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Towards urban climate justice: Integrating social vulnerability in climate adaptation planning

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ABSTRACT

Climate change causes an increase in occurrence and intensity of extreme weather events, especially in densely built cities. Consequently, inequities are created as not only the exposure varies across geographies, but also the sensitivity and adaptive capacity towards climate hazards, which can differ on an individual level. From an urban climate justice perspective, these inequities need to be considered in climate adaptation planning practices, something that is currently lacking in many municipalities. This research explores how municipalities can assess social vulnerability for a more just approach to climate adaptation planning. A case study of the coastal city of Oostende (Belgium) is used to illustrate the method, which combines exposure to climate hazards (fluvial flooding, pluvial flooding, storm surges, and heat) and an established social vulnerability index covering a wide range of social and cultural factors that influence sensitivity and adaptive capacity of those communities. The results are mapped and these facilitate prioritisation for just climate adaptation measures. Namely making parts of the population more visible, which serves to increase the recognition of disadvantaged groups and their realities, which is why adaption measures can be tailored to their specific needs. This can also be used to positively influence the distribution of adaptation measures across the city but also across its inhabitants. Maps such as the ones produced in this study can function as an aid to point towards areas that are especially vulnerable and make the communication of these issues within and outside of the municipality easier. The approach has proven to be user-friendly and easy to implement by Oostende as well as other European coastal cities.

1. Introduction

It is anticipated that the global temperature rise will surpass the 1.5 °C threshold by 2100. The impacts of this are already and will be increasingly far-reaching. Cities are especially at risk, as they are densely populated and hold crucial infrastructure and services (Allam et al., 2020). In the European Union (EU), 75 % of the population lives in cities (Statista, 2022). Mid-latitude cities are projected to, by 2050, suffer twice the levels of heat stress than rural areas (IPCC, 2023). Europe is also expected to suffer from effects of droughts on food production, of heat on the health of the population and of extreme weather events on people and infrastructure (EEA, 2024).

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The climate risk of people depends on their exposure to climate hazards, the spatial layout of their living areas and their socio-economic condition. (EEA, 2024). Overall, it has been found that cities are not adapted sufficiently to the risks they are facing, which is referred to as the urban adaptation gap (IPCC, 2023).

The same dynamic can also be seen on smaller scales, within cities and between neighbourhoods. Even when dealing with the same climatic changes, people can have different levels of vulnerability towards climate change hazards. Swanson (2021) describes how the city can be viewed within two categories: the climate-resilient elite and the climate-vulnerable poor. Vulnerability is becoming a more widely used concept (for example within the IPCC assessment reports) and is based on multiple factors that might be physical, socio-economic, or political. Generally, people who have a higher vulnerability experience stronger impacts from climate change (Tee Lewis et al., 2023). As an example, heat is an increasing hazard all over Europe, where in 2022 more than 60 thousand people died due to high heat, of which more than 36 thousand were over the age of 80 (Tagesschau, 2023). This demonstrates that elderly people are overall more at risk to be harmed by heat waves, an effect that can be reinforced if those people also have less income and cannot afford air conditioning or have less access to health care (Klimaateffectatlas, 2024). The EEA has concluded in the European Climate Risk Assessment that climate risks to health are disproportionately felt by the most vulnerable population groups. One reason for this is that climate change exacerbates the risks and crises that already exist (EEA, 2024). In environmental and climate justice research, it was observed that often household income is used as the sole factor to determine vulnerability (Calderón-Argelich et al., 2021), which does not consider how people can be affected by other factors or multiple factors, such as health or age, that amplify each other.

Climate adaptation planning has been making its way into urban planning practices. However, measures are often only taken where the highest climate hazards are, not taking the underlying conditions and processes into account (EEA, 2022). Climate adaptation is sometimes framed as a wicked problem, with many interconnections and implications for other matters (Perry, 2015). This can mean that understanding the system and understanding the problem can take so long, that in that time the conditions change, or it can mean that there are so many impactors and effects that it seems impossible to fully consider everything (ibid.). Simultaneously, climate adaptation has the potential to influence and decrease the (social) vulnerability of the population. An example of this would be to improve mental health through implementing green spaces as part of a Nature-Based Solution (Vujcic et al., 2017), improving people's ability to take preventive measures and cope with the effects of climate events.

Measuring social vulnerability can be data-intensive and difficult to balance. As such a number of tailor-made methods appear in the literature.

These identify the processes contributing to vulnerability and provide a means of monitoring vulnerability over space and time (Shah et al., 2013).

One type of index are climate vulnerability indices. One such method is made up of 184 indicators, connecting baseline vulnerabilities with climate change risks within 4 categories: Health, Social and Economic, Infrastructure, and Environment (Tee Lewis et al., 2023).

Another type of indices are flood vulnerability indices, which is a more specialised kind of index, focusing on vulnerability in areas affected by flooding (Ajtai et al., 2023). Moreira et al. (2021) conducted a review of 95 peer-reviewed articles (2002–2019) focusing on these indices and found that most indicators used are within the social dimension (e.g. population density, illiteracy rate), followed by economic (e.g. per capita income), physical (e.g. households without sanitation) and coping capacity (e.g. early warning system).

Both climate vulnerability indices and flood vulnerability indices are often complex and require data that is often not assessed by or available to municipalities as they often lack financial or human resources for these thorough analyses (Elliot et al., 2025). On the other hand, socioeconomic data is collected though censuses and thus more accessible. To use social or socioeconomic data for assessing vulnerability towards climate hazards, multiple researchers have combined the concept of social vulnerability with climate data and climate projections (see for example Englund et al., 2023; García and Dias, 2023).

Addressing the problem of urban climate justice requires understanding the role of social vulnerability on climate vulnerability and the adaptive capacity of exposed communities. The aim of this research is to apply and test a social vulnerability index and discuss its implications for applying an urban climate justice approach to adaptation planning. In the next section, we introduce the case study of Oostende, a coastal city in Belgium, then explain how climate exposure data and social vulnerability data are used to generate spatial indices with respect to the urban climate justice conceptual framework. In the results section we present maps showing the spatial variation of social climate vulnerability for different climate change threats. In the discussion, we reflect on the use of the combined social climate vulnerability method for addressing climate adaptation in cities in a just manner, before making recommendations for future urban climate justice strategies.

2. Methods

2.1. Case study: The city of Oostende, Belgium

The physical characteristics of Oostende make it an interesting case for climate hazard exposure and thus adaptation efforts. Oostende is situated in the West-Flanders province in Belgium, bordering the coastline of the North Sea. It spreads over an area of 4095.30 ha, has a population of approximately 72 thousand people, and a population density of 1762 inhabitants/km^2 (Statistiek Vlaanderen, 2023). Three sectors (a beach "Strand", a park "Maria Hendrikapark" and a lake "Spuikom") were excluded in the analyses as there are no inhabitants in these areas. The use of land by human activities is 60.4 % of the total area, with a total of 34.6 % of paved surfaces. This makes Oostende the city with one of the highest shares of paved surfaces in Flanders (average 15.3 %) (ibid.).

Oostende also makes for an interesting case for studying social vulnerability. The average age is 47 and 29 % of the population is older than 65. Between 1990 and 2023, this age group has grown by 55 %. This is likely due to many elderly moving to the coast after their retirement (CPC Oostende Municipality, 2024). Oostende is also a multicultural city with 28 % of its inhabitations having foreign origin. Economically, Oostende compares poorly to the Flanders region. There is high unemployment along with low median income (Vlaamse Overheid, 2023), high rental habitation (45 %), and 9 % of households live in social housing (Provincie West-Vlaanderen, 2024). 29 % of children are born in a deprived household (Vlaamse Overheid, 2023), leading to them having less opportunities for a positive development.

2.2. Climate hazard exposure analysis

Open access data from the Flemish government were used (Flemish Environment Agency, 2024a). The four largest climate threats for Oostende are extreme heat, pluvial flooding, storm surges (increasing due to the rising sea levels), and fluvial flooding. These threats were found in the Flemish climate maps as most important for the region, and this was confirmed by the CPC of the municipality of Oostende (CPC Oostende Municipality, 2024). For each threat, the most extreme scenarios, existing for each indicator within the category, were used. In-depth information on the indicators per threat can be found in Supplementary information A.

The climate projection data were divided into the smallest administrative scale in Flanders. These small neighbourhoods are called statistical sectors and correspond to on average 10 streets. The values per indicator were then normalised to provide values between 0 and 1.

Subsequently, the normalised values were aggregated per statistical sector for each category to illustrate which areas would be more or less affected by climate change compared to each other. The obtained values were then divided using a fixed rank ([0,0.2]; [0.2,0.4]; [0.4,0.6]; [0.6,0.8]; [0.8,1]) and assigned to a ranking scale from 1 (least exposed) to 5 (most exposed). With this approach it is possible to compare the different climate hazards to each other as well as within the city. The values of the climate hazard exposure and social vulnerability per statistical sector can be found in Supplementary information D and E.

2.3. Social vulnerability analysis

Due to the similarity in research objective, the indicators were largely based on the work of Englund et al. (2023) and García and Dias (2023), as well as on Flanders' previous analysis of deprived areas. 15 indicators were selected, which were considered to be the most representative for the social vulnerability analysis in Oostende. The result is the following list of indicators shown in Table 1. A more detailed explanation of these indicators can be found in the Supplementary information B.

After acquiring a list of necessary indicators for a social vulnerability analysis, the most recent (oldest 2021) corresponding data was accessed from the Flemish open database (Provincie West-Vlaanderen, 2024). The analysis was made on the same scale as the climate analyses: the statistical sectors. For some indicators, the data was not available on this scale. These data points were substituted

Table 1
Social vulnerability indicators per category. The column "effect on vulnerability" shows whether the indicator has a positive or negative correlation with social vulnerability.

Category	Indicator	Effect on vulnerability	Source
Age	Inhabitants younger than 15 years (% of total inhabitants)	+	Englund et al. (2023)
	Inhabitants older than 74 years (% of total inhabitants)	+	Englund et al. (2023)
Language proficiency	Non-EU birth nationality (% of total inhabitants)	+	Englund et al. (2023), Provincie West-Vlaanderen (2024)
	Children not speaking Dutch at home (% of children in primary and secondary school)	+	Provincie West-Vlaanderen (2024)
Health	Inhabitants with a statute of chronical conditions (% of inhabitants with health insurance)	+	Provincie West-Vlaanderen (2024)
Educational attainment	Highest educational attainment being primary school or less (% of all inhabitants over 25)	+	Englund et al. (2023)
	Highest educational attainment university or similar (% of all inhabitants over 25)	–	Englund et al. (2023)
Single parent households	Single parent households (% of all private households)	+	Englund et al. (2023)
Vehicle ownership	Number of vehicles per 100 households	–	Englund et al. (2023)
Housing	House renters (% of households with known property title)	+	Provincie West-Vlaanderen (2024)
Financial vulnerability	Disposable income per consumption unit (€)	–	Englund et al. (2023)
	Inhabitants with an increased compensation for health care (% of inhabitants with health insurance)	+	Provincie West-Vlaanderen (2024)
	Households with income below 60 % of the national median (% of total inhabitants between 20 and 64)	+	Englund et al. (2023)
	Households with income 200 % over the national median (% of total inhabitants between 20 and 64)	–	Englund et al. (2023)
Unemployment	People without a job searching for a job (WZW) on the 1st of January (% of inhabitants between 18 and 64)	+	Englund et al. (2023)

with the data from a bigger scale, which is the neighbourhood level. In a few instances, the indicator values were not available for either the statistical sector or the neighbourhood scale. In that case, the average available data from the statistical sectors per neighbourhood were calculated and used as a substitute. To correspond to the indicators in research as much as possible, some calculations were performed. This was for example summing up age classes or adding two separately collected indicators into one, more information on the data processing as well as the exact sources can be seen in the Supplementary information B. After calculations, the data were normalised to a scale of 0–1 for both positively and negatively correlated indicators.

This created values in the range [0,1] in order to make comparisons between the indicators. For each statistical sector, these values were then summed up. These aggregations were then divided into equal intervals to create five social vulnerability classes (SVC) ranging from 1, very low social vulnerability, to 5, very high social vulnerability. Using these classes, it is possible to point out where people are the most vulnerable, not on a total scale but in a relative way within the city. In addition, the data were mapped using the QGIS-software to represent the spatial distribution of the social vulnerability. The values of the climate hazard exposure and social vulnerability per statistical sector can be found in Supplementary information F and G.

2.4. Assessment of social climate vulnerability

First, the scores (1–5) from the climate factors were filtered and the statistical sectors with categories 1 and 2 were taken out in every category in order to focus on the areas that suffer the highest impact. Following this, the social vulnerability class, and the climate class were summed with equal weights, resulting in a scale ranging from 4 to 10. This way a storm surge, pluvial and fluvial flood and heat vulnerability score was obtained per statistical sector with at least a moderate issue for these categories. The classes were visualised using QGIS. The combined value will from this point on be called "social climate vulnerability", which always refers to the result of this analysis and not to other possible meanings of the term.

2.5. Urban climate justice conceptual framework

The debate about climate justice was, in the past, held mainly on an international scale (Schlosberg and Collins, 2014). More recently several researchers applied this conception to the urban scale, resulting in urban climate justice (UCJ) as a newer research avenue. UCJ is explicitly looking at the urban scale, recognising the diversity of human and non-human experiences in cities (Steele et al., 2015).

In UCJ research as well as works on justice in climate adaptation planning, justice is viewed within four dimensions: recognition, distribution, procedure, and restoration (Juhola et al., 2022; Prall et al., 2023). *Recognition* in an urban climate change context means acknowledging the systemic influences on (in)justice, for example through politics or policy (Fraser, 1998, 2005). *Distribution* refers to the distribution of climate hazards as well as of adaptive measures across the city and across the population (Prall et al., 2023). *Procedure* in climate adaptation planning means examining, which population groups are represented in or are part of decision-making processes (Juhola et al., 2022). *Restoration* is a more recent addition to the traditional dimensions of justice and refers to acknowledging the harm that has been or is being caused by injustice and climate change, pointing out responsible actors (Juhola et al., 2022) and then working towards decreasing injustices by prioritising adaptation measures for the ones that were harmed or are more vulnerable (Prall et al., 2023).

The UCJ concept is used to evaluate whether the strategy of combining climate hazard exposure with Social Vulnerability can contribute to a more just urban planning practice. This is measured in reference to expert interviews and their responses, described below.

2.6. Expert interviews

Seven interviews of about 1 hour were undertaken with experts from different backgrounds in order to get an insight from multiple perspectives. The interviewees were selected for their knowledge of the functioning of Belgian municipalities, specific knowledge of climate impacts and ongoing climate adaptation plans and projects in Oostende, and knowledge on application outside the case municipality. More information on the interviewed organisations and specific goals per interview can be found in the Supplementary information C. In order to verify the results for Oostende and to explore the application in other municipalities, a joint interview was held with the climate policy coordinators (CPC) of both Oostende and Esbjerg (Denmark). The interviews were semi-structured, meaning they were guided by questions but flexible towards an organic flow of conversation, exploring ideas and different topics with follow-up "why" and "how" questions. The dialogue can meander around topics on the agenda rather than determinately sticking to the fixed structure. This way thoughts and ideas can be explored, in the interest and knowledge of the participant, and unforeseen issues in the research area may be discovered (Adams, 2015). Each question was clearly connected to the purpose of the research, drawing data from the experience of the participant and data that are theory laden, guided by existing constructs in the field (Galletta, 2013). Examples of themes covered in the interviews are Climate adaptation planning practices in municipalities, cross-department collaboration within municipalities and social climate vulnerability in Oostende. The interview guide can be found in the Supplementary information C. For the analysis of the interviews, they were typed out and then coded with the help of the software NVIVO (Version 14), according to topics and types of statement, such as "actor collaborations", "climate adaptation plans", "vulnerability and justice" and "specific projects and solutions". Following the assessment of social vulnerability to exposure, follow-up interviews were conducted to explore the potential usability of this framework and the results. The themes of these interviews are also available in Supplementary Information C.

3. Results

3.1. Climate challenges in Oostende

Flanders is already experiencing climate change in multiple ways. The average temperature in the region has increased by 2.6 °C, the precipitation has increased as has the sea temperature. Based on climate projections, the region is expecting an increase in winter rainfall of 7 % by 2050 and up to 20 % by the end of the century, coupled with a higher intensity of rain events. Sea level is projected to rise by 80 cm by 2100 (McEvoy et al., 2021).

In Fig. 1 the climate hazard exposure for heat, storm surges and flooding are shown per statistical sector. At-a-glance, it is clear the city centre is most exposed to all climate hazards except fluvial flooding as there is no river in the city centre. The urban heat island effect is clearly visible in the figure. Also, the largely paved streets in the city centre cause a vulnerability to pluvial flooding and storm surges.

3.1.1. Heat exposure

By 2100, the entire municipality will have at least 28 days with an average temperature over 30 °C (Flemish Environment Agency, 2024a). The experts point out that heat, which currently does not play a large role in planning practices, will pose a great threat in the future (Consultant Sumaqua, 2024; CPC Oostende Municipality, 2024). This can be expected due to the high share of sealed surfaces as well as a lack of green spaces in the city centre. Another impactor mentioned by the interviewed consultant (Consultant Sumaqua, 2024) is that increased drought will lead to subsidence and damaged houses, which has already been observed in the last years in Flanders. As shown in Fig. 1, heat exposure is highest in the city centre and becomes less towards the fringes of the municipality.

3.1.2. Pluvial flooding

Yearly rainfall in Oostende will increase from 815 mm (2019) to 1029 mm (2100) following the high impact scenario (Flemish Environment Agency, 2024a). According to the interviews, water-related climate such as flooding, will become a great risk to the city (Consultant Sumaqua, 2024, CPC Oostende Municipality, 2024). This is partly due to the topography of the surrounding region and the city, where the city centre is located lower than the dyke and the northeastern part of the city. The centre therefore collects water and does not have a natural way of irrigation towards the canal or sea (CPC Oostende Municipality, 2024). Currently a large pump is active in the city. This pump is, however, not dimensioned for the future, where more intense pluvial flooding is very likely. The exposure to

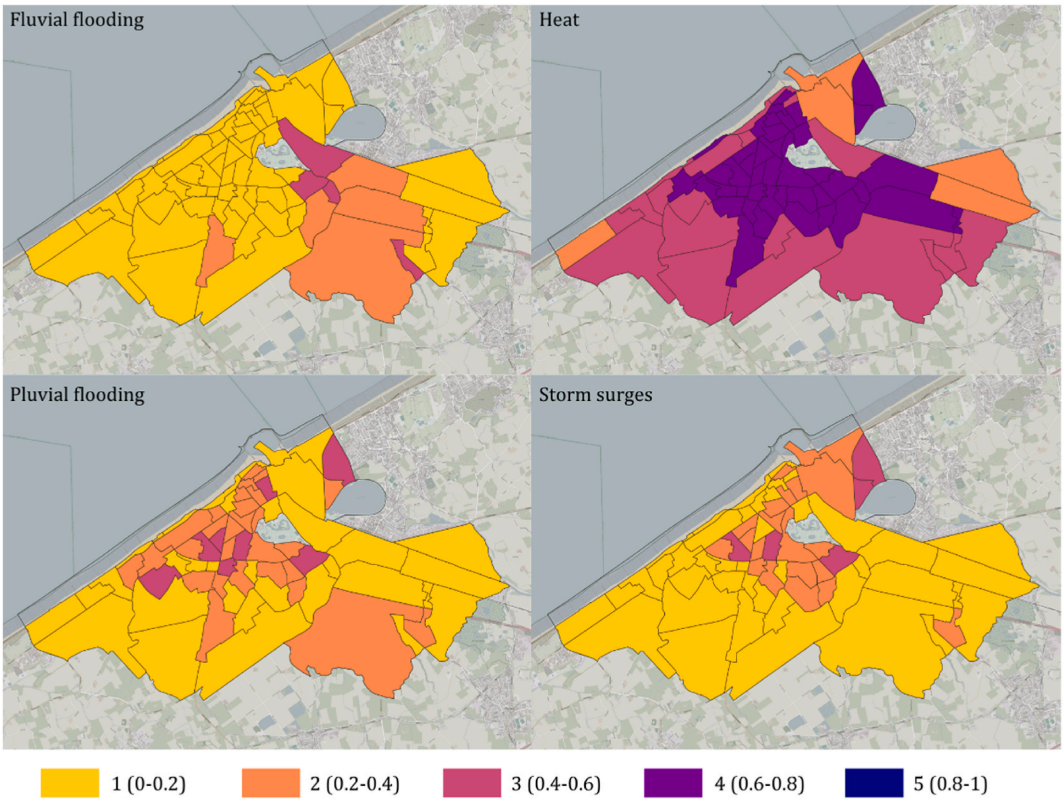

Fig. 1. Exposure to fluvial flooding (2050, 1000-year event), heat (2100, 20-year event), pluvial flooding (2050, 1000-year event) and storm surges (2075, 1000-year event). Data obtained from: Klimaatkaarten catalogus (Flemish Environment Agency, 2024a).

pluvial flooding is shown in. As mentioned, the city centre has a high risk due to the "valley" shape, but also because it houses many vulnerable institutions (childcare, pre-school, primary and special education, hospitals, and care homes). Important to remark is that the area "Renbaan", situated in the northwest next to the dyke is marked as a priority area. As pointed out during the interviews, this area consists primarily of a golf course, which is lying lower than the surrounding parts of the city (Proposal Writer Oostende Municipality, 2024). It is, however, still a priority area due to the many buildings affected in the area and the many vulnerable institutions that can flood, according to the province's models.

3.1.3. *Storm surge flooding*

Oostende is situated along the North Sea Coast. There, sea level is expected to rise by 80 cm towards the end of the 21st century (in a middle impact scenario). The dykes might still protect inhabitants from the sea at this level, but in case of storm surges (from the northwestern direction), many areas will be flooded as the water level can currently reach 7 mTAW and 7.5 mTAW by 2075 during a 1000-year storm event (Fig. 1). The mTAW (metres "Tweede Algemene Waterpassing") is the Belgian reference used for water height. It describes the water height at low tide and is 2.33 m lower than the sea level which is used as a reference. The Flemish government, who is in charge of protecting the Belgian coastline, has performed an assessment for the whole coastal area. Following this, they have made a Masterplan Coastal Safety in 2011 for protecting the coast until 2050, for example by sand replenishments (7 mTAW+ 30 cm sea level rise) (CPC Oostende Municipality, 2024, Flemish Environment Agency, 2024b). The harbour of Oostende and its surrounding areas will still be vulnerable however, as can be seen in Fig. 3. At a severe storm surge today, a zone of about 4000 ha would flood. For this, a climate adaptation design plan has been drawn up for, amongst other measures, a closable storm surge barrier (Flemish Agency for Maritime and Coastal Services, 2024). The government is also working on a long-term Coastal Vision for a scenario of 3 m sea level rise by raising and broadening the dunes and dykes and moving the shoreline 100 m seawards by 2100, creating a large buffer (Flemish Government, 2023).

3.1.4. *Fluvial flooding*

The canals and docks of the harbour are prone to floods, just like the many creeks in Oostende. This makes the municipality moderately vulnerable for fluvial flooding. As shown in Fig. 1, the statistical sectors "Konterdam" and "Konterdam Koebrug" are vulnerable due to the neighbouring dock and the "Keignaartwijk" neighbouring the Creek "Grote Keignaart".

3.2. *Social vulnerability in Oostende*

For this part of the analysis, the social vulnerability index was assessed for the whole city of Oostende, showing the vulnerability of the people living in the statistical sectors in relation to each other. As can be seen in Fig. 2, most socially vulnerable statistical sectors are situated in the city centre. According to the used indicators, in order of vulnerability, the most socially vulnerable sectors are "Cardijn" (0.74), "Hospitaal" and "Wapenplein" (both 0.69), "A. Buylstraat" (0.63), "Nijverheidsstraat" (0.62) and "Renbaan" (0.61).

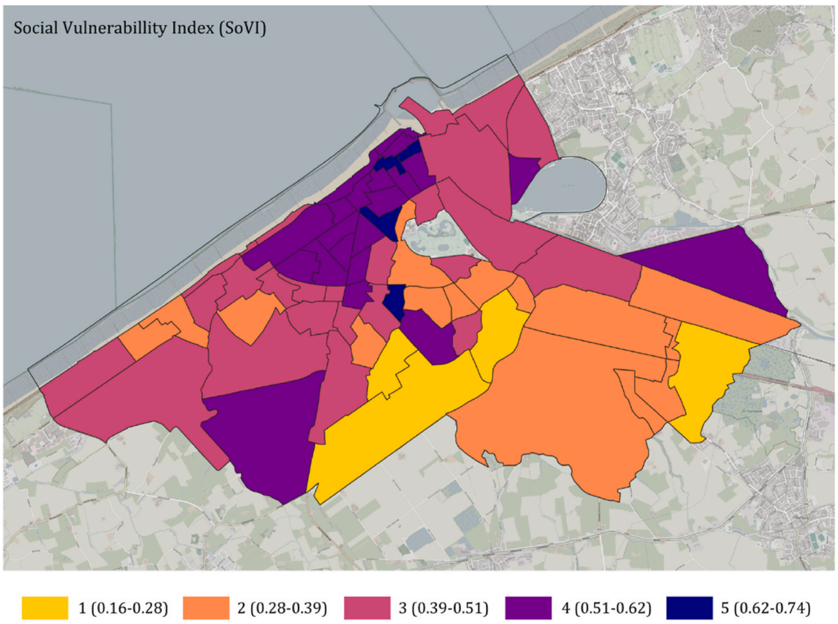

Fig. 2. Social Vulnerability Index (SoVI) for the statistical sectors in Oostende. Data obtained from: Provincies in Cijfers (Provincie West-Vlaanderen, 2024).

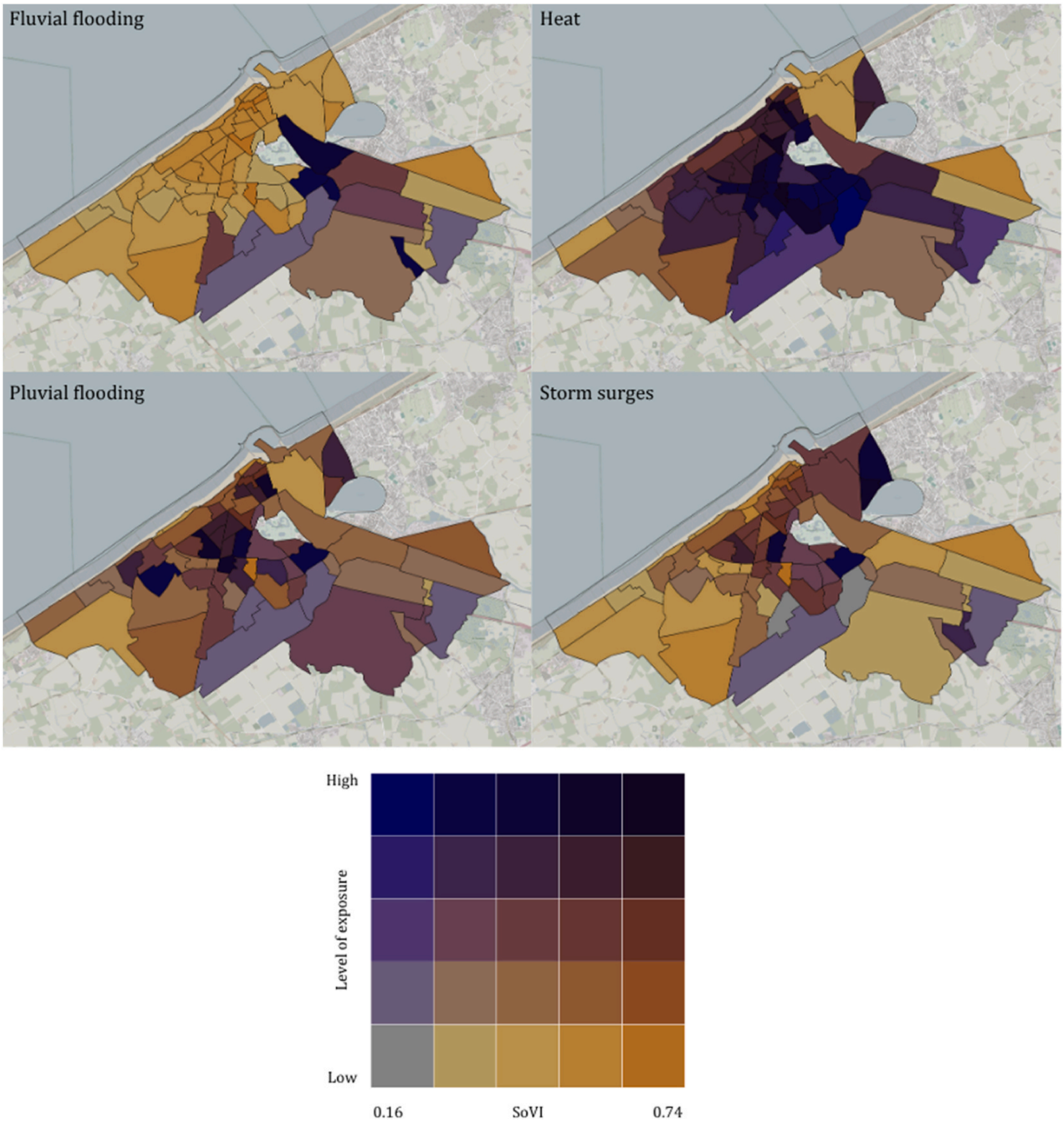

Fig. 3. social climate vulnerability per statistical sector in Oostende for fluvial flooding, heat stress, pluvial flooding and storm surges. The colour of the statistical sector depends on the SoVI (x-axis of legend) and the level of exposure to the climate hazard (y-axis of legend). For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.

3.3. Assessing social climate vulnerability in Oostende

After calculating the climate and social vulnerabilities for the different statistical sectors, the exposure to the events of fluvial flooding, pluvial flooding, storm surges and heat was combined with the social vulnerability to find areas where people are affected by both a high SoVI and high exposure.

Fig. 2 shows the social climate vulnerability per statistical sector in Oostende for the four climate hazards. The most vulnerable statistical sectors are depicted in black as they have a high score for both SoVI and exposure to climate hazards. On the maps it is visible that mostly people in the city centre and the western part of the city centre are affected. The outskirts of the city are either not exposed or not socially vulnerable.

3.3.1. Social vulnerability and heat exposure

Due to its high density and generally high share of sealed surfaces, the whole city will be affected by heat. As can be seen in Fig. 3, the distribution of high heat impacts is spread throughout the whole city, but especially in the areas that are mostly residential. The highest value can be found in the sector "Cardijn", which is located in the centre. It is also the sector with the highest SoVl. One reason for this might be that it includes a social housing project. The sector has a share of 31.2 % of inhabitants who are not born in Belgium and 57.4 % do not have a high school diploma. Furthermore, 96.8 % of inhabitants are home renters (Provincie West-Vlaanderen, 2024).The areas with a lower combined risk in the south-eastern part of the city have a lower building density as well as a high share of unsealed surfaces, as the houses in this area are mostly detached and semi-detached houses with adjoining gardens. These factors might be the reason for the difference in heat distribution in the area. Here, the SoVI is quite low, as the there is, for example, a low share of population over the age of 74 (7,82 %) as well as a lower amount of people not born in the EU (4.40 %) (Provincie West-Vlaanderen, 2024) *Social vulnerability and pluvial flooding exposure.*

The combined value for areas affected by pluvial flooding and SoVI is shown in Fig. 3. Partly explained by the topography of the city, the pluvial flooding exposure is highest in the central and northern parts of the city. This is also where the highest SoVI values can be found. The highest combined risk is in the sector “Renbaan”, a part of the city close to the centre and to the coast. As mentioned before, this area contains a large golf course but also many buildings and vulnerable institutions that get flooded. Next to this exposure, it is also a socially vulnerable area due to the 33 % of people over 74 years old (mostly living in the retirement home) and the low level of education, with 38.8 % having no secondary education (Provincie West-Vlaanderen, 2024).

3.3.2. Social vulnerability and storm surge exposure

For storm surges, the highest combined risk is again in the city centre (see Fig. 3). The sector with the highest value is “Nijverheidsstraat”. The population has a higher share of people not born in the EU (35.4 %) as well as a high share of renters (53.6 %). With 18,33 % being under the age of 15, the population is also younger than in most other sectors in the city (Provincie West-Vlaanderen, 2024). Similarly to the pluvial flooding effects, the water gathers in the city centre due to the topography (CPC Oostende Municipality, 2024) leading to a high value in the water depth (115 cm) and affected buildings (2373) in a 1000-year storm surge event in the year 2115.

3.3.3. Social vulnerability and fluvial flooding exposure

Fluvial flooding is only an issue in small parts of the city, as can be seen in Fig. 3. Due to the streams and creeks being located in the south-eastern part of the city, this is also where the flooding effects can be seen. As large parts of this area are being used agriculturally, not many people are affected by fluvial flooding. This was also confirmed by the CPC from the Municipality of Oostende, who does not evaluate fluvial flooding as a major concern for the city (CPC Oostende Municipality, 2024). Still, 3567 inhabitants live in the four depicted areas and are socially vulnerable as well as exposed to fluvial flooding. The area with the highest combined value is “Vlotdok”, located north-east of the city centre. This area has 216 people, of which 42 % do not have an education above primary school level and 47 % of children do not speak Dutch at home.

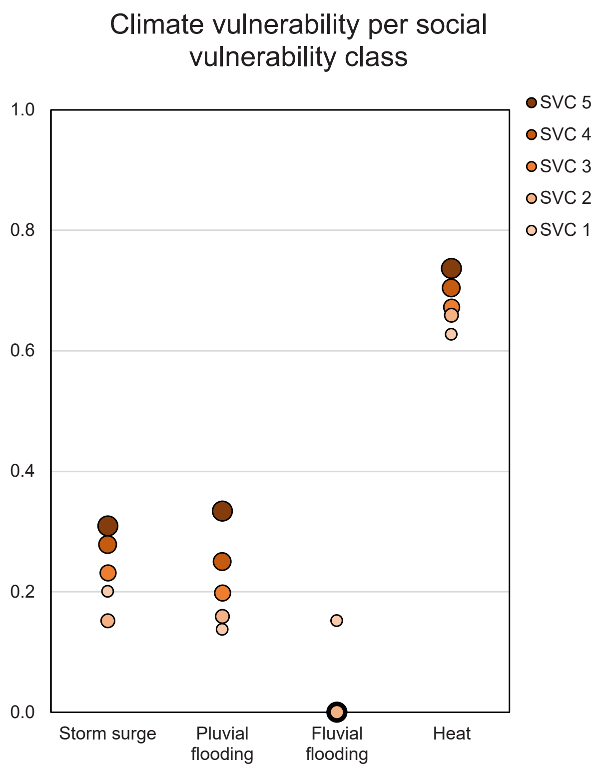

Fig. 4. Median climate vulnerabilities (0–1) for every social vulnerability class (SVC 1–5). Dot size and darkness correspond to SVC class.

3.3.4. Social climate vulnerability synergies

Fig. 4 shows for every social vulnerability class how the median climate vulnerabilities are scored. From this figure it is clear that heat is affecting Oostende on the largest scale, and fluvial flooding is only a minor vulnerability for the city. The chart also shows that the higher social vulnerability classes are also more impacted by heat, storm surges and pluvial flooding. This is in part due to the use of the indicator "vulnerable institutions" (childcare, hospitals, care homes) in the climate hazard exposure scores of storm surge and pluvial flooding and the indicator "number of vulnerable people exposed to significant heat stress" (aged between 0 and 4 and over 65 years) in the climate hazard exposure score of heat. These indicators are assumed to have a dependency with some of the social vulnerability indicators. Summarising, vulnerable populations in Oostende will be affected by climate change, especially by storm surges, pluvial flooding, and heat. Influencing factors are the density in the city centre as well as the topography of the city, which makes water flow towards the centre, where most of the more vulnerable people live. Priority in adaptation measures should be directed to the sector "Nijverheidsstraat" and the surrounding area (for example the two sectors with the identical name "H. Hartplein"). Those can be seen to be affected by a high SoVI as well as by all climate hazards excluding fluvial flooding.

3.4. Usability

In the review interview with the climate policy coordinators of both Oostende and Esbjerg municipality, the usability of the social climate vulnerability methodology was discussed (CPC Esbjerg Municipality, 2024, CPC Oostende Municipality, 2024). See Supplementary Information C for detailed themes of the review interview. The CPC from the municipality of Esbjerg found the social climate vulnerability maps easy to interpret as they are built up with the general climate risk mindset, namely risk = likelihood × impact. They compared it to the risk of floods where the municipality looks at the likelihood of flooding and the vulnerability of the environment, such as building materials, building threshold heights etc. They were confident that the methodology could be applied in their municipality as they have the necessary data available.

The CPC of the municipality of Oostende was enthusiastic about the results and mentioned it will help to reach a more just transition. They said "it's good to integrate social vulnerability in climate transition programs. […] The method to give labels is good because then you know where problems are. It helps if you also can add a sort of vulnerability rate on a certain area, also to prioritize where we are going to start. If it is high risk and there is no money for example, then you really have a big priority to do something. In that sense it adds some meaning in the analysis we already have (labels on climate risks)" (CPC Oostende Municipality, 2024).

The social climate vulnerability maps thus are a good conversation starter and help with breaking the climate/social department isolation. They are a starting point for setting up a climate adaptation strategy that includes social justice and facilitates setting priorities in a budget-restricted reality.

4. Discussion

4.1. The role of cities in just adaptation

Municipalities have the power to influence justice, by working on the moderating factors of vulnerability, namely the physical environment (e.g. climate adaptation measures such as flood prevention or Nature-Based Solutions), policy and planning (e.g. provide funding for people with low income and non-adapted houses, legislation for including climate adaptation in social housing) and the social environment (e.g. start the conversation, increase awareness, provide information in multiple languages). However, it can be hard for municipalities to make plans for increasing resilience since climate adaptation planning is a wicked problem due to the complexity, changing conditions and the abundance of impactors. As a result, measures are often only taken where the highest climate hazards are (exposure), not taking the underlying conditions and processes into account (European Environment Agency, 2022). This was also the case for the city of San Francisco (USA) where, according to a study of Strange et al. (2024), the city has predominantly focused on a technical and top-down approach to the climate adaptation plan until 2019. In an assessment of 112 climate adaptation plans published in the US between 2010 and 2020, only 26 included how people are socially vulnerable towards climate hazards (Brousseau et al., 2024). However, recent trends show more inclusion of vulnerable populations and more attention for social justice in climate plans. Still, this is often only contributing to the dimension of procedural justice, for example through public participation (Strange et al., 2024). The same study finds the UCJ approach a useful framework for incorporating climate justice into urban climate adaptation planning (Strange et al., 2022). In the next sections, this framework will be used to analyse the justness of the proposed methodology in this present study.

4.2. Social climate vulnerability through the lens of urban climate justice

To evaluate whether the strategy of combining climate hazard exposure with Social Vulnerability can contribute to a more just urban planning practice, the conceptual framework of UCJ as introduced in section 2.5 is employed. This framework defines justice within 4 dimensions: recognitional justice, distributive justice, procedural justice, and restorative justice. The following parts will dive into each of these justice dimensions for a qualitative assessment of the strategy proposed in this research.

4.2.1. Recognitional justice

The first dimension, recognitional justice, emphasises the diversity of societal actors, their varying adaptation needs and abilities. It is the recognition of the existence of disadvantaged positions of minority groups (Juhola et al., 2022). Bulkeley et al. (2014) suggest that recognitional justice should be regarded as the lens through which the other dimensions of justice should be viewed.

The CPC from the Municipality of Oostende recognises a lot of segregation depending on wealth (CPC Oostende Municipality, 2024). In Oostende there are different areas that are separated by income level. The city has made efforts to attract high income families to move to the area adjoining the coast, which is why the income level is especially high in that area (CPC Oostende Municipality, 2024). The suburban areas also have a higher income, while low-income populations tend to live in the city centre (ibid.). Due to this distribution the CPC from Oostende sees the priority for climate adaptation action in the city centre and not in the suburban areas, as those in most cases have the means to do some of this work themselves (CPC Oostende Municipality, 2024). In past floods (for example in 2021), many people were not insured for flood damage and were not aware of the risks, which is why the consultant from Sumaqua advocates for informing residents of climate risks (Consultant Sumaqua, 2024). However, neither climate change exposure nor social vulnerability are evenly spatially distributed, as also found in this study, so delivery information about climate risks needs to be commensurate to these disparities.

The strategy of combining climate hazard exposure with social vulnerability assists municipalities in identifying injustices in the city. The combined maps reveal areas where people are particularly affected by, for example, flooding. This assessment also highlights how vulnerability depends on multiple factors and not just poverty, as is often associated with the term. Implementing a multi-factor approach can help raise awareness for the complexity of the concept and raise awareness among local stakeholders, such as social housing organisations or citizens. Although this assessment considers a broad range of factors contributing to vulnerability, it is important to recognise that it cannot encompass every socially vulnerable individual. Individual situations can highly differ within the statistical sectors. By deciding on certain indicators, some people will, per definition, be excluded. Relevant factors for social climate vulnerability that were not taken into account in this research are people living in social isolation, disabled people (who might not always be included in the indicator “chronic diseases”), pregnant people (who for example will suffer more from heat stress) and incarcerated people (who do not have a say in their own living conditions) (Baciu et al., 2017). Other population groups that are socially vulnerable, which may indirectly affect their vulnerability for climate hazards are people of colour, people identifying as LGBTQIA+, women and other marginalized populations (ibid.)

It should also be noted that using indicators simplifies the reality which means that assumptions inevitably are made about people’s competences and financial means that might not be right for the individuals living in the statistical sector (CPC Oostende Municipality, 2024; Cutter et al., 2003). While the analysis makes overarching patterns across the city visible, it cannot account for individual assessments. It is merely a first step, after which it might be possible to go to a smaller scale on this basis.

4.2.2. Distributive justice

As the second dimension, distributive justice is concerned with how climate impacts are distributed in society as well as the distribution of adaptation measures and their impacts (Juhola et al., 2022). These can be both benefits and burdens carried by the area where the measures were implemented or elsewhere.

The climate and social vulnerability strategy aims at influencing distributions of climate measures and leads to a more targeted distribution to people who need them more. The maps aid municipal planners in setting just priorities for using their limited budget and resources. This way climate adaptive measures are distributed in an equitable rather than equal way across the municipality.

The houseowner is usually responsible for taking risk-prevention measures. That has the effect, that some people cannot afford the necessary adaptive measures at their properties. It can also mean that people who rent depend on their landlords or property management to protect them from extreme events. One way that the municipality of Esbjerg counteracts these effects is to use taxpayer money to build flood prevention to protect a low-income area in the city centre.

4.2.3. Procedural justice

As the third dimension of UCJ, procedural justice looks at how climate adaptation planning processes are designed and executed. It concerns the inclusivity of processes throughout planning, implementation, monitoring, and evaluation (Juhola et al., 2022). Taking on a perspective of integrating social vulnerability into climate adaptation planning can be a way to reflect on how these processes are implemented and who can take part in them. By doing so, more inhabitants’ reality can be depicted and integrated.

As this analysis was conducted using the data that is already available to the municipality, it poses a manageable and accessible option. This could make it less burdensome to include the notion of social vulnerability and adopt it as standard practice.

Furthermore, adopting these methods will make it possible to raise awareness about the importance of linking the climate and social domain within the municipality.

> “*It helps to go towards thinking in a collective way and open new innovative solutions of cooperation.*”
>
> —CPC Oostende Municipality (2024)

> “*We have to do everything. Addressing climate adaptation but also poverty, we have to do it collectively, we have to make a collective approach.*”
>
> —Proposal Writer Oostende Municipality (2024)

The maps (e.g., Fig. 3) are a visual and approachable result could help open up a conversation and be used as a communication tool for urban planners (CPC Oostende Municipality, 2024). Related to this is the breaking of the silos within the municipality. By showing the importance of the social-climate link, planners might see it useful to work together on this topic and form interdisciplinary project groups. This intention is starting to approach reality as the CPC from the Municipality of Oostende is seeking to restructure the workflow within the municipality to establish a more horizontal approach (CPC Oostende Municipality, 2024). Identifying common issues and points of action, such as through the applied analysis, might help start these collaborations. An important remark made here is that people making the decisions are often influenced by the predominant culture, learned habits as well as personal values (CPC Oostende Municipality, 2024).

An important consideration in the procedural justice is the responsibility of the municipality to monitor gentrification within the socially vulnerable areas. Researchers have identified the risk of “climate gentrification” (Keenan et al., 2018; Shokry et al., 2020, 2022). On the one hand this can mean that areas that are less affected by climate change have an increase in value, making safe housing less accessible to some (Keenan et al., 2018). It can also refer to the danger that implementing adaptation measures can increase the value of an area, pushing vulnerable populations to different areas of the city (Shokry et al., 2020). This has also been identified as a risk by the Proposal Writer from Oostende Municipality (Proposal Writer Oostende Municipality, 2024). They stress that if more vulnerable people are moved to other parts of the city, it might look like the vulnerability has changed, while there are other people living in the area. One strategy they mentioned is to keep social housing project in the areas of adaptation to prevent this process.

Influencing how much social considerations find room in the planning efforts of the municipality, is which consultancy is hired. In case of the developing climate adaptation plan, the consultancy that is responsible for the plan is specialised in blue-green solutions, which is why this is what the plan is focused on (CPC Oostende Municipality, 2024).

> “*If you don’t ask it very explicitly that they need to integrate the social component into the studies, the consultancy companies don’t deliver it. In that sense, it adds up a new layer.*”
>
> —CPC Oostende Municipality (2024)

The municipality holds the right to choose who to collaborate with and what aspects need to be included, thus impacting the outcomes.

Another layer to the procedural level is that, according to Dhar and Khirfan (2017), research on adaptation often highlights that community-led, bottom-up assessments of vulnerability are crucial, when in practice adaptation efforts mostly happen top-down. In this regard this analysis could be expanded, for example through having a dialogue with inhabitants and other stakeholders and point towards issues that cannot be assessed from socio-economic and climate data only.

4.2.4. Restorative justice

The last dimension of UCJ, restorative justice, addresses the restoration of negative impacts of climate change, by first acknowledging that an injustice exists due to the suffered losses and damages, subsequently identifying the victims and causes, thereafter taking inventory of possible compensations and repairs (Juhola et al., 2022).

Considering how the applied method could influence the aspect of restorative justice, it could be said that making differences in impacts for different kinds of populations visible could be the first step to taking action to decrease injustices. This could mean that special attention is paid to who was affected by extreme events in the past and seeing how they coped with it and if they need support in recovering. In Flanders, it was identified that in past floodings many people were not aware of the risks of flooding to their homes (Consultant Sumaqua, 2024). To work restoratively could mean increasing awareness and through that, increasing adaptive capacity, such as with ecosystem service delivery through Nature-Based Solutions Nykvist et al., (2017). For example, Manes et al. (2022) found that the ecosystem services most vital to safeguarding against climate change impacts, such as flood protection, can be delivered by tailored Nature-Based Solutions, that restore ecological elements and functions, can minimise unwanted trade-offs while reinforcing beneficial synergies. Moreover, Woroniecki et al. (2023) went on to show that such Nature-Based Solutions can reduce vulnerability to climate change impacts more equitably across social groups. Integrating restorative justice in Nature-Based Solutions implementations could even out disparities within the population and make vulnerable people more able to prepare for and be protected from future events (Waters and Adgar, 2017), leading to just climate adaptation (Cousins, 2021). Further, applying this method can highlight the need to adjust compensation according to the impact climate change has. This could be another part of recognising that not everyone shares the same baseline conditions.

4.3. Other initiatives and tools

Several other initiatives within the subject of social climate vulnerability indexing are under way but right now they seem to work with very different geographic scales. This is the case with Prall et al. (2024) where a national solution based on a raster model (hectare cells) was developed. In the dashboard solution from Joint Research Centre (JRC) they work in three scales (Eklund et al., 2023). Those are Country, NUTS2 and NUTS3. Another example would be the SVI tool from McCullagh et al. (2025) that can work at a scale comparable to the most detailed national census datasets and be linked to the Copernicus Climate Change Service (C3S) if needed.

The choice and calculation of indicators in other studies also seems to vary quite a lot at the moment. Looking into the specifications of the mentioned solutions from national (e.g. Prall et al., 2024), regional (e.g. Eklund et al., 2023), and local points of view (e.g. McCullagh et al., 2025)), there are trends that point in the same direction. Nevertheless, it is clear that to make this mapping useful in climate adaption planning and to be able to make comparisons and learn from each other, it will be necessary to include the SVI in a standardisation process and make it part of the climate data infrastructure.

4.4. Limitations and future research

For a more in-depth analysis, for example into one specific scenario, the municipality of Oostende would need to create more datasets that project the same event at the same intensity. Additionally, an analysis like this would benefit from a better data availability on the smallest possible scale in order to get the most specific results. This, however, requires that municipalities improve data collection on social vulnerability indicators.

Ideally, this effort would be harmonized across municipalities to facilitate inter-city comparisons. This would allow future investigations to apply this method in other European coastal cities. For example, the CPC from Esbjerg Municipality (2024) was confident that the municipality of Esbjerg (Denmark) would be able to conduct this analysis, the results highly depend on the indicators that are used and thus on data availability.

5. Conclusions

This research has focused on answering the question of how municipalities can assess social vulnerability for a more just approach to climate adaptation planning. It has attempted to do so by combining climate hazard exposure maps with the Social Vulnerability Index (SoVI) method, through the use of the case city of Oostende. Interviews with people from the municipality, a research centre and consultancy company were performed for gaining insights in the local context, identifying barriers for using social vulnerability in their climate adaptation plans and evaluating the proposed method.

The social climate vulnerability approach is reducing the urban climate injustice gap, as shown by evaluating the approach for each dimension of urban climate justice. The following conclusions can be drawn from applying UCJ in this context.

- The approach contributes most to *procedural* justice as it makes it more manageable and accessible for municipalities to include more inhabitants in the planning process and plan in a more integral way, across silos. A danger for the procedure is that the municipality might base decisions solely on the maps, instead of having dialogues with inhabitants and other stakeholders about their situations and needs. The maps should be regarded as an initial step in the process.
- The aspect of identifying injustices in the city and raising awareness, contributes to the *recognitional* justice dimension. It is important, however, to acknowledge that the social vulnerability per statistical sector does not account for every individual circumstance and assumptions are inevitably made due to simplifications.
- The *distributive* dimension is addressed, as the social climate vulnerability maps aid municipal planners in setting priorities for the limited budget and resources, to distribute climate adaptation measures in an equitable way.
- The approach is contributing less to *restorative* justice as this dimension focuses more on past events. It could be added in the future by attaching a new indicator to the SoVI, wherein existing adaptive structures are scored.

This study has shown that the method is feasible, valid and easy to implement for European municipalities, on the condition that the necessary data are available. The approach will help urban planners with raising awareness for social climate vulnerability within the municipality and make spatial priorities for climate adaptation measures. It will help with incorporating justice, not only in the procedures (public participation) as has been the case in Oostende and many other cities (Strange et al., 2024), but in a holistic just approach. The UCJ framework has proven to be useful in assessing the justness of this approach.

By combining social vulnerability with climate exposure, municipalities have the opportunity to transform climate adaptation practice in urban planning, ensuring a more equitable and just future.

CRediT authorship contribution statement

Saskia Neumann: Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Julie M.L. Berta:** Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Thomas Elliot:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Data curation, Conceptualization. **Lars Bodum:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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Data availability

All data are available in the citations or supplementary material.

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