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Research article

Natural hazard insurance outcomes at national, regional and local scales: A comparison between Sweden and Portugal

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A B S T R A C T

This study addresses the role of natural hazard insurance in two European countries with different insurance markets and socioeconomic conditions: Sweden and Portugal. The analyses were conducted at the national, regional (Southern Sweden and Lisbon Metropolitan Area – LMA), and local (Malmö and Lisbon cities) scales. Most damage caused by weather and climate-related (WCR) hazards during the 1980–2019 period was not covered by insurance companies in Sweden (71%) and Portugal (91%). An insurance affordability analysis was performed using income for the national and regional scales. Unaffordability is higher in Southern Sweden than in LMA, implying that better socioeconomic conditions do not necessarily mean a higher average capacity to pay for insurance.

At the local scale, urban flooding was analysed for Malmö (1996–2019) and Lisbon (2000–2011) using insurance databases, in which the most relevant 21st century rainfall events for each city are included (2014 and 2008, respectively). The influence of terrain features on flooding claims and payouts was determined using Geographic Information Systems (GIS) spatial analyses. The flat Malmö favours ponding and extensive flooding, while the distance to the drainage network and flow accumulation are key factors to promote flooding along valley bottoms in the hilly Lisbon. Flooding hotspots tend to result from a combination of higher depths/lower velocities (accumulation of floodwaters and ponding) and not from a pattern of lower depths/higher velocities (shallow overland flow).

More detailed data on insurance, flooding, and socioeconomic conditions, at regional and mainly local scales, is needed to improve affordability and urban flooding risk assessments.

1. Introduction

The worldwide economic annual losses due to meteorological, hydrological and climatological hazards have grown sevenfold during 1970–2019 (WMO, 2019). These natural hazards caused 446 billion Euros (€) of economic losses in the European Environment Agency (EEA) member countries during 1980–2019, corresponding to around 3% of their gross domestic product (GDP) in 2019 (EEA, 2021). In the same period, flooding represented 1 trillion US dollars in losses worldwide, about 40% of those caused by natural hazards (Munich Re, 2020). Flooding is particularly problematic, as singular events can be

devastating. In 2021, Austria, Belgium, Germany, Luxembourg, the Netherlands, and Switzerland suffered losses of billions of Euros and recorded hundreds of fatalities associated with flooding events (Apel et al., 2022; CRED, 2021; ECDC, 2021; EFAS, 2021; Fekete and Sandholz, 2021; Kreienkamp et al., 2021; Mohr et al., 2022).

The growing threat from flooding results from changes in three key areas: hazard (frequency/magnitude of events), exposure (number/value of elements at risk) and vulnerability (susceptibility to damage) (Hudson et al., 2019; Kron et al., 2019b). Hazard alters due to climate change, increasing the frequency and magnitude of extreme rainfall and flooding events (Alfieri et al., 2015; Botzen et al., 2010; Jha et al., 2012; Madsen et al., 2014; Quintero et al., 2018; Rojas et al., 2013). The

List of acronyms

APS	Portuguese Association of Insurers
DEM	Digital elevation model
EEA	European Environment Agency
EU	European Union
GDP	Gross domestic product
GIS	Geographic Information Systems
HICP	Harmonized index of consumer prices
ICSU	International Council for Science
LMA	Lisbon Metropolitan Area
NUTS	Nomenclature of Territorial Units for Statistics
OECD	Organisation for Economic Co-operation and Development
PPS	Purchasing Power Standards
SEK	Swedish krona
SMHI	Swedish Meteorological and Hydrological Institute
SNIRH	Portuguese National Water Resources Information System
VA SYD	Municipal water and wastewater utility (Malmö)
WCR	Weather and climate-related (hazards/events)

growing building/population densities and socioeconomic development increase exposure within flood-prone areas (Barredo, 2009; Butler and Davies, 2004; Diakakis et al., 2016; Franzke, 2021; Hoeppe, 2016; Kron et al., 2019a; Marchi et al., 2010). Vulnerability is also altered through socioeconomic development, as increased wealth, for example, allows households to finance property-level resilience measures, rendering them less susceptible to damage (Hudson et al., 2020; Jenkins et al., 2017; Owusu et al., 2015).

The complexity of managing disaster risk across these three areas has given prominence to the concept of resilience, where society should be able to resist (lower potential impacts), recover (bounce back), and adapt (learn from experiences and improve). In this framework, insurance has an important role (Atreya et al., 2015; Botzen and van den Bergh, 2008; Hudson et al., 2019; Lamond and Penning-Rowsell, 2014; Linnerooth-Bayer et al., 2018; Surminski et al., 2015). If correctly designed and well-functioning, insurance limits financial uncertainty following disasters, leading to a faster recovery after a damaging event through timely compensation. Additionally, insurance may incentivize the uptake of property-level resilience measures, particularly when insurance premiums are risk-based (Breckner et al., 2016; Tesselaar et al., 2020).

Insurance is differently implemented worldwide, corresponding to diverse design considerations. Within Europe there is a variety of flooding insurance arrangements, each with advantages and shortcomings for managing changing risk patterns (Atreya et al., 2015; Bradt et al., 2021; Hudson et al., 2019; Kron et al., 2019b; Tesselaar et al., 2020, 2022). Evaluating the success of these arrangements requires detailed information. Insurance companies have been reluctant to provide their databases to researchers, despite their importance, due to confidentiality restrictions (André et al., 2013; CNT, 2014). Recently, this has been changing (Gradeci et al., 2019), allowing insurance data to be used, for example, in urban flooding studies (Bernet et al., 2017; Cortès et al., 2018; Grahn and Nyberg, 2017; Leal et al., 2018, 2019, 2020; Mobini et al., 2020, 2021; Moncoulon et al., 2014; Sörensen and Mobini, 2017; Spekkers et al., 2013, 2015; Torgersen et al., 2015; Zhou et al., 2013). Urban flooding is an increasing problem worldwide, it is often neglected and not fully understood (Qi et al., 2020). Insurance data is particularly relevant for identifying the spatial distribution of urban flooding occurrences and hotspots, determining material damage, validating models, and assessing the role played by local controlling factors on ponding, flow paths, water depths and velocities (Bruni et al.,

2015; Diakakis et al., 2016; Djamres et al., 2021; Hossain and Meng, 2020; Jha et al., 2012; Knighton et al., 2020; Leal et al., 2018; McGrane, 2016; Thrysøe et al., 2021; Xing et al., 2021; Yu and Coulthard, 2015).

The main objective of this study is to assess the association between insurance and natural hazards using three spatial scales (national, regional/NUTS2[1] and local) and comparing two quite different European countries: Sweden and Portugal. This multi-scale and comparative approach has rarely been addressed in literature until now, namely in insurance research. The losses and insured losses caused by weather and climate-related (WCR) hazards and the characteristics of insurance markets are addressed at the national scale. The association between socioeconomic conditions, multi-hazard insurance and the respective affordability is used at the national and regional scales (Southern Sweden and Lisbon Metropolitan Area – LMA). The insurance claims triggered by urban flooding and its controlling factors are analysed at the local scale (Malmö and Lisbon). Each city's most important 21st century rainfall/flooding event is detailed. The specific goals of the study are the following: 1) to identify the major differences between the insurance markets of Sweden and Portugal, framing their losses and insured losses due to natural hazards in the European context; 2) to estimate insurance unaffordability rates based on premiums and income; and 3) to understand the influence drainage networks and terrain features on claims and payouts caused by urban flooding.

2. Study areas

2.1. Sweden, Southern Sweden, and Malmö city

Sweden is in Northern Europe and belongs to the Scandinavian Peninsula. It has a total surface of 447,424 km^2 and 10,230,185 inhabitants (23/km^2) in 2019. The Southern Sweden NUTS2-region represents 3% of the Swedish surface (14,341 km^2) and 15% of the national population (1,521,848 inhabitants, 106/km^2). Sweden is affected by several natural hazards, with riverine floods being prevalent and the costliest hazard (Van Well et al., 2018).

Malmö is the regional capital of Scania, located on the southwestern coast of Sweden (Fig. 1). This municipality occupies an area of 161 km^2 and is Sweden's third-largest city by population, with 347,949 inhabitants (2159/km^2) and 171,349 dwellings (1063/km^2) in 2020, according to Statistics Sweden. Climate is temperate oceanic (Köppen class Cfb). The average annual rainfall is around 660 mm and is distributed evenly throughout the year. Malmö is a flat city, with elevation ranging between mean sea level (m.s.l.) and 41 m above m.s.l. The sewer system in Malmö comprises around 30% combined and 70% separated systems (Sörensen and Mobini, 2017). For the local scale analysis, the city within the outer ring was chosen as the study area, occupying 88 km^2 and corresponding to the most urbanized area of the municipality (55% of the total surface). Built-up areas represent 67% of the study area.

2.2. Portugal, Lisbon Metropolitan Area (LMA) and Lisbon city

Portugal is in Southern Europe, in the Southwest of the Iberian Peninsula. It has a total surface of 92,225 km^2 and 10, 276, 617 inhabitants (111/km^2) in 2019. LMA is the most densely built-up Portuguese NUTS2-region (Fig. 1). Despite representing only 3% of the Portuguese surface (3002 km^2), it comprises 28% of the national population (2,846,332 inhabitants, 948/km^2). Portugal is affected by different natural hazards, with heat waves and flash floods being the deadliest, while wildfires and flooding cause the largest material damage.

Lisbon is the Portuguese capital and occupies 85 km^2 (Fig. 1). It is located by the Atlantic Ocean, at the mouth of the Tagus, the longest

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[1] Nomenclature of Territorial Units for Statistics: basic regions for the application of regional policies in the European Union.
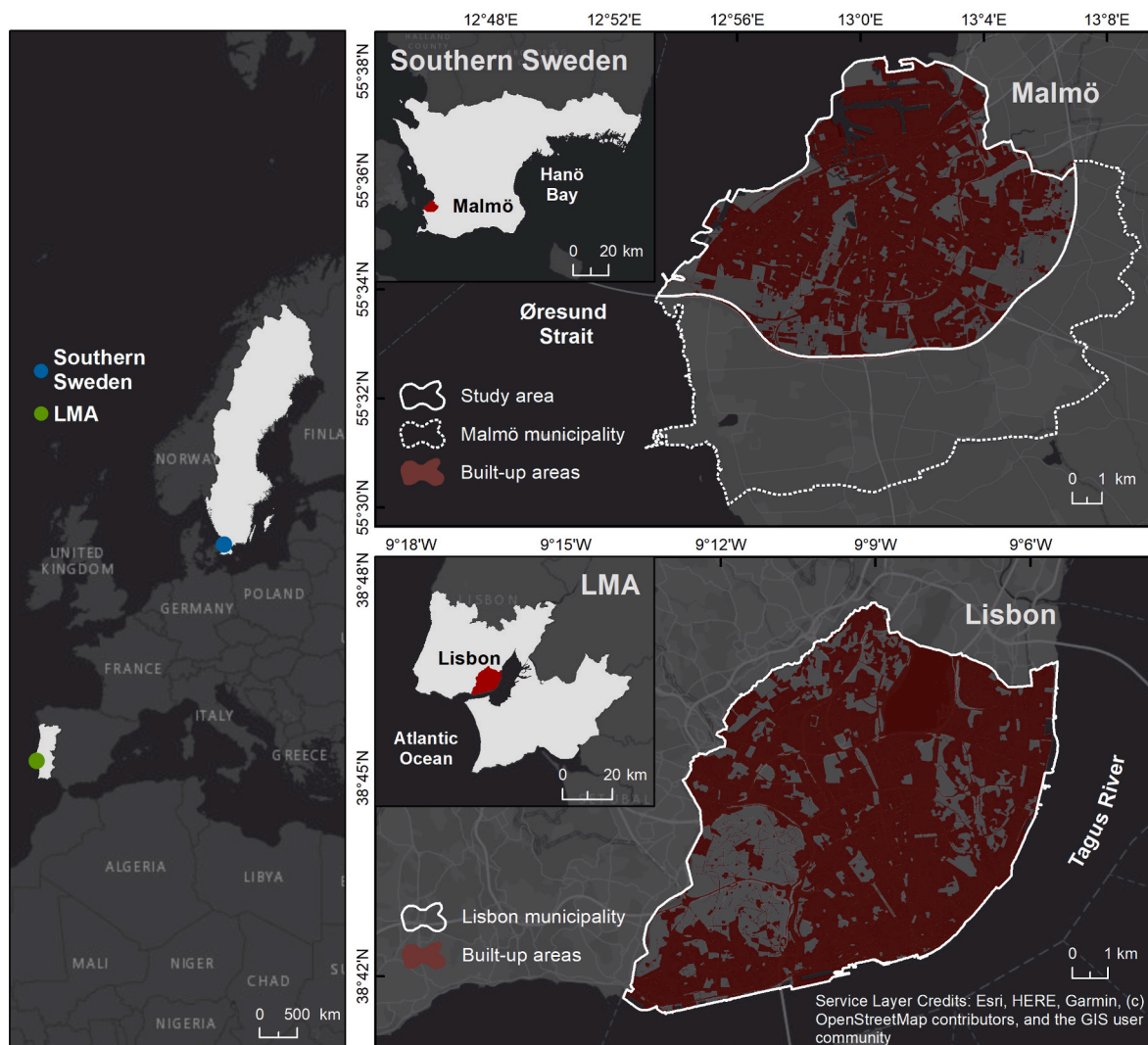
Fig. 1. Location of the study areas. Source of built-up areas: Urban Atlas 2018 (Copernicus Land Monitoring Service).

river in the Iberian Peninsula. Climate is Mediterranean (Köppen class Csa). The average annual rainfall is around 700 mm and is concentrated in autumn and winter. Elevation ranges between mean sea level (m.s.l.) and 227 m above m.s.l. Lisbon is known as the "city of the seven hills" and is drained by a set of small drainage basins whose watercourses were culverted/buried during the 19th and 20th centuries. The combined drainage system that exists in most of the city is old and often undersized, with the main sewers following the same paths as the culverted watercourses. Built-up areas correspond to 73% of the total surface. According to the 2021 Census, there are 320,143 dwellings ($3766/km^2$) and 545,923 inhabitants ($6423/km^2$) in Lisbon.

3. Data and methods

Fig. 2 represents the methodological framework, containing data, methods, and results at national, regional, and local scales.

3.1. Losses and insured losses data

Losses and insured losses from WCR hazards in the EEA member countries[2] and the United Kingdom for 1980–2019 were collected from the EEA website on January 2022 (EEA, 2021). The considered events were caused by meteorological (extreme temperatures, storms, and fog), hydrological (floods, landslides, and wave action) and climatological (droughts, glacial lake outbursts, and wildfires) hazards, according to the classification of the International Council for Science (ICSU). This dataset was based on Munich Re's NatCatSERVICE data and the Eurostat economic indicators. Small-scale property damage and/or one fatality are the criteria for an event to be considered. Losses and insured losses were adjusted for inflation by EEA and presented in 2019 Euros.

3.2. Insurance concepts and data

The concepts used in insurance-related research are often different. The definitions we employ are summarized in Table 1.
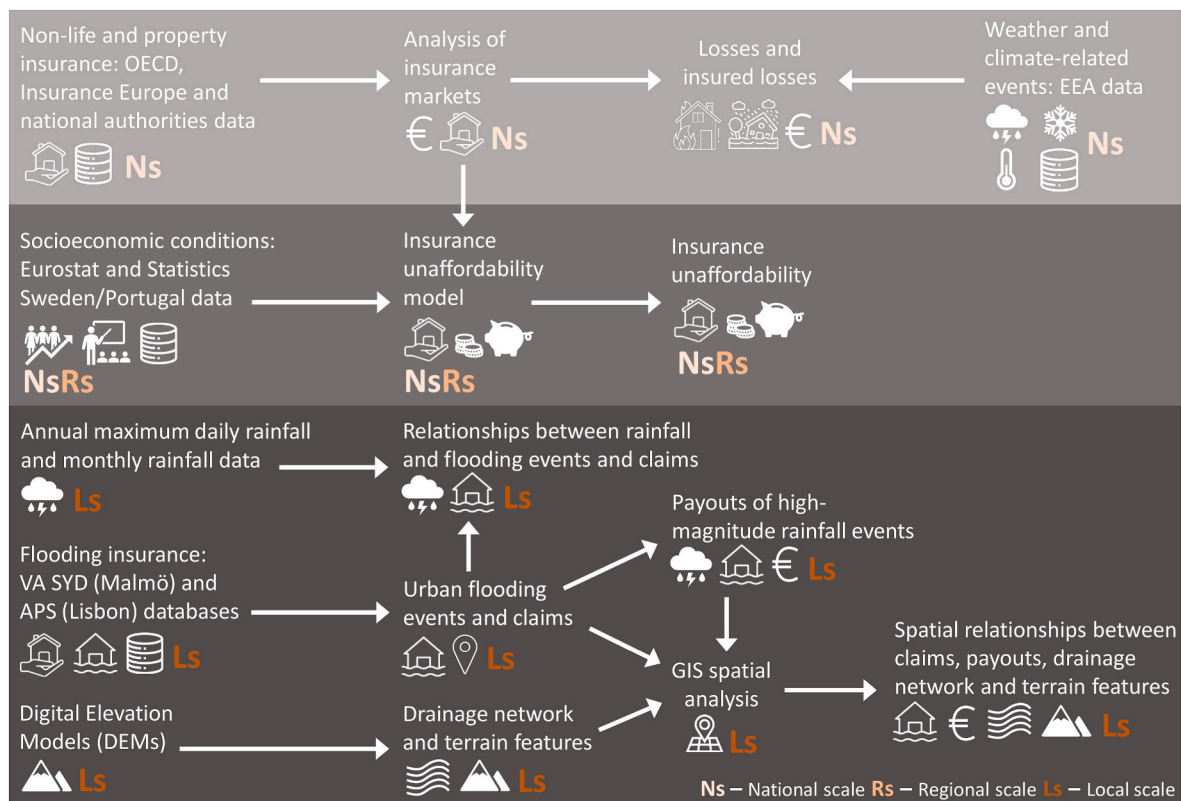
Fig. 2. The methodological framework used in this study. Note: the icons were extracted from MS PowerPoint and the Flaticon website (https://www.flaticon.com/).

Table 1
Concepts associated with insurance and definitions used in this study.

Concept	Definition
Insurance policy	A contract containing the conditions of the insurance agreed by the insurance company and the policyholder.
Direct insurance	The insurance coverage subscribed directly by a primary insurer, rather than by a reinsurance provider.
Non-life insurance	An insurance policy that protects the policyholder against losses other than those covered by life insurance (e.g., property, motor, or accident).
Property insurance	An insurance policy that protects the policyholder against losses related to properties (e.g., natural hazards, thefts/robberies, or civil liability to third parties). Property insurance is also known as multi-risk insurance and includes residential and business insurance.
Insurance density	The proportion of gross direct premium incomes to a country's total population.
Insurance penetration	The proportion of premiums to a country's GDP.
Insurance coverage	The proportion of dwellings with insurance policies.
Capital sum insured	Amount of money reported in the insurance policy, corresponding to the maximum value paid by the insurance company to the policyholder when a damaging event occurs.
Premium	Annual amount paid by the policyholder to the insurance company.
Claim	Request made by a policyholder when a damaging event occurs.
Payout	Amount of money paid by the insurance company to the policyholder when a claim is reported.

Several sources of insurance data were used for the national scale: OECD (Organisation for Economic Co-operation and Development), Insurance Europe and national insurance authorities.

The OECD data[3] refers to non-life insurance and is available for 2009–2019. The Insurance Europe data comprises property insurance and is available for 2004–2019. These databases primarily show the economic importance of each country's insurance markets.

The insurance data for 2011–2019 at a country scale was provided by Insurance Sweden and Portuguese Insurance and Pension Funds Supervisory Authority. Only the residential market was used for comparability. Insurance policies in both countries cover damage caused by fire, water, natural hazards, thefts/robberies, and civil liability to third parties (i.e., bundled insurance products). Premiums and payouts in Sweden were converted from Swedish krona (SEK) into Euros, using the 2019-year average exchange rate, according to the European Central Bank: 1 SEK = 0.094 Euros. After that, the Swedish and Portuguese values were adjusted for inflation (2019 Euros) using the harmonized index of consumer prices (HICP), available at Eurostat.

The insurance databases for Malmö and Lisbon were provided by sources different from those used on a national scale and comprise distinct periods according to data availability. For comparative purposes between the two cities, a flooding event is considered when one or more claims on the same day or consecutive days are reported in the respective insurance database. Only claims caused by rainfall were considered.

Insurance data for Malmö was collected indirectly from municipal water and wastewater utility for 1996–2019, which received the claims from insurance companies. A policyholder is compensated by the insurance company when a claim is reported, which can be reimbursed later by the municipal water and wastewater utility (VA SYD) if certain conditions are met. Each record contains geographic coordinates (latitude and longitude), ensuring an exact location. Data on payouts for Malmö were only available for the high-magnitude event of August 31, 2014.

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[3] Available for OECD countries at: https://www.oecd.org/finance/insurance/oecdinsurancestatistics.htm.

Insurance data for Lisbon was provided by the Portuguese Association of Insurers (APS). The flooding database is available for the period between January 2000 and October 2011, containing about 78% of the Portuguese insurance policies in 2011. Thus, we may estimate that around 78% of the claims recorded during the analysed period are present in this database. For each claim, there is information on payouts, but this data was only used for the February 18, 2008 event to allow a comparison with Malmö (payouts are only available for the 2014 event). The location of each claim is based on the postal code, which is represented by 4 or 7 digits in Portugal. Only claims with information for 7 digits (56%) can be georeferenced with a highly approximate location.

The payouts for the 2008 and 2014 events were adjusted to 2019 values in Euros. For Malmö, the exchange rate for August 31, 2014 was used (1 SEK = 0.10762 Euros).

3.3. Socioeconomic data

Socioeconomic data were mainly obtained from the Eurostat website for all scales, which was complemented with Statistics Sweden and Statistics Portugal data.

A set of indicators sufficiently diverse for a synthetic characterization of the socioeconomic conditions in the study areas in 2019 was chosen. This is coincident with the last year of the EEA data and the last year before the economic effects of the Covid-19 pandemic. The focus of the collection was to develop a broad set of data to aid in studying affordability in Southern Sweden and LMA. The data selection followed the criteria used by Sayers et al. (2018) but was adapted to the availability of data for these regions.

GDP per capita in Purchasing Power Standards (PPS) can be considered as a proxy of a country/region's wealth (Franzke, 2021), since both are highly correlated (Neumayer and Barthel, 2011), and a proxy of vulnerability but presenting a negative correlation: the higher the GDP, the lower the vulnerability (Formetta and Feyen, 2019; Jongman et al., 2015). Household income and wage indicators were used to complement GDP. For the social dimension, long-term unemployment, severe material deprivation and population with tertiary education were obtained.

3.4. Insurance affordability model

Affordability is a subjective concept, which may be approached from a microeconomic perspective, where insurance is considered affordable if people are willing to purchase it, which indicates that is part of their optimal consumption bundle (Bundorf and Pauly, 2006). However, this definition is difficult to apply in the case of disaster insurance, as individuals' decision-making concerning these types of hazards is prone to biases, such as the systematic undervaluation of low-probability-high-impact risks (Kunreuther and Michel-Kerjan, 2009). This cognitive bias reduces the likelihood of seeing insurance as cost-effective, which means that insurance uptake is not an accurate determinant of affordability. A more focused definition of affordability uses an external perspective to remove the influences of behavioural biases. This can be an expenditure cap style definition, i.e., the total expenditure on insurance must be less than X% of income (for example), or a residual income definition where the purchaser must be left with at least Y amount of income after the expenditure (Hudson, 2018).

In this study, we primarily assume a residual income definition based on the at-risk-of-poverty indicator used across the European Union (EU). This states that insurance is deemed unaffordable if, after paying the premium, a household's remaining disposable income is below 60% of the national median income.

3.5. Urban features and association with flooding claims

The distance to the drainage network, slope and flow accumulation were used as differentiating factors for the spatial distribution of claims

and associated payouts. The spatial analysis operations were performed in Geographic Information Systems (GIS) using ArcMap software. The distance to the drainage network represents the shortest linear distance between the sewers/watercourses and each claim. Slope and flow accumulation are generated in a raster data structure. The first presents the steepness at each cell and the second represents the accumulated weight of all cells flowing into each downslope cell.

The digital elevation model (DEM) used for Malmö has a 2 m cell resolution and it was obtained from the Swedish official DEM (Ny Nationell Höjdmodell). The drainage network and slope were created using this DEM. 400,000 m^2 is the minimum accumulated area for representing the main flow paths, corresponding to the main sewers and the ancient watercourses represented in old maps (Sörensen and Mobini, 2017). The flat terrain requires a high-resolution DEM in order not to compromise the correct location of main flow paths. On the other hand, only a coarser DEM would enable the spatial intersection between claims and flow accumulation. For this reason, the spatial analysis between claims and flow accumulation was not made for Malmö.

In Lisbon, two DEMs were built from elevation data at 1:10,000 scale with 2 m and 50 m cell resolution. The drainage network and slope were generated from the 2 m-DEM. 50,000 m^2 is the minimum accumulated area for representing the culverted/buried watercourses, which preserve their former location (coincident with valley bottoms). The derived drainage network was validated by topographic maps of the 19th and 20th centuries. The 50 m-DEM was used to understand the relationship between the claims' location and flow accumulation, which is highly important in Lisbon due to its terrain features. Although a 50-m DEM implies some level of generalization of the urban drainage network of Lisbon, this does not substantially compromise the model's accuracy, contrary to what happens for Malmö. In most cases, a 50 m cell covers buildings on both sides of a Lisbon's street. If the 2 m-DEM was used, two claims reported on different sides of a street may have substantially different values of flow accumulation, which would be a misinterpretation of flow behaviour.

3.6. Rainfall data

Hourly rainfall data for Malmö during the 2014 event was collected from 8 rain gauges owned by VA SYD and the Swedish Meteorological and Hydrological Institute (SMHI) Malmö A rain gauge, which are located within the study area. Hourly rainfall data during the 2008 event was gathered from 15 rain gauges located inside the Lisbon municipality or up to 10 km away from its boundaries. These rain gauges belong to the Portuguese National Water Resources Information System (SNIRH) and the Portuguese Institute for Sea and Atmosphere.

4. Results

The results are organized according to the three sections of Fig. 2: 1) national scale (light grey); 2) national and regional scales (intermediate grey); and 3) local scale (dark grey).

4.1. Losses and insurance at a national scale

4.1.1. Losses vs. insured losses caused by WCR hazards

On average, less than 1/3 of the total reported losses caused by WCR hazards in 1980–2019 were insured in the EEA countries. Sweden and Portugal presented lower values than the European average (Table 2 and Fig. 3). Sweden was the 5th and the 12th country with the lowest losses per km^2 and losses per capita, respectively (Fig. 3A and B). Losses in Sweden can be compared to other countries with a similar climate and socioeconomic context (Scandinavia) or to countries with lower GDP per capita, i.e., lower values to be lost. Portugal was the 15th and 14th country with the highest losses per km^2 and losses per capita (Fig. 3A and B), respectively. All countries with losses per capita higher than Portugal have higher values of GDP per capita, but there are seven

Table 2

Losses and insured losses caused by WCR hazards in the EEA countries, Sweden, and Portugal (1980–2019).

Territory	Losses	Losses/year	Losses/km²	Losses per capita	Insured losses	Insured losses
	Million €	Million €	€	€	Million €	%
EEA countries (average)	15,136	378	119,948	821	5444	28
Sweden	4205	105	9588	468	1230	29
Portugal	7591	190	82,310	743	650	9

Note: all monetary values are in 2019 Euros.
Source: EEA (2021).
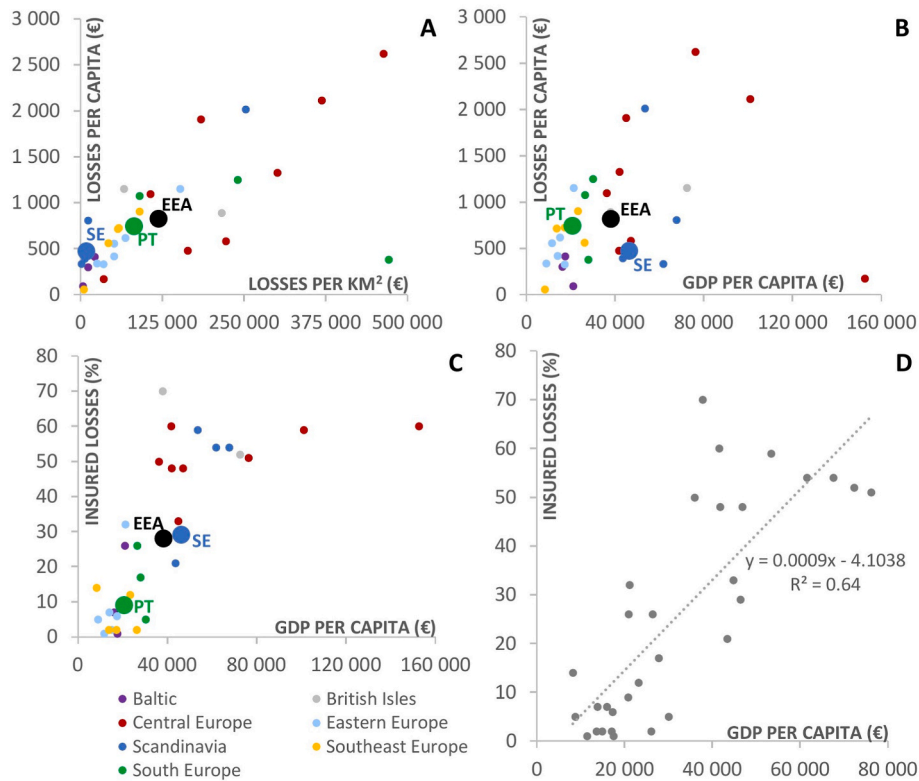
Fig. 3. Losses caused by WCR hazards (1980–2019): losses per km² vs. losses per capita (A); losses per capita vs. GDP per capita (B); insured losses vs. GDP per capita (C); and insured losses vs. GDP per capita without outliers (D). Notes: EEA – Average values of the EEA member countries; PT – Portugal; SE – Sweden. All monetary values are in 2019 Euros. Countries per region: **Baltic** – Estonia, Latvia, and Lithuania; **British Isles** – Ireland and the United Kingdom; **Central Europe** – Austria, Belgium, France, Germany, Liechtenstein, Luxembourg, the Netherlands, and Switzerland; **Eastern Europe** – Bulgaria, Czech Republic, Hungary, Poland, Romania, and Slovakia; **Scandinavia** – Denmark, Finland, Iceland, Norway, and Sweden; **South Europe** – Italy, Malta, Portugal, and Spain; **Southeast Europe** – Croatia, Cyprus, Greece, Slovenia, and Turkey. Sources: EEA (2021) and Eurostat.

countries with lower losses per capita and higher GDP per capita than Portugal. GDP may influence the losses caused by WCR hazards, as suggested by Franzke (2021). GDP acts as a proxy of wealth exposed (e. g., there is more that can be lost) but also as a vulnerability proxy (e.g., better defence and emergency response infrastructure can be developed).

GDP per capita is also a relevant factor in the proportion of insured losses (Fig. 3C). The higher-income countries tend to have higher levels of insured losses. Excluding two outliers (Liechtenstein and Luxembourg), the correlation coefficient between GDP per capita and insured losses of the remaining countries is 0.80 (Fig. 3D). Sweden is the closest country to the EEA average regarding the percentage of insured losses (Table 2), although it has a considerably higher GDP per capita (46,390€ vs. 38,144€). In opposition, Portugal has less than 10% of insured losses (Fig. 3C).

4.1.2. Insurance markets in Sweden and Portugal

The Swedish and Portuguese flooding insurance markets have significant differences. According to Insurance Sweden, 96% of the Swedish households have a degree of home insurance coverage. The insurance offered tends to bundle extreme weather coverage into a home insurance policy (Le Den et al., 2017), as there is no separate flooding insurance policy (Grahn and Nyberg, 2014). In Portugal, property insurance is divided into fire (mandatory) and multi-risk policies

(voluntary). The residential insurance coverage rate was around 57% in 2019. The distinct coverage rates of these two countries contribute decisively to different ratios of insured losses (Table 2 and Fig. 3C).

Gross premiums and density of non-life insurance in Sweden represent more than double the values for Portugal (Table 3). A Swedish policyholder pays on average almost twice as much as a Portuguese one (264€ *vs.* 140€). The insurance penetration in the non-life sector is almost equal between the two countries and higher for Sweden regarding property insurance (Table 3).

The differences between residential insurance markets (Table 4 and

Table 3

Main features of non-life insurance (2009–2019) and property insurance (2004–2019) in Sweden and Portugal.

Country	Gross premiums[a]	Density[a]	Non-life penetration[a]	Property penetration[b]
	Million €	€	%	%
Sweden	9798	930	2.29	0.68
Portugal	4261	361	2.31	0.39

Notes: all values correspond to average values of the considered periods and are presented in 2019 Euros.
[a] Source: OECD. Non-life insurance data (2009–2019).
[b] Source: Insurance Europe. Property insurance data (2004–2019).

Table 4

Residential insurance data and indicators for Sweden and Portugal (2019 and 2011–2019)[c].

| Country	Coverage rate	Insurance policies (IP)	Premiums (PR)		Claims (CL)	Payouts (PA)	
	2019	2019	2019		2011–2019 (average)	2011–2019 (average)	
	%	Thousands	Million €	€/IP	Nr.	Million €	€/CL
Sweden[a]	96	5730	1511	264	786,938	984	1250
Portugal[b]	57	3378	473	140	186,218	214	1147

Note: all monetary values are in 2019 Euros.

[a] Source: Insurance Sweden.

[b] Source: Portuguese Insurance and Pension Funds Supervisory Authority.

[c] Reinsurance values are not included.
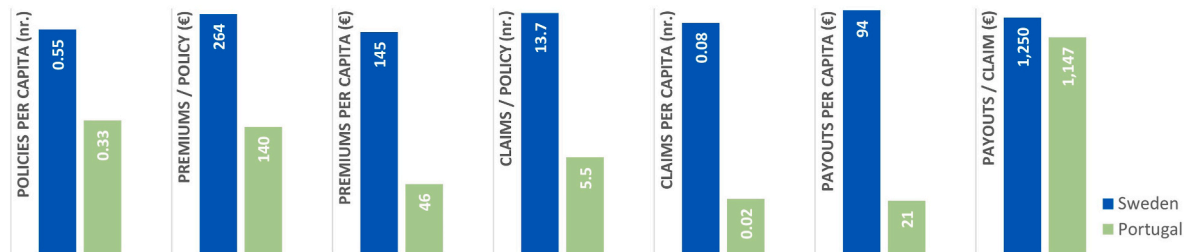
Fig. 4. Property insurance indicators of Sweden and Portugal. Notes: population data is from 2021; insurance policies and premiums are from 2019; claims and payouts correspond to average values from 2011 to 2019; all monetary values are in 2019 Euros.

Fig. 4) are partially imposed by the distinct coverage rates. Insurance policies and premiums, and their respective ratio per capita, were higher for Sweden, as happened with total claims, claims per capita and claims per insurance policy. Payouts showed a different pattern, which were larger in Sweden for total and per capita values, but more similar values were found for payouts per claim. Claims and payouts were analysed using the average values of 2011–2019 to minimize the possible effects of a particularly damaging year. The higher amount paid by insurance companies in Sweden than in Portugal can also be explained by differences in capital sum insured, distinct coverage included in multi-risk insurance policies or different criteria when payouts are granted to policyholders.

4.2. Socioeconomic conditions and insurance unaffordability at national and regional scales

4.2.1. Socioeconomic conditions

The different socioeconomic conditions of Sweden and Portugal in the EU context (Table 5) are also reflected in noticeable differences between the studied NUTS2-regions and cities. Portugal's GDP PPS per capita in 2019 was 79% of that of the EU and 66% of Sweden's. The disposable income of households in Portugal represented 74% and 58% of the values of the EU and Sweden, respectively. The average monthly gross salary in Sweden was almost three times higher than in Portugal, allowing to accommodate the higher average value of an insurance premium (Table 4).

The relative differences between Southern Sweden and LMA are not as stark as on the national scale. LMA is the richest NUTS2-region in Portugal, with a GDP PPS per capita slightly above the EU average (102%) and the value of Southern Sweden (101%) in 2019. On the other hand, the household disposable income, and the average monthly gross wage in LMA were significantly lower than in Southern Sweden: 68% and 45%, respectively. This picture shows a situation of greater material well-being in Southern Sweden than in LMA. In opposition, LMA presents a more favourable situation concerning people under 60 living in households with very low work intensity (i.e., 20% or less of their potentially available work time), less than half the value for Southern Sweden. Considering the socioeconomic situation in both NUTS2-regions, one would lead to suppose that in LMA the insurance

Table 5

Socioeconomic indicators (2019).

Indicators	EU 27	Sweden	Southern Sweden	Portugal	LMA
GDP PPS per capita	31,300	37,100	31,800	24,600	32,000
Disposable income of households (€ per capita)	17,100	21,800	21,000	12,700	14,800
Average monthly gross salary (€)	n.a.	3334	3286	1209	1477
Long-term unemployment (12 months and more, %)	2.8	0.9	1.2	2.8	3.1
People in households with very low work intensity (0–59 years, %)	n.a.	11.8	11.8	6.2	5.7
Severe material deprivation (%)	n.a.	1.8	1.9	5.6	4.6
Population (25–64 years) with tertiary education (%)	31.6	44.0	45.6	26.3	35.2

Sources: Eurostat, Statistics Sweden, and Statistics Portugal.

EU 27: European Union (27 countries).

n.a.: non-available.

affordability would be lower or similar to that of Southern Sweden.

4.2.2. Insurance unaffordability

An income distribution for Sweden and Portugal can be estimated based on equivalised net income (i.e., average disposable income per household). Using the Eurostat data for the 5th, 10th, 20th, 50th, 80th, 90th, and 95th income percentiles, income distributions for 2019 can be created. The missing percentiles were inferred by linear interpolation between known values. This replicates the observation that 17% of residents of these countries are at risk of poverty, which would mean their disposable income is less than 60% of the national median income. This indicator forms a minimum degree of insurance unaffordability. When the two respective average premiums are considered (Table 4), the rate of unaffordability remains at 17% for Sweden and increases to 18% for Portugal.

For the NUTS2-scale, comparable income on equivalised income is difficult to find. However, we rescale the national distribution until it matches the risk-of-poverty level provided by Eurostat (25% and 18% for Sweden and Portugal, respectively). This was achieved by rescaling each interpolated percentile by a fixed ratio, which was 0.85 for Southern Sweden and 0.97 for LMA. When exposed to the same premiums as before, the final rates of unaffordability are 26% and 19%, respectively.

The difference in unaffordability rates is likely due to LMA having the highest income of Portugal's NUTS2-regions, while Malmö is undergoing a transition into a post-industrial economy, with a GDP PPS/inhabitant below the Swedish average (Table 5). Therefore, while the Swedish studied area has lower values of long-term unemployment and severe material deprivation as compared to the LMA, Southern Sweden has more than twice the rate of households with a very low work intensity. This difference likely provides the difference in the at-risk-of-poverty rates because of how the different income distributions appear.

The above was calculated for average premiums that may not have considered a direct risk-based premium, and as such the estimated 264€ and 140€ premiums are not fully reflective of the flooding premiums at the specific locations for which an insurance policy may be issued for. This likely also applies at the national scale as well, as premiums are calculated using a bundle of risks, including the extreme weather proportion of the thread faced, and as such it is likely that these insurance policies are, to varying extents, cross-subsiding each other through an increased degree of risk-sharing between those at higher and lower risks. Thus, the average premiums may be an underestimate of the premium charged in areas with above-average risk and are therefore potentially optimistic rates of unaffordability.

One could also use an expenditure cap definition. This supposes that the insurance premium cannot exceed 5% of net income for example. The 5% income threshold has been used in studies concerning the United States (Kousky and Kunreuther, 2014; Zhao et al., 2016). Setting a suitable threshold in practice, however, will require local consultation as, unlike the residual income definition above, there is no pre-existing threshold (i.e., the existing relatively poverty threshold), which can be uniformly applied across all levels of this study. In all cases, only the bottom two percent of households would find insurance unaffordable for both Portugal and Sweden. One may argue that for these households the 264/140€ charged would be an overestimation of the premium charged for these individuals as they are unlikely to own the property where they reside (thereby requiring only limited contents insurance coverage). However, it must be recalled that affordability is judged separately from a person's decision to purchase insurance, but rather the potential burden that is placed upon the purchaser.

4.3. Material damage caused by urban flooding at a local scale

4.3.1. Flooding claims and the high-magnitude events of 2014 (Malmö) and 2008 (Lisbon)

Malmö recorded 66 flooding events (2.7/year) and 2213 claims (92/year) during 1996–2019. Lisbon registered 110 events (9.2/year) and 1166 claims (97/year) during 2000–2011. The highest number of claims recorded in a year in Malmö (2014) was more than three times higher than in Lisbon (2008). The lowest annual number of claims in Lisbon

exceeded the values in more than half of the years (13) in Malmö. The events of August 31, 2014 in Malmö and February 18, 2008 in Lisbon were the most relevant during the considered periods.

The cloudburst of August 31, 2014 was a historic flooding event regarding the number of claims in Sweden and the amount of rainfall in Malmö (Hernebring et al., 2015; Mobini et al., 2021; Sörensen and Mobini, 2017). The maximum rainfall values (Table 6) exceeded a 100-year return period for durations equal to or greater than 2 h (Hernebring et al., 2015; Sörensen and Mobini, 2017). The February 18, 2008 event is the most important rainfall/flooding event in the LMA since 1983 and the only one that caused fatalities (3) during the 21st century. The rainfall magnitude was significantly higher for longer durations (from 9 h onwards), exceeding a 50-year return period for 24 h (Fragoso et al., 2010; Leal et al., 2019, 2020). The most noticeable distinction between these two events refers to the 3 h duration. The claims and payouts associated with both events are summarized in Table 6.

4.3.2. Claims and flooding controlling factors

The distinct terrain features of Malmö and Lisbon (Table 7) impose different spatial patterns on the urban flooding claims. Due to the previously mentioned limitations of the APS database, only 654 of the Lisbon's claims (56%) can be georeferenced. Regarding the 2008 event, 67% of the claims (161) and the corresponding payouts (74%, 1,140,822€) can be georeferenced.

The claims in Malmö during the 2014 event (Fig. 5B) were more spatially concentrated when compared to the claims during 1996–2019 (Fig. 5A). 9% of the claims (1996–2019) were located within 50 m of the drainage network (Fig. 6A), increasing to 11% during the 2014 event. During a high-magnitude rainfall event, areas near the main sewers are more heavily flooded when compared to less intense events (Sörensen and Mobini, 2017), exceeding the 50 m buffer due to the flat terrain of the city. The area contained in the 50 m buffer corresponds to only 7% of Malmö's surface (Table 7). However, there were high-density areas in both maps, representing flooding hotspots regardless of the magnitude of an event. A similar situation occurred in Lisbon (Fig. 5C and D), where 47% of the claims were located less than 50 m from the drainage

Table 7
Drainage network and terrain features of Malmö and Lisbon.

	Malmö		Lisbon	
	Class	Surface (%)	Class	Surface (%)
Distance to the drainage network	<50 m	6.8	<50 m	38.6
	≥50 m	93.2	≥50 m	61.4
Slope	<1°	66.3	<2°	47.9
	1-2°	11.9	2-5°	26.0
	>2°	21.8	>5°	26.1
Flow accumulation	–	–	0 km²	29.8
	–	–	0–0.05 km²	57.3
	–	–	0.05–0.25 km²	7.6
	–	–	0.25 – 1 km²	3.1
	–	–	≥1 km²	2.2

Table 6
Rainfall and insurance data for the events of 2014 (Malmö) and 2008 (Lisbon).

Study area	Rainfall (mm)								Claims (Nr.)	Claims (Nr./built-up km²)	Payouts (thousand €)	Payouts per claim (€)
	1 h		3 h		6 h		24 h					
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.				
Malmö	30.1	41.6	64.9	90.4	83.0	104.4	96.0	166.2	931	13.8	12,285	13,195
Lisbon	25.6	53.1	44.4	66.1	69.1	99.7	114.0	153.6	239	3.9	1553	6496

Notes: Avg. – average values; Max. – maximum values.
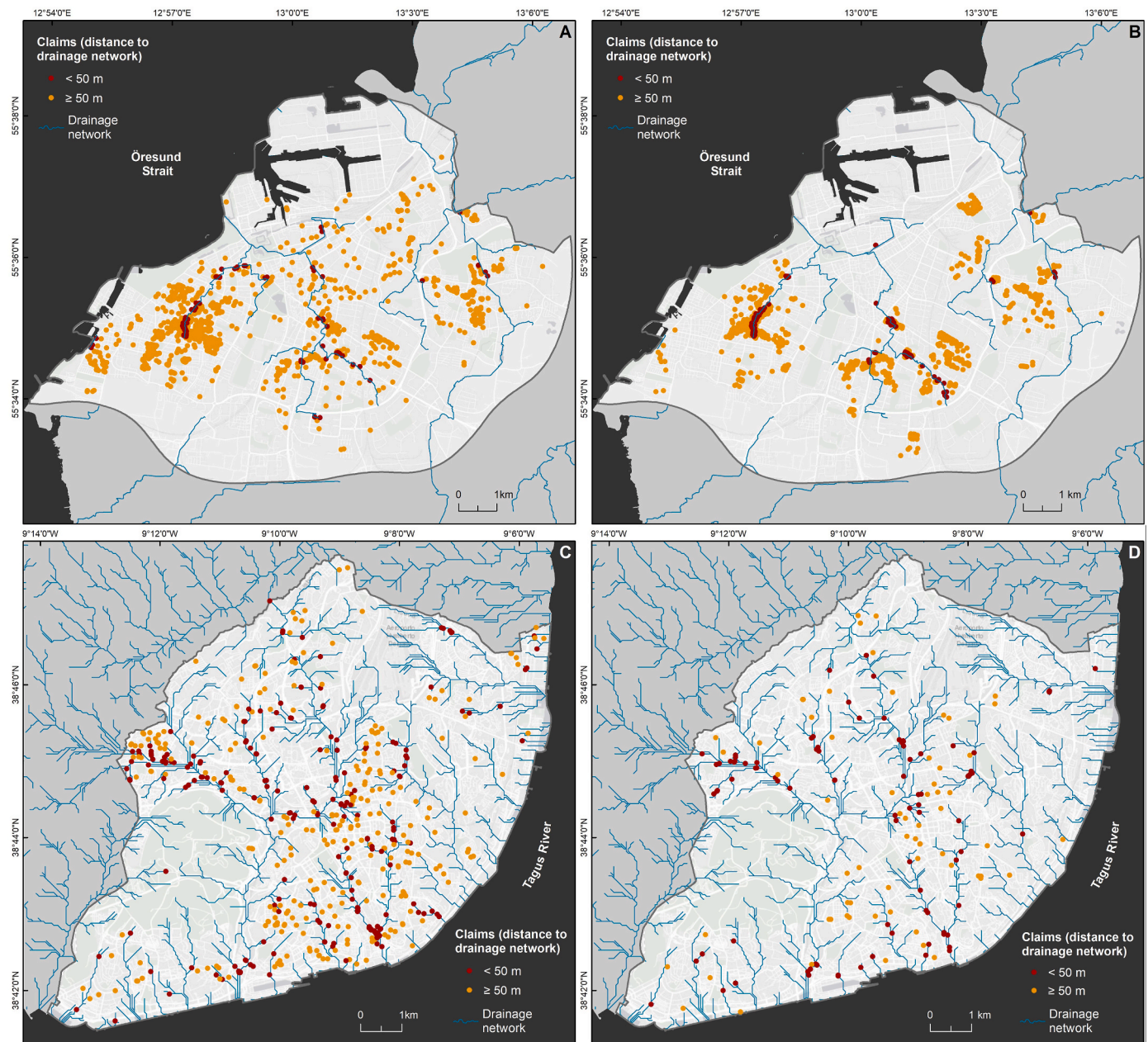
Fig. 5. Spatial distribution of claims by distance to drainage network in Malmö for 1996–2019 without the 2014 event (A) and only for the 2014 event (B), and in Lisbon for 2000–2011 without the 2008 event (C) and only for the 2008 event (D).

network (39% of the surface, Table 7), rising to 60% for the 2008 event. This points to a more natural behaviour when a high-magnitude rainfall event occurs, i.e., flooding tends to occur in streets coincident with valley bottoms and ancient watercourses.

Considering the distinct importance of relief in both cities, different classes of slope were used (Table 7). 78% of Malmö's surface has slope values below 2º. More than 99% of the claims occurred in these cells (Fig. 6C). The flat terrain hinders flow to downstream areas and favours ponding, which is aggravated during high-magnitude events when rainfall values exceed the capacity of the stormwater drainage systems. The hilly terrain of Lisbon makes slope a decisive factor for flow behaviour and velocity. Nevertheless, less than a quarter of the claims occurred in cells above or equal to 5º (26% of the surface), while around half of the claims were associated with cells below 2º (48% of the surface) (Fig. 6D). This trend was accentuated during the 2008 event with 19% and 57%, respectively. The areas below 2º are uplands/interfluves

and old floodplains, which is related to another controlling factor: flow accumulation. Upland areas present low values of flow accumulation, unlike floodplains. Thus, no direct conclusions can be drawn by looking only at the slope.

Flow accumulation (Fig. 6E) partially controls the amount of overland flow, together with permeability and the capacity of urban drainage systems. Flow accumulation was computed only for Lisbon, as explained in section 3.5. The number of accumulated cells is higher in the downstream sections of basins and along valley bottoms. However, most claims occurred in the second class (0–0.05 km^2), which is the most representative one (57%, Table 7). 41% and 32% of the claims were associated with this class during 2000–2011 and the 2008 event, respectively (Fig. 6E). The first class (0 km^2) was the second most important in 2000–2011 (19% of the claims), while the last class ($\geq$1 km^2) was the second most relevant in the 2008 event (23%). During this event, the importance of the last two classes increased and the relevance
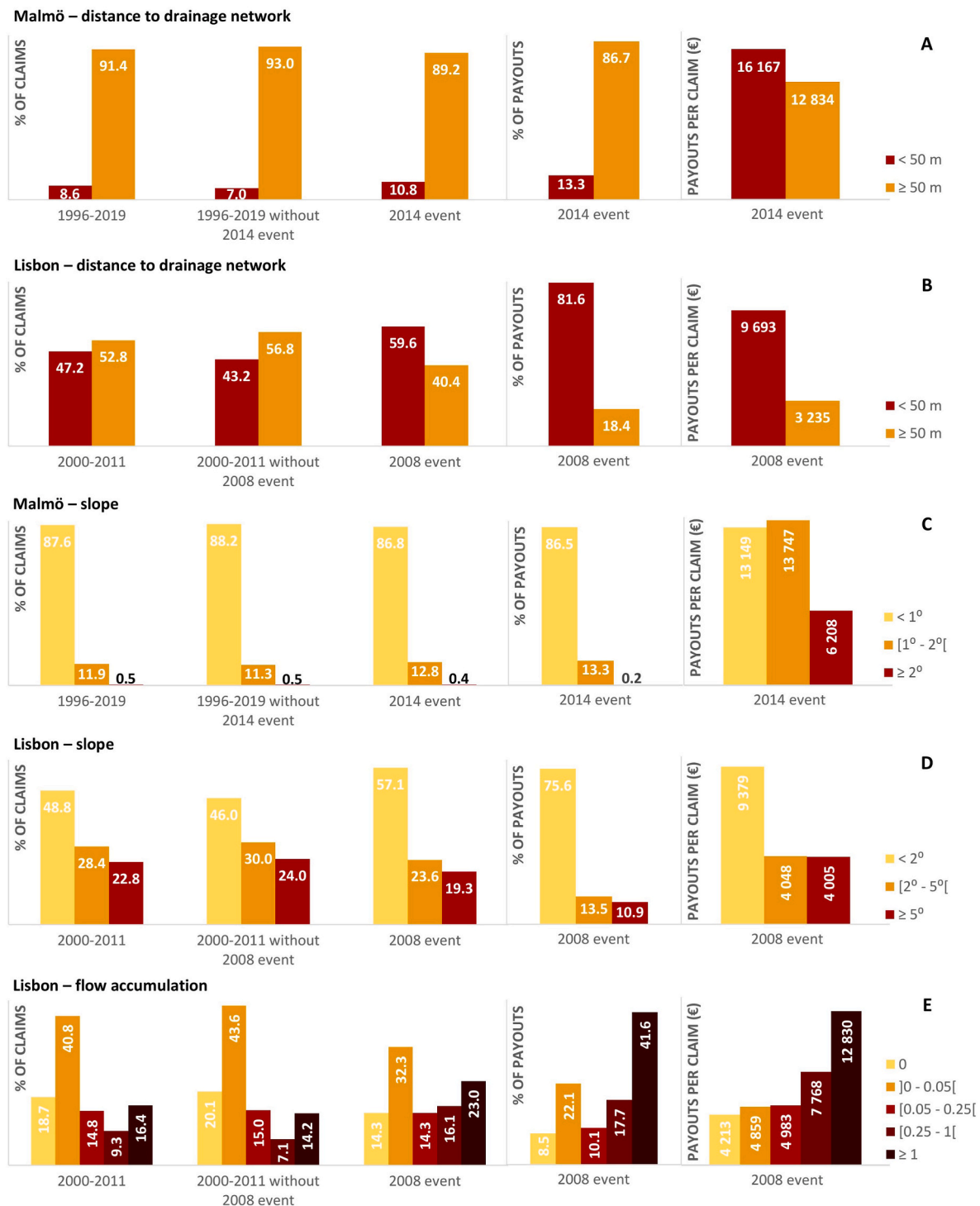
Fig. 6. Claims, payouts, and payouts per claim associated with the distance to drainage network (A and B), slope (C and D) and flow accumulation (E) for the 2014 event in Malmö (A and C) and the 2008 event in Lisbon (B, D and E). Flow accumulation was not computed for Malmö.

of the first classes decreased (Fig. 6E).

*4.3.3. Payouts during the two high-magnitude rainfall events*

In Malmö, 13% of the payouts recorded during the 2014 event were located less than 50 m from the flow paths (Fig. 6A), but payouts per claim were higher close to the drainage network: 16,167€ *vs.* 12,834€ (Figs. 6A and 7A). In Lisbon, 82% of the payouts were located less than 50 m from the drainage network during the 2008 event. Flooding that occurred close to the ancient watercourses was capable to produce much higher payouts (Figs. 6B and 7B). The payouts per claim in the first class

(<50 m) were almost three times higher: 9693€ *vs.* 3235€.

In Malmö, 87% of the claims occurred in cells with slope values below 1° (Fig. 6C). However, payouts per claim and boxplots reveal that the second class (1–2°) reached slightly higher values than the first (Figs. 6C and 7C). In Lisbon, the first class (<2°) is even more relevant for payouts: 76% (Fig. 6D). This is corroborated by payouts per claim (9379€ *vs.* around 4000€ of the other classes) and boxplots (Fig. 7D), revealing that higher payouts were not recorded on the steepest streets, where higher flow velocities are achieved.

There is an increasing trend of payouts with the increment of flow
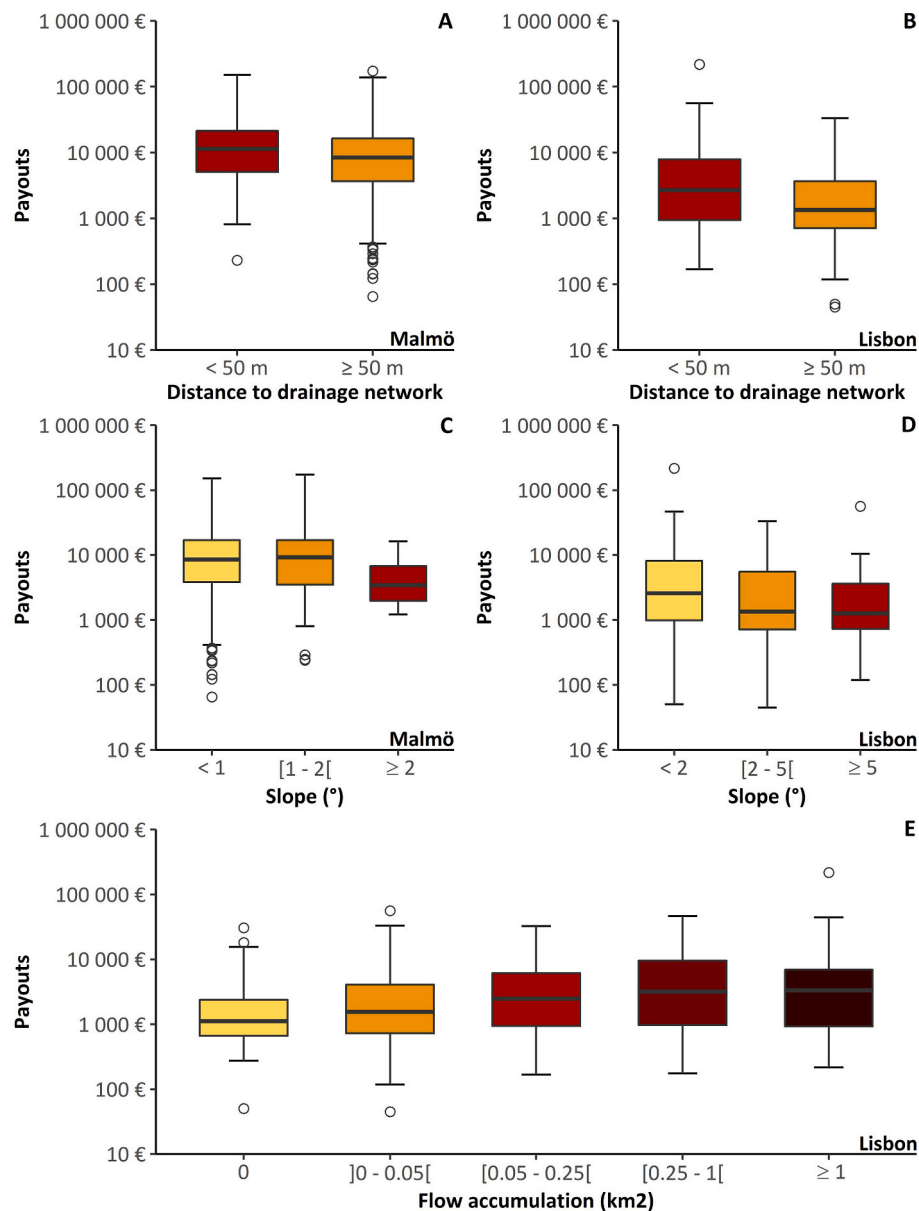
Fig. 7. Boxplots of payouts associated with distance to the drainage network (A and B), slope (C and D) and flow accumulation (E) for the 2014 event in Malmö (A and C) and the 2008 event in Lisbon (B, D and E). Flow accumulation was not computed for Malmö.

accumulation in Lisbon (Figs. 6E and 7E). 42% of the payouts were associated with the last class: ≥1 km². Almost 60% of the payouts belong to the last two classes, which represent only 5% of Lisbon's surface (Table 7). The payouts per claim in the last class (12,830€) are the closest to Malmö's values (Fig. 6).

5. Discussion

5.1. Losses and insured losses: the reasons that explain differences

The losses caused by WCR hazards were different during 1980–2019 in the EEA countries due to several factors: 1) the number and types of natural hazards that affect the countries; 2) the frequency and magnitude of events that occurred during the considered period; 3) the amount and value of exposed/affected elements; and 4) the vulnerability degree of the exposed elements. The degree of exposure and vulnerability often depends on the type of hazard. A country may have different levels of exposure and vulnerability to different phenomena. These levels may

also have changed during the studied period, resulting in distinct losses through time. Formetta and Feyen (2019) demonstrated that vulnerability, income, and losses are deeply related, i.e., lower-income countries have higher vulnerability levels and higher loss rates. Despite absolute losses tend to be higher in richer countries (due to the high value of the exposed elements), relative losses (percentage of GDP) are higher in countries with lower income (CRED, 2018). Regarding the insured losses, these are connected to the insurance coverage rates and the willingness to purchase insurance, which mainly depend on the socioeconomic conditions, educational characteristics, risk perceptions, and disaster experiences of the populations (Botzen and van den Bergh, 2012; Diakakis et al., 2018; Hung, 2009; Lave and Lave, 1991; Lo, 2013; Thieken et al., 2007). During 1980–2019, both insurance coverage rates and willingness to purchase insurance changed, also affecting the insured losses over time. For instance, the flood insurance penetration rate in Germany has increased from about 15% in 2002 to nearly 45% in 2019 (GDV, 2020). Lastly, the increasing frequency and magnitude of extreme events due to climate change may have intensified losses in

recent years, although several authors attribute the past increase only to social development (Barredo, 2009; Franzke, 2021).

Sweden did not record losses as high as Portugal during 1980–2019, which can be explained by lower levels of hazard, exposure and/or vulnerability. The baseline of the WCR hazards places Portugal in a more unfavourable position compared to Sweden (Lung et al., 2013). This inequality is particularly sensitive regarding flood hazard. The predisposing topographic and hydrographic features, together with the climatic conditions, make Portugal more prone to hazardous flood occurrence when compared to Sweden.

According to Forzieri et al. (2017), the exposure of people to WCR hazards has been only slightly higher in Southern Europe in comparison to Northern Europe. However, during 1981–2010, the deaths resulting from floods were much higher in Southern Europe than in Northern Europe: 2.22 and 0.33 per 10 million inhabitants, respectively (Forzieri et al., 2017). These features reflect not only the higher level of flood hazard in Portugal, but also a higher level of exposure and vulnerability. In opposition, Sweden is among the least vulnerable countries in the world regarding natural hazards (Van Well et al., 2018).

5.2. Insurance unaffordability

Affordability is a concern for all study areas, as a non-negligible proportion of the lowest income households were deemed to face an unaffordable premium (between 17% and 26%). The Portuguese study areas had higher affordability rates than Sweden because of the different shapes of the income distribution regarding the lowest incomes (assuming that, to a degree, national income distributions can be rescaled to lower spatial scales). Moreover, these households were facing an unaffordable premium even before fully risk reflective premiums could be assessed. While, to some extent, the premiums currently charged do reflect the underlying risk, different insurers will employ different pricing models with varying degrees of cross-subsidization between higher and lower risk policyholders, as well as different risk-pooling models with other types of underwritten risks. Insurance companies employ these varying degrees of cross-subsidization to maintain the financial attractiveness of the premium and their solvency. Charpentier (2008) noted that this is fundamental for WCR hazard insurance so that insurers maintain a diversified pool of policyholders, but also maintain a premium that potential customers are willing to pay. The smaller this cross-subsidization the larger the premiums for those at higher risk will become, deterring more households from obtaining insurance coverage. This is potentially problematic as several studies have found that if fully risk reflective premiums were introduced for flooding across Europe, unaffordability would become a major concern (Hudson, 2018; Tesselaar et al., 2020, 2022). Therefore, if insurance premiums become more risk-reflective, which is found to be economically attractive from an efficiency perspective (Tesselaar et al., 2020), while simultaneously improving insurance penetration of WCR hazards, additional policies should be implemented to preserve affordability of premiums.

Moreover, the affordability of the premium could be considered in ways outside of a direct comparison of income and premiums to account for wider justice and distributional concerns. While a definition of affordability based on income is a start, it would be useful to have a more comprehensive definition employing a wider range of indicators in a similar way to social vulnerability indicators. For example, an affordability indicator could also consider the capability to implement and maintain adaptation measures more holistically. Additionally, with concerns of underinsurance (i.e., the purchase of insufficient insurance coverage), this also raises the question of whether "affordability" should be measured only by the premium but by the expected damage that the policyholder may have to pay, or the speed at which insurance coverage pays out to capture a fuller picture of the burden placed on a (potential) policyholder.

However, how affordability is defined, either in the form of a simple or expanded, determines the consequences of how affordability impacts risk management. For example, a 5% expenditure cap identifies no affordability concerns, while the residual income definition indicated a 26% unaffordability rate. The large difference between the two sets of results creates a significant space for ambiguity and uncertainty in decision-making, which is problematic as policymakers tend to be ambiguity averse (Berger and Bosetti, 2019), while in practical terms there is no strict reason to prefer one above the other. The affordability definition is a political choice, which will have significant impacts on how insurance markets may evolve in response to public policy choices, as the extent of new instruments to support insurance purchases will be radically different.

5.3. Urban flooding and controlling factors

The different geographic contexts of Malmö and Lisbon affect the conditioning (terrain features) and triggering factors (rainfall) of urban flooding, and, consequently, the number of events and claims.

The higher number of flooding events recorded in Lisbon is favoured by its high imperviousness, propitious terrain features, the combined and undersized drainage system (in critical sectors), and the combined effect of rainfall and high tides in low-lying areas. In contrast, the flat terrain and the high percentage of the separated drainage system of Malmö allow that low-magnitude rainfall events do not result in significant flooding. On the other hand, high-magnitude rainfall events caused many claims in Malmö (Sörensen and Mobini, 2017).

The scattered distribution of claims in Malmö and Lisbon seems to result from their extended built-up areas (more than 2/3 of their surface) and high imperviousness degrees. Nevertheless, major flooding areas/hotspots were identified in Malmö, especially during the 2014 event, which were associated with neighbourhoods connected to combined drainage systems (Mobini et al., 2021). However, no substantial differences in payouts were found in terms of distance to the drainage network and type of system, i.e., combined or separated (Mobini et al., 2021). The influence of relief was mainly relevant in Lisbon due to its hilly terrain, particularly during the 2008 event, when more claims occurred along the ancient watercourses. This trend was already identified by Knighton et al. (2020) and accentuated for payouts.

The role of the slope is worth to be discussed. The accumulation of floodwaters occurs both on uplands/interfluves and valley bottoms/former floodplains. Most claims occurred in flat areas, but the highest payouts occurred along valley bottoms with low values of slope and high values of flow accumulation. High flow velocities, whose highest values occur in steep streets, cause human instability in floodwaters (Arrighi et al., 2017; Jonkman and Penning-Rowsell, 2008; Kvočka et al., 2016; Xia et al., 2011), but the results pointed to a much lower relevance in terms of claims and payouts. This leads to two opposite aspects. On the one hand, slope alone has little relevance to material damage caused by urban flooding even in a hilly city, since it is dependent on flow accumulation to be a relevant factor. At the same time, the slope can be considered as a key factor, inducing (in steep streets) or hindering (in flat areas) the floodwaters movement, resulting or not in ponding.

The socioeconomic conditions also affect the spatial distribution of claims. The lowest number of claims per built-up km^2 in Lisbon occurred in a city area with the highest material deprivation rates (Costa et al., 2020; Santana et al., 2015; Silva and Padeiro, 2020). Malmö also has considerable social inequalities (Scarpa, 2015). The neighbourhoods with the lowest density of claims present lower levels of income and education, and higher concentrations of people born outside Sweden (Mobini, 2021).

Although Lisbon has the more favourable terrain for generating urban flooding, Malmö presented substantially higher payouts. This may be due to the capital sum insured in the insurance policies and/or different criteria in assigning the value of payouts by insurance companies.

5.4. Constraints, limitations, and uncertainties related to scale and data

The scale is a key element for natural hazards research because each level of analysis has benefits and profits, but also imposes direct and indirect constraints that affect the accuracy of results.

A given country can be affected by a set of natural hazards, but the importance and territorial prevalence of each one of them changes, i.e., each natural hazard has its specific geographical distribution, with distinct frequencies and magnitudes further depending on the region, resulting in different damage.

The losses and insured losses associated with each type of WCR hazard were not available by country, making it impossible to establish spatial differences. The losses were previously adjusted to inflation by EEA, preventing their normalization based on the GDP of each country, as suggested by Franzke (2021) and Neumayer and Barthel (2011). Furthermore, GDP per capita corresponds to 2019 values and the losses are cumulative values from 1980 to 2019. Formetta and Feyen (2019) also noted other issues in relying upon major commercial datasets (e.g., overly focused on large events, gaps in historical records, etc.), which reinforces the need for more precise data sharing and reporting.

Data on income distributions and inequality were found to be more easily accessible at the national scale. This is noticeable for the affordability results; the preferred definition of affordability is driven by the patterns of inequality within a region relative to the wider nation. Therefore, the results may be influenced by how the income distribution is modelled from the available data. Using commonly available data on GDP, employment rates, etc., it would be assumed that Sweden would face lower unaffordability rates as compared to Portugal. Nevertheless, for the definitions employed we see that Portugal has a lower unaffordability rate. This reinforces the discussion where affordability is strongly determined by local conditions and nuances, which can differ greatly from more aggregated levels of study. More data on socioeconomic conditions and insurance premiums for each municipality, and ideally for each city block, is needed for a more accurate affordability analysis, especially for cities where risk-based premiums are applied. The available data on socioeconomic conditions at the municipal scale is sometimes scarce and frequently does not allow comparisons between two cities of different countries. Even the municipal scale is not detailed enough to fully capture the spatial patterns that arise from a highly localized hazard such as urban flooding. Insurance data, specifically premiums and capital sum insured, are often only available at a national scale, hiding the existing differences in the regions and cities of a country.

The insurance data limitations also affect the results for the local scale. First, the APS database only contained about 78% of the Portuguese insurance policies in 2011, so part of the claims recorded in Lisbon during 2000–2011 was not included in this study. It was not possible to know exactly what the insurance coverage rates are in Malmö and Lisbon. We can only assume that these should be significantly lower in Lisbon than in Malmö, considering the respective national realities. This may mean that Lisbon's households have lower levels of willingness to purchase multi-risk insurance than Malmö's, which may be due to several factors (or a combination): 1) different degrees of fully voluntary purchasing choices (Hudson et al., 2020); 2) lower level of education (Atreya et al., 2015; Botzen et al., 2019); 3) differing risk perceptions (Botzen et al., 2019; Petrolia et al., 2015); 4) different degrees of trust in the insurance industry (Booth and Tranter, 2018; Wang et al., 2012); and 5) lower willingness of insurers to provide coverage (Born and Klimaszewski-Blettner, 2013; Cremades et al., 2018). Among other possibilities that require deeper study. This translates into a lower resilience to urban flooding in Lisbon as the affected households may have a lower ability to bounce back from high-magnitude events. Furthermore, the controlling factors of urban flooding pointed to a higher susceptibility/hazard in Lisbon than in Malmö. This confirms the results presented by Lung et al. (2013) when referring to the higher flooding risk and the lower adaptive capacity of Portugal and LMA when compared to Sweden and Southern Sweden. These limitations and difficulties prevented a major connection between the national/regional scale and the local scale in this study.

6. Conclusions

Sweden and Portugal have different insurance markets and distinct levels of hazard, exposure, vulnerability, and resilience. A large part of the losses caused by WCR events in the last four decades was not covered by insurance companies. The national scale can hide regional inequalities and local patterns. More spatially detailed insurance data are needed to improve the understanding of regional and local differences within and between countries, and the relationships between pre-event insurance costs (premiums) and post-event insured losses (payouts).

The affordability analysis points out that it is not always higher where socioeconomic conditions are better. Although the data collected shows that socioeconomic conditions in Southern Sweden are, in general, not much higher than in LMA, they are so for indicators directly related to the material situation of the populations, as indeed would be expected given the lower inequality in Sweden than in Portugal. This lends support to the idea that the prevailing concept of affordability may benefit from being more comprehensive, by broadening it to indicators other than income.

At the local scale, Lisbon's terrain features favour the occurrence of flooding alignments and higher payouts along valley bottoms and in flat areas with high values of flow accumulation. The flat terrain of Malmö promotes ponding and extensive flooding, mainly affecting the properties connected to the combined system during high-magnitude rainfall events. In both cities, urban flooding hotspots tend to result from a combination of higher depths/lower velocities (accumulation of floodwaters and ponding) and not from a pattern of lower depths/higher velocities (shallow overland flow).

Better data collection and recording are needed. Suitable data was a limitation of this study because of how accessible disaster data limits what can be done to understand and manage disaster risk. The European Commission Climate Change Adaptation Strategy aims to encourage suitable data sharing practices; however, the process is reliant on the "goodwill" of those who collect data. Suitably incentivised data sharing can overcome major limitations that were mentioned in the discussion section. A combination of detailed data on insurance, flooding, and up-to-date knowledge of urban development and drainage systems can create highly detailed maps and understandings of how urban flooding manifests and how it can be managed. Nevertheless, the data expertise required to generate and maintain such datasets is beyond the management capacities of many city governments.

Credit author statement

Miguel Leal: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. Paul Hudson: Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. Shifteh Mobini: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. Johanna Sörensen: Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. Paulo Miguel Madeira: Methodology, Validation, Formal analysis, Writing – original draft, Writing – review & editing. Max Tesselaar: Methodology, Validation, Formal analysis, Writing – original draft, Writing – review & editing. José Luís Zêzere: Validation, Writing – original draft, Writing – review & editing.

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.

Data availability

Acknowledgments/Funding

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