ECONOMIC IMPACTS OF SEA LEVEL RISE CAUSED BY CLIMATE CHANGE

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Abstract
Purpose – Sea level rise represents potentially one of the costliest impacts of climate change on the Croatian coast. Therefore, the purpose and goal of this paper is analysing the potential effects of sea level rise on Croatia and the preventive measures to be taken in order to reduce the negative effects of sea level rise.
Methodology – In the paper, the authors developed a model which allows calculations of the cost of land loss, the cost of relocating people and the cost of protection as a result of future sea level rise by 50 and 88 cm in Croatia.
Findings – The main findings of this work refer to the estimate of economic costs of future sea level rise. The model consists of three parameters to be considered, namely: the value of the submerged land, the cost of protection as a result of sea level rise and the costs caused by the displacement of people due to the loss of land.
Contribution – The main contribution of this work lies in the fact that, in Croatia, there is presently a limited number of studies dealing with current and future sea level rise caused by climate change. In case of a significant sea level rise in the future, certain problems are to be expected, such as: the destruction of a number of commercial and fishing ports, the contamination of coastal freshwater springs, potential damage to swamps and wetlands, destruction and submersion of beaches, and the negative impact on tourism. It is important to emphasize that the rise of sea level is a slow and gradual process, and that the possibility of a sudden large increase of sea level is very low.
Keywords economic impacts, climate change, sea level rise, mitigation measures

INTRODUCTION

Climate change is already having dramatic effects on forests, natural resources and people's livelihoods. During the past century, the Earth has warmed by approximately 0.7°C (Climate Change and Tourism – Responding to Global Challenges, 2008, 25). Although climate change will equally impact all parts of the world, the adjustment and costs to this change will be especially long and difficult for the world's less developed and less flexible areas. The Mediterranean, including the Croatian Adriatic coast, is under the influence of global sea-level rise (the change in average sea-level over an extended period of time), with low-lying islands and estuaries particularly vulnerable and prone to flooding. Sea levels have been naturally changing for thousands of years, as the result of glaciers melting and climate variability. However, during the 20th century, global sea level rose at a rate of 1.7 mm per year. The estimated sea-level rise of 100-400 mm by 2100 depends on the method of measurement (Snow, Snow, 2009, 424). These data clearly show that the rate of sea-level rise is dramatically increasing, and that future increase will have a significant effect on the environment. Since Croatian coast is a tectonically active region, the long-term trends in sea-level change are unclear, which makes it difficult to accurately predict the effects of sea-level rise. The goal of the research, i.e. the research question, is determining the costs caused by sea level rise in the future.

The first part of this paper analyses the existing climate changes in Croatia and predicts the future changes. The second part explains the costs of sea-level rise and, using the model, calculates the future costs and economic consequences for the Republic of Croatia. Based on these indicators, the last part of this paper proposes some possible measures for mitigating the effects caused by sea-level rise.

1. CLIMATE CHANGE PROJECTIONS FOR CROATIA

Climate change is a long-term change in climate patterns. It may be a change in average weather conditions, a change in the distribution of climate events around that average, or the occurrence of more extreme weather events. Meteorological data confirm that the Earth's global temperature has been increasing from the beginning of the 20th century, especially after 1976. Air temperature records that go back fifty or, at some stations, more than a hundred years, show an increase in global average air temperatures of 0.3ºC to 0.6ºC in the past 80-100 years. In 2013, the global average surface temperature was 0.5 °C higher than the 2001 – 2010 decadal average (Praćenje i ocjena klime u 2013, 2014, 1). Moreover, many parts of the world recorded extreme weather events, including devastating floods, severe droughts, snowstorms, heat waves and cold waves (Praćenje i ocjena klime u 2009, 2010, 1). This resulted in several effects of global warming, including (Müller, 2004, 143):

- Sea level rise: as a result of global warming, sea temperatures also rise which leads to an increase in its mass. Another cause of sea level rise is the melting of polar ice caps and glaciers.
- Adaptive capacity of ecosystems: the temperature significantly increases, and the effects on the regional ecosystems differ considerably
- Changes in Earth's water systems: climate change affects the distribution of surface water runoff. More intense rainfall and probably higher annual rainfall will cause flooding.
- Health impacts: wormer summers and more frequent heat waves in temperate climate zones lead to an increased number of deaths; increased air pollution causes health problems. This impacts the distribution and prevalence of infectious diseases.
- Increase in extreme weather events: with climate change, extreme weather events such as drought, cold, storms, floods, etc. could increase and become more frequent. This will lead to serious damage to infrastructure and the loss of human lives.

Thus, climate change will not only affect sea level rise, but also storm formations, temperature, precipitation and other climatic factors. These changes will have a significant influence on long-term coastal development (Ferreira, Dias, Taborda, 2008, 318). These, and many other consequences, clearly indicate the interdependence of climate change and the overall human activity.

Contrary to the generally accepted theory, which considers global warming to be the result of greenhouse gas emissions, there are also alternative explanations. Thus, climate change theories can be divided into two groups: astronomical and terrestrial. The astronomical theory postulates that changes in solar activity, i.e. alternations between cold and warm periods, lead to ice age, associated with changes in three astronomical elements regarding the Earth's position in space: precession of the equinoxes (axial precession), Earth's axial tilt (obliquity) and the Earth's orbit around the Sun (Sijerković, Pandžić, 1991, 538). The terrestrial theories can be divided into geological and atmospheric theories. The first group connects changes in the Earth's climate system throughout its geologic past (causing changes in the shape, height and arrangement of land and water) with the changes in ocean currents, ice caps etc. Atmospheric theories link climate change with the changes in atmospheric composition and circulation; the most important are those that link climate change with changes in the amount of aerosols or CO_2 in the atmosphere. However, the scientific circles predominantly view greenhouse gas emissions as the main cause of climate change. Evidence of a connection between changes in CO_2 concentration, soil temperature and sea temperature was found in the survey of the Vostok ice core that recorded the past changes in the concentration of CO_2. The temperature was reconstructed based on the data on glaciations and natural cycles of flora and fauna over the past 400,000 years (Sijerković, Pandžić, 1991, 540). The comparison of the Vostok ice core temperatures and CO_2 concentrations clearly indicates the connection between carbon dioxide and temperature.

Most climate change experts agree that, unless the greenhouse gas emissions caused by human activities are reduced and controlled, further increase in global average surface temperature can be expected over the next few hundred years (Črnjar, 2002, 131).

2. IMPACTS OF SEA LEVEL RISE

Today, a large part of the world's population lives in coastal areas, and the rate of population growth in these parts of the world is higher than average. Thus, 20% of the world's population lives within 30 km of the coast (Snow, Snow, 2009, 426). A large number of cities are located on the coast. Future Asian megacities are also expected to be located in this area. In developed countries, people in coastal areas depend on coastal infrastructure and, in order to obtain the economic, social and cultural benefits, their safety against natural hazards (huge waves, storms and tsunamis) must be ensured. Coastal areas have experienced quick growth (coastal urbanism) at the beginning of the tourism offer creation, but have also become victims of non-planned activities – particularly in space, which has irreversibly destroyed numerable unique landscape units (Krstinić, Nižić, Drpić, 2013, 160). The projected sea-level rise will have significant socio-economic consequences for small island nations, where people will have to move to other areas. As the result of sea level rise, the reduction of GDP in developing countries (Asia, Africa and Latin America, except China) is lower than the direct costs of land loss, while the opposite situation occurs in the developed countries (except Canada). It can be concluded that there is no simple correlation between the environmental and economic impacts (Bigano, Bosello, Roson, Tol, 2008, 773). In the early 1990s, several studies analysed the costs of sea level rise in the United States, with the goal of devising a national response strategy. Other studies followed the same methodology in approaching the problem (Impacts, Adaptation and Vulnerability, 2014, 426).

Sea level represents the measure for the total volume of water in the world's oceans (Snow, Snow, 2009, 423), while sea level rise is defined as the global average sea level rise (Yoskowitz, Gibeaut, McKenzie, 2009, 3). Sea level rise began with the end of the last glaciation, about 15,000 years ago. However, the rate of sea level rise increased significantly between the mid-19th and mid-20th centuries. Projections of sea level rise are uncertain and depend on the emission scenarios and projected surface temperature (Brown, Nichollos, Vateidis, Henkel, Watkiss, 2011, 8). The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) predicted that the global seal level may rise as much as 88 cm by the end of the 21st Century. According to the Fourth Assessment Report of the IPCC, global sea level rise in the second half of the 20th century was estimated as 1.8 ±0-3 mm year (Dutta, D., 2011, 806). Certain regions will be significantly affected, while others will achieve a modest growth. One of the more important studies on the subject conducted in Croatia was published by the United Nations Development Programme (UNDP) under the title "A Climate for Change". Sea levels can change globally and locally, depending on the changes in size and mass of the world's oceans.

The Croatian territorial sea occupies an area of 31,067 km2, which is roughly one-third of the total Croatian territory. The length of the coastline is 5835 km, with 1246 islands and islets, of which only 47 are inhabited (Dobra klima za promjene, 2008, 68). The Adriatic Sea is directly responsible for the welfare of Croatian citizens, not only those living on the coastal areas, but also those who living on the continent. In addition to its cultural significance, the coast is also the main area for tourism. Maritime transport, offshore gas production, shipbuilding, agriculture, fishing and mariculture are all important economic activities that take place on or near the coast. All of these activities are of great importance and affect the well-being of a large part of the Croatian population.

The analysis of the tide gauge stations at four points along the Croatian Adriatic coast (Rovinj, Bakar, Split and Dubrovnik) showed very different trends. For example, in Rovinj and Split, sea-level is falling relative to the land by a rate of -0.50 mm/y and -0.82mm/y respectively, while in Bakar and Dubrovnik, sea-level is rising relative to the land by a rate of +0.53mm/y and +0.96mm/y, respectively (Dobra klima za promjene, 2008, 71).

In case of a significant sea level rise in the future, the following problems are predicted:

- Commercial and fishing ports may be threatened - even if the seawalls remain above the projected sea levels, the ports can still be affected during stormy weather, by high waves and extreme seawater levels, which will make them vulnerable to flooding.

- Possible contamination of coastal freshwater springs affecting drinking water supply – a great number of coastal settlements in Croatia use coastal or near-coastal freshwater springs in karst terrain. Higher levels of seawater could displace the freshwater from those springs, resulting in their contamination. There is also a possibility of new springs emerging. Moving wells to a new location or desalinising the water would require additional funds.
- Potential damage to wetlands and swamps– in particular, Croatian Nature Park Vrana Lake, could be directly threatened and potentially destroyed by a sea level rise of 0,5m. Lake Vrana is a special ornithological reserve – a habitat of endangered bird species, with immense biodiversity and extraordinary scientific and unique ecological value. In Croatia, there are a number of wetlands and swamps whose destruction would irreversibly affect biodiversity.
- Faster coastal erosion may result in the destruction or submersion of beaches. Although it is possible that new, naturally created beaches could appear further inland, artificial beach repair and replenishment of the beach gravel or sand may be necessary, which would require additional funds. In addition, sea level rise can negatively affect many of the plants and animals of the coastal ecosystems, including forests.
- Tourism and other recreational businesses that depend upon coastal areas may be severely affected. Since tourism is predominantly seaside-oriented, sea-level rise can have both a direct and indirect impact on this sector. The most prominent direct impact is the threat to coastal tourist and cultural sites (hotels, historical sites). The most prominent indirect impact would be the threat to freshwater springs, water-pipes and sewerage systems.

3. ECONOMIC COSTS OF SEA LEVEL RISE

3.1. Research methodology

The first consequence of sea level rise will lead to the loss of land, which is the basis for economic production. In other words, the land is part of natural capital; the loss of land means the loss of capital and negative effects on production output (Hallagate, 2012, 2). This loss will be by far the most substantial of all model parameters. The UNDP's report "A Climate for Change" made an estimate of the amount of submerged land in case of sea level rise by 50 and 88 cm. The 50 cm rise represents a high potential sea-level rise described by the IPCC, while the 88 cm rise represents the maximum projected rise in case the Greenland and Antarctic ice sheets do not melt (Dobra klima za promjene 2008, 75). The model developed in this paper uses the amounts of submerged land from this research. Another parameter to be calculated in the model is the cost of relocating the people who lived in areas submerged due to sea level rise. The costs can be calculated by multiplying the annual average income by 3 and by the number of people who will have to move (Anthoff, Nicholls, Tol, 4). The population of the coastal area of the Republic of Croatia is estimated at 960,850 people. In case of a 50 cm sea level rise, it will be necessary to move about 10% of the population; in case of an 88 cm rise, it is estimated that 15% of the population will be affected[1]. The cost of land loss and the cost of relocating people can be calculated by the following formula:

$$\partial = \{(p \times C) + (BDP\ per\ capita\ \times 3 \times v)\}$$

Where:
∂ - cost of sea level rise; p – area affected by sea level rise; C- land value; v – number of people to be relocated

In addition to the cost of land loss, the model must also include the cost of protection due to sea level rise. Based on available research, these costs will represent 3% of the realized annual GDP (Anthoff, Nicholls, Tol, 5).

3.2. Results and Discussion

Based on the parameters mentioned above, the following table provides calculations of the potential costs caused by sea level rise (of 50 cm and 88 cm) in Croatia.

Table 1: **Calculation of Potential Costs Caused by Sea Level Rise in Croatia**

Type of Land	**Total surface covered at 50 cm sea level rise of (m^2)***	**Total surface covered at 88 cm sea level rise of (m^2)***	**Value per m^2 (EUR)***
Loss of land due to sea level rise			
Agricultural land	12,393,750	12,410,000	17.5
Sport/ leisure facilities	2,386,875	2,499,375	75
Roads/railways	60,625	559,375	75
Urban semiurban	9,803,125	10,010,625	350
Ports/marine installations	965,000	2,682,500	250
Industrial activity	2,303,125	2,308,125	250
Total cost of the loss of land, in case of a sea level rise of: • 50 cm, using average value per square metre = 4,648,578,125 EUR • 88 cm, using average value per square metre = 5,197,956,250 EUR			
Annual costs of protection due to sea level rise			
Realised GDP in Croatia 2012 = 43,959,000 EUR** X 3% = 1,318,770 EUR - annual costs of protection due to sea level rise			
Cost of relocating people due to sea level rise			

Number of relocated people***	GDP per capita in 2012 (EUR)**	Coefficient
96,000 –50 cm rise	10,297	3
144,128 –88 cm rise	10,297	3
Total cost of relocating people, in case of a sea level rise of: • 50 cm, using average value per square metre = 2,965,536,000 EUR • 88 cm, using average value per square metre = 4,452,258,048 EUR		

Source: Author's calculation; *Dobra klima za promjene 2008, 75; **www.dzs.hr; *** Author's estimation

[1] Authors' estimate; based on GIS information and the 2011 population census.

The calculation shows two possible projections, namely for a 50 cm and 88 cm sea level rise. In case of a 50 cm sea level rise, the total projected costs amount to €7,614,114,125, with an annual cost of €1,318,770. In the 88 cm sea level rise scenario, the total projected costs will amount to €9,645,214,298, with annual cost of €1,318,770. It must be emphasized that these costs will not occur all at once, since the projected sea level rise is a gradual process taking place over a number of years. Thus, the costs will accumulate over a certain period. As seen from the above-calculated figures, the economic damage is substantial. This calculation does not include the value of forests, beaches, wetlands, flora and fauna that would be destroyed, since estimates of their value could not be measured in economic terms. However, this calculation gives an overview of the value of the property at risk if no preventive measures are taken.

Hence, the success or failure of protection remains one of the major uncertainties about the effects of sea level rise, in terms of both direct and indirect effects. Cost estimates have a number of limitations. Several studies dealing with estimates of the costs of coastal area protection from sea level rise concluded that the global annual cost, depending on the scenario, will range between $28 billion and $90 billion up to 2050 (Nicholls, Kebede, 2012, S43). These estimates assume that there is a good existing infrastructure to be upgraded. However, since this is not the case in most countries in the world, the costs will consequently be higher.

4. SEA LEVEL RISE MITIGATION MEASURES

The timing of sea-level rise is a very important factor in analysing the adaptation options and decisions on the mitigation measures to be taken. In case of a gradual sea level rise, the population and economic activities at risk have adequate time to carefully evaluate the alternative actions to be taken. On the other hand, in case of a sudden rise of sea level, it will be necessary to ensure immediate substantial financial investments, with a risk of relying on faulty sea-level rise projections. Assessing the impacts of sea level rise (such as flooding the coastal cities) and preparing long-term risk management plans is both crucial and urgent. This will help the legislators to better understand the vulnerability of coastal areas to the socio-economic and climate changes.

Adaptation has a long history in coastal areas. Although it has often focused on protection, the available adaptation measures can be grouped into the following three strategies (Nicholls, Kebede, 2012, S41):

- Protection: the probability of occurrence to reduce the risk of an event via hard of soft engineering
- Accommodation: increasing the ability of a society to cope with the effects of an event
- Retreat: limiting the potential effects to reduce the risk of an event

Information measures such as disaster preparedness, hazard mapping, and flood warning are also important and in many ways cross-cut and complement the three approaches listed above.

Further adaptation is a process that should take into account the development needs of the society and that must be up-to-date with monitoring and assessing the existing adaptation responses. Thinking of adaptation as a process is consistent with the commitment to adaptation where appropriate portfolios of measures are identified and adaptation pathways are identified for implementation. The possible sea level rise mitigation measures can have a wide range of application. The following table shows the main impacts of sea-level rise and examples of adaptation responses.

Table 2: **Major Physical Impacts of Sea Level Rise and Examples of Adaptation Responses**

Physical impact of sea-level rise		Potential adaptation responses
Direct inundation, flooding, and storm damage	Storm surge (sea) Back – water effect (coastal rivers)	Dykes/surge barriers (P) Building codes /flood-wise buildings (A) Land-use planning (A/R)
Loss of wetland area (and change)		Land-use planning (A/R) Managed realignment/forbid hard defences (R) Nourishment/sediment management (P)
Erosion (both direct and indirect)		Coastal defences (P) Nourishment (P) Building seatbacks (R)
Saltwater intrusion	Surface waters Ground waters	Saltwater intrusion barriers (P) Change water abstraction (A) Freshwater injection (P) Change water abstraction (A)
Rising water tables and impeded drainage		Upgrade drainage systems (P) Polders (P) Change land use (A) Land-use planning (A/R)

Note: P-protection, A-Accommodation; R – retreat

Source: Nicholls i Kebede, 2012, S42

Croatia needs to take a series of steps in order to prevent, but also to reduce the damage that will be caused by sea level rise. These steps should also improve the institutional capacity for comprehensive planning and management of coastal resources. Furthermore, coastal planners, managers and entrepreneurs in both public and private sectors must take future changes into account when designing regulations on coastal land use, disaster risk management and planning major infrastructure projects. It is necessary to develop alternative measures and sea level rise adaptation projects, and to constantly evaluate their costs and benefits relying on the increasingly available complete information. Croatia should cooperate with the existing agencies that are constantly developing various databases and projection models of sea level rise, economic damages, and the costs and benefits of adaptation options. This would allow better prediction of the physical and economic damages caused by sea level rise, as well as prevention of certain damages.

CONCLUSION

The existing scenarios predicting increasing greenhouse gas concentrations in the atmosphere all include predictions of sea level rise in the following years. But apart from sea level rise, climate change will bring numerous other problems that need answers, such as extreme weather events, negative health impacts and ecosystem adaptation. Changes in these factors, varying according to different emission scenarios, will affect the long-term coastal area development.

Today, 20% of the world's population lives in the coastal area. In the future, these areas will be exposed to even greater pressure. In developed countries, people in coastal areas depend on coastal infrastructure in ensuring their overall well-being. In countries where coastal infrastructure is well developed, the costs of sea level rise will be lower than in the countries with less developed infrastructure. In other words, richer countries will suffer lower costs due to sea level rise, while in poorer countries, the situation will be reversed. Coastal area is extremely important to Croatia. In case of a significant sea level rise, the following problems are to be expected: the destruction of commercial and fishing ports, the contamination of coastal freshwater springs, potential damage to swamps and wetlands, erosion of coastal areas and negative impacts on tourism and recreational activities.

This paper analysed the costs of sea level rise through three components: the cost of land loss, the costs of relocating people living in the affected area, and the cost of defending against sea-level rise. The calculated costs are significant, and indicate the need for certain sea level rise mitigation measures. These steps include the following: taking future changes into account when planning future infrastructure projects; developing alternative measures and sea level rise adaptation projects; cooperation with various agencies that develop projection models of sea level rise and economic damages. All these steps will allow better prediction of the physical and economic damages and help reduce the negative impacts of climate change.

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