historical data on the area of maize production and the average annual producer price and came up with estimates of economic (revenue) losses on the order of EUR 6-16 million for the year 2050 and EUR 31-43 million for the year 2100, compared to revenues of EUR 199 million for the historical base case.

<sup>25</sup> This method was successfully used in the PESETA study of the economic impacts of climate change in the EU. See Ciscar et al. (2010).

One of the biggest benefits of these types of models is that they can be used in a wide variety of different applications, not just climate change. In that sense, developing the capacity to use such a model in a country is one of those “no regrets” decisions, as previously mentioned in Chapter 1. Another important strength of this approach lies in the accuracy of its estimates of yields, compared to older, empirical models. There are several weaknesses. The number of crops for which these models have been developed is limited largely to row crops. Also, the structure of these models is not amenable to simulating the growth of long-term crops (fruit trees, berry and vine-crops). The models also assume technologically-efficient production under modern commercial agricultural conditions, which may not accurately represent a country’s situation. Finally, these models cannot simulate how farmers and markets will react to climate change. Climate change has the potential to influence the relative profitability of crops and this will, in turn, influence not only how much land farmers allocate to different crops, but also the cost/price at which the commodity can be produced and/or purchased. An agronomic model cannot simulate the effects of climate change in the framework of economic farm-level decision-making or agricultural commodity markets. These models can be used to simulate management actions, such as row spacing, different tillage methods and planting date, but these inputs are not determined by the model. The user must enter this information into the model. The model can then simulate the resulting effects on crop yields.

## Agro-Economic Models

Agro-economic sector models overcome the main limitation of agronomic models by using the projections from agronomic crop yield (and also from livestock) models to drive very sophisticated agricultural sector models, sometimes known as spatial equilibrium models (McCarl and Spreen 1980). Spatial equilibrium models simulate the decision making processes of producers and consumers in many different agricultural commodity markets, accounting for trade and shipments between sub-national and international regions. In that regard, they can be characterized as multi-commodity market models of food supply and demand in many demand and supply regions.

Simulating the effects of climate change on a single crop even over many different locations is far from the end of the story since, once a farmer knows that the climate is changing, he also knows it will affect the relative profitability of many different crops he can grow. He also knows that he will have to sell the crop into a national and/or international market where the effects of climate will influence the crop selection, management and production levels of many other farmers, not to mention the equilibrium market price for each crop and, ultimately, his net income. This knowledge will motivate him to think about what crops he will plant and when and how he will manage them, based on his expected net income and the climate and market-price risks associated with different crop combinations. Farm-level agro-economic models simulate these kinds of decisions, assuming the farmer faces a constant price for each commodity that is produced.

Sector models can take these farmer-market interactions into consideration in both a climate variability and climate change context. Like crop yield simulation models, agricultural sector

models represent a “no regrets” approach to improving the agricultural modelling expertise of a national government. These types of models are used in developed countries to assist policy makers to explore a variety of policies related to the impact of climate variability on the sector, as well as to support national agricultural development and marketing strategies in the context of modern market economies.

To model how climate change will affect crop mixes, production levels and crop prices at the market level there needs to be a “price-endogenous” spatial equilibrium (SE) sector model for the agricultural sector. Price-endogenous simply means that crop and food product prices are an output, not an input, of the model. Spatial equilibrium means the model represents differentiated production possibilities over space and transport of products across space to markets. Both features are very important for modelling the impacts of climate change, because changes in climate will be non-uniform over space and, because many producers and consumers in many places will be affected differently by climate change at the same time, market prices will also be affected. Sector models differ from farm models in that they “include” demand functions for the agricultural commodities in the market. Small countries, whose domestic and trade prices cannot be influenced greatly by domestic production levels can be modelled as large, multi-commodity farms with constant commodity prices, at least as a start. This may be a good idea for the country.

An example of an Agro-Economic Model, currently in use inside the EU is the EU Forest and Agricultural Sector Optimization Model (EUFASOM) developed by Schneider et al. (2008)<sup>26</sup>. FASOM is actually a land use model. It contains an agro-multi-country, multi-commodity economic model for the agricultural sector and a multi-country, multi-product dynamic forest sector model that are linked by a common land base and economic objective function. This allows the model to simulate how land moves back and forth between the two sectors as a result of environmental and policy impacts. The model was originally developed in the US (Adams and McCarl 1999) to examine the market impacts of carbon sequestration policies in the United States that involved reforestation and afforestation (Alig et al. 2001). However, it has also been used extensively to assess climate change damages in the two sectors, as well as the benefits and costs of avoiding climate change damages through adaptation. The EU version of the model is currently being used to explore the mitigation potential of the agricultural and forest sectors in the EU; to examine how other EU energy policies, such as bio-fuels policy, will affect this potential; and finally to determine how climate change impacts in both sectors will affect their mitigation potential and mitigation costs.

The current version of EUFASOM models both sectors at the country level. However, the newest accession countries are not yet included in the model. This is also true of countries, including Serbia, Croatia, Montenegro and FYR Macedonia which will join the EU in the next rounds of EU enlargement. One interesting aspect of the Croatian Human Development report, *A Climate for Change*, is that it has led to the preparation of a project proposal that is now being circulated among both Croatian and multi- and bi-lateral donor agencies, to develop the capacity to develop and implement a Croatian “module” for the EUFASOM, which can be used to address a variety of pressing farm and rural development policy issues, including climate change, even before the country joins the EU.

| 130 | <sup>26</sup> Schneider, et al. 2008.

## Valuing the Economic Damages of Climate Change on irrigation Water Availability and the Benefits and Costs of Additional Reservoir Storage for Irrigation

Valuing the economic losses due to climate change under ideal circumstances requires to additional types of models:

- Rainfall-runoff models to account for the effects of projected climate changes on runoff into the water supply reservoir, and
- A Hydro economic model to allocate water from the reservoir to meet irrigation water demands.

### Rainfall-Runoff Models

The main effects of climate change on the potential to store and use more water for irrigation will occur primarily through changes in the quantity, timing and type of runoff that will be available for capture in storage reservoirs due to changes in precipitation and temperature, and through increased surface water evaporation due to higher temperatures. These physical changes can be modelled by means of catchment-level rainfall-runoff models. These are process-based simulation models that link all of the processes of the hydrologic cycle to the geophysical and climate characteristics of specific river basins. Such models can be used to simulate the flow of water, over land, from rainfall to river discharges, through such processes as overland flow, infiltration, evapotranspiration from natural and managed vegetation, and groundwater recharge and flow. There are a very large number of such models available in the private and public sectors, one of which MIKE-SHE, developed by the Danish Hydrologic Institute (DHI 1998)<sup>27</sup>, has been calibrated for the country (according to DHI).

Models, like MIKE-SHE, have fairly data-intensive calibration requirements for soils, elevations, vegetation and various geo-morphologic characteristics in a basin. Automatic calibration routines make these models easy to use in developed countries, but this becomes more difficult in data-poor environments. Once a model is calibrated for a specific basin, hydrologic processes can be simulated using hourly or daily or, in some cases, monthly (depending on the model) weather/climate data. Examples of the use of rainfall-runoff models to estimate the effects of climate change on monthly runoff, surface water evaporation on a monthly time scale to evaluate the economic impacts of climate change and evaporation include a study of four large US Basins (Hurd et al. 1999) using the variable infiltration capacity (VIC-2L) model (Nijssen et al. 1997 and Lettenmaier and Wood 1994), studies by Callaway et al. (2008 and 2009) of the Berg River Basin and its associated tributaries using the WATBAL model (Yates 1994) and on ongoing study of several basins in the Western Cape of South Africa using the ACRU model (Smithers and Schulze 1995).

### Hydro-Economic Models

All of the studies, cited previously, used what Hurd et al. (1999) termed a “hydro-economic” model to simulate the economic impacts of climate changes. This type of model was first de-

<sup>27</sup> Danish Hydraulic Institute (DHI). 1998. MIKE SHE Water Movement - User Guide and Technical Reference Manual, Edition 1.1.

veloped by Vaux and Howitt (1984) for estimating climate change damages for large water resource regions in California. It has been successfully implemented for climate change and other applications by Booker and Young (1991, 1994) for the Colorado River Basin, by Hurd et al. (1999) for the Missouri, Delaware and Apalachicola-Flint-Chattahoochee River basins in the US, and by Ward et al. (2006) for the Rio Grande River Basin in the American Southwest. More recently, this approach was applied by Callaway et al. (2008, 2009) to the Berg River basin in South Africa to estimate both climate change damages and the benefits and costs of specific adaptation measures to avoid these damages.

These models basically transform the physical impacts of reduced runoff and increased surface water evaporation into economic values. They do this by simulating not only the spatially distributed flow of runoff in a basin to reservoirs and points of water use, but also the dynamic operation of reservoirs, the optimal allocation of water to consumptive and non-consumptive uses, and long-term investment in infrastructure based on a mix of objectives. Most hydro-economic models assume welfare maximizing objectives (economic benefits minus economic costs) on the part of water users, super-imposed on traditional safety-first criteria of water planners and the existing allocation procedures in the basin used by water managers.

A graphic representation of a generic model is presented in Figure II-1. The schematic shows three external sources of information that drive hydro-economic models:

- ***A Regional Climate Model:*** This model down-scales GCM information about total precipitation and average daily temperature, by month usually, over a long time period (30-50 years) for specific weather stations and runoff gages used in a basin for climate variability/change scenarios.
- ***A Regional Hydrologic (Rainfall-Runoff) Model:*** This model converts the spatially-differentiated monthly temperature and precipitation data for the planning horizon in the model from the regional climate model into: 1) Monthly runoff at different runoff gages, 2) monthly reservoir evaporation coefficients for each storage dam, and 3) temperature-driven monthly adjustment factors to change agricultural and urban water demands.
- ***Inputs about Policies, Plans and Technologies:*** This represents the source of information that can be used to alter various parameters in the dynamic programming core model to reflect alternative demand- and supply-side policies, plans and technologies.

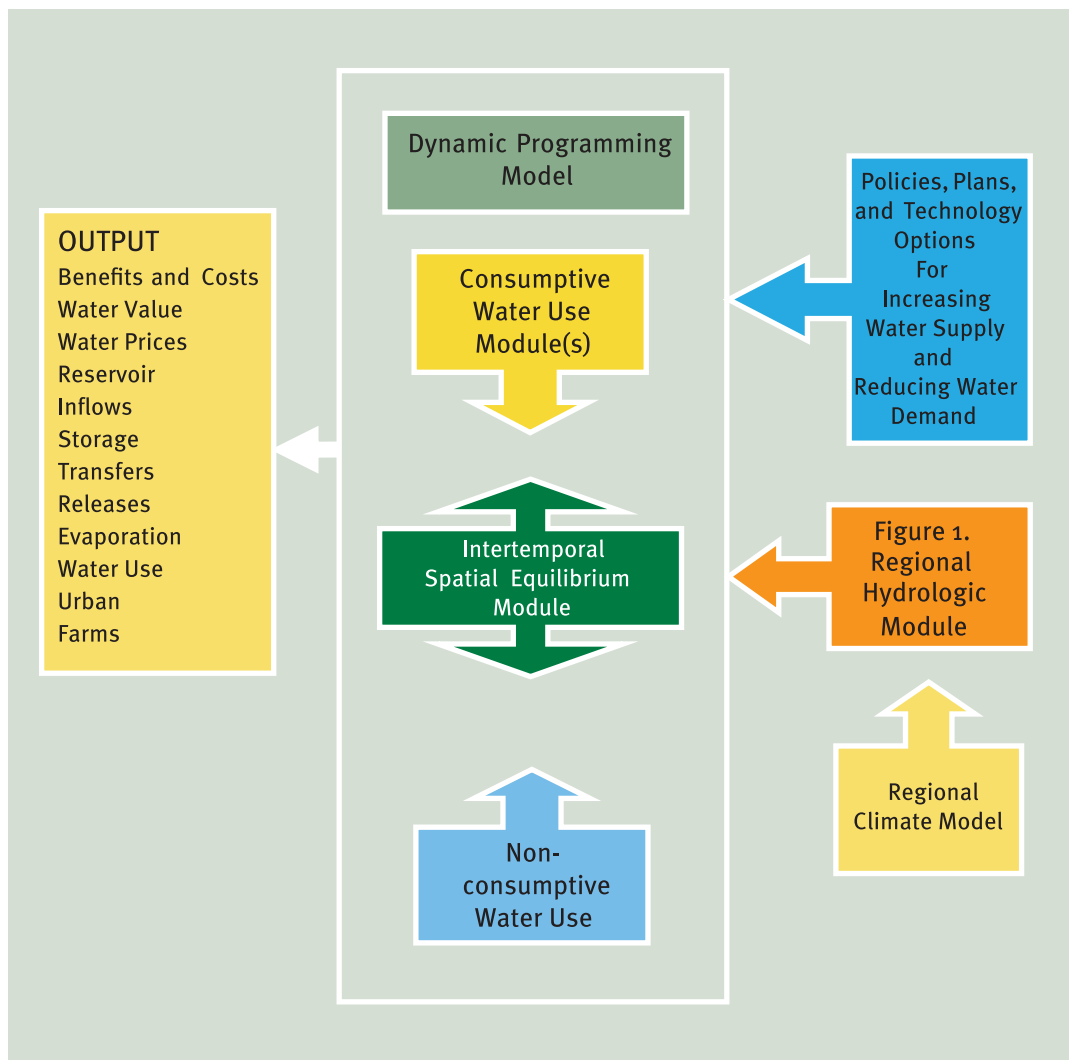


Figure II-1: Schematic Diagram of a Generic Hydro-Economic Model Used to Simulate the Economic Impacts of Climate Change on River Basins

The core of a hydro-economic model is generally a dynamic, non-linear programming (optimization) model. As depicted, it contains three interlinked modules, as follows. Two of the modules represent the explicit processes associated with top-down or bottom-up representations of the consumptive or non-consumptive water uses included in the model, as relevant to the basin. In all of the hydro-economic models, irrigation water demand is determined either by explicit demand curves for water or by demand curves that are derived from process models of a particular sector or set of water-using activities. For example, in the studies by Callaway et al. (2008, 2009) the demand for irrigation water was derived from a series of seven farm-level optimization models that were nested in the consumptive water use module, while municipal and industrial water use in Cape Town were represented by explicit downward sloping demand curves. In many applications, non-consumptive water use is modelled using a so-called

“damage function” approach. For example, in Hurd et al. (1999) several of the basin models included a damage function for water born transportation in which the loss of net revenue by shippers was a function of runoff, which is a proxy for channel depth in specific river reaches. The water demand and damage functions in these modules, serve as the basis for determining the economic impacts of climate change.

An important feature of the studies in South Africa is that they all looked at how the adding additional reservoir storage capacity would benefit consumptive and non-consumptive users of water in their respective basins. The idea behind this was that the existing reservoir capacity, while economically optimal for the “current” climate would not be optimal for a different climate, as it changed over time. One interesting finding of this part of these studies was that, in some cases, adding additional reservoir capacity to cope with (adapt to) climate change was not as physically effective or economically efficient as some other measures, for example changing the legal water allocation system. Physical effectiveness was found to be related to economic efficiency through the higher and higher costs of providing additional amounts average annual storage yield as runoff declined.

## Results

---

### The Base Case

Table II-1 and Table II-2 give the main results for the Base Case, including the major crops grown, the crop mix by land area, irrigation water use by crop and crop yield. There is no irrigation water use in the Base Case for rain-fed crops. The tables also contain information obtained from the crop budgets, including gross income (which includes both revenues and subsidies) per ha, fixed and variable costs per ha, and net income per ha for each crop. These net income figures are totalled at the bottom of the last column in each table. It should be noted that the crop mixes shown in these tables are heavily based on the observed crop mixes in the region for irrigated and rain-fed crops with some adjustments to account for transient economic and climatic factors which cause the crop mixes to move around from year to year. The results of the Base Case are mainly a reference point for the analysis of climate change damages and adaptation. However, it is instructive to note that the net income margins for the rain-fed crops are much smaller than for the irrigated crops. Therefore, it is likely farmers on rain-fed led will be made worse-off than farmers on irrigated lands, because the former have much lower net incomes and lack access to water.

Table II-1: Base Case Crop Results – Irrigated Agriculture

CROP	% of Total ha	Crop Area ha	Water Use m <sup>3</sup> /ha	Yield/ ha kg/ha	Price Denar/ kg	Gross Income/ha 10 <sup>3</sup> MKD	Cost/ha 10 <sup>3</sup> MKD	Net Inc./ ha 10 <sup>3</sup> MKD	Net Income 10 <sup>3</sup> MKD
Corn	38.37%	1998	4,116	7,000	9	71	53	18	36,031
Alfalfa	16.15%	841	4,793	10,000	7	78	59	19	15,932
Wheat	10.04%	523	3,263	5,000	10	61	46	15	7,927
Corn for silage	8.20%	427	2,822	35,000	2	78	61	17	7,219
Meadow	5.53%	288	5,716	8,000	6	48	39	9	2,648
Soya	3.51%	183	2,775	3,000	18	62	49	13	2,464
Orchards	2.94%	153	5,379	27,000	12	366	316	50	7,694
Vegetable garden	2.61%	136	3,807	15,000	15	245	199	46	6,254
Green pepper	2.32%	121	3,714	15,000	20	500	423	77	9,354
Sugar beet	1.98%	103	5,210	50,000	3	133	108	25	2,532
Pepper industrial	1.77%	92	3,714	25,000	12	358	293	65	5,964
Water melon and melon	0.98%	51	3,379	25,000	7	195	160	35	1,763
Sour cherry	0.96%	50	5,011	15,000	20	318	255	63	3,170
Sunflower	0.73%	38	3,429	2,500	16	48	39	9	331
Tobacco oriental	0.61%	32	3,753	2,000	170	460	336	124	3,970
Onion	0.60%	31	4,035	20,000	20	420	354	66	2,057
Potato	0.48%	25	4,035	30,000	12	380	333	47	1,165
Tomato industrial	0.40%	21	4,496	45,000	5	313	260	53	1,113
Grass mixture	0.38%	20	5,716	8,000	6	48	39	9	180
Cabbage	0.35%	18	3,807	40,000	8	340	295	45	805
Tobacco broad live	0.35%	18	4,116	15,000	8	120	95	25	453
Barley	0.33%	17	2,392	5,000	9	56	42	14	243
Tomato	0.23%	12	4,496	28,000	15	560	503	57	685
Bean	0.10%	5	3,807	1,500	90	155	128	27	136
Grape	0.08%	4	5,379	15,000	10	220	162	58	233
<b>Total</b>		<b>5207</b>							<b>120,323</b>



Table II-2: Base Case Crop Results – Rain-Fed Agriculture

CROP	% of Total ha	Crop Area ha	Water Use m <sup>3</sup> /ha	Yield/ha kg/ha	Price Denar/kg	Gross Income/ha 10 <sup>3</sup> MKD	Cost/ha 10 <sup>3</sup> MKD	Net Inc./ha 10 <sup>3</sup> MKD	Net Income 10 <sup>3</sup> MKD
Wheat	50.00%	7496		3,000	10	36	34	2	14,586
Barley	20.00%	2998		3,500	9	37	33	4	11,624
Tobacco oriental	2.00%	300		1,200	170	244	235	9	2,658
Sunflower	5.00%	750		1,500	16	29	26	3	2,494
Soya	3.00%	450		1,800	18	37	33	4	1,704
Meadow & grasses	19.00%	2848		4,000	6	21	19	2	5,206
Grape	1.00%	150		10,000	10	148	123	25	3,738
<b>Total</b>		<b>14,992</b>						<b>Total</b>	<b>162,332</b>

# Index of Figures

Figure 2-1: Graphic illustration and text showing how economists measure climate change damages in welfare terms	28
Figure 2-2: Graphic illustration of the systems and linkages, globally and locally that influence the impacts of climate change and adaptive adjustments to these impacts	31
Figure 3-1: Key demand drivers - GDP and population growth rates	41
Figure 3-2: Electricity demand projection in commercial and residential sector for heating, cooling and the total under the base case (ktoe)	42
Figure 3-3: Shares of end-use services in total energy demand in 2006 and 2030, for commercial and residential sectors - Base Case	42
Figure 3-4: Electricity generation capacity mix - Base Case	44
Figure 3-5: Difference in the heating and cooling demand for the residential and commercial sectors in the climate change damage cases compared to the Base Case	47
Figure 3-6: Difference in generating capacity between the adaptation case AC1 and the Base Case	50
Figure 3-7: Difference in generating capacity between the adaptation case AC2 and the Base Case	50
Figure 3-8: Difference in generating capacity between the adaptation case AC3 and the Base Case	51
Figure 4-1: Schematic Diagram of Mavrovo Hydroelectric Generating System	65
Figure 4-2: Projections of Annual Electricity Demand for 2050 and 2100	67
Figure 4-3: Monthly runoff for the Base Case (Current Climate) for low, average (medium) and high precipitation Conditions	67
Figure 4-4: Monthly Runoff for Mavrovo Reservoir for Low Precipitation Conditions in 2050 and 2010 (With Climate Change) Compared to the Base Case (Without Climate Change)	69
Figure 4-5: Monthly Runoff for Mavrovo Reservoir for Medium Precipitation Conditions in 2050 and 2010 (With Climate Change) Compared to the Base Case (Without Climate Change) (m <sup>3</sup> /sec)	69
Figure 4-6: Monthly Runoff for Mavrovo Reservoir for High Precipitation Conditions in 2050 and 2010 (With Climate Change) Compared to the Base Case (Without Climate Change)	70
Figure 4-7: Monthly Hydro-electric Power Generation for Mavrovo for Low Precipitation Conditions in 2050 and 2010 (with Climate Change) Compared to the Base Case (without Climate Change) (GWh/month)	71
Figure 4-8: Monthly Hydro-electric Power Generation for Mavrovo for Medium Precipitation Conditions in 2050 and 2010 (with Climate Change) Compared to the Base Case (without Climate Change)	72
Figure 4-9: Monthly Hydro-Electric Power Generation for Mavrovo for High Precipitation Conditions in 2050 and 2010 (with Climate Change) Compared to the Base Case (without Climate Change)	72
Figure 4-10: Change in Annual Hydro-Electric Power Generation for Mavrovo for Low, Medium and High Precipitation Conditions in 2050 and 2010 (with Climate Change) Compared to the Base Case (without Climate Change) in GWh	74
Figure 4-11: Change in Annual Hydro-Electric Power Generation for Mavrovo for Low, Medium and High Precipitation Conditions in 2050 and 2010 (with Climate Change) Compared to the Base Case (without Climate Change) in percentage (%)	74



Figure 5-1: Per Cent Reduction in Area-Weighted Crop Yields due to Low, Medium and High Climate Change Projections for 2050 and 2100	93
Figure 5-2: Per Cent Reduction in Area-Weighted Net Income/ha from Crop Production due to Low, Medium and High Climate Change Projections for 2050 and 2100	95
Figure 5-3: Climate Change Damages due to Low, Medium and High Climate Change Projections for 2050 and 2100	95
Figure I-1: Illustration of how changes in outdoor temperature influence the space heating and cooling demands of residential and commercial electricity customers	117
Figure I-2: Illustration of electricity market adjustments to changes in the effect of outdoor temperatures on residential and commercial electricity customers	119
Figure I-3: Projections for the monthly average temperatures	123
Figure II-1: Schematic Diagram of a Generic Hydro-Economic Model Used to Simulate the Economic Impacts of Climate Change on River Basins	133

# Index of Tables

Table 3-1: Adjustment factors used in MARKAL Model, 2009-2030	40
Table 3-2: Annual energy system expenditure by cost type (EUR 10 <sup>6</sup> ), 2006-2030 – Base Case	44
Table 3-3: Percentage change (from the Base Case) in residential and commercial and electricity demand for the three Climate Change Damage cases, 2006-2030	45
Table 3-4: Present value of total system cost for the Base Case and Damage Cases (EUR 10 <sup>6</sup> )	48
Table 3-5: Optimal generation capacity mix (MW) - AC1, AC2 and AC3	49
Table 3-6: Present value of total system cost for the Base Case and Damage Cases (EUR 10 <sup>6</sup> )	52
Table 4-1: Projected Runoff for Low, Medium and High Precipitation Conditions for the Base Case (No Climate Change) and 2050 and 2100 (With Climate Change)	70
Table 4-2: Projected Hydropower Generation for Low, Medium and High Precipitation Conditions for the Base Case (With No Climate Change) and 2050 and 2100 (With Climate Change)	73
Table 4-3: Annualized Life-Cycle Generation and Total Cost Estimates for Different Types of Power Plants in FYR Macedonia in 2010	75
Table 4-4: Annualized Cost (10 <sup>6</sup> EUR/year) of Replacing Lost Hydropower Production due to Climate Change with Coal, Gas and Nuclear Alternatives	76
Table 4-5: Annualized Cost (10 <sup>6</sup> EUR/year) of Replacing Lost Hydropower Production due to Climate Change with Renewable Energy Alternatives	77
Table 4-6: Projected Increase in Annualized Total System Cost in 2050 and 2100 due to Reductions In Runoff from Climate Change for Mavrovo Hydro System Under Low, Medium and High Precipitation Conditions	78
Table 5-1: Base Case and Climate Projections for Average Monthly Temperature and Precipitation for the “Medium” Climate Change Scenarios	91
Table 5-2: Economic Values for Climate Change Damages, Net Benefits of Adaptation and Residual Damages Associated with Low, Medium and High Climate Change Projections for 2050 and 2100 for Restoring Full Yields to Irrigated Land and Supplemental Irrigation of Rain-fed Lands	97
Table 5-3: Estimated Water Availability for Strezevo Reservoir	98
Table 5-4: Preliminary Annual Results for a Benefit-Cost Assessment of Refurbishing and Fully Irrigating the Remaining 14,992 ha in the Project	98
Table 5-5: Economic Values for Climate Change Damages, Net Benefits of Adaptation and Residual Damages Associated with Low, Medium and High Climate Change Projections for 2050 and 2100 Comparing Full Irrigation + Refurbishment on All Lands with Full Irrigation on Irrigated Land + Supplemental Irrigation on Rain-fed Lands	99
Table I-1: Total Net Welfare of Consumers and Producers for Increases in the Demand for Space Heating and Cooling as Illustrated in Figure I-2	120
Table I-2: Benefit-Cost Measures Defined in Figure I-2	121
Table I-3: Projections for HDD and CDD in the country	125
Table I-4: Energy demand projection in commercial and residential sector by end-use services	126
Table II-1: Base Case Crop Results – Irrigated Agriculture	135
Table II-2: Base Case Crop Results – Rain-Fed Agriculture	136

© Copyright 2011  
By the United Nations Development Programme  
8-ma Udarna Brigada – 2  
1000 Skopje

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without prior permission.

**Design and cover photo:**

BRIGADA DSGN  
Varsavska 62b  
1000 Skopje  
[www.brigada.mk](http://www.brigada.mk)

**Printed by:**

PROPOINT  
Bul. Partizanski odredi 151 1/47  
1000 Skopje







