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Economic Commentaries

Rising sea levels due to global warming will entail increased risks to housing

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If a house risks being affected by extensive flooding and thereby falls in value, the borrower's loan-to-value ratio will rise and the lender's collateral will lose value. Higher loan-to-value ratios for households and lower collateral quality for credit institutions may have a negative effect on financial stability.

This Economic Commentary aims to investigate how large a proportion of Sweden's housing stock may be affected by flooding as the result of rising sea levels caused by climate change, and the effect that this may have, in turn, on financial stability. More specifically, the Riksbank has estimated the value of coastal owner-occupied and tenant-owned homes that may be particularly exposed to rising sea levels over the coming century.

The analysis show that the risk of flooding in Sweden will increase in the future (the coming 100 years). How much this risk will increase depends on how serious climate change becomes, but even in a scenario with a relatively small degree of climate change, the risk will increase from today's level. The extent to which this will affect financial stability is hard to assess, among other things because it depends on how society adjusts to the new level of risk.

Climate change is one of the greatest challenges of our time in that it creates climate-related risks of various kinds. Rising sea levels form one such risk. Over the next century, higher average temperatures due to climate change will lead to higher sea levels and new coastlines higher up on what is now dry land. Rising sea levels thus mean that coastal housing and property will be more exposed to extreme weather and flooding. Sweden has a long coastline, reflected by the fact that about 8 per cent of Sweden's owner-occupied and tenant-owned homes are situated within 3 kilometres of the coast and no more than 5 metres above sea level.[2,3] This housing thus runs a greater risk of material damage in a future climate scenario in which sea levels have risen.

This physical climate risk may have negative effects on financial stability in Sweden.[4] For example, an increased risk of flooding could lead to prices falling in parts of the housing market, to insurance costs for coastal housing becoming higher and, in the worst case, to housing actually being flooded and destroyed. Climate risk may thus entail increased credit risk for lenders, but also for the credit institution that lent money to the borrower with this housing as collateral.

With the aim of gaining a better view of these stability risks, the Riksbank has estimated the value of housing that is particularly exposed to rising sea levels. More specifically, we use data on how high sea levels along the Swedish coast can be expected to rise temporarily in the event of extreme weather in the year 2100 under three different climate scenarios, as well as data on which currently existing housing could then find itself under water. This means that account is taken both of rising sea levels caused by global warming and temporarily higher sea levels due to storms, and of the position of the housing.

The results show that the risk of coastal housing ending up below water in the event of extreme weather increases and that owner-occupied and tenant-owned homes of a value corresponding to about 5 per cent of the banks' lending to the public with housing as collateral would be exposed to this climate risk under the most serious climate scenario. Furthermore, the results show that southern Sweden can be affected more by these risks compared to the rest of the country.

[1] The author would like to thank David Farelius, Maria Ferlin, Mia Holmfeldt and Jakob Winstrand for their valuable comments.
[2] Statistics Sweden (2020).
[3] Valueguard (2020)
[4] Climate risks are usually divided into physical risks and transition risks. Physical risks mean risks for physical destruction due to the effects of climate change, such as drought, flooding and so on, while transition risks are risks for the negative financial consequences of society transitioning to sustainability from a climate perspective.

Climate data is combined with housing data

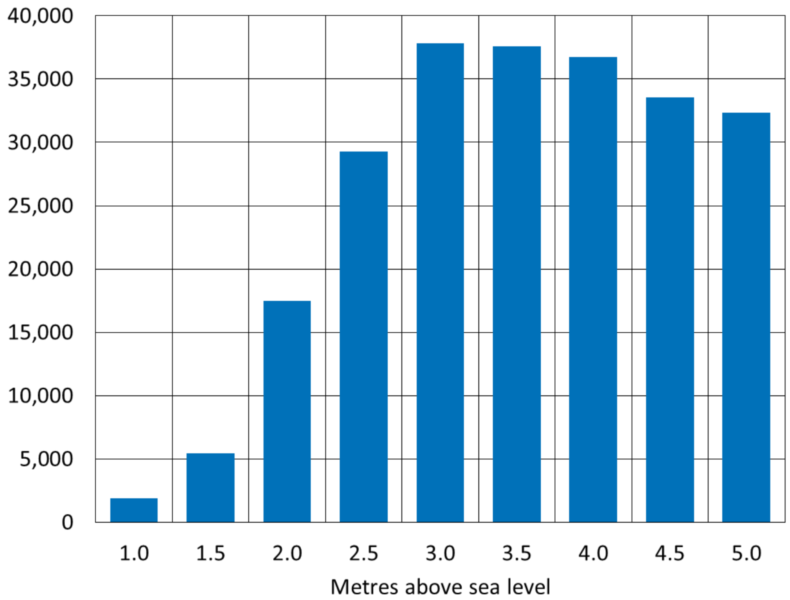
Data on coastal housing

Three types of data have been used in this analysis. The first data set concerns coastal housing in Sweden.[5] This data set includes data on owner-occupied and tenant-owned homes situated within 3 kilometres of the coast and up to 5 metres above sea level. Each data point includes location, height above sea level and an estimate of the value of the housing.[6] The number of these owner-occupied and tenant-owned homes lying at different levels above sea level is presented in Diagram 1. According to these criteria, the number of coastal owner-occupied and tenant-owned homes in Sweden is about 230,000, corresponding to about 7.5 per cent of the number of owner-occupied and tenant-owned homes in Sweden. The diagram shows that the number of homes per half metre up to 3 metres above sea level increases rapidly. The number of coastal homes situated around two metres above sea level is about double that of the number situated 1.5 metres above sea level or lower. Furthermore, there are almost twice as many homes situated at around 2.5 metres as at 2 metres above sea level, and also significantly more homes situated around 3 metres above sea level than at 2.5 metres.

The low number of coastal homes below 2 metres above sea level can be interpreted as showing that the risk of flooding was taken into account when the housing was built. The low number of homes on these low levels may thus partly be due to the risk of flooding being high if a house is too close to sea level and it being safer to build houses at a higher point above sea level. The rapid increase in the number of owner-occupied and tenant-owned homes at 2-3 metres above sea level also means that, should the sea level rise much, even more housing will be exposed to the risk of flooding, as significantly more housing is situated 2.5-3 metres above present sea level than at levels of up to 2 metres.

[5] Valueguard (2020), data purchased spring 2020.
[6] Valueguard's method for estimating the value of housing is empirical and uses data on sales prices for similar housing in the near vicinity of the housing under valuation. This estimation was updated on 25 October 2019.

Diagram 1. Number of coastal owner-occupied and tenant-owned homes situated at different points above sea level at present



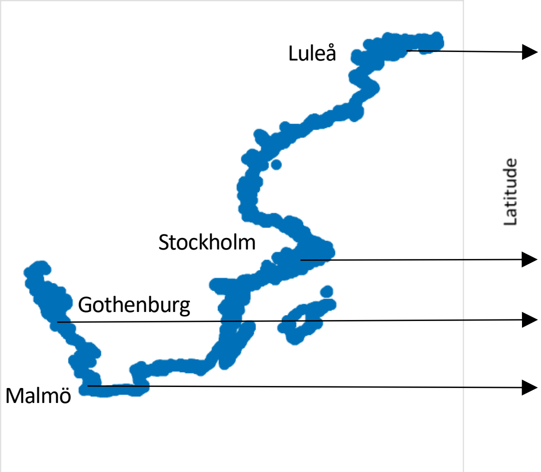
Source: Valueguard.

Diagram 2 illustrates how these coastal owner-occupied and tenant-owned homes are located along the Swedish coast. Each coastal home is represented by a blue dot in the diagram. It can be seen in Diagram 2 that housing close to lakes and watercourses further inland has been excluded. This means that the risk of flooding from lakes and watercourses has been excluded from the analysis. Diagram 3 presents a distribution of the number of owner-occupied and tenant-owned homes in Sweden on a latitudinal scale. Each bar indicates how many coastal owner-occupied and tenant-owned homes in Sweden are located at these latitudes. The bars towards the bottom of the graph represent the number of coastal homes in the southernmost parts of Sweden, while the bars towards the top of the diagram represent coastal housing along the northernmost parts of Sweden's coast. The two largest bars furthest down represent Skåne. The third largest bar represents housing located at the same latitude as Gothenburg. The fourth largest bar, just below the midpoint of the diagram, corresponds to housing in the Stockholm area. The bars furthest up in the diagram correspond to housing at the same latitudes as Luleå and Haparanda.

To make it clearer how Diagram 2 relates to Diagram 3, the three largest cities and Luleå have been marked with arrows. The arrows between the diagrams show which bars are attributable to these cities. As there are buildings along the entire coast, a bar does not correspond exactly to a city, but represents owner-occupied and tenant-owned homes located at approximately the same latitude. The bars corresponding to Gothenburg and Malmö also include housing located at the same latitude but on the other side of Sweden. For example, in Gothenburg's case, this means that housing on Gotland at the same latitude contributes to the size of the bar. Judging from the diagram, the largest share of coastal housing is located in Svealand and Götaland, with Skåne being the region with the largest amount of coastal housing.[7]

[7] Coastal housing meeting the requirements of being within 3 kilometres of the coast and no more than 5 metres above sea level.

Diagram 2. Locations of coastal owner-occupied and tenant-owned homes along the Swedish coastline

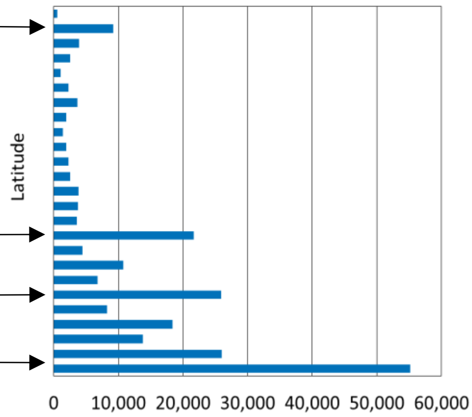


Source: Valueguard

Note: Each blue point represents an owner-occupied or tenant-owned home in Sweden.

Diagram 3. Histogram showing number of coastal owner-occupied and tenant-owned homes by latitude in relation to the map in Diagram 2.

Number



Note: The bars towards the bottom of the graph represent the number of coastal homes in the southernmost parts of Sweden, while the bars towards the top of the diagram represent coastal housing along the northernmost parts of Sweden's coast.

Future climate scenarios

The second type of data used is estimates of how much sea levels may rise over the next century according to three different climate scenarios. These scenarios, called Representative Concentration Pathways (RCPs), have been developed by the UN Intergovernmental Panel on Climate Change (IPCC).[8,9,10] The scenarios are complex and do not correspond to any specific temperature rise, but are a combination of different factors affecting how large greenhouse gas emissions may be over the coming century and what global sea levels may look like by 2100.

The first scenario, RCP2.6, is the mildest scenario used in this analysis.[11] Under RCP2.6, the world's countries have agreed on a strict global climate policy, leading to a gradual reduction of carbon dioxide emissions after 2020. In the second scenario, RCP4.5, which we define as a medium scenario, there is also a global climate policy, although it is not as effective as the one in RCP2.6. The result of this is that carbon dioxide emissions continue to increase for some time to come but culminate around 2040. The final, most severe scenario, RCP8.5, assumes that no further global measures are taken to reduce carbon dioxide emissions and that, by the end of the century, these are three times current levels.

Each of the IPCC scenarios has an estimated interval for expected sea levels by 2100. When climate risks are calculated, particularly climate risks due to rising sea levels, sea levels at the end of the century are usually used. To estimate how great the consequences may be under each scenario, we use the highest conceivable sea level rise, which is to say the upper bound of the estimated interval given by the IPCC for each scenario.

[8] SMHI (2020b).
[9] Intergovernmental Panel on Climate Change (2014).
[10] The IPCC designates these scenarios as RPC2.6, RCP4.5 and RCP8.5. The numbers 2.6, 4.5 and 8.5 specify the level of radiative forcing reached by 2100 expressed in W/m², meaning they are a measure of how strong the greenhouse effect will be by 2100.
[11] "Mildest" means how severe climate change will be in this scenario in relation to today's climate.

Sea level rises during storms indicate local variations

The third type of data used has been developed by the Swedish Meteorological and Hydrological Institute (SMHI) and estimates the highest level to which the sea can be expected to rise during a storm.[12] This estimate is based on historical measurement values from 27 different monitoring stations along the entire coastline of Sweden. The historical data shows that temporary sea level rises in extreme weather are local in nature. This means that sea levels have risen to varying extents historically, depending on where along the Swedish coast the storms have occurred. In addition, in some parts of Norrland, centred around the High Coast, natural land elevation occurs independently of climate change, meaning that rising sea levels due to climate change will not be as substantial at these monitoring stations. The estimated highest sea level rise thus also varies between monitoring stations. Data from the IPCC and SMHI is summarised in Table 1.

Table 1 Climate scenarios and sea levels

Climate scenario	Highest mean sea level in 2100 compared with current levels (cm)	Highest temporary sea level rise due to extreme weather in 2100 (cm)	Carbon dioxide emissions
Current climate	-	210	-
Mild scenario (RCP2.6)	53	257	Carbon dioxide emissions decrease gradually starting in 2020
Medium scenario (RCP4.5)	63	267	Carbon dioxide emissions culminate around 2040
Severe scenario (RCP8.5)	90	294	Carbon dioxide emissions continuing to increase

Note. Highest mean sea level and highest temporary sea level rise refer to the maximum sea level rise at all monitoring stations along the coast of Sweden.

Source: SMHI (2020a), SMHI (2020b).

[12] SMHI (2020a). The SMHI has combined this data with data on rising sea levels in different future climate scenarios.

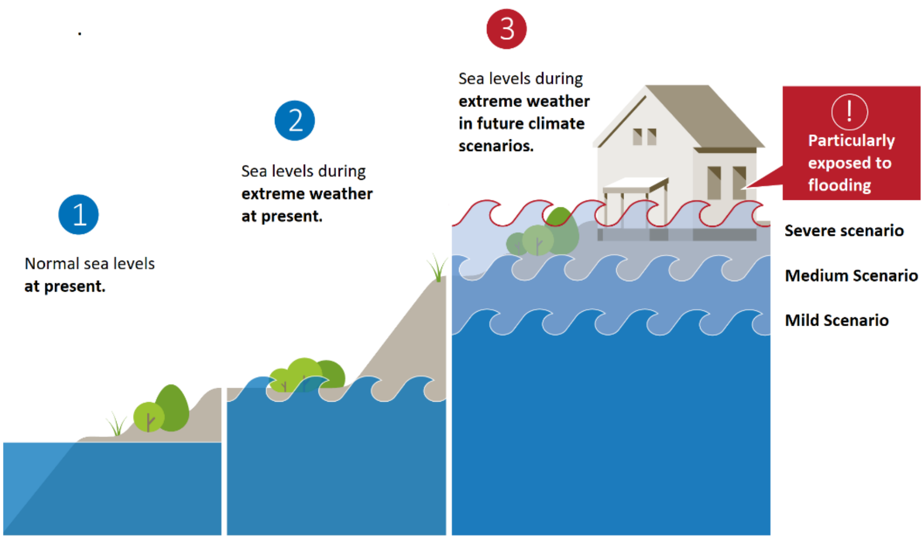
Method for assessing vulnerability of housing

Using the three data types above (data on the location of coastal housing, sea level rises caused by climate change, and temporarily higher sea levels due to extreme weather), it becomes possible to determine whether coastal housing risks being flooded. To determine whether housing runs such a risk under a certain climate scenario, we compare its position above sea level to how high the sea may rise locally in extreme weather in the various climate scenarios. The simulated rising sea levels can be described, in simple terms, as follows:

$$\begin{aligned} &\textit{Simulated sea level rise} \\ &= \textit{future expected sea level rise due to climate change} \\ &+ \textit{highest estimated temporary sea level rise in extreme weather}. \end{aligned}$$

If the coastal housing lies below the simulated sea level under a given scenario, it is considered to be particularly exposed to the risk of flooding. If it lies above the simulated sea level, it is not deemed to be particularly exposed. This assessment is made for all coastal housing in Sweden, using current sea levels and the three scenarios described as starting points. An illustration of how the sea levels relate to each other can be found in Figure 1. The straight line at the bottom is the sea level at the coast under normal circumstances with the current sea level. The first wavy line from the bottom corresponds to the highest temporary sea level rise that can occur today in extreme weather such as storms. The three wavy lines above this correspond to temporary sea levels during storms in each respective future climate scenario. The house in the figure would be considered particularly exposed to the risk of flooding in the most severe climate scenario, as the wavy line for the most severe scenario is higher than the level above the sea at which the house lies. In the other scenarios, the house would not be considered to be particularly exposed to the risk of flooding.

Figure 1 Temporary sea levels in extreme weather



Note: Sea levels in extreme weather means the temporary sea level rises that can occur during storms.

As was mentioned above, the estimated sea level rises in storms depend on where along the coast of Sweden the storm occurs. To bring this factor into our calculations, we compare the position of housing above sea level to how high sea levels can be expected to rise under a future climate scenario in the event of extreme weather at the monitoring station closest to the housing in question. Using these calculations, it can be determined whether a home on the coast is particularly exposed to the risk of flooding in a given scenario.

Risks increase even with minor climate change

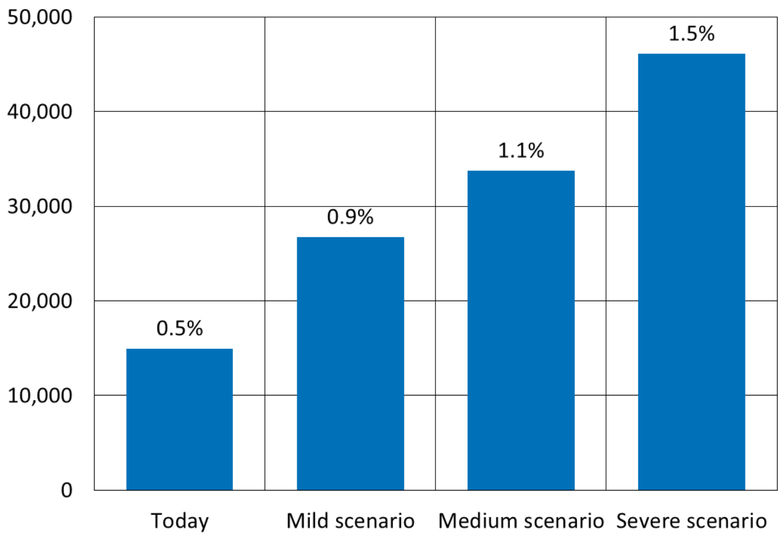
Calculations using the three data sources aim to determine how much financial stability risk is linked to the risk of flooding in extreme weather under the future climate scenarios. In particular, this concerns the risk that arises for borrowers and lenders on the housing market when housing risks suffering physical damage and thereby losing value.

How large these risks may be in the future is entirely dependent on how high the sea could rise in each scenario. The more severe the scenario, the greater the sea level rise. With current sea levels, the temporary sea level rise in extreme weather is calculated to be no more than 210 centimetres above current normal levels, which corresponds to the first wavy line from the bottom in Figure 1. In the mildest scenario, sea levels in 2100 will reach a maximum of 257 centimetres above current normal levels (the next lowest wavy line in Figure 1). In the medium scenario, the temporary sea level reaches up to 267 centimetres and, in the most severe scenario, the sea level reaches up to 294 centimetres by 2100 (the second highest and highest wavy lines in Figure 1 respectively). If these levels are compared to the different positions of the coastal housing above sea level in Diagram 1, it becomes clear that the risk increases the most at around 2 and 3 metres. As mentioned above, the number of coastal homes per metre above sea level increases rapidly up until three metres above sea level.

The number of owner-occupied and tenant-owned homes that will be below water in temporary sea level rises in each scenario and that are thus particularly exposed to this physical climate risk is given in Diagram 4. The diagram also shows the percentage of the total number of owner-occupied and tenant-owned homes in Sweden that are particularly exposed to this risk. At present, slightly fewer than 15,000 homes are particularly exposed to the risk of flooding. In the mildest future climate scenario, the number almost doubles to just under 27,000. In the medium and most severe scenarios, the corresponding figures are almost 34,000 and about 46,000. In relative terms, the increase in the number of particularly exposed homes against today is 179, 225 and 307 per cent. In terms of the percentage of owner-occupied and tenant-owned homes in Sweden, this corresponds to 0.5, 0.9, 1.1 and 1.5 per cent, respectively, of the total stock.[13]

[13] It is highly unusual for extreme weather to affect all of Sweden with equal force. It is likely that a storm resulting in flooding in part of the country will leave other parts unaffected. Now and again, however, heavy storms occur across the entire country.

Diagram 4. Coastal owner-occupied and tenant-owned homes that are particularly exposed to rising sea levels
Number



Note: The percentage shows the proportion of owner-occupied and tenant-owned homes in Sweden that are particularly exposed. The figure of 0.9 per cent in the mild scenario thus indicates the percentage of existing owner-occupied and tenant-owned homes in Sweden that will be particularly exposed to rising sea levels in 2100 under this scenario.

Source: Valueguard and Statistics Sweden

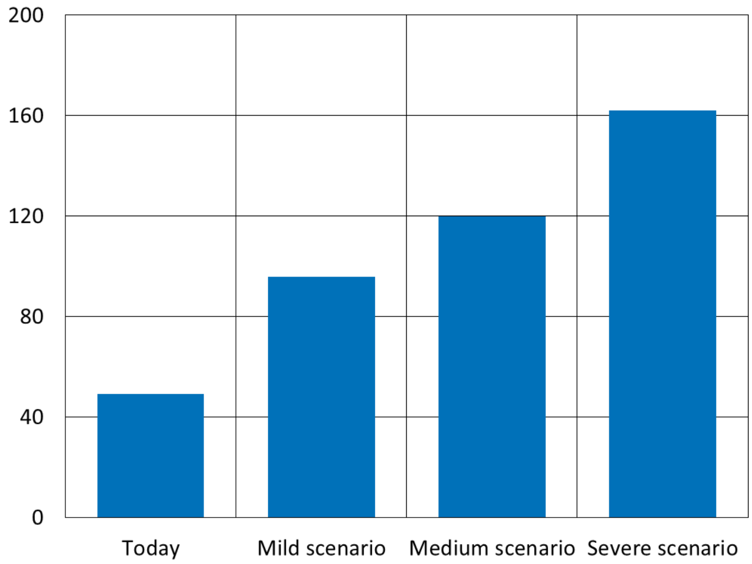
Another way of measuring the risk is to estimate the value of the housing that is particularly exposed to flood risk. This can be done by taking Valueguard's estimate of the market value of housing as per 25 October 2019 and then totalling the estimated value of the housing that is particularly exposed to flooding in each scenario; see Diagram 5. The estimated value of the housing that is particularly exposed at present is about SEK 50 billion, corresponding to just over 1 per cent of the banks' lending to households with housing as collateral.[14,15] In the mildest climate scenario, the estimated value of particularly exposed housing will amount to about SEK 96 billion, while in the medium scenario it will have increased to about SEK 120 billion and in the final scenario to about SEK 160 billion. SEK 160 billion corresponds to just under 5 per cent of the banks' lending to households with tenant-owned housing or property as collateral.

Regardless of the measure used, the picture is the same, namely that the risks of negative consequences for owner-occupied and tenant-owned homes will increase in all three climate scenarios due to rising sea levels in a warmer climate.

[14] Swedish Bankers' Association (2020).

[15] However, the housing only makes up this share of the total mortgage stock under the assumption that it is fully mortgaged, which most probably is not the case.

Diagram 5. Estimated value of owner-occupied and tenant-owned homes that are particularly exposed to rising sea levels
SEK billions



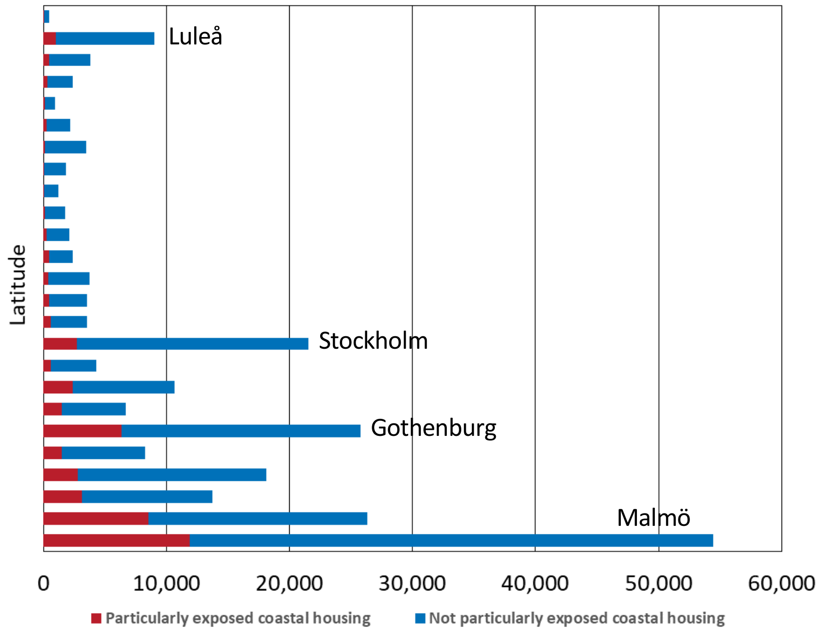
Note: The valuation of housing was carried out by Valueguard and was updated on 25 October 2019.

The risk of flooding is greater in southern Sweden

As sea rises in extreme weather are locally conditioned, the risk of flooding is also locally conditioned and varies across the country. Diagram 6 illustrates how the particularly exposed housing in the most severe climate scenario is distributed across Sweden on a latitudinal scale. Each bar is composed of a part that corresponds to the particularly exposed coastal housing (red) and a part that corresponds to the coastal housing that is not particularly exposed (blue). The sum of the red part and the blue part of each bar amounts to the total number of coastal homes (corresponding to the bars in Diagram 3). The sum of all the red bars corresponds to the total number of particularly exposed homes (which is to say it corresponds to the bar farthest to the right in Diagram 4), about 46,000 homes. The distribution follows the same trend as in Diagram 3. The particularly exposed housing is primarily found in the far south. There are several reasons for this. Firstly, Sweden's three largest cities are located by the coast in southern Sweden; secondly, population density is higher in the south; and thirdly, there is a coastal strip along both sides of the country, from Södermanland in the east to Bohuslän in the west. The greatest risks for flooding should therefore be found in the most southerly parts of the country. One notable difference in the distribution of the red bars in this diagram, compared with that in Diagram 3, is that the number of particularly exposed homes along the southern and central coasts of Norrland is relatively low. This is due to the natural land elevation in the area around the High Coast, which is independent of rising sea levels caused by climate change.

Focusing solely on the southernmost part of Sweden, Skåne, and the proportion of particularly exposed owner-occupied and tenant-owned homes among the total number of owner-occupied and tenant-owned homes in the region, we see that this proportion amounts to about 5 per cent under the most severe climate scenario.[16] This can be compared with the approximately 1.5 per cent in Diagram 4, seen across the country as a whole. This means that the proportion of particularly exposed housing in Skåne is more than three times that of the rest of the country. This also illuminates how much the regional differences, both in geography and population density, affect the risk of flooding in extreme weather.

Diagram 6. Histogram of particularly exposed owner-occupied and tenant-owned homes along the Swedish coast under the most severe climate scenario, RCP8.5



Note: The bars towards the bottom of the graph represent the number of coastal homes in the southernmost parts of Sweden, while the bars towards the top of the diagram represent coastal housing along the northernmost parts of Sweden's coast. The sum of the red parts of the bars corresponds to the bar furthest to the right in Diagram 4. The sum of the red and blue parts of each bar corresponds to the equivalent bar in Diagram 3.

The proportion of owner-occupied and tenant-owned homes in Sweden that are exposed to this risk in the most severe scenario is comparable to the proportion estimated by Danmarks Nationalbank in its study last year.[17] This estimated that upwards of 13 per cent of mortgages in Denmark may be exposed to the same risk over the coming century in the most severe scenario (RCP 8.5). One reason for the risk being higher in Denmark than in Sweden (13 per cent compared to 5 per cent) is that Denmark is significantly more low-lying: its largest cities are at lower elevations, its highest point is 173 metres above sea level and its coastal strip encloses more or less the entire country. This becomes clear when the regional differences are compared, where Skåne, which is more like Denmark than the rest of Sweden in terms of geography and population density, is more exposed to the risk of flooding than the rest of the country.

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[16] Statistics Sweden (2020).
[17] Danmarks Nationalbank (2019).

Difficult to assess impact on financial stability

From the perspective of financial stability, the risks resulting from material damage to coastal housing are more or less negligible at present. However, the analysis shows that the risks of climate-related damage to coastal housing will increase in the future, regardless of climate scenario. Furthermore, the risks will increase to varying degrees depending on where in the country the housing is located. Some parts, such as the areas around the High Coast will probably not experience any heightened risk of flooding, while it is conceivable that the southernmost parts of the country will be affected to a greater degree. Overall, this means that the effects on the financial system and on financial stability as a whole are difficult to assess. Another important aspect, on one hand, is that the analysis does not consider that climate change takes place slowly over a relatively long time horizon. This means that its impact on financial stability may also take place gradually over time, which would have the consequence of the effects being smaller. On the other hand, this analysis focuses solely on the risk of flooding of coastal housing. However, it is conceivable that other risks may arise as sea levels rise. For example, the risk of landslides and flooding will increase for housing located near watercourses flowing into the sea. Future sea levels will thereby make it possible for extreme weather also to affect housing located further inland or higher up than the sea can reach when there is extreme weather in a warmer climate. In other words, it is possible that this analysis may both underestimate and overestimate the actual risks to financial stability.

There are various conceivable channels through which the risks could affect financial stability and consequently there are several different questions that may be relevant from the perspective of financial stability. Households, banks and insurance companies may be impacted if the risks increase. Increased physical climate risk could cause housing prices to fall, which could affect household loan-to-value ratios. If the risk of flooding and material damage increases, the quality of the collateral in the mortgages issued by the banks will decrease, which will, in turn, impact the banks' credit risk. It is also likely that the insurance companies will weigh the increased risk of flooding into the pricing of home insurance or that they will become unwilling to insure excessively exposed housing. Such consequences may have a major negative impact on individual households, as well as affecting some regions more and others less. However, as has been mentioned, how notable the increased risk of flooding can be expected to be is difficult to assess and, ultimately, the actual consequences will depend entirely on how global emissions are restricted and to which degree society adapts to climate change.

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