AALBORG UNIVERSITY

Master's Thesis

Classification of Coastal Towns and Cities for implementation of Climate Change Adaptation Initiatives in Denmark

Submitted by

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I will have very fond memories of my time here at Aalborg University and will cherish them forever.

Madhuri Gotety

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"… WE'RE THE FIRST GENERATION TO FEEL THE IMPACT OF CLIMATE CHANGE, WE'RE THE LAST GENERATION THAT CAN DO SOMETHING ABOUT IT. WE ONLY GET ONE HOME. WE ONLY GET ONE PLANET. THERE'S NO PLAN B…"

- Barack Obama at COP21 in Paris, 2015

1. Background

1.1 The Climate Change Facts

Climate change trends: Climate change in mainland Europe is recognised to be faster than the global average with various potential implications for different countries depending on their respective climate, geographic and socio-economic situations. European land temperatures, over the past decade on average 1.3°C higher than in the pre-industrial era, compared with a global average rise of 0.8°C (Strengthening Europe's preparedness against natural and man-made disasters, 2013) .

Increased incidences of extreme weather events, especially in southern and central Europe, point to a future that warrants collective action on knowledge building and informed decision making to ensure climate readiness. Greater chances of heavier precipitation and flooding are projected for northern and north-eastern Europe thus leading to a higher exposure to rising sea levels, coastal flooding and erosion. Such dire predictions, are especially important when considered in conjunction with inferences on importance of our coasts from studies on distribution of global population density and location of cities which indicate that more than half of the major cities across the globe are located inside the "near-coast" zone, an area that produces 42% of world's GDP and accounts for 27% of global population, while exhibiting the highest urbanization rate leading to ever-increasing population densities (Matti Kummu, 2016) . Overall, a total of 40% of the global population resides in the coastal zone (Percentage of total population living in coastal areas)

Climate change effects: Considering the above, there is an obvious and concrete need to strategize and execute climate mitigation and adaptation measures at an international level, especially to mitigate climate driven long-term changes, such as rising sea levels, which pose a serious threat to human and economic capital aspects of our planet. One such institutional policy response is the "EU strategy on adaptation to climate change" states three key objectives: Adoption of adaptation strategies by its member states, safeguarding key "vulnerable" sectors such as agriculture, fisheries, while minimizing impacts on employment and livelihoods by building specific adaptation capacity and finally to drive informed decision making for greater penetration of the strategy. The current research aims to develop and recommend adoption of one such model to assess vulnerability of coasts, specifically the along the Danish coastline, as part of Denmark's adaptation strategy and incorporates key variables that indicate different dimensions of national vulnerability. The ultimate objective is to drive informed decision making based on a scientific and data-inclusive methodology.

1.2 The Vulnerability assessment models for Policy driven climate response mechanism

Climate change studies – Index based Vulnerability Models: Historically several studies have been conducted and many papers published around the concept of creating indices at different levels of scale of study assessing the vulnerability of coastal regions based on multiple variables (Cooper, 2010). The multi-scale coastal vulnerability index that was developed by the authors banked on the idea that the variables considered in the calculation of the index are to be seen in the context of the end users that will eventually implement the climate adaptation measures. For example, at a national level a different set of variables becomes salient for the stakeholders as against at a municipality level where generalizations fail to give any concrete insights on the specific measures to be implemented.

Besides variable selection and inclusion, another constraining factor is the data availability itself, considering many of the coastal areas especially the smaller settlements are not necessarily mapped by the National mapping agencies in their studies. The vulnerability assessment carried out by the authors depend on three central ideas of coastal character, characteristics of climate resilience and susceptibility due to coastal morphology and coastal forcing and socioeconomic factors. The last of these factors has been largely neglected in a majority of studies but were incorporated in the above study.

The research presented here takes elements of the approach used by McLaughlin and Cooper (Cooper, 2010)and applies it to the Danish coast, with a focus upon infrastructure, socioeconomic value, and climate readiness. Several new variables have been introduced to examine and evaluate local variables with a view to prioritise areas with the maximum ratio of socio-economic impact to the investment into climate adaptation to eventually arrive at a curated list of coastal regions for action by relevant stakeholders.

Climate change indices – a scientific and data driven approach to steer adaptation strategy: As opposed to the three types of vulnerability ranking arrived at by McLaughlin and Cooper (Cooper, 2010) at a national level followed by regional and local levels, the current study aims to develop a single index focused solely on different strata of coastal regions as categorised by their distance from the coastline, elevation, and population level. Therefore, it is simultaneously useful from a Danish National coast preservation perspective while providing guidance on the specific municipalities that may be prioritised for roll out of search national strategies.

In their policy paper on the shift towards " Low Carbon Climate Resilient Development" (LCCRD) (Boyle, 2013) the patterns that are governing such a shift, Jessica Boyle and others explored a few case studies with following key inferences that strongly support the case for a relook at the way climate resilient development necessitates certain fundamental changes in our approach towards climate readiness with respect to climate risk mitigation through better adaptation:

1. A need for developmental agencies, global and local, to enable an emergence of LCCRD actions, especially in places where they are absent, largely relevant for coastal areas which may not be economically or culturally important but still hold salience considering their climate change mitigation importance.

   On the other hand, in case of important socio-economic centres, the need for such measures is self-evident. The authors push the case for such a foundational approach as a key lever in the transition of the developing world on their way to future economic greatness while still holding in good stead, their unwavering focus on their climate related strategies for sustainable development.

2. Further, capacity building, both institutional and infrastructural (technical support, knowledge sharing and financing, amongst others), is identified as a fundamental need for any meaningful climate adaptation engagement globally. This is especially true at national level where relevant stakeholders need to balance the allocation of their finite resources with those of the demands of their hinterlands that are most prone to climate related disasters.

   It is also argued that climate finance forums should play an important role in facilitating such exchange of capabilities and resources, especially international financing. In addition, there is an acknowledgement of

   That several national LCCRD frameworks are still in a nascent stage with a clear emerging gap between planning and effective implementation. However, this gap has been an increasing focus of modern climate related research, especially to arrive at concrete action plans for the climate administration bodies around the globe.

1.3 Case Studies to illustrate the application of index-based models for climate vulnerability assessment around the globe

Following are some of the case studies from around the world to understand how index based approaches have been used in conjunction with GIS software to arrive at vulnerability and impact assessments.

Case Study I – Jamaica:

In their work for "The Office of Disaster Preparedness and Emergency Management" (OPDEM), Jamaica (Aikens-Mitchell, 2015), the researchers first profiled the local community of Negril before proceeding with a quantitative risk and vulnerability assessment through multi-temporal analysis pivotally based on 3 key parameters: Physical assets (infrastructure), Social assets (population – numbers, age & gender mix and critical assets) and lastly economic assets (economic loss).Incidentally, the main economic activity of Negril is tourism, it being the third largest tourist resort area – rather unsurprisingly, Jamaica derived 7.7% of its total GDP from travel and tourism.

On careful review of the variables utilized in the study, there seems to be an unwavering focus on the "hard" indicators like economic and infrastructural impact and does not include certain other variables covered in the current research like socio-cultural importance, distance to coast and elevation. Like all other projects, the efforts and modelling scenarios therefore depend on the set of variables deemed important as per the ultimate mandate set by the governing body, thus setting the tone for the researchers to frame their problem statement. This is exactly where the current research strives to shed light on the need for a more holistic approach to both framing and meeting the climate mitigation and adaptation objectives by using a broader portfolio of variables – in addition to the "hard" ones.

Case Study II – Auckland, New Zealand: A separate research conducted by the above group to arrive at a vulnerability assessment for Auckland, New Zealand (Spaulding, 2016), also had the "Research Problem" defined as building a GIS vulnerability assessment model to measure highly exposed "assets" to multiple hazards thereby restricting the "elements at risk" - this underlines our argument to have a more "rainbow" approach to variable inclusion.

Challenges beyond numbers – Political motivations & "Tone at the Top": The current research aims to extend this global school of thought by seeking to add further structure to this effort to build practical GIS-enabled models with scientific rigor by taking a bottom-up approach to evaluating and ensuring climate readiness, specifically in the

Danish context. However, there is a need to recognize that climate action, often a major agenda item for major world leaders, is very likely to be subject to political challenges, as witnessed in the case of the recent fall-outs of the Paris Accord where United States government announced that they are pulling out of this much-awaited climate agreement (Shear, 2017).

In addition, it can be a daunting task to coordinate public, private and other stake holders in the overall process of selection and prioritization of climate actions, as any successful approach to mitigation or adaptation depends to a large extent on the concerted efforts by different actors. The results of a climate project can only truly successful if it effectively accommodates and steers through possibly conflicting intentions and varying levels of ability of these players. Each one of them enters the fray with their respective cost-benefit analysis (economic, political etc.,)

1.4 Challenges related to institutional capacity

Lack of relevant data and qualified manpower can bottleneck the rapid and effective percolation of scientific approaches to climate action: All the studies mentioned above, mainly concern larger cities. The smaller cities and towns are generally not in focus. The other challenges may stem from data availability especially in small cities and towns with no dedicated public services to collect or monitor climate related data, let alone take concrete actions based on scientific analysis.

In face of such lack of scientific infrastructure, the onus can be laid on international bodies as a knowledge sharing platform that can dole out practical advisory to interested governments / administrative bodies. This can also address any lack of institutional capacity to train and deliver quality personnel trained on climate related topics. Most small cities and towns may find this challenge to be true as their skilled workforce (PhDs, Professors etc.,) tends to move to the big cities or the more urban areas of the world.

Therefore, in the long term, there is a need to creating an enabling environment where governments with the above challenges are hand-held in the medium term for effective implementation of obvious actions while also aiming to improve their capacity to own and operate a self-sustained model of climate governance that effectively takes care of all challenges.

2. Project Introduction

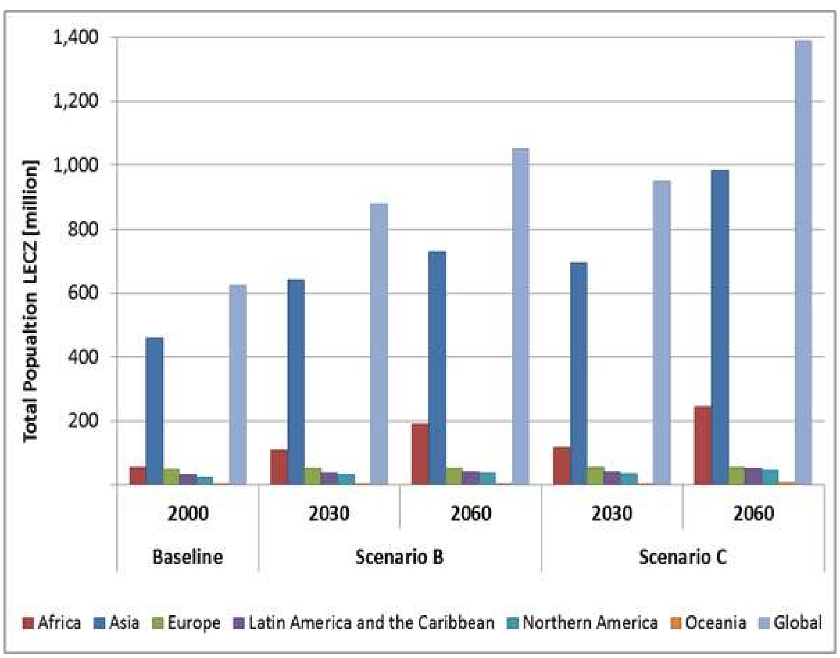
Denmark has an extensive coastline (7,300 km) with the highest point in the country only at 170 meters above sea level. A quintessential coastal nation and a major exporter of wind-turbines, it has 406 islands and an average wind speed of 7.6 metres per second (Denmark, 2018)

The specificities of different geographical locations in the country necessitate different approaches to improving their climate resilience by mitigation of risks that may emerge from natural disasters or a rise in sea level. Below, we explore certain key facets of its spatial specificities that will allow us to delve a bit deeper to arrive at key questions in the objectives section. That is followed by a discussion of the data driven methodology adopted to eventually arrive at a system of classification of towns, villages and cities along the coast as well as the resultant shortlist of regions themselves. This research aims at helping stakeholders or government identify the smaller towns and cities that are more susceptible to climate change events, by developing a ***Vulnerability Index*** using various parameters that will be discussed at length later in this report.

2.1 Key Variables I to III – Population, Distance from coast & Elevation

The following graph shows the distribution of global population concentration in terms of elevation from sea level. It shows that the population exposed to climate related disasters, especially those arising out of a Sea Level Rise (SLR) is going to be in the increase for all predictable future (Barbara Neumann, 2015).

Figure 1: Increasing global population located at coast and at low elevation (Low Elevation Coast Zone – LECZ < 10 metres elevation)



Global to Local perspective – **Copenhagen, Denmark – Heavy population and significant exposure**

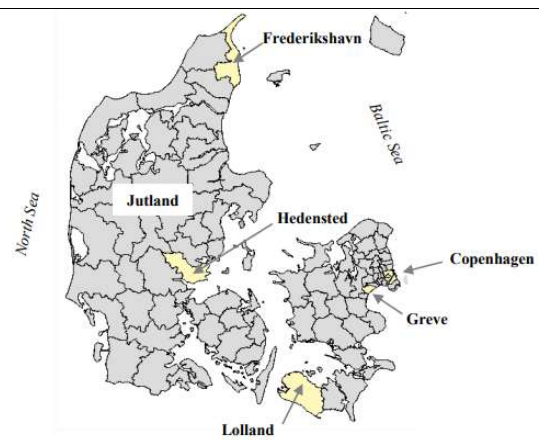
Coming to Denmark, though most of Copenhagen's coastline of 60 km is well-protected, the actual city itself is not well-adapted to deal with extreme though temporary spikes in water levels of at least 1.5m. Added protection was proposed towards key locations like harbors, and historic heritage centers. In a simulation, a 50 cm sea level rise combined with an exceptionally big storm is estimated to exposure of around € 5 billion of damages due to floods in this cosmopolitan city.

The three parameters that are salient in our research methodology are elevation of a given landscape, its distance from coast (near-coastal regions are more prone to disaster risks) and its population intensity. The chart below brings all of these variables together in the Danish context. It extracted from the European Commission Policy Research Corporation's "Country overview and assessment – Denmark" report and indicates that all of Denmark's population lies within 50 km zone from the coast, a zone that accounts for an extremely significant 72% of its GDP (Commission, 2006).

The country is rather exposed to climate related risks as 22% of near-coastal zone (<10km) is below 5 meters of elevation. The Jutland coast in the west especially is vulnerable to coastal erosion by North Sea waves, averaging 2m/year. A dearth in the capacity of sewage system to handle the key climate risks of increased rainfall and storms is also highlighted, as they have been historically planned without taking into account the climate change induced Sea Level Rise (SLR).

Again, there exists considerable research on Copenhagen and the other few largest cities of Denmark. These extensive plans are generally reviewed periodically, and necessary changes or additions made. At the same time, national plans for smaller coastal towns and cities do not happen as frequently.

Figure 2: Municipalities of Denmark and the main physical and socio-economic indicators of the coastal zones



Physical and socio-economic indicators	*North sea*	*Baltic Sea*
Sea Level Rise	High	Low
Coastline length	4 605 km	
10 km coastal zone below 5 metres elevation	22%	
Coastline subject to erosion	607 km (13%)	
GDP in 50 km zone (€ million)	104 043 (72%)	
Population in 50 km zone	5 397 640 (100%)	

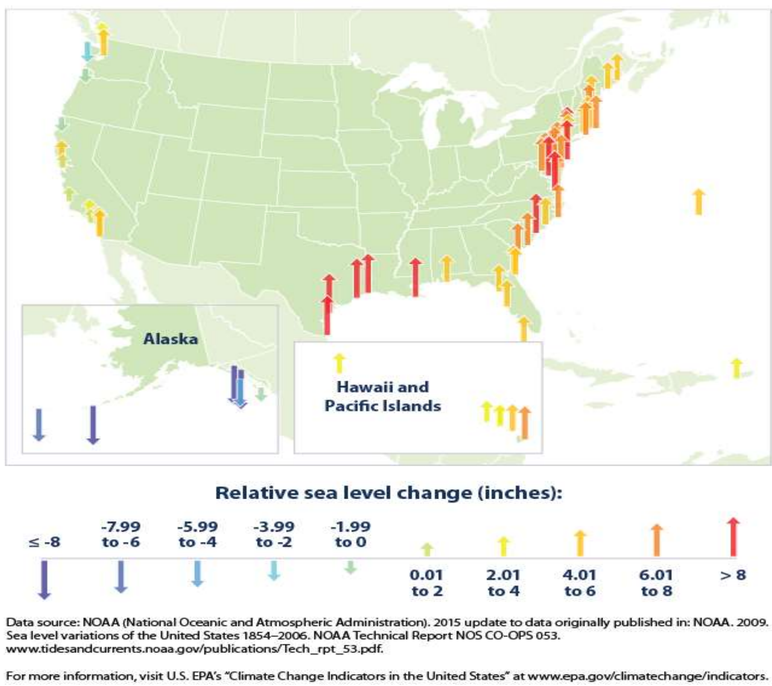
Source: Policy Research based on EEA, 2006, The changing faces of Europe's coastal areas (for Sea Level Rise and 10 km coastal zone below 5 metres elevation); European Commission (Eurosion study), 2004, Living with coastal erosion in Europe: Sediment and space for sustainability (for coastline length and coastline subject to erosion); Eurostat 2004 (for GDP and population in 50 km zone)

2.2 Key Variable IV – Infrastructure / Economic activity

Climate change can crumble decades old capital-intensive infrastructure – Detrimental effects on World Economy

US: As shown in the figure below, the sea level change along US coasts is unmistakably progressive putting several sectors like Coastal and marine transportation, offshore drilling and mining, fisheries and tourism that generate approx. 58% of nation's GDP at risk of detrimental exposure to climate related events (Climate Impacts on Coastal Areas, 2017)

Figure 3: Relative Sea Level Change Along U.S. Coasts, 1960 - 2014



The Caribbean: Coastal Transport Infrastructure in Small Island Developing States (SIDS) at risk

In a report presented at UN conference on trade and development in 2017 (Monioudi, 2018) the climate change impacts on Saint Lucia were assessed, especially from a coastal transport perspective which is key for this small island developing state. Tourism contributed to 41% of its GDP (2015), an economy which is heavily exposed to climate risks - Hurricane Allen (1980) led to loses of 60 % of its GDP and Hurricane Tomas (2010) led to an extremely significant 43.4 % of GDP.

Looking at such a highly climate-sensitive case-study where an impending sea-level rise was projected, the established objective of safeguarding **"**tourism infrastructure" which combines 2 variables of our current research "tourism" and "infrastructure" into just one is a very interesting mutation of variable selection, depending on the specificities of the geographies being assessed. Impacts on coastal infrastructure were understood by modelling flood scenarios, especially due to sea level rises was one of the approaches adapted to assess the vulnerability.

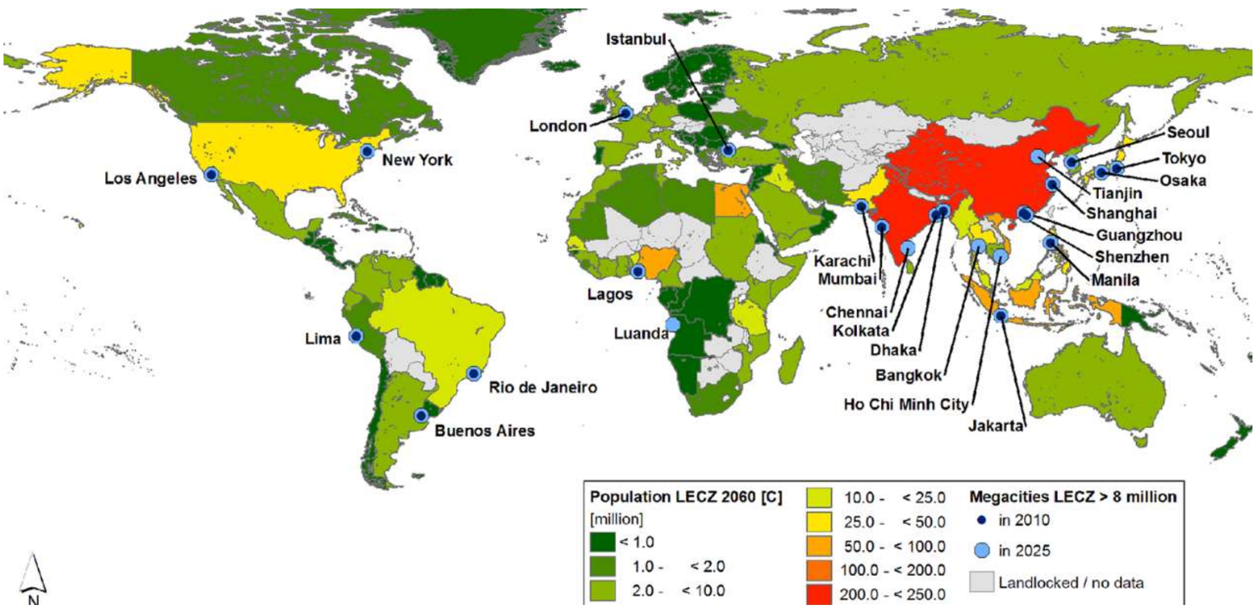
2.3 Key Variable V – Tourism

Climate action key to sustain the Tourism "Backbone" of world economy - The magnitude and economic importance of coastal tourism

Tourism, a topic area of national importance for several countries, is a major contributor to the economic value generated by the world economy. In fact, UNWTO statistics (UNWTO, 2007a) indicate that this industry, who fate is intrinsically dependent on the implementation of initiatives for a sustainable climate future, is the world's largest and fastest growing industry in terms of total workforce employed and economic value generation (Sustainable Coastal Tourism - An integrated planning and management approach, 2009).

Coastal Tourism is an important global economic driver: If we zoom out and look at the earth with a focus on coastal tourism variable, megacities with more than 8 million residents in 2025 (Barbara Neumann, 2015), whose infrastructure and populations are at an elevated risk of flooding.

Figure 4: Megacities with Low Elevation Coastal Zones



In the majority of all the studies referred during this research, the main focus is on Mega cities or in general terms, aimed at large cities. The smaller coastal towns and cities are not as researched as the larger cities of the world. By identifying the knowledge gap, this study aims to fill it, as a pilot for Denmark.

To illustrate further, one can look at the facts that indicate the importance of this variable, through some sample geographies from around the world.

Case study I - Europe: According to European Commission (INRA EUROPE, 1998), coastal tourism is the clear winner in the tourism preference pecking order, with 63% of European citizens preferring the coastal abodes against 25% favouring mountains. For example, countries with the coastal relaxation factor comprised 12 of the top 15 top touristic spots (Year 2000). Viewed differently, 25% prefer cities against 23% for the countryside.

Case study II - Unites States: On the other side of the Atlantic, 3 US coastal states (Florida, California, and New York) accounted for 74% of foreign tourist count while generating 85% of tourism revenues in 1995 as per a report Bridges report (1997). In addition, US beach tourism contributes a significant USD 640 billion annually to the economy.

Case study III - Mediterranean: Despite data collection constraints, UNWTO reported that the Mediterranean coast was visited by 250 million visitors in 2008 which could increase to 312 million by 2025. A popular vacation destination, the Mediterranean records more than doubled population densities in summer as compared to the winter time (EEA, 2005)

Looking at the above case-studies from across the globe, it is obvious that coastal tourism is important both from an economic value generation as well as a livelihood perspective. Employment generation by coastal tourism is an important driver of economic activity in terms of supply and demand generation of various coastal offerings. For example, according to EEA data (2005), tourism provides 43% of jobs across all of French coast, surpassing even fishing or shipping in terms of revenue generation (Sustainable Coastal Tourism - An integrated planning and management approach, 2009).

Inferences from the above case-studies: All of this underlines the need to protect our coastal regions in a scientifically guided manner via evolution of suitable yet different indices to determine the sustainability governance strategy depending on whether the data aggregation is at a global / regional / national or municipal level. Natural disasters along coasts have frequently impacted many coastal settlements with climate change aggravating the severity of their adverse impact remaining our most significant collective challenge in the future.

Small coastal towns and cities are especially under-equipped with any form of financing and concurrent institutional capacity for information collection, processing and dissemination for envisioning and effective implementation of mitigation or adaptation measures. Hence there is a need to identify and protect coastal regions most at risk, from an index-driven holistic perspective. The identification exercise can be conjoined with a logical “grouping” exercise to place towns and cities of similar ‘types’ so that, knowledge and best practices for a given group can be readily shared and assimilated thereby decreasing the overall “search and implementation” costs of a successful umbrella climate mitigation campaign while also improving the chances of achieving successful adaptation.

3. <u>Objectives</u>

3.1 Research Questions

The outputs of the current vulnerability assessment of Danish coastal regions are expected to provide answers to certain key questions like:

- To identify areas of Denmark that are at most risk given an overlay of spatial distribution of the total population, economic activities (key assets/investments) & economic value.
- Exploring ways to enlist, classify and re-organize the Danish coastal regions based on certain geographical criteria. To develop a ranking system that is comprehensive, intuitive and simple to use.
- The research also seeks to provide inputs to state / private actors (Danish government, coastal municipalities etc.,) as part of their strategic road-map to improve climate resilience over the long term in the regions with higher levels of exposure as identified in this study.
- To establish a model of classification and analysis suggested by this projected, that is potentially scalable to analyse all such countries in the world with vast tracts of vulnerable coastal areas that are indeed most exposed to climate-related vagaries, of course starting with those that are geographically similar to Denmark (extensive coastline, high wind speeds, flat terrain etc.,)

3.2 Research Design

As mentioned in the above section, the main goal of this research is to develop an indexation tool to measure the susceptibility of the coastal towns and small cities to climate related disasters. To do this, the necessary steps are;

- Develop a methodology and assign values to convert the different aspects into a more coherent relatable/comparable unit scale

- Use GIS for more simple/visual attributes

- Gather data analogically about the coastal settlements for any anomalies and to verify the data extracted using remote sensing technology, ArcGIS, in this case.

- Arrive at a final list of locations as an input to policy makers or stakeholders.

4. Data & Methodology

The data necessary for the project could be acquired by remote sensing technology. However, benchmarking would not be possible as this data is previously non-exist to cross reference against. Hence, an analogue data set was necessary to compare and contrast against the data acquired through remote sensing technology to be able to authenticate as well as expansion to other regions of the world.

Historically, the choice of a vulnerability assessment methodology (Assessing risks and vulnerability to climate change, 2018) is guided by:

- Availability of Resources: Data, Literature, Human and financial
- Activism: Level of public as well as private stakeholder involvement
- Estimated outcomes of potential risks

4.1 Incorporation of non-GIS data - More than what the GIS eye can see

Though a highly valuable data source for a scenario analysis perspective, the GIS information extracted from the GIS database solely is insufficient in the sense that it doesn't render itself to the analysis of locations with population counts below the threshold of 1000 which could be otherwise sensitive from national security perspective, or salient from a sheer cultural importance perspective. Some small towns have military bases/ airports in close proximity making them more important. But again, this has to be known/found out manually through an examination of maps (e.g. Aalborg airport is in Nørresundby) instead of proceeding uni-dimensionally based on population, elevation etc. Imagine an aircraft carrier base or strategic military base location which is rather exposed to the coastal dangers as are many other populist locations. Therefore, a weight must be assigned to such locations from a security or simply national relevance point of view even if their populations are sparse or non-existent.

Alternately, locations with immense heritage value but sparsely populated may be missed out. This is exactly why the current work emphasizes a customized and discretion driven analysis instead of one-size-fits-all GIS analysis approach to ready our major stakes for climate disasters.

4.2 Collective heritage at decisive climate stages

At a macro level, anywhere between 100 – 140 world heritage sites are at the risk of being submerged due to climate change (Parvini, 2014)

As a case study, for example, the Ayutthaya world heritage site, which is located on a Thai island was inundated during the July – October flood (Wittgenstein, 2011) in Thailand which forced the UNESCO to develop a post-disaster 2 year flood risk mitigation project in mid-2013 (UNESCO launches project to develop a flood risk mitigation plan for Ayutthaya World Heritage site, 2013) with financing from Asian Development Bank. Such post-facto responses are more expensive than the proper identification and mitigation strategies that could have averted/minimized the effects of this unfortunate disaster in the first place.

Post-disaster work typically entails carrying out restorative work in addition to conservative work, in an environment that is already extremely resource constrained thanks to the disruptions arising from the disaster itself, thus driving up the overall disaster recovery cost for such cultural landmarks. Also, over the long term, proactive and continuous maintenance and upkeep along with mitigation measures is a more economical alternative than occasional restorative work and drastic measures to restore post disaster strikes (Dávid Kutasi, 2011). Not to mention, it also takes substantial time (years) as most ruins are fragile and worse, may not lend themselves any sort of restorative work thus either leading to complete loss or partial loss (loss of authenticity) of the world heritage site as it was originally conceived.

Considering the above arguments, it becomes important that we exercise and include a certain extent of discretion or subjectivity for locations that may be not retrieved from the GIS dataset but are critical / important nevertheless. Such offline “analog” data collection is of course a resource intensive task and does introduce a certain element of subjectivity while incorporating, assimilating and communicating results on such a subset.

Such an exercise may necessitate consulting several publicly available data sources or can be obtained from the governmental body directly / indirectly involved in the climate vulnerability assessment initiative (especially if the information sought is considered confidential or restricted from a public usage perspective). It is important that the scenario modeler then, has such locations carefully cross-assessed with relevant local stakeholders, subject matter expert groups and climate experts to ensure that the final indexation of locales with sparse population is also representative of the overall climate-sensitivity heat-map generated in conjunction with the GIS analysis.

In face of constraints such as results being, to certain extent, inherently empirical, analogous due to the subjective nature of such auxiliary analysis, the limitations of such an approach warrant a discussion in the limitations section to guide any future research similar to/extending from the current one but will be attempted to strategize climate risks in other countries / municipalities. The availability of data can be, of-course, a hard stop constraint thus introducing greater chances of “out of the box” data gathering and processing techniques to establish a comprehensive result set to the decision-making bodies. Therefore, the local knowledge gathered from historical precedents and from local cultural expert groups is often useful to successfully measure the full potential impact of any unfortunate turn of events.

4.3 Data Sources

The study banks on Danish public records for social variables. And an extensive online research based on web based methods. There are also references to existing literature and scholarly articles (academic papers). This research utilises Danish public data and GIS datasets for variables such as population, key infrastructure, tourist footfall, in addition to reports and academic literature. Telephonic communications with some Danish municipalities was required to fill gaps in the publicly available data. Danish coastal regions were classified according to their urban/rural status. These urban areas were then measured for their exposure through an analysis of key geographical variables, such as mean elevation, proximity to the coast, flood risk, local geology, and historic coastal erosion rate. A classification and ranking of such localities was undertaken on an ordinal scale to derive the locations with the highest risk level.

4.4 Methodology

As part of the methodology followed to arrive at results of this research, publicly available data pertaining to the following parameters have been used.

A. Population

B. Distance to Coast

C. Elevation

D. Economic importance (Industries, Infrastructure, Ports)

E. Socio-cultural importance (Museums, Tourism, Historic places)

POPULATION: Population data has been retrieved through usage of Denmark statistics / public records for the GIS shape files and data sets available on Arc GIS. For the purposes of this research, towns with populations with ranging between thousand and one hundred thousand have been used to ensure a uniformity with respect to the underlying demographic conditions involved. Further, a scale has been constructed as shown below to rank all relevant geographies in the above population spectrum by the level of their respective populations.

Details of Scale to index Target sites by the level of their population are as below:

Table 1: Population rating scale

Rating	Criterion
1	1000 to 5000
2	5000 to 10000
3	10000 to 25000
4	25000 to 50000
5	50000 to 100000

It is important to note that the above indices are also aligned to the stratification criteria laid out as per DK statistiks data. A salient observation is that the target sites do not render themselves to a uniform distribution because their frequency distribution as a function of population is rather diverse in their spread i.e., there are several towns with relatively smaller sized populations and very few with heavy populations.

DISTANCE TO COAST (Mean): The data pertaining to the "distance to coast" parameter has been derived from the global coastal dataset and EEU coastal dataset. For this research, only settlements with the minimum distance of less than 2000 meters are considered when filtering the dataset on ArcGIS. By doing this, the dataset that resulted had a minimum distance of 0 (zero) for almost all the towns. But, if the filter was placed to extract towns and cities with a mean distance of less than 2000 metres, there is a risk of losing towns that have a larger spread inland and hence will have a higher mean distance value, thus making the data not as reliable.

Consequently, the filter of minimum distance to coast was placed to extract the towns and cities of interest and the rating scale is developed considering the mean distance to coast values arranged as per the scale shown below:

Table 2: Distance to Coast rating scale

Rating	Criterion
1	1600 and above
2	1600 to 1200
3	1200 to 800
4	800 to 400
5	400 to 0

The inclusion of other well evaluated criteria is critical to make the current study more comprehensive and holistic.

ELEVATION (Mean): Denmark Statistiks datasets have also served as the source for the elevation data. Overall, towns with elevations less than 10 meters have been included in the analysis as they are the ones that are most susceptible to a remarkable change in sea levels and are in the immediate "at-risk" category.

As mentioned above for the distance parameter, the same method has also been applied to extract the elevation data. The filter of minimum elevation of 10 metres was placed to extract all towns of interest, but the scale is developed for the mean elevation values to weigh the results of the current analysis over an altitudinal dimension.

Table 3: Elevation rating scale

Rating	Criterion
1	30 and above
2	20 to 30
3	10 to 20
4	5 to 10
5	5 and below

Interestingly, a few towns were noted to be below mean sea level as some elevation measurements are in negative numbers, the current study brings them to the forefront, at least to the extent of the relative importance of the current parameters and implicitly as part of the overall study perimeter.

ECONOMICS: From a purely economic standpoint, infrastructure (commercial establishments, heavy public and private hard invested facilities like ports, business districts, power plants, refineries, industrial zones, heavily populated urban centres etc.,) is a key parameter to be considered in any study of the effects of climate change on any economy. Depletion or total loss of infrastructure can have both immediate (loss of capability and wasted investment) as well as more long-term demographic effects (displacement of population, loss of heritage, loss of revenue and employment generation etc.,) on the populations involved, and pose a major risk area for the local and national governments.

In the current study, towns with Industries, Ports, Marinas, Bridges, Hospitals, Universities and other Infrastructures have been selected and duly indexed. The scale for the indexation based on the economic parameters is as shown below:

Table 4: Economic Importance rating scale

Rating	Criterion
1	No major infrastructures + Very small Population (less than 5000)
2	Small Bridges / Road connections + small Marinas + small towns
3	Tiny Port + Marian + Medium Sized town
4	Bigger port + Bridges + Small Industries + Bigger town
5	Major port + Airport + Hospitals + Universities + Industries + densely populated

TOURISM/ SOCIO-CULTURAL:

Tourism is an area of national importance as it is a major contributor to the economic value created by the country's economy. Also, the culturally significant towns are considered in this study. Denmark, being one of the most developed countries of the world, has many public amenities available for its citizens. There is also a big emphasis on activities especially during the summer months. Additionally, many Danes go camping and /or sailing, hence the abundance of camping grounds and existence of marinas even in small coastal towns. To develop a scale for a country with all basic amenities available in almost every small town, it was necessary to build a master list of such amenities and activities available which were then grouped into different categories and are indexed as below:

Table 5: Tourism / Socio-Cultural Importance rating scale

Rating	Criterion
1	No activities / No or Very few accommodation available / No Camping grounds / Very few or non-existent amenities / Very few hiking trails
2	Basic amenities like bathrooms & picnic areas available / Small camping grounds / few Bibbs or hotels
3	Camping grounds with more amenities / Small tourist footfall / Some monuments present / few hotels and other accommodations
4	More amenities / Availability of many hotels and BnBs / Museums / Multiple tourist attractions and activities
5	Large tourist footfall / Airport / Military base / Many tourist attractions / Many different types of amenities easily available / Large number of hotels, Bnbs and other accommodations

The towns with social, historical or cultural importance are also included, as will be represented in the results section.

5. Results & Discussion

5.1 ArcGIS data

1. POPULATION: The following are the cities with most population while still being less than 100000. The data was extracted from GIS dataset of Denmark cities published by Danmarkstatistiks and is based on the data from the year 2012.

Table 6: Population rankings

NAVN	Population	Rating
Frederiksberg	99336	5
Gentofte	72200	5
Esbjerg	71579	5
Randers	61121	5
Kolding	57540	5
Horsens	54450	5
Vejle	51804	5
Hvidovre	50491	5
Roskilde	47828	4
Herning	46873	4
Helsingør	46368	4
Horsholm	45865	4
Silkeborg	42807	4
Næstved	41857	4
Greve Strand	40901	4
Fredericia	39797	4
Viborg	37365	4
Køge	35295	4
Hostelbro	34378	4
Taastrup	32719	4
Slagelse	32133	4
Hillerod	30570	4
Tårnby	27460	4
Sønderborg	27304	4
Holbæk	27195	4
Svendborg	26897	4

The cities/towns highlighted in grey are the places that are mostly not coastal. And these cities do not appear after the subsequent parameter filters of Distance to coast and elevation are placed.

2. DISTANCE TO COAST: The table presents all towns considered in his study, with a rating of ‘5’ which signifies that the mean distance to coast for all of these towns is less than 400 metres.

Table 7: Distance to Coast rankings

NAVN	Minimum Distance	Maximum Distance	Mean Distance	Rating
Skodsborg	0,00	353,55	113,86	5
Svaneke	0,00	500,00	169,12	5
Thyborøn	0,00	707,11	204,01	5
Thurø By	0,00	500,00	205,18	5
Strøby Egede	0,00	901,39	206,28	5
Rantzausminde	0,00	707,11	213,95	5
Tejn	0,00	1060,66	221,76	5
Allinge-Sandvig	0,00	790,57	228,21	5
Egernsund	0,00	707,11	242,31	5
Mikkelborg	0,00	790,57	262,85	5
Troense	0,00	1030,78	266,28	5
Taarbæk	0,00	790,57	270,36	5
Hvide Sande	0,00	707,11	272,11	5
Nysted	0,00	901,39	293,72	5
Stege	0,00	901,39	304,21	5
Søvang	0,00	707,11	309,21	5
Veddelev	0,00	559,02	312,12	5
Karrebæksminde	0,00	1060,66	322,03	5
Stubbekøbing	0,00	1030,78	325,77	5
Hellebæk	0,00	1250,00	340,15	5
Rødvig	0,00	1000,00	341,67	5
Vindeby	0,00	1060,66	352,04	5
Kerteminde	0,00	1030,78	366,60	5
Præstø	0,00	1000,00	379,57	5
Korsør	0,00	1274,75	381,86	5

3. ELEVATION: Like the parameter ‘Distance to coast’, the elevation values are also similarly processed. The table shoes all the towns with a rating ‘5’ which corresponds to the mean elevation to be less than 5 metres.

Table 8: Elevation rankings

NAVN	Minimum Elevation	Maximum Elevation	Mean Elevation	Rating
Søvang	-0,83	3,31	0,98	5
Harboøre	-0,32	3,09	1,11	5
Rødbyhavn	-1,24	8,65	1,70	5
Thyborøn	-0,17	11,07	1,77	5
Bogense	-1,77	9,98	1,87	5
Nakskov	-2,63	12,45	2,67	5
Hals	-0,59	12,91	2,80	5

Tårnby	-7,72	12,10	2,80	5
Ålbæk	-0,26	7,48	3,10	5
Kastrup	-5,05	9,10	3,11	5
Dragør	-0,36	13,27	3,18	5
Strandby	-0,37	6,64	3,26	5
Skagen	-0,27	13,54	3,30	5
Hvide Sande	-1,04	21,52	3,53	5
Vallensbæk Strand	-0,01	10,44	3,54	5
Solrød Strand	-2,01	16,00	3,55	5
Mou	1,25	8,74	4,25	5
Ishøj	-1,39	17,42	4,27	5
Hvidovre	-4,54	20,73	4,27	5
Brøndby Strand	-1,46	13,58	4,55	5
Korsør	-4,54	20,58	4,57	5
Sakskøbing	-1,51	10,05	4,67	5
Nordby	1,92	11,92	4,72	5
Asaa	1,02	10,07	4,77	5
Højer	-0,50	10,23	4,77	5
Kerteminde	-0,85	19,97	4,86	5
Rørvig	0,00	13,21	4,91	5

4. ECONOMIC IMPORTANCE: While studying effects of any impact on a settlement, including that of climate change, it is necessary to assess the economic impact as it is most frequently quantified. Quantification of parameters is generally performed by evaluating the said parameter on a scale of economic significance. The table represents the towns with a rating of '5', it also lists a few of the most notable aspect of the towns.

Table 9: Economic Importance rankings

NAVN	Rating	Comments
Esbjerg	5	Second largest harbor in Denmark, Airport, Branches of Universities of South Denmark and Aalborg
Fredericia	5	One of Denmark's largest traffic hubs, Barracks, Royal Danish Army's Signals regiment
Frederiksberg	5	Part of Capital region of Denmark, Copenhagen Zoo, University of Copenhagen
Frederikshavn	5	Important traffic portal with ferry connections to Sweden and Norway, Fishing and industrial harbor, Strategically important naval base
Frederikssund	5	Frederik bridge connection to Copenhagen
Gentofte	5	Part of Capital region of Denmark, 12th Century church
Grenaa	5	Commercial sea port, large marina, small production industry
Helsingør	5	Ferry connection to Helsingborg, Sweden. Busiest ferryline in the world with 70+ departures in each direction everyday
Hirtshals	5	One of Denmark's largest Fishing harbors and ferry connection to Norway, one of the largest aquariums in Europe, Nordsoen Oceanarium
Holbæk	5	Commercial seaport and Industrial center, Marina,

Horsens	5	Expanding Industry, only Industrial museum in Denmark, VIA University College
Hvidovre	5	Bridge connection to Sjaelland (E20)
Ishøj	5	Part of Copenhagen's suburban area
Kalundborg	5	Eco-Industrial estate, Largest Coal-fired power station in Denmark, Ferry connection to Samso, Commercial port
Kastrup	5	Copenhagen Airport, National Aquarium of Denmark
Køge	5	Part of Copenhagen Metropolitan area, Transport center port, Large business park, Netto headquarters
Kolding	5	Seaport, Transport, Commercial and manufacturing centre, Branch campus of University of Southern Denmark
Korsør	5	Landing of the Great Belt Bridge
Middelfart	5	Train connection to Copenhagen
Næstved	5	Industries, Glass factory, Naestved Harbour
Nørresundby	5	Industries, Aalborg airport, connected to Aalborg by Limfjordsbroen, (roadbridge) a railway bridge and motorway (E45) passing under Limfjord
Nyborg	5	Nyborg Harbour, Nyborg Voldspil (Denmark's oldest outdoor theater)
Nykøbing Falster	5	Waterway to Lolland, small commercial district, Largest city on the islands of Lolland and Falster
Rønne	5	Largest town on the island of Bornholm,
Roskilde	5	Research parks, Industry, Trade and transport hub, Denmark's 10th largest city, Roskilde University
Rudkøbing	5	Bridge connection to the island of Langeland
Skælskør	5	Harboe Brewery, one of Denmark's largest breweries
Skagen	5	Port of Skagen, Fishing, Denmark's main Herring processing facility, World's largest fish oil factory, Northern railway station on mainland Denmark
Skive	5	Skive airport operating private jets,
Sønderborg	5	Branches of University of Southern Denmark, Royal Danish Army's Sargent school, Sønderborg harbour
Svendborg	5	Road connection to Langeland, Svendborg Harbour, Industries
Vejle	5	Industry, Software companies in recent years, connection to Billund airport
Vordingborg	5	Imdustry, Vordingborg Castle, Danish Army's barracks

5. TOURISM & SOCIO-CULTURAL IMPORTANCE: Coastal tourism, as discussed earlier in the report, is essential to generate economic growth and provide livelihood to the local population. The table below lists the towns and small cities with rating '5' among those considered in this study and a few salient features.

Table 10: Tourism and Socio-Cultural Importance rankings

NAVN	Rating	Comments
Assens	5	Assens Church, Assens Marina, Popular summer holiday destination
Ebeltoft	5	Very popular summer town with many summer houses and rentals, Ebeltoft Marina, Child friendly beaches
Faaborg	5	Touristy town, speciallt during the summer, Faaborg Church, Faaborg Museum
Fredericia	5	Fredericia Marina, Summer town

Frederiksberg	5	Frederiksberg Gardens, Copenhagen Zoo, Shopping
Frederikshavn	5	Art museum, Frederikshavn Shipyard historical society
Grenaa	5	5 km sandy Grenaa beach, Many rentals and summer cottages
Haderslev	5	Popular 3-day festival in the public park ‘Kloften’
Helsingør	5	Popular summer vacation town. Ferry to Sweden, Danish Maritime museum
Hirtshals	5	Nordsøen Oceanarium (one of the largest aquariums in Europe)
Horsens	5	Horsens New theatre (a cultural center holds over 200 events annually)
Hvide Sande	5	Fishing port, Holmsland dunes, Outdoor activities
Jyllinge	5	Leisure marina, Jyllinge church,
Kastrup	5	Copenhagen airport, Kastrup Church, Denmark National Aquarium
Køge	5	Køge Harbour, Køge Museum, Køge Torv (olderst town square in Denmark outside Copenhagen)
Kolding	5	Former ferry port from Sjaelland to Fyn, World’s oldest still operating movie theater
Lemvig	5	Summer holiday town, Lake and Limfjord
Løkken	5	Popular summer holiday town
Middelfart	5	Former Porpoise fishing port, Gammel Havn dating back to 1830s, Middelfart church, Middelfart museum
Næstved	5	Gavnø Castle, Rich in medieval architecture, Suså river with fishing & canoeing
Nørresundby	5	Site of Lindholm Hoje settlement and burial ground from Germanic Iron age and Viking times
Nyborg	5	Nyborg Castle, One of three major fortified towns of Denmark, Nyborg Church
Nysted	5	Nysted Harbour, AalholsCastle
Ringkøbing	5	Ringkøbing Church, quaint old town, Ringkøbing Horbour
Roskilde	5	Roskilde cathedral, Roskilde Palace, Roskilde Convent, Roskilde Museum, Viking ship Museum, Roskilde annual music festival
Skagen	5	Attracts 2 million visitors annually, lighthouse, Skagen Church, Paintings and local artistry, Beaches
Skive	5	Skive art museum, Monsted Limestone caves, 14^{th} century Spottrup Castle opened as museum and medicinal herb garden
Sønderborg	5	Sonderborg Castle
Stege	5	Stege Church, Microbrewery Bryghuset Mon, Thorsvang Museum
Thurø By	5	Road connection to nearby bigger cities, Beaches, Fishing harbour

TOTAL RATING: After placing all the above filters and extracting a dataset from ArcGIS, there are a total of 160 towns included in this research project. After rating all the individual parameters, the ratings are then added up to give a total rating which could range between 05 and 25 as each parameter ranges between 01 and 05 and there are 5 parameters considered in this study. The following, table 11 shows the towns/cities with the highest vulnerability index, and all the comprising parameter ratings.

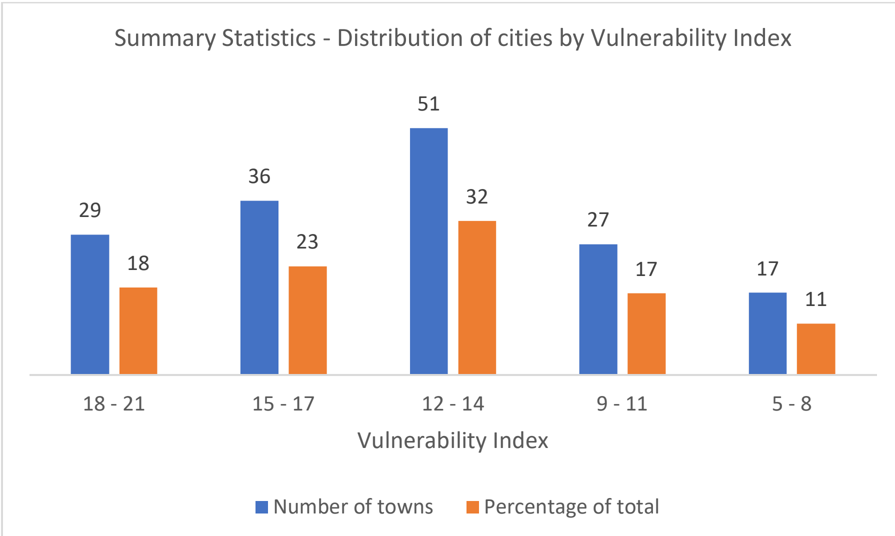
Table 11: Vulnerability Index rankings

NAVN	Tourism Rating	Economic Rating	Population Rating	Elevation Rating	Distance Rating	Vulnerability Index
Nørresundby	5	5	3	4	4	21
Skagen	5	5	2	5	4	21
Kastrup	5	5	3	5	2	20
Korsør	2	5	3	5	5	20
Nyborg	5	5	3	4	3	20
Sønderborg	5	5	4	3	3	20
Dragør	3	4	3	5	4	19
Faaborg	5	4	2	4	4	19
Fredericia	5	5	4	3	2	19
Frederiksberg	5	5	5	3	1	19
Frederikshavn	5	5	3	3	3	19
Helsingør	5	5	4	2	3	19
Hvide Sande	5	3	1	5	5	19
Kerteminde	4	3	2	5	5	19
Køge	5	5	4	4	1	19
Middelfart	5	5	3	3	3	19
Nakskov	4	4	3	5	3	19
Esbjerg	4	5	5	3	1	18
Grenaa	5	5	3	4	1	18
Hirtshals	5	5	2	3	3	18
Horsens	5	5	5	2	1	18
Hvidovre	2	5	5	5	1	18
Jyllinge	5	3	3	3	4	18
Næstved	5	5	4	3	1	18
Nykøbing Falster	3	5	3	4	3	18
Rønne	3	5	3	3	4	18
Rudkøbing	4	5	1	4	4	18
Skive	5	5	3	3	2	18
Vordingborg	3	5	3	4	3	18

As mentioned previously, there are a total of 160 towns and small cities considered in the study. Table 12, below shows the number of towns in each of the categories in the Vulnerability Index along with their percentages of the total number of towns studied. The most vulnerable towns amount to 18% of the sampled towns according to this study, using the paraments and methods described.

The below figure 5 presents the statistics of all the categories.

Figure 5 : Summary Statistics



Addressing earlier listed research questions specifically, the inferences are:

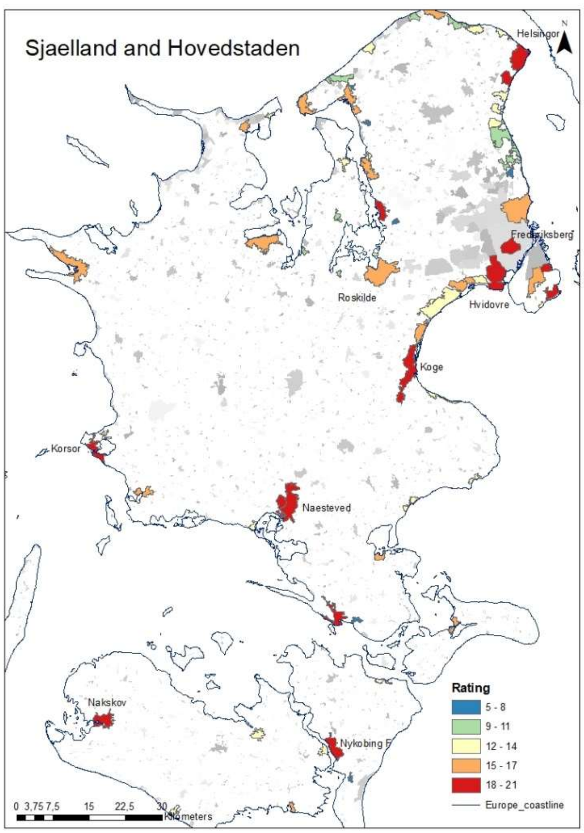
A. The current identification exercise led to the key observation that the expected impacts of adverse climactic events like sea level rise leading to flooding is expected to be high on all parameters like tourism, infrastructural damage besides effects on population. Regions that are simultaneously rated higher on many of the individual variables are also rated high on the overall rating thereby narrowing the initial mitigation effort scope to the top regions identified by the current study. It doesn't in anyway, however, restrict the implementation scope and the efforts can be implemented in phases starting with the most vulnerable locations.
B. We have explored the datasets available at hand with respect to the selection of variables themselves, including some analog and not-so-readily available ones besides the choices of rating scales to be used and thresholds to be set. Overall, the methodology behind enlisting all relevant locations and processing data regarding the key variables pertaining to such locations has led to the current shortlist of top rated Danish coastal regions that are most at risk. We have utilised Danish public data and GIS datasets for variables such as population, key infrastructure, tourist footfall, in addition to reports and academic literature. Danish coastal regions were classified according to their exposure through an analysis of key geographical variables, such a mean elevation, proximity to the coast, flood risk, local geology, and historic coastal erosion rate.
C. A classification and ranking of such localities was made to derive the locations with the highest risk level. Overall, a key resulting output is a system of classification and ranking of Denmark's villages, towns and cities in terms of their potential exposure in case of extreme climate related events, especially flooding. Through the current research, we have executed the intention to prioritize the towns and cities (urban areas) as per the need for strong climate resilience measures based on the laid out variable selection.

D. The research also seeks to provide inputs to state / private actors (Danish government, coastal municipalities etc.,) as part of their strategic road-map to improve climate resilience over the long term in the regions with higher levels of exposure as identified in this study.
E. The current research can be utilized as a guiding measure by the Danish administration to aid their effort to identify pertinent locations with major climate related risks in Denmark. Similarly, it can be scaled for regions around the globe on an on-demand or a global-initiative basis to assist building of their strategic roadmaps to improve their respective climate resilience over the long term.
F. Lastly, a key objective was indeed to provide inputs to the government and private actors (e.g. coastal bodies/ municipalities) as part of their strategies to improve climate resilience over long term in the regions identified in this study. Thus, overall, there is an opportunity for generalization, expansion and broader application of the current work.

5.2 Results from ARC-GIS analysis

Following are the maps from ArcGIS for each of the regions of Denmark. A few things are to be noted while reading the maps. The **grey** areas are all the inhabited settlements, including the towns and villages that are not included in the study. Finally, the maps are divided into 4 ; (i) the regions of Sjaelland and Hovedstaden, mapped together for ease of reading the map, (ii) Region Nordjylland (iii) Region Midtjylland (iv) Region Syddanmark

Figure 6: Vulnerability Index Mapping – Sjaelland and Hovedstaden



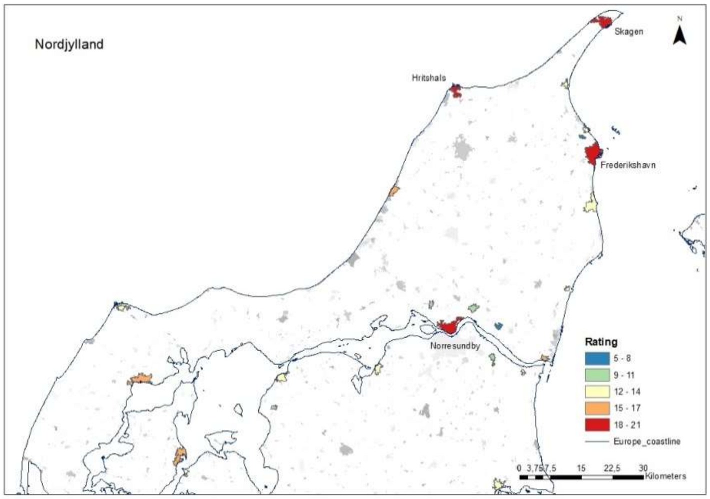
The regions of Sjaelland and Hovedstaden (capital region of Denmark) together have the highest population (BEV107: BEFOLKNINGENS UDVIKLING EFTER KOMMUNE, BEVÆGELSESART OG KØN, 2018)

The Hovedstaden map highlights the towns of Helsingor, multiple towns of Copenhagen metropolitan area like Gentofte and Frederiksberg among other towns.

In Sjaelland, the highlighted towns include Koge, Naestved, Nykobing Falster, Korsor and Nakskov.

These two regions together have the majority of the most vulnerable towns, roughly equaling the other three regions combined.

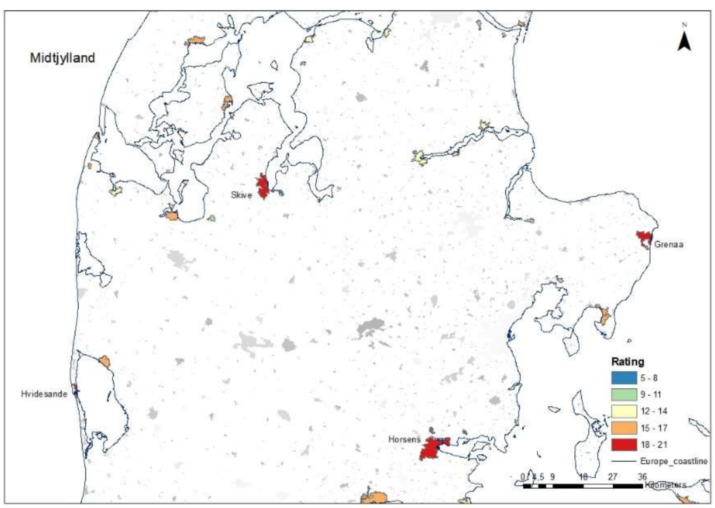
Figure 7: Vulnerability Index Mapping – Nordjylland



The region Nordjylland of Denmark is the least populated compared to the other regions (BEV107: BEFOLKNINGENS UDVIKLING EFTER KOMMUNE, BEVÆGELSESART OG KØN, 2018)

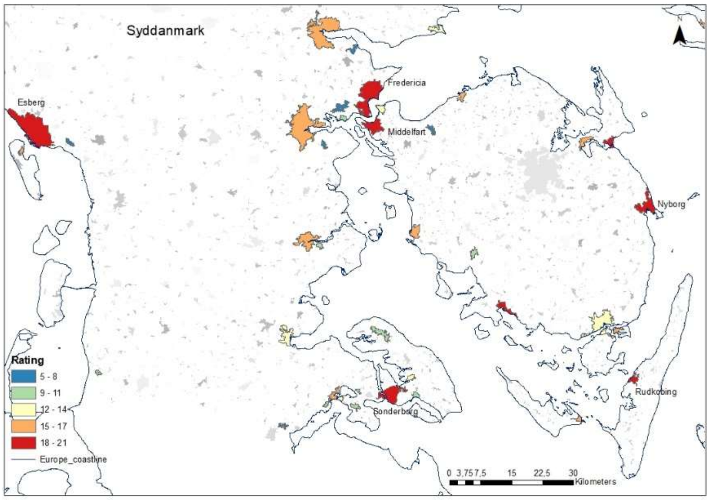
The towns highlighted in this region are Skagen, Hritshals, Frederikshavn and Norresundby.

Figure 8: Vulnerability Index Mapping – Midtjylland



Region Midtjylland highlights towns of Grenaa, Hvidesande, Skive and Horsens.

Figure 9: Vulnerability Index Mapping – Syddanmark



The towns of significant importance in the Region Syddanmark include Esberg, Rudkobing, Nyborg, Fredericia, Middelfart and Sonderborg.

Trends of key climate variables change across timescale, leading to delineation of short-term/medium-term/long-term impacts under different climate scenarios. An indication of likelihood of the most expected outcome(s) can also guide the drafting of a relevant adaptation strategy that is dynamic and quickly adaptable.

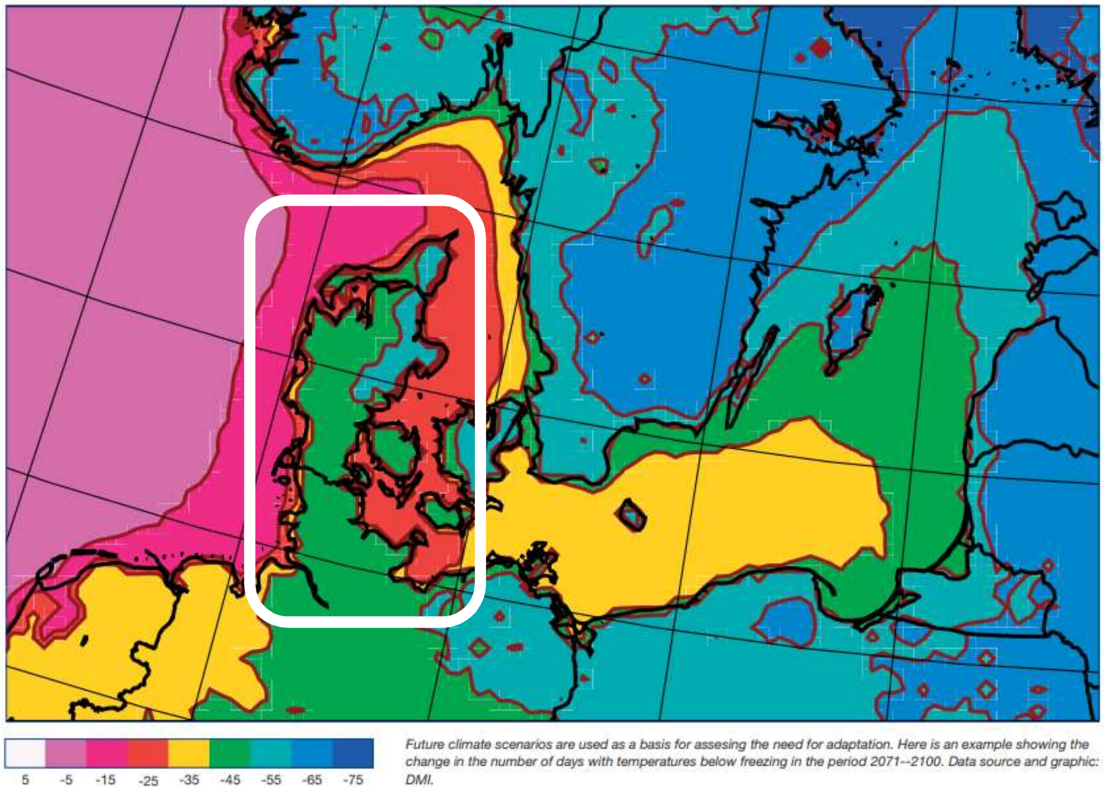
The towns that are most vulnerable are marked in red in the above maps. There is a higher incidence of more vulnerable towns in the regions of Sjaelland and Hofstede, followed by the regions of Syddanmark, Midtjylland and Nordjylland.

5.3 What Next - Denmark's Climate Future

Looking back a decade, in a "Danish strategy for adaptation to changing climate" presentation in 2008 (Government, 2008) , the Danish government's Minister for Climate and Energy had stressed the importance of protecting Danish infrastructure and heritage through a well-planned adaptation strategy aided by organization of a well-directed research framework on climate adaptation while also underscoring the information of information dissemination to all relevant stakeholders like citizenry, private players – especially in the construction sector and public bodies (municipalities etc.,).

A climate change scenario, considered in assessing the need for adaptation, shown below, indicates that Denmark's number of days below freezing temperature were forecasted to significantly decrease (by approx. 45 days – green zone) during the future period 2071 - 2100:

Figure 10: Change in number of days with temperatures below freezing in Northern Europe, in the period 2071-



Future climate scenarios are used as a basis for assesing the need for adaptation. Here is an example showing the change in the number of days with temperatures below freezing in the period 2071--2100. Data source and graphic: DMI.

Post an evaluation of three climate change scenarios (against 2 IPCC and 1 EU commitment levels respectively), Danish Meteorological Institute had concluded that a warmer climate was to be expected in all scenarios. In addition, an average sea level rise of 0.15 to 0.75 meters was forecasted on the Danish west coast and wind speeds could rise by up to 10% in one of the scenarios, both on land and sea.

Infrastructural aspects like building, roads & railways and sewer systems were identified as key elements to guide the future adaptation strategy. An interesting perspective is that of relocating water extraction points to match the realigned water source and sink configurations brought about by climate change. Thus, climate change impacts on infrastructure also highlight its impact on lifestyle elements.

5.4 Community resilience is the key: Softer side of institutional climate change capacity

In Mie Thomsen's Master's Thesis on "Community resilience in a Danish coastal context" (Thomsen, 2016) , the municipalities of Løgstør and Thyborøn in Denmark were evaluated. This study highlights the local community's preparedness as a derivative of their earlier exposure to climate calamities, as they are better experienced in the information sharing, cooperation and coordination activities as well as adapting an active stance to climate mitigation owing to their prior unfortunate experiences.

While Thyborøn did not have as much experience with storms as Løgstør which experienced unfortunate damages from storm floods many a time during the last few decades, Løgstør were said to have extracted learnings from their previous fallacies.

5.5 Blooming State Activism

In their May 2012 report, the “Task Force on Climate Change Adaptation” of Danish Nature Agency (Adaptation, 2012) , a two pronged approach to climate action were proposed both for existing buildings and infrastructure and for future construction work.

The “Danish Building and Property Agency” was suggested certain tangible steps to incorporate climate change adaptation in current as well as future construction. For example, locating buildings in areas with least climate exposure, better rainwater management, prior studies and climate assessment of building sites, ensuring protection against water in installations below ground level were proposed in future buildings. Similarly, for existing establishments, limitations of IT / electrical assets below the ground level, storm water protection mechanism enhancement, population relocation etc., were proposed.

The report also discusses in detail the challenges for each of the sectors like railways, roadways, agriculture etc., and identified bottlenecks that may curtail the intended transformations.

Diverse coast-scapes: A case for flexible climate models and deeper local data collection.

Reminiscent of data vacuum on certain variables used in the current study, an official study by SafeCoast (Sørensen, 2008) reveals that a national data collection program be initiated in Denmark keeping in mind the different data types and volumes available at a national level versus local coastline level data. It stresses that, in face of a non-transferable model between national and local scales, the spatial scale of assessment often becomes an unintended but important variable in the vulnerability assessment, thus impacting the predictability of results.

Thus, a need for better models along with better information will augur well for the ability to account for local variations in the Danish coastal zones thus leading to the recommendation of initiating a Danish national data collection program to aid specific local vulnerability assessments.

5.6 Future Research Scope

This research considers the parameters discussed above. But there is a scope to add more categories in the future for a more sensitive Vulnerability Index. There are a few parameters that are predictable to some extent. For instance, forecasting Coastal erosion and Rainfall is possible. Such features may have the added benefit of enhancing research quality thus making the Vulnerability Index, a more holistic ranking system.

6. Limitations & Replicability

6.1 Qualitative judgment: Salience of Local knowledge

The methodology discussed above can also mean certain imitations regarding the data collection and processing steps that can be followed for similar / additional research in the future. Analog data collection and offline data research are indeed time-consuming and can sometimes lead to subjectivity and judgment related errors which may or may not affect the result set. However, adequate care can be taken by cross-checking the entries against research across different websites so as to ascertain the accuracy of inputs to the extent possible. It is also possible to have an institutional approach through well designed, dedicated IT systems or tools that can collate the data used in the current research automatically from different authentic sources to reduce this margin of error further.

A key learning and guideline is the need to use disparate data sources while dealing with small coastal towns or villages, especially when their respective populations are in the less than thousand inhabitants classification. The location itself may happen to be salient from a different input (eventually auto-accounted by the index output), however may not yield sufficient or sensible information while using the GIS as the sole approach. This GIS-inherent selection gap needs to be identified and strategy is to be carefully built to deal with such lack in data availability so that research resources and capacity are planned accordingly. If we used population as the basic cut-off threshold variable, then there is a risk that we introduce a strong bias into the research model by automatically eliminating locations with populations less than 1000 inhabitants. It is important to clearly delineate this limitation and plan the research methodology to address all the research questions to the maximum accuracy extent possible. In addition, mere data crunching is not enough as there could be precious local knowledge that is either overseen or unincorporated by such an approach – a knowledge that could mean key gaps in climate mitigation planning effort, a potentially incomplete strategy and recommendations that we would eventually arrive at.

On a data completeness/sufficiency dimension, the datasets published by different authorities/entities focus on different aspects, not necessarily complementary, thus making some of the data only partially usable which is where local knowledge is useful again to know what can or cannot be used. Therefore, the importance of such well – guided qualitative treatment in addition to the quantitative processing can't be stressed enough. Therefore, Interactions with local expert groups or institutions accompanied by thorough research and understanding of the specificities of small coastal regions of different countries is an agreeable foundation for such pillars of research.

6.2 Information asymmetry: Nationally important locations

Another limitation is that certain establishments that are strategically kept away from the public domain (military bases, airports and other locations important due to national security concerns) can also limit the accuracy of the true vulnerability assessment generated by research that does not take into account such information, for the above stated understandable reasons. Such information can be and must be duly incorporated into the decision-making process through collaboration with the public research bodies that can facilitate required access to such information, albeit under controlled terms and conditions. National security perspective can drastically change the risk ranking of a location and can significantly impact its risk mitigation strategy design. Such information is not available through GIS or manual research online and thus is a limitation of the current research.

6.3 Paths untread: Sparse, distributed and risk of unauthentic data

A novelty of current research can also mean an important obstacle while arriving at its results, namely, it can be difficult, and time consuming to gauge and consequently incorporate inputs on economic importance or the extent of touristic significance for a given location; making room for subjective choices through further qualitative evaluation. For example, there could be multiple places with the same name but are located in different places which necessitates a further evaluation of whether the touristic importance rating is accurate for the pin code that is included in the current research. Since there are no precedents for such approach, it is necessary to highlight this aspect so that future research is well-informed and accordingly well-guided.

7. Exceptions

There are a few towns that attract a multitude of tourists or are culturally important, but these towns do not show up in the data extracted from ArcGIS as they have populations so low that they do not meet the filter criteria. By analogically researching towns and cities of Denmark, these towns can be identified manually.

A few of these villages are listed in table 12 below;

Table 12: Examples of Exception towns

Name	Population	Comments
Blokhus	441	- Pristine blue flag white sand beach - About a million visitors annually - Shops, Restaurants, inns and concert venues in the summer months - Horse riding, forest, Dunes, Cycling
Klitmøller	822	- Paradise for windsurfing - Northern Europe’s best surf spot, colloquially termed “Cold Hawaii” - National Park Thy - Abundance of outdoor activities

Owing to industrialization and modernization, the small old fishing towns and villages are no longer inhabited by as many fisherfolk as they used to at the turn of the last century. Local knowledge is extremely useful in identifying such places, due to the possibility of missing out on a few towns when trying to locate details from a single source (could be traditional or nontraditional sources)

Another Exception is the existence of smaller towns that sometimes more than double in population size during the summer months. This happens due to a huge number of summer houses in the area along with the availability of long term rentals in the area. Examples of such towns: Ebeltoft & Assens.

8. Conclusion

This project develops a ‘Vulnerability index’ to aid in identification of coastal towns and small cities that are more susceptible to climate change events thus facilitating governments or other stakeholders to prioritize certain towns and cities that need focus and hence build climate resilience.

It is also interesting to observe that the towns and cities generally being talked about or included as high risk in the national plans for climate resiliency also show up as highly vulnerable in this research, thus validating the research. The national strategies are generally reactive, making plans adapt to past events like flooding or erosion; while the Vulnerability Index developed here is more pro-active in the sense that stake holders can assess and make preventative measures conveniently.

The main purpose of this study, that was achieved, was to develop an index as a pilot for Denmark, which can then be duplicated in other regions of the world. This Index can be easily adapted to Scandinavia at first, due to the similarity in national development and being exposed to similar risks. Subsequently, the Index can be duplicated to other regions of the world after modifications to the rating scales depending on the location specific differences.

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APPENDICES

APPENDIX I: LIST OF FIGURES

APPENDIX II: LIST OF TABLES