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Challenges entailed in applying ecosystem services supply and demand mapping approaches: a practice report

Supplementary Materials S1

Table S1. Data used for the ES supply/demand mapping and assessments.

Data	Temporal resolution	Spatial resolution	Source
Administrative boundaries of Europe	2020	1:1 Mio	[1]
Urban Atlas	2012	Minimum Mapping Unit: Class 1: 0.25 ha Class 2 - 5: 1 ha Minimum Mapping Width: 10 m	[2]
Corine Land Cover	2012	Minimum Mapping Unit: 10 ha / 25 ha	[3]
Population density	2011	100 m x 100 m grid	[4,5]
Tree cover density	2015	20 m	[6]
Potential evapotranspiration over grass	2019	1 km x 1 km	[7]
Potential evapotranspiration	2019	Point data	[8]
Temperature	2019	Point data	[9]
Nightly magnitude of the urban heat island effect	2019	1 km x 1 km	[10]
Flood hazard and flood risk	2019	Polygon and point data	[11]
ATKIS	2017	1:25.000	[12]
Biotops	2015	1:10.000	[11]
Run-off paths	2013	Polylines	[13]
Digital elevation model (DEM)	2020	10 m x 10 m	[12]
Crop coefficient (K_c)	-	Literature data	[14]
Crop coefficient (K_c) values for LULC	-	Literature data	[15,16]
Albedo values for LULC	-	Literature data	[17]
Building intensity values for LULC	-	Literature data	[17]
Nesting suitability and floral resources for LULC	-	Literature data	[18]

Table S2. Overview of the indicators, methods and categorisation used. If possible, indicators were mapped at a regional scale.

Ecosystem services	Component	Indicator (Unit)	Method	Tier	Data categorisation
Food (from cultivated terrestrial plants)	Supply	Agricultural area (%)	Calculation of the percentage of agricultural area in a 10-ha x 10-ha grid.	1	5 – very high: >80 - 100 4 – high: >60 - ≤80 3 – medium: >40 - ≤60 2 – low: >20 - ≤40 1 – very low: >0 - ≤20 0 – not relevant: 0
	Demand	Population density (Inhabitants ha^{-1})	Spatial join of population density data with a 100-m x 100-m grid [4,5]	1	5 – very high: >100 4 – high: >75 - ≤100 3 – medium: >50 - ≤75 2 – low: >25 - ≤50 1 – very low: >0 - ≤25 0 – not relevant: 0
Raw materials (from cultivated terrestrial plants)	Supply	Forest area (%)	Calculation of the percentage of forest area in a 10-ha x 10-ha grid.	1	5 – very high: >80 - 100 4 – high: >60 - ≤80 3 – medium: >40 - ≤60 2 – low: >20 - ≤40 1 – very low: >0 - ≤20 0 – not relevant: 0

Ecosystem services	Component	Indicator (Unit)	Method	Tier	Data categorisation
	Demand	Population density (Inhabitants ha^{-1})	Spatial join of population density data with a 100-m x 100-m grid [4,5]	1	5 – very high: >100 4 – high: >75 - ≤100 3 – medium: >50 - ≤75 2 – low: >25 - ≤50 1 – very low: >0 - ≤25 0 – not relevant: 0
Pollination	Supply	Pollinator Abundance (Index 0 to 1, Dimensionless)	Wild bee abundance has been modelled using InVEST "Pollinator Abundance: Crop Pollination" [19]	2-3	5 – very high: >0.8 - 1 4 – high: >0.6 - ≤08 3 – medium: >0.4 - ≤0.6 2 – low: >0.2 - ≤0.4 1 – very low: >0 - ≤0.2 0 – extreme low: 0
	Demand	Dependence of crops on pollination by insects (%)	Dependence of crops on pollination by insects [18,20] was assigned to relevant LULC.	1	5 – very high: >80 - 100 4 – high: >60 - ≤80 3 – medium: >40 - ≤60 2 – low: >20 - ≤ 40 1 – very low: >0 - ≤20 0 – extreme low: 0
Local climate regulation	Supply	Green and blue areas (%)	Calculation of the percentage of green and blue area in a 10-ha x 10-ha grid.	1	5 – very high: >80 - 100 4 – high: >60 - ≤80 3 – medium: >40 - ≤60 2 – low: >20 - ≤40 1 – very low: >0 - ≤20 0 – extreme low: 0
	Supply	f-evapotranspiration (f-ETP) (Index 0 to 1, dimensionless)	Value-transfer of literature data [21,22].	1	5 – very high: >0.8 - 1 4 – high: >0.6 - ≤0.8 3 – medium: >0.4 - ≤0.6 2 – low: >0.2 - ≤0.4 1 – very low: >0 - ≤0.2 0 – extreme low: 0
	Demand	Surface emissivity (Index 0 to 1, dimensionless	Value-transfer of literature data [21,22].	1	5 – very high: >0.8 - 1 4 – high: >0.6 - ≤0.8 3 – medium: >0.4 - ≤0.6 2 – low: >0.2 - ≤0.4 1 – very low: >0 - ≤0.2 0 – extreme low: 0
Coastal protection	Demand	Coastal flood risk (Index 0 to 1, dimensionless)	Calculation of the coastal flood risk for the assets (human health, the environment, infrastructure and human economic activities) by multiplying flood hazard with the potential damage of each asset [13].	1-2	See explanations below.

Table S3. Overview of the indicators used in the ES modelling. If possible, indicators were mapped at a regional scale.

Ecosystem services	Component	Indicator (Unit)	Method	Tier	Data categorisation
Pollination	Supply	Pollinator Abundance (Index 0 to 1, Dimensionless)	Wild bee abundance has been modelled using InVEST "Pollinator Abundance: Crop Pollination" [19]	2-3	5 – very high: >0.8 - 1 4 – high: >0.6 - ≤0.8 3 – medium: >0.4 - ≤0.6 2 – low: >0.2 - ≤0.4 1 – very low: >0 - ≤0.2

Ecosystem services	Component	Indicator (Unit)	Method	Tier	Data categorisation
					0 – extreme low: 0
Local climate regulation	Supply	Heat mitigation (Index 0 to 1, Dimensionless)	Heat mitigation index has been modelled using InVEST "Urban Cooling Model" [23].	2-3	5 – very high: >0.8 - 1 4 – high: >0.6 - ≤0.8 3 – medium: >0.4 - ≤0.6 2 – low: >0.2 - ≤0.4 1 – very low: >0 - ≤0.2 0 – extreme low: 0

1. Food (from cultivated terrestrial plants)

LULC data can be used as proxies for ES supply [24]. We calculated the percentage of LULC types (Urban Atlas 2012), which are highly associated with producing food (arable land, permanent crops (vineyards, fruit trees, olive groves)) in geospatial units. The calculation of the percentage share can also be applied to official administrative units. Since these vary in size in the urban regions, we decided to use a uniform raster with a grid size of 10 ha. The demand for food has been mapped using population density data (inhabitants/ha) [4,5].

2. Raw materials (from cultivated terrestrial plants)

For ES supply, we calculated the percentage of LULC types, which are highly associated with providing timber (forest). We used a uniform raster with a grid size of 10 ha. The demand for food has been mapped using population density data (inhabitants/ha) [4,5].

3. Pollination

ES supply has been assessed using the indicator pollinator abundance [19], calculated with the InVEST Model P*ollinator Abundance: Crop Pollination*. This model considers that wild bees need suitable nesting sites and sufficient floral resources to survive. If these resources are available, the insects can fly to nearby plants and pollinate them. We used CLC 2012 and Urban Atlas 2012 and intersected them (see Table S4).

Table S4. Selected LULC classes from CORINE Land Cover (CLC) and Urban Atlas.

CORINE Land Cover (CLC)		Urban Atlas		Selected LULC classes for InVEST Models	
Code	Label	Code	Label	CLC	Urban Atlas
111	Continuous urban fabric	11100	Continuous urban fabric (S.L.: > 80%)		x
112	Discontinuous urban fabric	11210	Discontinuous dense urban fabric (S.L.: 50% - 80%)		x
112	Discontinuous urban fabric	11230	Discontinuous medium-density urban fabric (S.L: 30% - 50%)		x
112	Discontinuous urban fabric	11220	Discontinuous low-density urban fabric (S.L.: 10% - 30%)		x
112	Discontinuous urban fabric	11240	Discontinuous very low-density urban fabric (S.L.: < 10%)		x
121	Industrial or commercial units	12100	Industrial, commercial, public, military and private units		x
122	Road and rail networks and associated land	12210	Fast transit roads and associated land		x
122	Road and rail networks and associated land	12230	Railways and associated land		x
122	Road and rail networks and associated land	12220	Other roads and associated land		x
123	Port areas	12300	Port areas	x	
124	Airports	12400	Airports	x	
131	Mineral extraction sites	13100	Mineral extraction and dump sites	x	
132	Dump sites	13100	Mineral extraction and dump sites	x	
133	Construction sites	13300	Construction sites	x	
141	Green urban areas	14100	Green urban areas		x

142	Sport and leisure facilities	14200	Sports and leisure facilities		x
211	Non-irrigated arable land	21000	Arable land (annual crops)	x	
212	Permanently irrigated land	21000	Arable land (annual crops)	x	
213	Rice fields	21000	Arable land (annual crops)	x	
221	Vineyards	22000	Permanent crops (vineyards, fruit trees, olive groves)	x	
222	Fruit trees and berry plantations	22000	Permanent crops (vineyards, fruit trees, olive groves)	x	
223	Olive groves	22000	Permanent crops (vineyards, fruit trees, olive groves)	x	
231	Pastures	23000	Pastures	x	
241	Annual crops associated with permanent crops	0		x	
242	Complex cultivation patterns	24000	Complex and mixed cultivation patterns		x
243	Land principally occupied by agriculture, with significant areas of natural vegetation	25000	Orchards		x
244	Agro-forestry areas	0		x	
311	Broad-leaved forest	31000	Forests	x	
312	Coniferous forest	31000	Forests	x	
313	Mixed forest	31000	Forests	x	
321	Natural grasslands	32000	Herbaceous vegetation associations (natural grassland, moors…)	x	
322	Moors and heathland	32000	Herbaceous vegetation associations (natural grassland, moors…)	x	
323	Sclerophyllous vegetation	32000	Herbaceous vegetation associations (natural grassland, moors…)	x	
324	Transitional woodland-shrub	32000	Herbaceous vegetation associations (natural grassland, moors…)	x	
331	Beaches, dunes, sands	33000	Open spaces with little or no vegetation (beaches, dunes, bare rocks, glaciers)	x	
332	Bare rocks	33000	Open spaces with little or no vegetation (beaches, dunes, bare rocks, glaciers)	x	
333	Sparsely vegetated areas	33000	Open spaces with little or no vegetation (beaches, dunes, bare rocks, glaciers)	x	
334	Burnt areas	33000	Open spaces with little or no vegetation (beaches, dunes, bare rocks, glaciers)	x	
335	Glaciers and perpetual snow	33000	Open spaces with little or no vegetation (beaches, dunes, bare rocks, glaciers)	x	
411	Inland marshes	40000	Wetlands	x	
412	Peat bogs	40000	Wetlands	x	
421	Salt marshes	40000	Wetlands	x	
422	Salines	40000	Wetlands	x	
423	Intertidal flats	40000	Wetlands	x	
511	Water courses	50000	Water		x
512	Water bodies	50000	Water		x
521	Coastal lagoons	50000	Water		x
522	Estuaries	50000	Water		x
523	Sea and ocean	50000	Water		x
		11300	Isolated Structures		x
		13400	Land without current use		x

The data has been transferred into a raster (2.5 x 2.5 m resolution). The model needs a) a biophysical table with nesting suitability and floral resources across seasons for each LULC type (Table S5) and b) a guide table with information about wild bee species' active seasons, nesting preferences, mean flight distances, and relative abundances for each species or group of wild pollinators [19]. Information about twenty wild bee species (=average wild bee species) was combined for the guide table. For the biophysical table, values from Zulian et al. (2013) [18] were used and adapted for the Urban Atlas LULC (Table S6).

Table S5. Biophysical table, adapted from Zulian et al. (2013) [18]. Marked LULC (*) shows adjusted values for the Urban Atlas dataset.

lucode	Label	nesting_cavity_availability_index	nesting_ground_availability_index	floral_resources_index
1	Water bodies*	0	0	0
2	Sea and ocean	0	0	0
3	Peat bogs	0.3	0.3	0.5
4	Inland marshes	0.3	0.3	0.75
5	Beaches, dunes, sands	0.3	0.3	0.1
6	Transitional woodland-shrub	1	1	0.85
7	Natural grasslands	0.8	0.8	1
8	Broad-leaved forest	0.8	0.8	0.9
9	Coniferous forest	0.8	0.8	0.3
10	Mixed forest	0.8	0.8	0.6
11	Fruit trees and berry plantations	0.4	0.4	0.9
12	Pastures	0.3	0.3	0.2
13	Complex cultivation patterns*	0.4	0.4	0.4
14	Land principally occupied by agriculture, with significant areas of natural vegetation *	0.7	0.7	0.75
15	Non-irrigated arable land	0.2	0.2	0.2
16	Green urban areas*	0.3	0.3	0.25
17	Sports and leisure facilities*	0.3	0.3	0.05
18	Land without current use*	0	0	0
19	Mineral extraction sites	0.3	0.3	0.05
20	Dump sites	0.05	0.05	0
21	Construction sites	0.1	0.1	0
22	Fast transit roads and associated land	0.3	0.3	0.25
23	Other roads and associated land	0.3	0.3	0.25
24	Railways and associated land	0.3	0.3	0.25
25	Port areas	0.3	0.3	0
26	Airports	0.3	0.3	0.1
27	Continuous urban fabric (S.L.: > 80%)	0.1	0.1	0.05
28	Discontinuous dense urban fabric (S.L.: 50% - 80%)	0.2	0.2	0.175
29	Discontinuous medium-density urban fabric (S.L: 30% - 50%)	0.3	0.3	0.3
30	Discontinuous low-density urban fabric (S.L.: 10% - 30%)	0.3	0.3	0.2875
31	Discontinuous very low-density urban fabric (S.L.: < 10%)	0.3	0.3	0.2625
32	Isolated structures*	0	0	0
33	Industrial or commercial units *	0.1	0.1	0.05

Table S6. Guide table for the InVEST model *Pollinator Abundance: Crop Pollination*.

SPECIES	nesting_suitability_index	foraging_activity_spring_index	alpha	relative

				abundance
average_bee	1	0,5	600	1

The ES demand for pollination was assessed using the degree to which a crop is dependent on pollination by insects. This degree was first assessed by Klein et al. (2007) [20], who provided a list of important crops and their dependence on animal pollinators. These values are also used at the EU level to assess ES demand for pollination (Zulian et al. 2013) [18]. In an ideal situation, information on the pollination dependence of crops is linked to agricultural cultivation data to obtain explicit spatial information on ES demand. In Germany, these data are saved in an agricultural database (Integrated Administration and Control System, InVeKoS), which has restricted access for data protection reasons [25]. Therefore, we followed a methodological approach used by Schulp et al. 2014 [26] and Perennes et al. (2021) [27], who linked land use data on which potentially pollinator-dependent crops can grow with pollinator dependence values. We have assigned exemplary pollination dependencies to the LULC classes. For example, rapeseed is in Germany an important crop that is dependent on pollination by insects. The location of rapeseed fields usually changes annually due to crop rotations, varying market prices and changing political regulations and subsidies. Hence, the demand for pollination of rapeseed can potentially occur on all arable land [27]. Similar considerations took place in allocating crops for land-use "permanent crops (vineyards, fruit trees, olive groves)". We used the EUROSTAT dependence levels for these crop types as used in Zulian et al. (2013) [18] (Table S7).

Table S7. Pollination dependencies (%) of crops that could grow on selected LULC (adapted from Zulian et al. (2013) [18]).

Land use and land cover	**Crop type**	**Pollination dependence**
Arable land (annual crops)	Rape seed	25 %
Fruit trees and berry plantations	Apples, pears & peaches	65 %

4. Local climate regulation

Indicator *green and blue areas (%):* We calculated the percentage of green and blue areas (forests, agricultural areas, wetlands, water bodies, urban green areas, cemeteries and other vegetation areas) in each grid cell (10 ha).
Indicator *f-evapotranspiration (f-ETP)*: Evapotranspiration (ETP) covers water evaporation from soil surfaces (evaporation) and vegetation (transpiration) [28]. In this process, heat energy is converted into latent heat of vaporisation, which can result in a noticeable cooling effect [21]. We used the *f-ETP* index as a proxy to assess the ES supply for local climate regulation. Schwarz et al. (2011) and Larondelle et al. (2014) provided standardised ETP values for CLC and Urban Atlas LULC classes [21,22].
Indicator *surface emissivity:* ES demand for local climate regulation has been assessed using *surface emissivity* as a proxy. Surface emissivity expresses the land surface thermal emissions, which indicate the total amount of energy that is emitted by a surface [22]. For this indicator, too, Schwarz et al. (2011) and Larondelle et al. (2014) provided standardised surface emissivity values for CLC and Urban Atlas LULC classes [21,22].
We used an equation (1) that normalises the f-ETP and surface emissivity values to a scale between 0 and 1, where 0 indicates low and 1 high ES potential/demand:

$$ES' = (ES - ES_{min})/(ES_{max} - ES_{min}) \tag{1}$$

where ES' is the normalised ES, ES_{min} is the minimum and ES_{max} is the maximum value of ES [29]. Finally, those values were classified into the six ES matrix classes.

We used the InVEST Model *Urban Cooling* [23]. This model calculates a heat mitigation index that estimates the cooling effect of urban green areas based on shade, evapotranspiration, albedo, building intensity, and the distance from green and open spaces. This information must be provided in a biophysical table and linked to LULC types (see Table S5 and S6). We used LULC data, which has also been used for the InVEST pollination model, in raster format (5 x 5 m resolution).
Shade has been calculated using Tree Cover Density [6] from 2015 and the ArcGIS tool zonal statistics to table. For the values of albedo and building intensity, literature data from Stewart and Oke (2012) [17] were used. We used the monthly 1 x 1 km raster of the potential evapotranspiration (ETp) over grass [7] to calculate the crop coefficient (K_c), which is needed in the biophysical table. The Food and Agriculture Organization of the United Unions provides K_c values for crops and for the different crop growth stages [14]. Nistor (2018; 2016) [15,16] provided a list of the different crop growth stages (spring (k_c ini), summer (k_c mid), autumn (k_c end), and winter (k_c cold)) for each LULC of the CLC dataset. We adapted those values for the Urban Atlas classes (see Figure S1).

Code CLC	CLC Label	Kc cold	Kc ini	Kc mid	Kc end	Urban Atlas Code	Urban Atlas Label	Kc cold	Kc ini	Kc mid	Kc end
111	Continuous urban fabric	0	0.2	0.4	0.25	11100	Continuous urban fabric (S.L. : > 80%)	0	0.2	0.4	0.25
112	Discontinuous urban fabric	0	0.1	0.3	0.2	11210	Discontinuous Dense Urban Fabric (S.L. : 50% - 80%)	0	0.1	0.3	0.2
						11220	Discontinuous Medium Density Urban Fabric (S.L. : 30% - 50%)	0	0.17	0.51	0.34
						11230	Discontinuous Low Density Urban Fabric (S.L. : 10% - 30%)	0	0.22	0.69	0.46
						11240	Discontinuous very low density urban fabric (S.L. : < 10%)	0	0.26	0.78	0.51
121	Industrial or commercial units	0	0.2	0.4	0.3	12100	Industrial, commercial, public, military and private units	0	0.2	0.4	0.3
121	Road and rail networks and associated land	0	0.15	0.35	0.25	12210	Fast transit roads and associated land	0	0.15	0.35	0.25
121		0	0.15	0.35	0.25	12230	Railways and associated land	0	0.15	0.35	0.25
122		0	0.15	0.35	0.25	12220	Other roads and associated land	0	0.15	0.35	0.25
123	Port areas	0	0.3	0.5	0.4	12300	Port areas	0	0.3	0.5	0.4
124	Airports	0	0.2	0.4	0.3	12400	Airports	0	0.2	0.4	0.3
131	Mineral extraction sites	0	0.16	0.36	0.26	13100	Mineral extraction and dump sites	0	0.16	0.36	0.26
132	Dump sites	0	0.16	0.36	0.26	13100	Mineral extraction and dump sites	0	0.16	0.36	0.26
133	Construction sites	0	0.16	0.36	0.26	13300	Construction sites	0	0.16	0.36	0.26
141	Green urban areas	0	0.12	0.32	0.22	14100	Green urban areas	0	0.12	0.32	0.22
142	Sport and leisure facilities	0	0.1	0.3	0.2	14200	Sports and leisure facilities	0	0.1	0.3	0.2
211	Non-irrigated arable land	0	1.1	1.35	1.25	21000	Arable land (annual crops)	0	1.12	1.33	1.07
212	Permanently irrigated land	0	1.2	1.45	1.35						
213	Rice fields	0	1.05	1.2	0.6						
221	Vineyards	0	0.3	0.7	0.45	22000	Permanent crops (vineyards, fruit trees, olive groves)	0	0.42	0.82	0.53
222	Fruit trees and berry plantations	0	0.3	1.05	0.5						
223	Olive groves	0.5	0.65	0.7	0.65						
231	Pastures	0	0.4	0.9	0.8	23000	Pastures	0	0.4	0.9	0.8
241	crops	0	0.5	0.8	0.7						
242	Complex cultivation patterns	0	1.1	1.35	1.25	24000	Complex and mixed cultivation patterns	0	1.1	1.35	1.25
243	Land principally occupied by agriculture, with significant areas of natural vegetation	0	0.7	1.15	1	25000	Orchards	0	0.7	1.15	1
244	Agro-forestry areas	0.3	0.9	1.1	1.05						
311	Broad-leaved forest	0.6	1.3	1.6	1.5	31000	Forests	0.6	1.3	1.6	1.5
312	Coniferous forest	1	1	1	1						
313	Mixed forest	0.8	1.2	1.5	1.3						
321	Natural grasslands	0	0.3	1.15	1.1	32000	Herbaceous vegetation associations (natural grassland, moo[illegible]	0	0.5375	1.0125	0.95
322	Moors and heathland	0	0.8	1	0.95						

Figure S1: Standardised Kc values for CORINE Land Cover and Urban Atlas, adapted from Nistor (2018; 2016) [61,62].

We used 120 m as the maximum air temperature blending distance based on the literature values of Huang et al. (2018) and Goldenberg et al. (2017) [30,31]. The Climate Data Center (CDC) provided data for the rural reference temperature (°C) [9]. The Global Surface UHI Explorer [10] provided the nightly magnitude of the urban heat island effect, which expresses the difference between the maximum temperature in the city and the rural areas by night.

Table S8. Biophysical table for the InVEST model *Urban Cooling*, urban region of Munich.

lucode	lulc_desc	shade	kc	albedo	green_area	building_intensity
211	Non-irrigated arable land	0.02	1.09	0.2	1	0.05
222	Fruit trees and berry plantations	0.02	0.69	0.225	1	0.05
311	Broad-leaved forest	0.75	1.38	0.15	1	0.05
312	Coniferous forest	0.84	1	0.15	1	0.05
313	Mixed forest	0.82	1.32	0.15	1	0.05
321	Natural grasslands	0.17	0.79	0.2	1	0.05
322	Moors and heathland	0.68	0.8	0.225	1	0.05
324	Transitional woodland-shrub	0.65	0.8	0.225	1	0.05
331	Beaches, dunes, sands	0.03	0.23	0.275	0	0.05
332	Bare rocks	0.07	0.15	0.225	0	0.05
333	Sparsely vegetated areas	0.20	0.46	0.25	1	0.05
411	Inland marshes	0.19	0.34	0.225	1	0.05
412	Peat bogs	0.25	0.29	0.225	1	0.05
512	Water bodies	0.03	0.5	0.06	1	0.05
11100	Continuous urban fabric (S.L.: > 80%)	0.05	0.29	0.15	0	0.55
11210	Discontinuous dense urban fabric (S.L.: 50% - 80%)	0.14	0.2	0.15	0	0.55
11220	Discontinuous medium-density urban fabric (S.L: 30% - 50%)	0.14	0.35	0.185	0	0.3
11230	Discontinuous low-density urban fabric (S.L.: 10% - 30%)	0.12	0.47	0.185	1	0.3
11240	Discontinuous very low-density urban fabric (S.L.: < 10%)	0.05	0.53	0.185	1	0.15
11300	Isolated Structures	0.06	0.53	0.185	1	0.15

12100	Industrial, commercial, public, military and private units	0.07	0.29	0.185	0	0,35
12210	Fast transit roads and associated land	0.09	0.25	0.2	0	0,4
12220	Other roads and associated land	0.08	0.25	0.2	0	0,4
12230	Railways and associated land	0.10	0.25	0.2	0	0,4
12300	Port areas	0.00	0.38	0.16	0	0,25
12400	Airports	0.02	0.29	0.225	0	0,05
13100	Mineral extraction and dump sites	0.02	0.26	0.275	0	0,05
13300	Construction sites	0.03	0.26	0.275	0	0,05
13400	Land without current use	0.15	0.2	0.25	0	0,05
14100	Green urban areas	0.41	0.22	0.2	1	0,05
14200	Sports and leisure facilities	0.13	0.2	0.2	1	0,05
21000	Arable land (annual crops)	0.05	1.07	0.2	1	0,05
22000	Permanent crops (vineyards, fruit trees, olive groves)	0.05	0.59	0.2	1	0,05
23000	Pastures	0.03	0.65	0.2	1	0,05
31000	Forests	0.53	1.38	0.175	1	0,05
32000	Herbaceous vegetation associations (natural grassland, moors…)	0.05	0.75	0.2	1	0,05
40000	Wetlands	0.14	0.34	0.06	1	0,05
50000	Water	0.17	0.53	0.06	1	0,05

Table S9. Biophysical table for the InVEST model *Urban Cooling*, urban region of Rostock.

lucode	lulc_desc	shade	kc	albedo	green_area	building_intensity
211	Non-irrigated arable land	0.01	1.11	0.2	1	0.05
222	Fruit trees and berry plantations	0.01	0.71	0.225	1	0.05
311	Broad-leaved forest	0.79	1.4	0.15	1	0.05
312	Coniferous forest	0.79	1	0.15	1	0.05
313	Mixed forest	0.79	1.33	0.15	1	0.05
321	Natural grasslands	0.08	0.8	0.2	1	0.05
322	Moors and heathland	0.1	0.82	0.225	1	0.05
333	Sparsely vegetated areas	0.04	0.47	0.25	1	0.05
334	Burnt areas	0.74	0.47	0.275	0	0.05
411	Inland marshes	0.17	0.34	0.225	1	0.05
412	Peat bogs	0.24	0.29	0.225	1	0.05
511	Water courses	0	0.5	0.06	1	0.05
512	Water bodies	0	0.5	0.06	1	0.05
521	Coastal lagoons	0	0.5	0.06	1	0.05
523	Sea and ocean	0	0.5	0.06	1	0.05
11100	Continuous urban fabric (S.L.: > 80%)	0.02	0.29	0.15	0	0.55
11210	Discontinuous dense urban fabric (S.L.: 50% - 80%)	0.1	0.21	0.15	0	0.55
11220	Discontinuous medium-density urban fabric (S.L: 30% - 50%)	0.1	0.35	0.185	0	0.3
11230	Discontinuous low-density urban fabric (S.L.: 10% - 30%)	0.08	0.48	0.185	1	0.3
11240	Discontinuous very low-density urban fabric (S.L.: < 10%)	0.09	0.54	0.185	1	0.15
11300	Isolated Structures	0.06	0.54	0.185	1	0.15

12100	Industrial, commercial, public, military and private units	0.05	0.3	0.185	0	0.35
12210	Fast transit roads and associated land	0.05	0.25	0.2	0	0.4
12220	Other roads and associated land	0.08	0.25	0.2	0	0.4
12230	Railways and associated land	0.11	0.25	0.2	0	0.4
12300	Port areas	0.03	0.38	0.16	0	0.25
12400	Airports	0.02	0.3	0.225	0	0.05
13100	Mineral extraction and dump sites	0.02	0.26	0.275	0	0
13300	Construction sites	0.02	0.26	0.275	0	0.05
13400	Land without current use	0.18	0.21	0.25	0	0.05
14100	Green urban areas	0.4	0.23	0.2	1	0.05
14200	Sports and leisure facilities	0.16	0.21	0.2	1	0.05
21000	Arable land (annual crops)	0.01	1.1	0.2	1	0.05
22000	Permanent crops (vineyards, fruit trees, olive groves)	0.15	0.6	0.2	1	0.05
23000	Pastures	0.04	0.66	0.2	1	0.05
31000	Forests	0.66	1.4	0.175	1	0.05
32000	Herbaceous vegetation associations (natural grassland, moors…)	0.29	0.77	0.2	1	0.05
33000	Open spaces with little or no vegetation (beaches, dunes, bare rocks, glaciers)	0.01	0.47	0.275	0	0.05
40000	Wetlands	0.16	0.34	0.06	1	0.05
50000	Water	0.17	0.54	0.06	1	0.05

5. Coastal protection

The demand for coastal protection can be expressed in different ways. It can, for example, be expressed by the need or desire of the population to reduce or avoid the risks caused by flooding, increased current velocities, storm surges, sediment erosion or sea-level rise. The assessment of the demand can be assessed following the Floods Directive (Directive 2007/60/EC) of the European Parliament on the assessment and management of flood risks. In Germany, the Floods Directive is used to assess and manage flood risks and to protect assets (in german: Schutzgüter) like human health, the environment, cultural heritage and human economic activities. The directive considers both river and coastal flood events. Flood hazard and risk maps show areas at significant risk, expected flood extents and water depths for three scenarios [11]. We mapped an exemplary coastal flood event with a statistical 200-year recurrence interval and followed the methodology steps from INTEK (2014) [13]:

1. Classification of expected water depths (=flood hazard) into six classes (see Table S10);

Table S10: Classification of flood hazard

Classification	Flood hazard	Expected water depth (m)
5	Very high	>4
4	High	>2 - ≤4
3	Medium	>1 - ≤2
2	Low	>0.5 - ≤1
1	Very low	>0 - ≤0.5
0	Extreme low	0

2. Classification of the potential damage for each asset into six classes (Table S11 – Table S14). The assets were derived from population density, biotopes, runoff paths, digital elevation model, historical buildings, LULC;

Table S11: Classification of the potential damage for the asset cultural heritage.

Classification	Potential damage	Buildings
5	Very high	Historical buildings

4	High	-
3	Medium	-
2	Low	-
1	Very low	-
0	Extreme low	-

Table S12: Classification of the potential damage for the asset environment.

Classification	**Potential damage**	**Biotops**
5	Very high	-
4	High	-
3	Medium	-
2	Low	Biotopes downstream of industrial buildings classified as IED buildings/areas (Industrial Emissions Directive (2010/75/EU))
1	Very low	Other biotopes
0	Extreme low	Water and wetland biotopes

Table S13: Classification of the potential damage for the asset infrastructure.

Classification	Potential damage	Infrastructure
5	Very high	-
4	High	-
3	Medium	Main roads, port facilities, railway lines
2	Low	Other streets
1	Very low	Paths
0	Extreme low	-

Table S14: Classification of the potential damage for the asset human economic activities.

Classification	**Potential damage**	**LULC**
5	Very high	-
4	High	Industrial and commercial area, residential area
3	Medium	Tree nursery, orchard, garden, sport and leisure area
2	Low	Cemetery
1	Very low	Agricultural area, pastures, forest
0	Extreme low	-

3. Calculation of the coastal flood risk by multiplying flood hazard values with the potential damage values;
4. Classification of the coastal flood risk of each asset into six ES classes (Table S15).

Table S15: Classification of the coastal flood risks into six ES classes

Asset	**Classification**
Human health	5 – very high: >100 4 – high: >75 - ≤100 3 – medium: >50 - ≤75 2 – low: >25 - ≤50 1 – very low: >0 - ≤25 0 – extreme low: 0

Cultural heritage	5 – very high: ≥4.5 4 – high: ≥3.5 - <4.5 3 – medium: ≥2.5 - <3.5 2 – low: ≥1.5 - <2.5 1 – very low: >0 - <1.5 0 – extreme low: 0
Environment	5 – very high: >7 4 – high: >5 - ≤7 3 – medium: >3 - ≤5 2 – low: >2 - ≤3 1 – very low: >1 - ≤2 0 – not relevant: 0
Infrastructure	5 – very high: >7 4 – high: >5 - ≤7 3 – medium: >3 - ≤5 2 – low: >2 - ≤3 1 – very low: >1 - ≤2 0 – not relevant: 0
Human economic activities	5 – very high: >7 4 – high: >5 - ≤7 3 – medium: >3 - ≤5 2 – low: >2 - ≤3 1 – very low: >1 - ≤2 0 – not relevant: 0

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