Bergen Climate Change Impact Scenarios – Sea Level Rise

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Bergen city is situated at the West coast of Norway, and is the capital of Hordaland County. It is a city in close proximity to the sea and the mountains, and the Bergen region is characterised by fjords, mountains and islands, cf. figure 1.1. Bergen is surrounded be several fjord systems which create entrances to Bergen inner harbour. To prevent sea level rise in Bergen by controlling these entrances is difficult and demanding both from a technical, economical and environmental point of view. Adaptation measures in these outer areas are not so necessary in a short term perspective (before 2060) either. However, the inner harbour areas are more exposed and measures probably have to be taken before in order to avoid damages on economic activities in the harbour, of ports, infrastructure, build environment, cultural heritages and so forth.

Figure 1 The Bergen region – geographical characteristics

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Estimated sea level rise in the Bergen region

The future sea level rise in the Bergen region will mainly be affected by the global sea level rise but local factors such as land uplift will also play a role. Taking the figures from Drange et al. (2007) which is based on Rahmstorfs (2007) model for future global sea level rise and the ”business-as-usual” emission scenario from UNs Climate panel (scenario A2; IPCC, 2007), the expected global sea level rise vary between 65 to 110 cm in 2100, with 80 cm as the most probable value (Drange et al. 2007). A global sea level rise of 80 cm is significantly higher than the estimates from the IPCC 2007 which vary between 23 and 51 cm for scenario A2. IPCC, however, makes clear that their estimates do not take into account all factors that contribute to future sea level rise. In addition, the uncertainty of temperature projection is not fully used when calculating the sea level rise (IPCC, 2007). The report from the Delta Commision is also in line with the estimates from Drange (2007) with an expected sea level rise between 40 and 110 cm in 2100. (www.deltacommisie.com/en).

Sea level rise is expected to biggest on the South, West and Northern coast of Norway because the land uplift is smallest in these areas. Estimates are made for all coastal municipalities in Norway and table 1 shows the Upper and lower level of sea level rise and storm surge in the five largest cities in the country.

Table 1 Upper and lower level of sea level rise and storm surge in the five largest cities in Norway ((Havstigning = Sea level rise, stormflo = storm surge) Source: NOU 2010:10 Tilpassing til eit klima i endring

	2050				2100			
	Havstigning (cm)		Stormflo (cm) Relativt NN1954		Havstigning (cm)		Stormflo (cm) Relativt NN1954	
	Min.	Maks.	Min.	Maks.	Min.	Maks.	Min.	Maks.
Tromsø	10	32	229	251	43	98	267	322
Trondheim	–1	21	246	268	22	77	274	329
Bergen	15	37	178	200	53	108	221	276
Stavanger	17	39	143	165	58	113	189	244
Oslo	–1	21	189	211	21	76	216	271

Potential impacts of sea level rise

In coastal areas as in the Bergen region settlements and infra structure are often located close to the sea. Vast parts of the larger region are un-built areas whereas in the central city the built area is concentrated at the sea front, such as the World heritage Site of Bryggen, cf. figure 3. If the estimated sea level rise of 75 cm in 2100

and the expected storm surge rise up to 2,37 meters it will overflow buildings related to settlements and industries, historical sites, quays and port facilities, fish farming, roads and transport systems, sewage systems and wetlands. Most port facilities in the region will be flooded and useless at a sea level as with the expected the storm surge. But also a sea level rise of 75 cm will make most of the quays unfit for mooring many vessels.

The impacts of sea level rise will be most harmful in the central city area. Large part of the business area is located at the waterfront where also new settlements are developed. A sea level rising up to 2.37 meter will cause power outage, damaging of waste water system and roads, tunnels will be filled with water and the railway station will be flooded. This situation is illustrated on the animated picture in figure 3.

The harbour plays a particularly important role in the city. A lot of ships call at Bergen port every year, both cargo ships and cruise ship. In 2007 nearly 19 000 ships came to Bergen, out of this 231 cruise ships carrying app. 200 000 passengers (Regional Havstigning 2009). Tourism may be adversely affected by flooding and sea level rise because the arrival by ships will be strongly restricted and the most popular harbour areas (Bryggen and Vågen) will be flooded. The World Heritage Site of Bryggen is a living illustration of the city's history, with 61 protected buildings covering about 13,000 m2 (www.stiftelsenbryggen.no/). Even today the site is harmed by storm surges and flooding. In combination with sinking ground water this causes irreparable damages on the historical buildings.

Figure 2 The World heritage Site of Bryggen

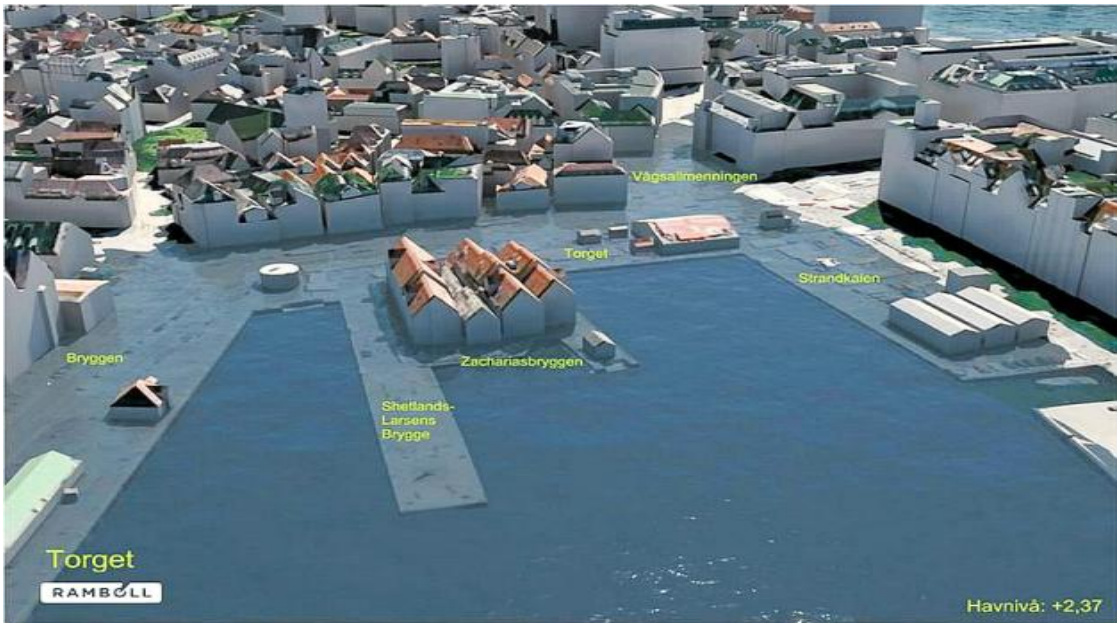

Figure 3 Animated picture of Bergen harbour with sea level rise and storm surge on 2, 37 meter

Adaptation measures – costs and benefits

The municipality of Bergen and private actors from the business community has analysed several possible adaptation measures against sea level rise. The measures range from far-reaching protection of the whole metropolitan area by building outer barriers to simple sheltering of limited areas in the inner harbour.

There seems to be no need for immediate adaptation measures with regard to sea level rise in Bergen. The increase will first accelerate in the second part of this century, see figure 4. Based on the assumptions in figure 4 table 2 shows the time when adaption measures have to be implemented. As can be seen, even with a sea level rise of 75 cm measures need not to be implemented before 2065. The exception, however, is the World Heritage Site Bryggen which already today is exposed due to settling ground and flooding of the sea front in storm surges.

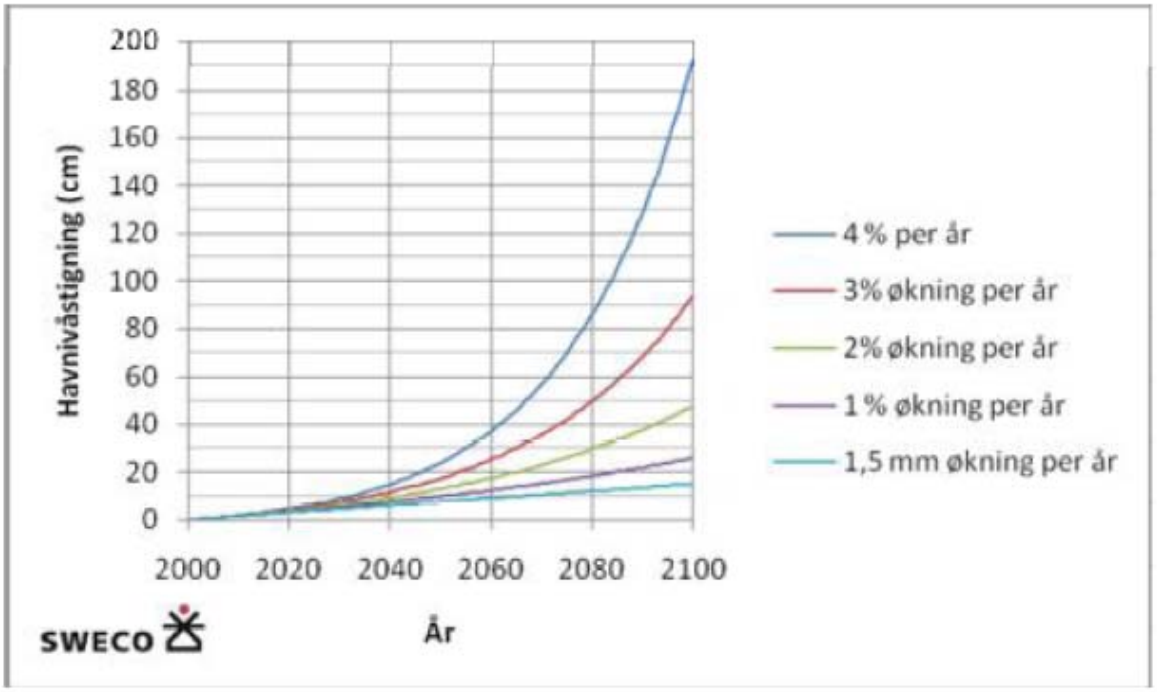

Figure 4 Sea level rise in Bergen by constant yearly increase

Table 2 estimated time for adaptation measures (Source: Regional havnivåstigning 2009)

Yearly sea level rise	**Year for implementing adaptation measure**	**Sea level rise year 2100**
As today	Measures not necessary	15 cm
1 % increase	2100	26 cm
2 % increase	2075	48 cm
2,7 % increase	2065	75 cm
3 % increase	2060	94 cm
4 % increase	2050	193 cm

There exist no comprehensive cost-benefit analyses (CBA) of adaptation to sea level rise for Bergen only some rough cost estimates for some of the measures. The most probable measures are different barriers (spunt solutions) in the inner Bergen area, see figure 5. Table 3 shows the estimated cost for the different measures (Regional Havnivåstigning 2009). The benefits of the measures are not estimated just some qualitative assessments are given. NIBR has carried out a modified CBA for some of these measures which indicate that the benefits are lower than the investment costs for most of the measures. However, is most likely that the underlying assumption underestimate the benefits related to avoided damages.

Figure 5 Adaptation measures against sea level rise in the inner Bergen area

Table 3 Cost assessment and consequences of adaptation measures (Source: Regional havnivåstigning 2009)

Measures	**Consequences**	**Costs NOK 2008**
Outer barrier	Large environmental and economic consequences	> 30 Billion
Inner barrier, Vågen (1)	Limited benefits	500 Million
Inner barrier, Damsgårdssundet (2	Limited benefits	500 Million
Inner barrier, Strømmen (3)	Large benefits	< 30 Million
Spunt solution, World heritage Site Bryggen	Ground water control and protection of water front towards storm surge	< 50 million
Protection of selected areas and buildings	Flexible solution. Secure vulnerable buildings and areas against SLR and storm surge	< 100 000 per meter

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