A Survey of Croatia's NSDI Performance: A Task-Based Assessment

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Abstract We introduced a novel, task-based approach to Spatial Data Infrastructure (SDI) assessment that differs significantly from the predecessor's methods. Rather than employing generic metrics, our framework evaluates SDI performance through the experience of developers addressing specific spatial challenges. By answering the specific research question "Where can trees be planted in Croatian cities to effectively mitigate the Urban Heat Island effect?" as our use case, we assessed Croatia's national SDI from a practical perspective. This approach prioritized actual data accessibility and usability for real-world applications over theoretical completeness. Through our proposed Key Performance Indicators (KPIs), we identified limitations of Croatia's SDI when applied to our use case. Building on these findings, we offered targeted recommendations to enhance data completeness, optimize user experience, and generate high-value datasets. The contributions of this paper are threefold: (1) a novel, use case-driven SDI evaluation framework; (2) a detailed assessment of Croatia's national SDI using this framework; and (3) suggestions for SDI enhancement based on identified performance gaps.

Keywords: Spatial Data Infrastructure; Assessment Framework; Croatia; Urban Heat Island; Climate Initiative.

1. Introduction

The role of spatial data in shaping our future cities cannot be overstated, particularly when addressing global challenges such as climate change, urbanization, resource management, and environmental sustainability (United Nations General Assembly, 2015). High-quality spatial data and well-structured Spatial Data Infrastructures (SDIs) are essential for informed decision-making and effective policy implementation. However, ensuring the usability and accessibility of these infrastructures requires continuous assessment and improvement.

Various frameworks have been developed to evaluate SDIs (Kok and van Loenen, 2005; Giff, 2006; Grus et al., 2007; Giff and Crompvoets, 2008), often focusing on structural components such as compliance with INSPIRE criteria or data availability. While these approaches provide valuable insights, they frequently overlook the practical experiences of end users in real-world applications. Additionally, the complexity of existing assessment methods can make it difficult to measure the true effectiveness of an SDI.

This study evaluates the performance of Croatia's SDI through a task-based approach, focusing on its ability to support developers decision-making in urban reforestation. The effectiveness of an SDI lies in its capacity to provide easy access to spatial data that enables informed economic, social, and environmental decision-making at all levels, from local governance to global sustainability efforts (Rajabifard et al., 2003). In this context, we assess how well Croatia's SDI facilitates the creation and use of spatial datasets to advance the country's green transition. Specifically, this research examines the SDI's role in supporting urban tree-planting initiatives aligned with the EU's goal of planting 3 billion trees by 2030. This initiative follows the principle of "the right tree in the right place for the right purpose" (European Commission, 2021).

In the context of Croatia, the Urban Heat Island (UHI) effect presents a significant challenge for sustainable city planning (EBRD and DG Reform, 2024a,b). Expanding tree cover in urban areas is a well-documented strategy for mitigating rising temperatures, improving air quality, and enhancing biodiversity. This leads to the central case study question of this research: "Where can trees be planted in Croatian cities to effectively mitigate the UHI effect?" which is summed up in Figure 1.

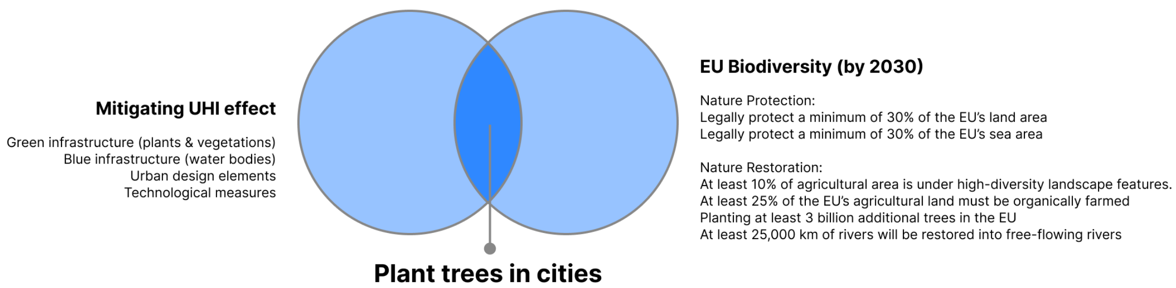


Figure 1: *How the proposed research question intersects with EU and Croatia's green transition.*

To address this, we propose a structured, novel methodology that evaluates the Croatian SDI's ability to support spatial analysis and decision-making for urban reforestation. The study follows a 5-step approach:

1. Identifying the necessary spatial datasets (see Table 2).

2. Collecting relevant data for the defined use case in reference to the NSDI.
3. Collecting relevant data for the defined use case in reference to international SDI's and open data initiatives, for supplementation and comparison.
4. Conducting spatial analysis to determine optimal planting locations (see Figure 7).
5. Validating results for accessibility and applicability (see Tables 3 and 4).

The effectiveness of the NSDI will be assessed and presented in Section 3, by documenting the challenges encountered in obtaining the necessary datasets, which are defined in Section 2 for calculating the UHI index. In the case of inadequate capacity, International SDI's and open datasets will be used to supplement the data. Section 4 will make recommendations to the Croatian NSDI, in order to develop the Green Transition, and better support developers. Finally, Section 5 will present the conclusions.

2. Methodology

2.1 Approach

This study employs a structured approach to evaluate SDI through open government data portals. Figure 2 presents the research flow chart. Our research focuses on Croatia's capital city—Zagreb—where we aim to determine the optimal locations for planting trees to mitigate the UHI effect. To address this, we use UHI mapping data (temperature, radiation, sky view factor, etc.) and tree data. Data collection is not limited to Croatia's official sources; however, we prioritize official sources first, specifically from government-hosted data portals and designated data management companies. We conduct a practical survey of SDI evaluation by identifying relevant data portals, retrieving available datasets, and assessing their usability. This approach provides deeper insights into how developers perceive portals data while ensuring a reliable assessment of its applicability to our research question.

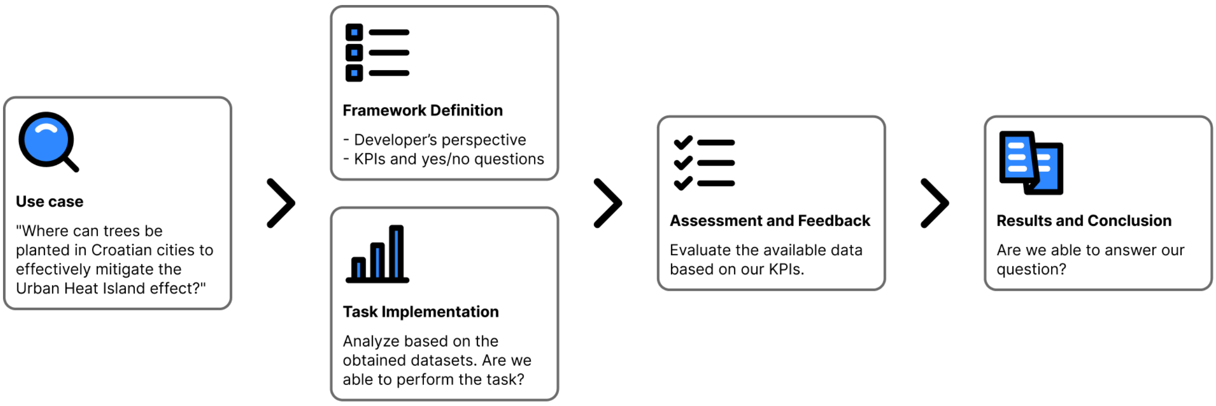


Figure 2: *Research flow chart.*

2.2 Proposed Assessment Framework

Building on the ecosystem approach from the work of Seljan et al. (2022), we simplified our evaluation model to focus solely on the question, "Can we conduct our use case study or not?" and its related tasks involved in the process. The originally assessment framework from referenced work consists of five categories:

1. Supply side;
2. Demand side by researcher / developer;
3. Demand side by ordinary users (only conceptually developed);
4. Legal and privacy aspects (only conceptually developed);
5. Impact side through innovation perspective (only conceptually developed).

In the referenced work, only two categories—supply and demand by researchers or developers—are explicitly defined, while the remaining three—demand by end-users, legal aspects, and impact—are conceptually developed for assessing future applications. Although the demand from inexperienced end-users introduces a critical dimension for pushing the ecosystem to a next generation of SDI, having them perform this task is impractical. The analyses and operations require a certain level of geographic information system (GIS) proficiency, and defining the exact skill level of all the inexperienced users is challenging—let alone creating an imaginary persona to do the task.

In our proposed assessment framework, we chose to only focus on needs of researchers, developers or data analysts (the second category of the referenced framework). We prioritized fulfilling the use case's requirements from the perspective of these groups of people rather than to develop a more objective and comprehensive assessment framework. Figure 3 presents the proposed model.

Moreover, we simplified the complex key performance indicators (KPIs) and the corresponding 5-point Likert scale by focusing only on aspects relevant to our use case study, using a binary assessment: true or false. For each KPI, a detailed description is provided to facilitate the process, as shown in Table 1. We also offer suggestions and draw conclusions for each indicator based on the SDI's performance.

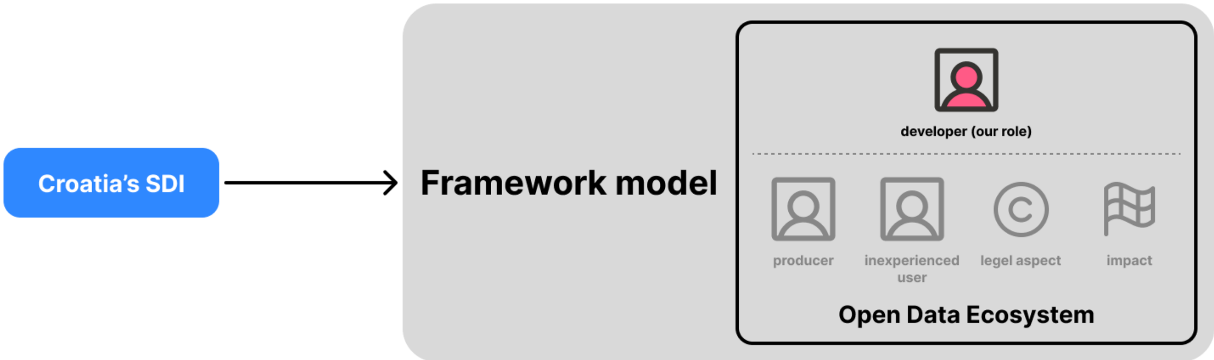


Figure 3: *Proposed assessment framework*

Domain	KPI	Description	Answer
Timeliness	Up-to-date	Are the data up to date according to our purpose?	Yes / No (suggestion)
Processability	Processable	Data provided in a machine-processable format(s) fit for our use case.	Yes / No (suggestion)
Licensing	Licensed for Our Use	Does the license allow for usage fitting our use case?	Yes / No (suggestion)
Ease of access	Availability	Can the data be found?	Yes / No (suggestion)
	Downloadable	Are data available for download via the portal or its associated webpage?	Yes / No (suggestion)
	Free to Use	Is the dataset available free of charge?	Yes / No (suggestion)
	Direct Download	Can the data be downloaded directly without needing permission from others?	Yes / No (suggestion)
	Download Filters	Can the data be filtered before download?	Yes / No (suggestion)
	Multilingual	Is the portal and its data multilingual (or in English)?	Yes / No (suggestion)
Task specific	Completeness	Downloaded data is complete and without defects (according to our use case)	Yes / No (suggestion)
	Other	Other task depending issues	Suggestion

Table 1: *Evaluation criteria according to the use case*

2.3 Required Data

The following formula, derived from Tygron Support Team (2024), is used to calculate UHI, and thus the following data are necessary:

$$UHI_{max} = (2 - S_{vf} - F_{veg}) \cdot \sqrt[4]{\frac{S \cdot (T_{max} - T_{min})^3}{U}} \quad (1)$$

- S_{vf} is the calculated average sky view factor.
- F_{veg} is the calculated average vegetation fraction.
- S is the calculated daily average global radiation in $K \cdot m/s$ (Kelvin meter per second).
- T_{max} is the maximum temperature measured at a weather station between 8 AM and 7 AM the next day.
- T_{min} is the minimum temperature measured at a weather station between 8 AM and 7 AM the next day.
- U is the daily average wind speed measured at 10 meters above ground at a weather station.

Both completing the task and assessing Croatia's NSDI are equally important in this study. We utilize data from Croatia's national portals first, and if it is unavailable, we will then explore other international data sources. Note that some datasets are actually derived from others and thus have alternative substitutes when specific data is missing. We prioritize data that best meets our needs while minimizing processing effort. For instance:

- Sky view factor can be derived from a normalised digital surface model (n-DSM).
- Vegetation fraction can be derived from a land cover map.
- Global radiation can be derived from digital surface model (DSM) and weather data.
- Both temperature and wind speed map can be derived from a discrete weather station data with spatial interpolation techniques.

In addition, we plan to also utilize the existing buildings, traffic, and trees data to decide what specific region are suitable to plant. The datasets and their portal are stated in Table 2.

Purpose	**Dataset (ID)**	**Source**	**Link**
To obtain S_{vf}	Sky View Factor (**SVF**)	National	not found
		International	not found
	n-DSM (**NDSM**)	National	dgu.gov.hr
		International	not found
To obtain F_{veg}	Fraction of Vegetation (**FV**)	National	not found
		International	copernicus.eu
	Land Cover Map (**LC**)	National	geoportal.nipp.hr
		International	ESA (google.com)
To obtain S	Global Radiation (**GR**)	National	not found
		International	globalsolaratlas.info
	DSM (**DSM**)	National	dgu.gov.hr
		International	not found
To obtain T_{max} and T_{min}	Temperature (**T**)	National	meteo.hr
		International	ECMWF (google.com)
To obtain U	Wind Speed (**WS**)	National	meteo.hr
		International	ECMWF (google.com)
To obtain existing trees	Tree Data (**TREE**)	National	not found
		International	not found
To obtain land use zoning	Land Use Map (**LU**)	National	geoportal.nipp.hr
		International	not found
To obtain buildings	Building Objects (**BO**)	National	data.gov.hr
		International	not found
To obtain traffic contours	Traffic Objects (**TO**)	National	data.gov.hr
		International	not found

Table 2: *The required datasets and their providers*

3. Implementation and Results

3.1 UHI Modeling Process

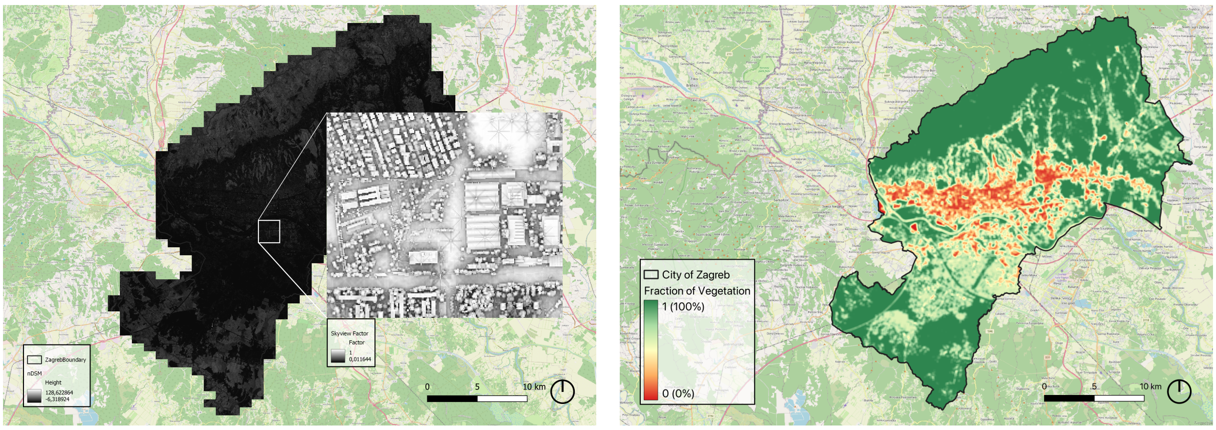
To model the UHI effect, we utilized the open-source Quantum GIS (QGIS) and GRASS GIS software, integrating both collected datasets and derived datasets obtained through open-source plugins.

The Sky View Factor (SVF) was computed using the 'Terrain Shading' plugin (Landscape Archaeology, 2024). This analysis was conducted on the normalized Digital Surface Model (nDSM) obtained from dgu.gov.hr. Due to time constraints, the original nDSM was rescaled to a lower resolution to optimize processing performance. The resulting SVF values, ranging from 0 to 1, are presented in Figure 4a, illustrating the distribution of sky visibility within the study area.

The Vegetation Fraction was computed using the land cover dataset obtained from ESA WorldCover v200. The dataset was processed by reclassifying individual pixels based on their land use categories. A moving window averaging algorithm was applied with the following vegetation fraction parameters:

- **1.00** – Tree cover (10), Shrubland (20), Grassland (30), Mangroves (95)
- **0.60** – Cropland (40)
- **0.50** – Herbaceous wetland (90), Moss and lichen (100)
- **0.10** – Bare/sparse vegetation (60)
- **0.05** – Built-up areas (50)
- **0.00** – Snow and ice (70), Permanent water bodies (80)

The results, presented in Figure 4b, were validated against the vegetation fraction dataset developed by the Copernicus Land Monitoring Service (CLMS). Although the CLMS dataset could have been used, we opted against it due to the extended wait time required for access. Nevertheless, both datasets provide comparable results and are viable for this analysis.



(a) nDSM and Sky View factor *(b) Fraction of Vegetation*

Figure 4: *Computed Sky View Factor, and Vegetation fraction*

The UHI_{max} was calculated using the Raster Calculator in QGIS, following the previously defined formula (Equation 1). The results, presented in Figure 5, indicate that the highest temperature increases occur in heavily urbanized areas in the center of Zagreb, however, several cooler zones are distributed throughout the city, primarily influenced by vegetation. The maximum recorded temperature increase is 9.9 °C, with a mean increase of 2.34 °C, and a standard deviation of 1.69 °C.

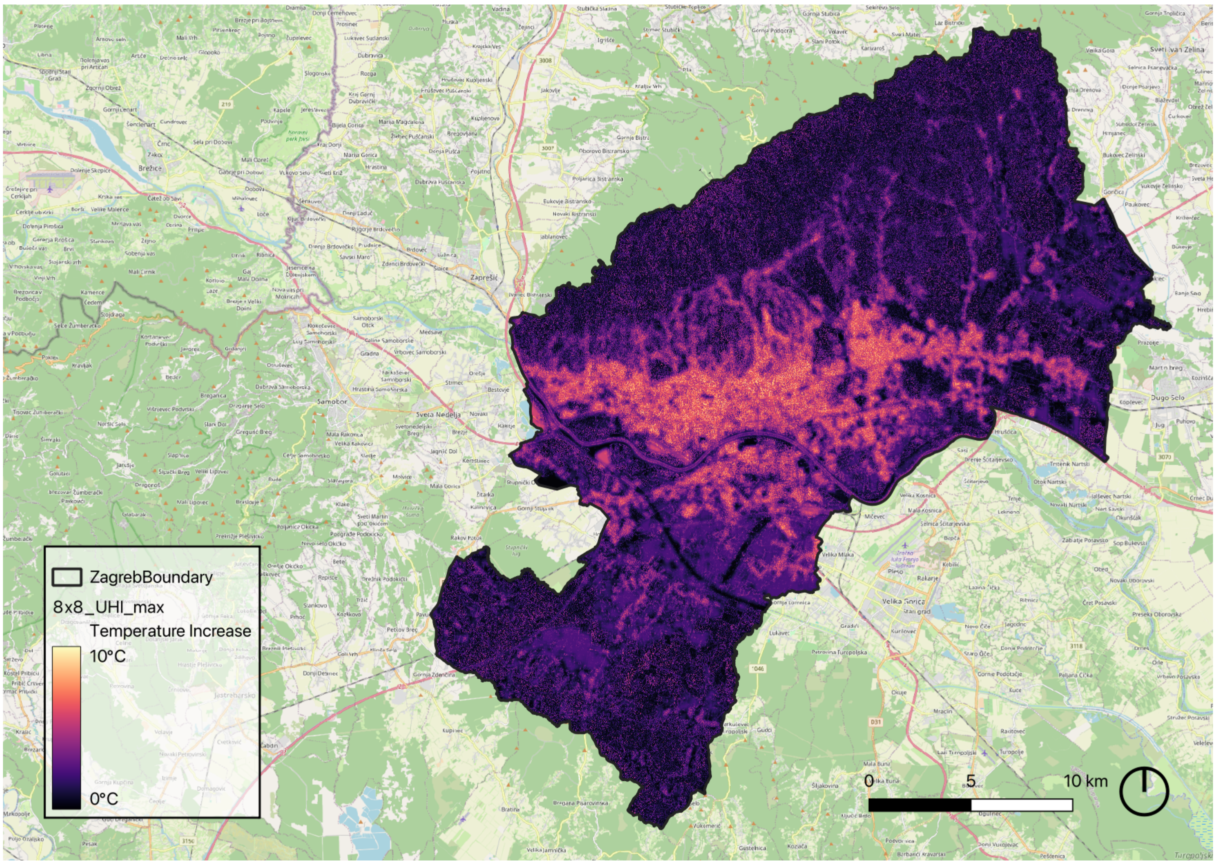


Figure 5: *Maximum temperature increase in July 2024 due to UHI*

3.2 Results

Based on the results of the UHI_{max} calculation and a set of predefined selection criteria, we created a map identifying potential intervention sites for tree planting (Figure 7). This selection aligns with UHI mitigation strategies and the EU's 3 Billion Trees by 2030 initiative. To maximize impact while avoiding disruption to existing infrastructure, the following criteria were applied when selecting suitable locations. Relevant land use data was sourced from ESA WorldCover v200, while building and infrastructure data was obtained from Portal Otvorenih Podataka (POP).

- Does not intersect existing trees,
- Does not intersect water bodies, swamps, or ice-covered areas,
- UHI Index greater than 4,
- Not classified as a building,
- Not located on roads or railway infrastructure.

Several iterations of the UHI_{max} are presented in Figure 6, illustrating the spatial extent of areas experiencing varying levels of overheating. We selected the UHI_{max} with a threshold of 4 °C for further analysis, as it provided the best balance between urban and semi-urban locations.

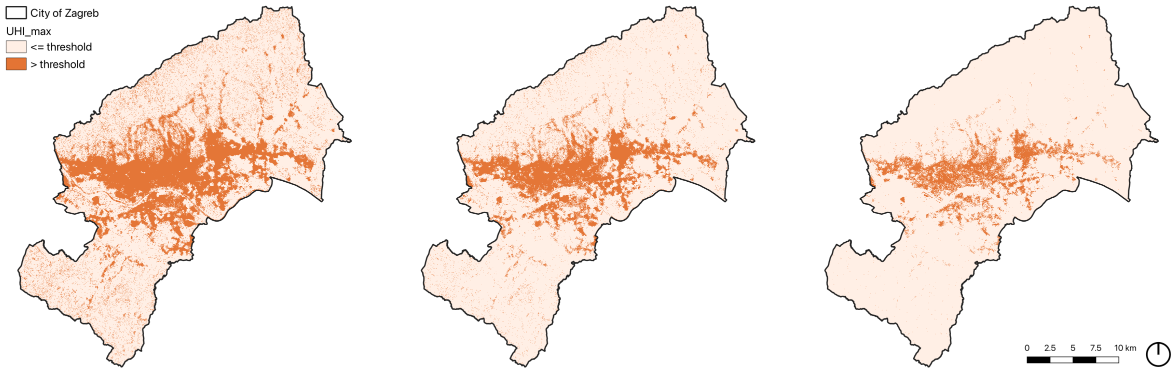


Figure 6: *UHI_{max} with different threshold values (left to right: $3°C$, $4°C$, $5°C$)*

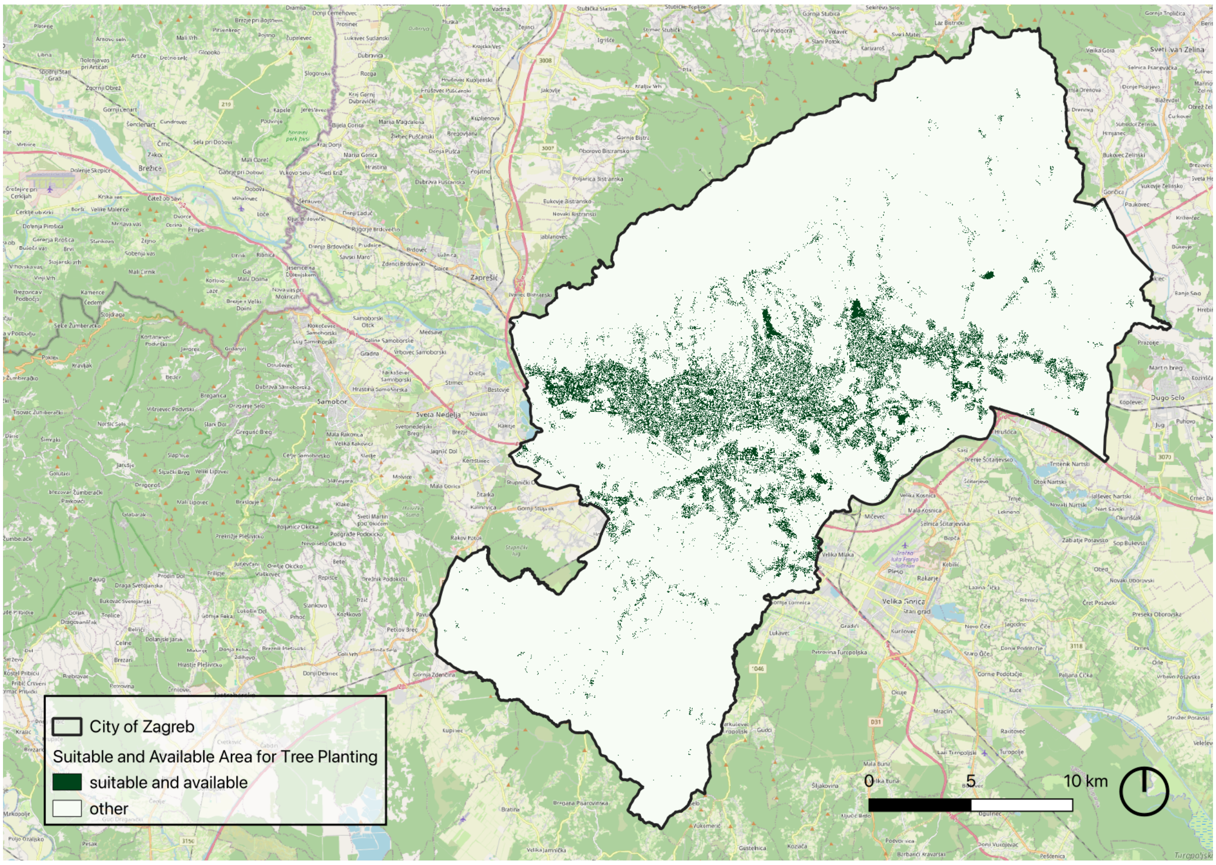


Figure 7: *Resulting plantable area for trees according to UHI mitigation principles*

3.3 Discussion and verification of results

To justify and validate our results, we searched for comparable datasets to assess the distribution of urban overheating. We identified two datasets: one from the EEA (European Environment Agency, 2020) and another from EBRD and DG Reform, 2024b. While the spatial distribution patterns align, the generated values differ due to variations in methodologies and data representation. Our model presents maximum temperature values, whereas the other datasets provide averages. Additionally, the EEA dataset has a spatial resolution of 100x100m, and the second dataset is structured by land use, making both insufficient for our case study on optimal tree planting locations.

Although all three models effectively analyse large Urban areas, such as Zagreb, further investigation is needed to fully understand the extent and impacts of urban overheating. However, our model can serve as a valuable tool for identifying suitable locations for deploying high-precision weather loggers, enabling more accurate monitoring of overheating effects. Additionally, further observations in areas with lower recorded overheating could help identify mitigating factors and refine future analyses.

4. Use case and SDI performance

4.1 Use Case Evaluation

This case study evaluated the potential of the Croatian SDI to generate complex thematic maps that can inform decision-makers on optimal locations for tree planting. The task-based approach focused on developing an Urban Heat Island (UHI) model that practitioners could create using both national and international SDI resources. By aligning this model with the EU's 3 Billion Trees by 2030 initiative, we aimed to demonstrate the multipurpose nature of such maps and indicators, thereby increasing their applicability and potential integration into national policies.

The results of our case study indicate that while it is feasible to develop such models, significant improvements are needed in data availability and public engagement to maximise the Croatian SDI's effectiveness. Enhancing these aspects would allow for broader adoption and better utilisation of geospatial data in the decision-making process.

4.2 Croatian SDI

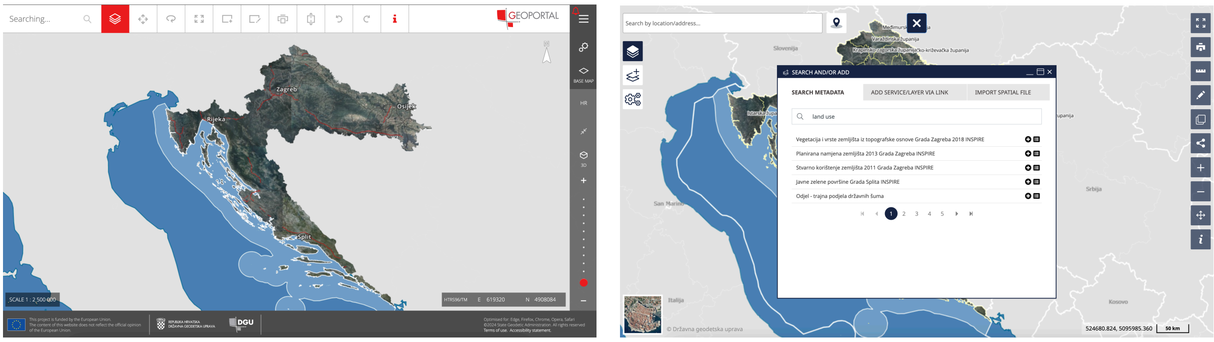
We explored datasets that can be used, starting with the government's datasets from national portals. In Croatia, the government primarily relies on four websites to host geo-spatial data, which we also use as our main sources:

- Državna geodetska uprava (DGU) – State Geodetic Administration geoportal.dgu.hr
- Nacionalna infrastruktura prostornih podataka (NIPP) – National Spatial Data Infrastructure (NSDI) geoportal.nipp.hr
- Portal otvorenih podataka (POP) - Open Data Portal data.gov.hr
- Državni hidrometeorološki zavod (DHMZ) - State Hydrometeorological Institute meteo.hr.

The overall evaluation of national datasets, based on our assessment framework, is summarized in Table 3. This chapter also includes reflections and recommendations for each dataset and data portal.

KPI	SVF	NDSM	FV	LC	GR	DSM	T	WS	TREE	LU	BO	TO
	Dataset ID (National)											
Up-to-date	-	✓	-	✗	-	✓	✓	✓	-	✗	✓	✓
Processable	-	✓	-	✓	-	✓	✓	✓	-	✓	✓	✓
Licensed for Our Use	-	✓	-	✗	-	✓	✗	✗	-	✗	✓	✓
Availability	✗	✓	✗	✓	✗	✓	✓	✓	✗	✓	✓	✓
Downloadable	-	✓	-	✓	-	✓	✓	✓	-	✓	✓	✓
Free to Use	-	✓	-	✓	-	✓	✓	✓	-	✓	✓	✓
Direct Download	-	✗	-	✓	-	✗	✗	✗	-	✓	✓	✓
Download Filters	-	✓	-	✗	-	✓	✓	✓	-	✗	✗	✗
Multilingual	-	✗	-	✗	-	✗	✓	✓	-	✗	✗	✗
Completeness	-	✗	-	✗	-	✗	✓	✓	-	✗	✓	✓

Table 3: *Evaluation result for data from Croatia's official portals*



(a) DGU data viewer

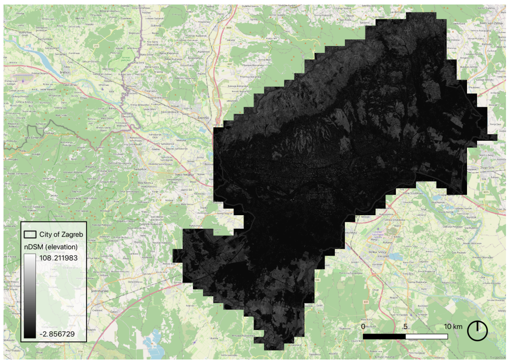
(b) NIPP data viewer

Figure 8: *Screenshots from DGU and NIPP viewers*

DGU: DSM and n-DSM DGU primarily provides data for administrative purposes, such as the spatial units registry, cadastral plans, transportation, buildings, and more. While users can perform basic measurements and draw on the platform, there is no direct option to download the data (Figure 8a). It is designed for simple operations and the convenience of average users, rather than meeting the needs of researchers or developers.

Surprisingly, for our essential raster data, such as n-DSM and DTM, we discovered that they were only available on another website under DGU domain, dgu.gov.hr, and were not directly accessible. Obtaining these datasets was challenging, as it required submitting an application form to the Office for Cadastre and Geodetic Affairs of the City of Zagreb, and the form was only written in Croatian. We received a response in one day and the data was delivered the following day. The data quality from this office was significantly better compared to what we obtained from the other data portals. While the dataset contained minor errors, such as some unrelated image tiles, we were able to quickly clean the data and make it usable (see Figures 9a and 9b).

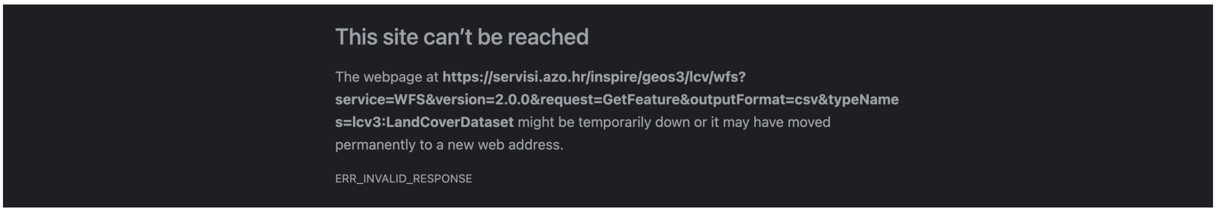
(a) N-DSM raw data



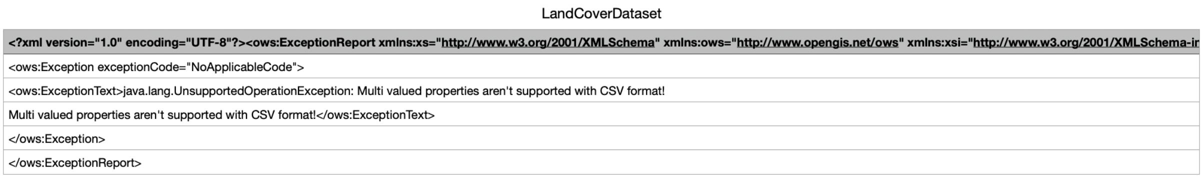
(b) N-DSM after data cleansing

Figure 9: *Data obtained from DGU*

NIPP: Land Cover and Land Use Map NIPP and DGU offered similar services—they both feature their own online data viewers and are both funded by the European Union (Figure 8b). While NIPP offers more comprehensive features, including a data viewer, a list of datasets, options to import additional data, and some analysis functions, it still faces significant challenges. The platform provides access to 398 datasets for online viewing and 149 for download. However, the data import function often fails, and the download links for most of the datasets (`.csv` and `.shp` file) are not functioning (see Figure 11).



(a) The download link cannot be reached

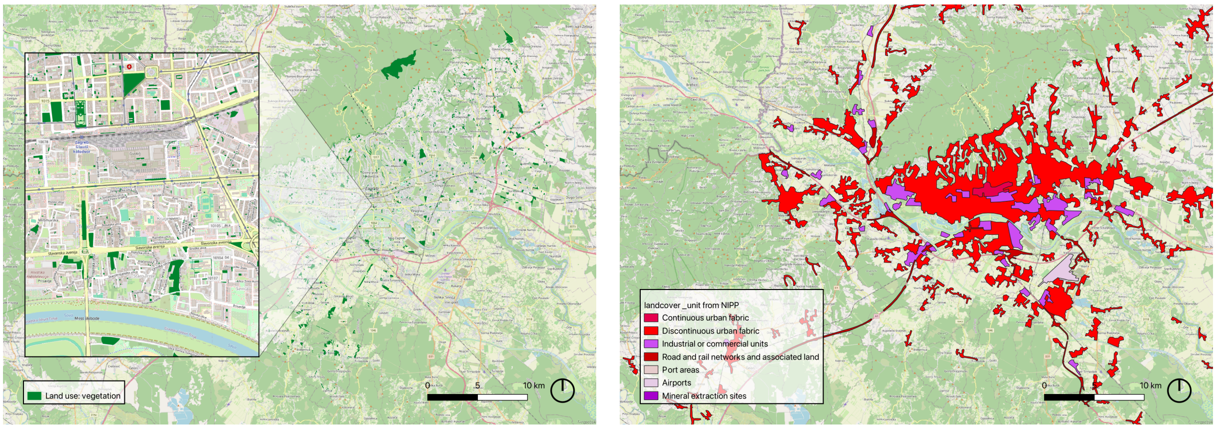


(b) The downloaded file contains nothing

Figure 10: *Malfunctions in NIPP*

We were eventually able to download the vegetation data and land cover data from NIPP in `.csv` and `.json` format. However, this brought about a new set of challenges—these datasets were either incomplete, did not match their titles, or were not suitable for our use case. For instance, the vegetation data (Figure 11a) clearly omits large areas of green land, while the land cover data is missing several classes when compared to the official CORINE dataset (Figure 11b).

POP: Building Objects and Traffic Objects POP is Croatia's data portal for all types of data, including geospatial datasets. The POP utilize CKAN (Comprehensive Knowledge Archive Network). It is an open-source data management system designed for publishing

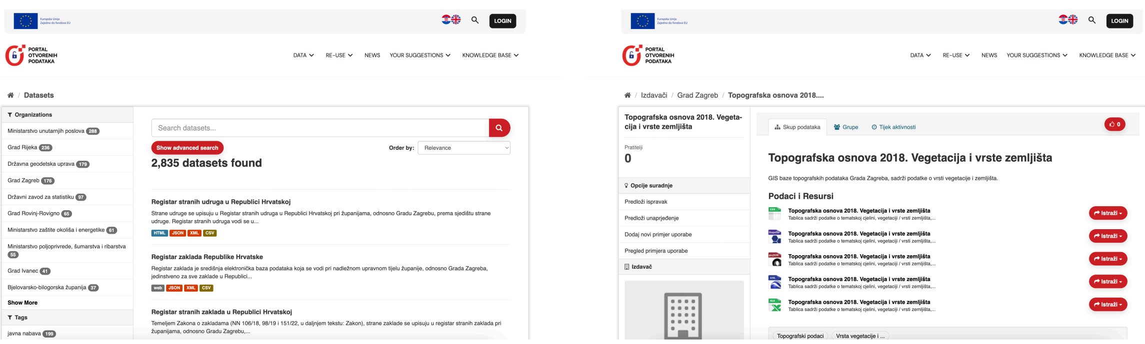


(a) Land use map for vegetation *(b) Land cover data*

Figure 11: *Land cover data from NIPP in the extent of the city of Zagreb*

and managing datasets. It provides tools for dataset search, access control, and metadata management, making it better compare to other Croatia's data portals (Figure 12).

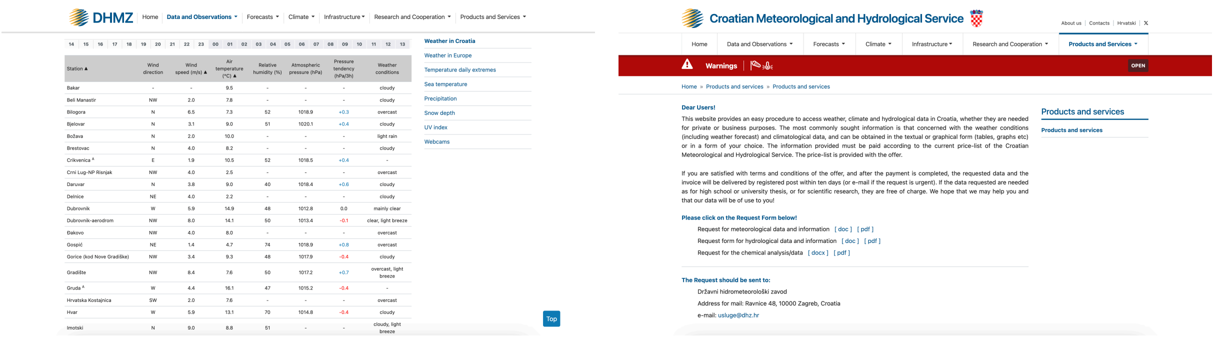
We obtained Building Objects and Traffic Objects datasets from POP. The overall completeness, quality, and even download instructions were nice for these two datasets. POP also hosts some of the same datasets from NIPP (such as vegetation and land cover maps) but offers more download options beyond WFS. However, the datasets remain incomplete and ultimately unusable (Figure 11).



(a) POP data list *(b) POP download options*

Figure 12: *POP: open data portal*

Weather data from DHMZ: Temperature and Wind Speed The weather data from DHMZ meteo.hr is not directly downloadable (Figure 13). However, data for individual stations can be requested by submitting an application form. Instead, we obtained historical weather data from a third-party portal. While it was provided as numerical values rather than the desired raster format, it was still usable since we could directly input the numbers into our calculation formula.



(a) DHMZ weather for today *(b) DHMZ download request description*

Figure 13: *DHMZ weather data*

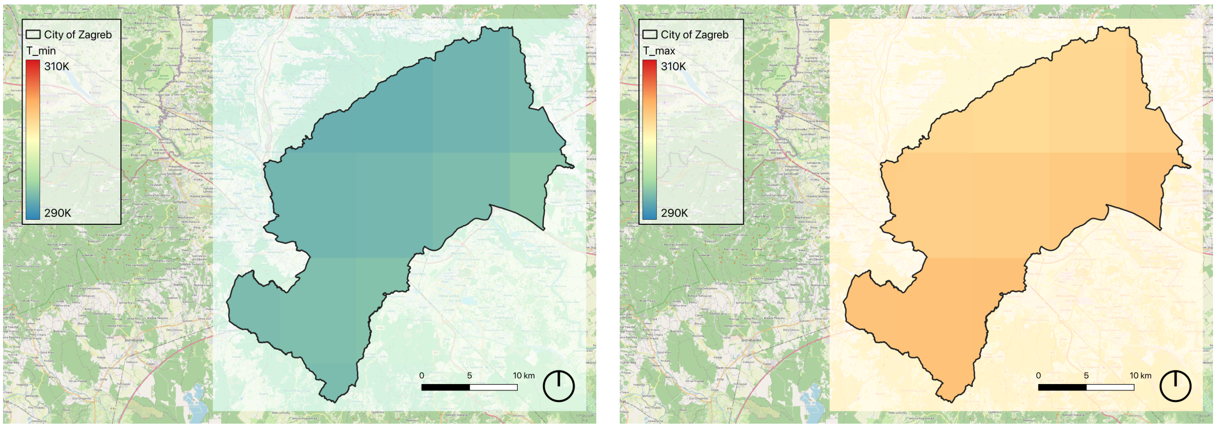
4.3 EEA and International Data Supplement

To supplement data which is lacking in the NSDI we will focus on the different thematic maps that the European Environment Agency (EEA) supplies. We consider this a reliable data source, as it is partially funded by Croatia through the EU, and can therefore be regarded as an extension of the country's own SDI. By integrating these external datasets, the gaps left by NSDI can be filled, improving the overall completeness and usability of geospatial analysis. The overall evaluation of government datasets, based on our assessment framework, is summarized in Table 4.

	Dataset ID (International)											
KPI	SVF	NDSM	FV	LC	GR	DSM	T	WS	TREE	LU	BO	TO
Up-to-date	-	-	✓	✓	✓	-	✓	✓	-	-	-	-
Processable	-	-	✓	✓	✓	-	✓	✓	-	-	-	-
Licensed for Our Use	-	-	✓	✓	✓	-	✓	✓	-	-	-	-
Availability	✗	✗	✓	✓	✓	✗	✓	✓	✗	✗	✗	✗
Downloadable	-	-	✓	✓	✓	-	✓	✓	-	-	-	-
Free to Use	-	-	✓	✓	✓	-	✓	✓	-	-	-	-
Direct Download	-	-	✓	✓	✓	-	✓	✓	-	-	-	-
Download Filters	-	-	✓	✓	✓	-	✓	✓	-	-	-	-
Multilingual	-	-	✓	✓	✓	-	✓	✓	-	-	-	-
Completeness	-	-	✓	✓	✓	-	✓	✓	-	-	-	-

Table 4: *Evaluation result for international datasets*

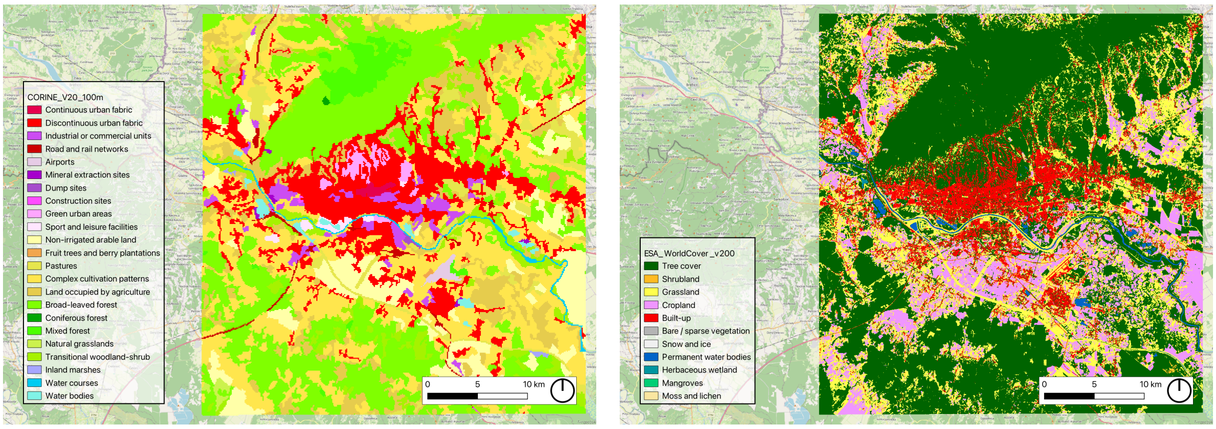
ECMWF: Temperature and Wind Speed European Centre for Medium-Range Weather Forecasts (ECMWF) Climate Reanalysis offers continuous weather data, providing high-resolution historical and real-time (till 2025-03-03) climate variables. We obtained T_{max}, T_{min} and wind speed data from Google Earth Engine using its built-in code editor to filter the desired spatial extent and time period.



(a) *Min temperature (T_{min}) map* *(b)* *Max temperature (T_{max}) map*

Figure 14: *T_{min} and T_{max} in the extent of the city of Zagreb*

ESA: Land Cover Map ESA WorldCover v200 supplies detailed and up-to-date (till 2022-01-01) land cover classification with global coverage at 10-meter resolution. This dataset is also hosted by Google Earth Engine and was obtained in the same way as the ECMWF weather data.



(a) *Copernicus CORINE Land Cover* *(b)* *ESA WorldCover v200*

Figure 15: *Land cover maps in the extent of the city of Zagreb*

Solaratlas: Global Radiation Solar irradiation data, sponsored by The World Bank Group and Solargis, provides high-quality estimates of solar energy potential for direct download. It has a decent viewer, complete metadata, and can be filtered before download. However, the dataset does not account for buildings, making it unsuitable for a solar radiation study in an urban area.

Google Earth Engine Many of the international datasets are hosted on Google Earth Engine, allowing for easy filtering, cropping, and pre-processing before download using its work environment and code editor. It offers a vast collection of geospatial data with a well-organized catalog, providing detailed metadata such as band names, color schemes, resolution, and available time periods. For instance, when selecting a land cover dataset, we can choose between the CORINE Land Cover and the ESA WorldCover v200 map, making it possible to prioritize either the most up-to-date information or the dataset with greater completeness (see Figure 15).

It is expected that the EEA and other international portals do not provide DSM, DTM, or n-DSM data at a resolution suitable for this investigation. However, aside from these limitations, nearly all other necessary datasets are accessible. These datasets are also better organized, offer multilingual interfaces, and often allow filtering before download, making data retrieval more efficient and user-friendly.

4.4 Weaknesses and Suggestions to the Croatian SDI

Through performing the case study we recognised several strengths and weaknesses present in the Croatian NSDI. Broadly speaking, Croatia demonstrates an openness to develop its SDI according to international standards, as is set out by INSPIRE. However, in our case study, adherence to INSPIRE was not directly tested in our evaluation criteria (Table 1). And simply complying with this standard does not ensure the successful completion of our task.

In this section, we highlight the weaknesses identified in our 10 evaluation KPIs and provide suggestions for improvement.

Up-to-date The up-to-date-ness of data depends on their update cycles and is relevant to intended use case. The Land Cover and the Land Use Map were last updated in 2018, following a six-year update cycle as defined by INSPIRE and CORINE. While this ensures consistency with European spatial data policies, it also means that the data may not fully capture recent landscape changes. In this context, the adherence to INSPIRE and CORINE turned out to be a limitation, as a more frequent update cycle would be preferable for applications requiring higher temporal accuracy. In contrast, the n-DSM (Normalized Digital Surface Model), created in 2024, and the DSM (Digital Surface Model), created in 2022, do not have a specified update cycle, but their recency makes them highly suitable for our use case, minimizing concerns about outdated data.

We recommend the Croatian government to modify the current six-year update cycle into a three-phase, two-year cycle. This would maintain compliance with the INSPIRE standard while significantly improving temporal resolution.

Processable All the datasets we found existing are machine-processable. However, the reliance on web feature service (WFS) introduces some limitations, as WFS is designed to encode and serve data in vector format. While this ensures readability, it may not always provide the most convenient or readily usable format for applications. On the other hand, for weather data, the ideal data would be a raster map with temperature values assigned to each cell, allowing for more detailed analysis. However, the only available data consists of a single numeric value representing the entire City of Zagreb. In cases where more detailed information is needed, alternative delivery methods may improve usability and processing efficiency.

Licensed for Our Use Both n-DSM and DSM from the DGU portal have clear licensing statements included in their data request application forms, as does POP. However, for datasets from NIPP, we were unable to locate explicit licensing. Their websites either lack license statements entirely or provide only vague descriptions, such as "Other restrictions". Some datasets include a link to a detailed license statement (https://data.gov.hr/otvorena-dozvola), but the link is not functioning. Regarding weather data, we found only a general statement indicating that the data is free of charge if used for high school or university theses or scientific research. However, there are no further details clarifying permissions or restrictions beyond this.

We strongly recommend that these portals provide clear and detailed legal regulations, including relevant laws, policies, and standards. Transparent licensing information would ensure proper usage, and support researchers and developers in complying with legal requirements.

Availability This KPI solely concerns whether the data exist and can be found online, making the results straightforward, as shown in Table 3. We strongly suggest expanding the available datasets by introducing higher-value derivative datasets such as Fraction of Vegetation, Sky View Factor, Solar Irradiation, and the UHI index. In our case study, we made these datasets from existing raw data, and the process was relatively simple. Providing such by-products directly would significantly enhance usability and efficiency, especially for users who may lack the expertise or resources to process raw data.

Downloadable and Free to Use All the available datasets are downloadable and free to use, despite some lacking detailed licensing information. This is beneficial for our use case, and we have no further suggestions regarding these two aspects.

Direct Download and Download Filters Our analysis of the Direct Download and the Download Filters indicators revealed an interesting pattern. Datasets that are not directly downloadable typically offer filtering services handled manually by their administrators, likely due to their large file sizes. On the other hand, datasets that do not require a formal request lack filtering options before download, meaning users must download the entire dataset, even when a subset is already sufficient.

We speculate that this paradigm came from a lack of advanced database management techniques. In reality, it is possible to host large datasets online with filtering services, but the absence of such implementations may suggest that Croatian users simply do not have a high demand for these datasets. If the need for efficient data access rises, investing in better database solutions could greatly enhance usability.

Multilingual Only DHMZ meteo.hr provides true multilingual support, while other portals offer only partial or superficial translations. Typically, search pages and dataset lists have multilingual options, but once users attempt to access detailed dataset information, they are forced to rely on third-party translations.

We recommend ensuring that at least the metadata is available in multiple languages, allowing users to access key information without language barriers. This would greatly improve accessibility and usability for a broader audience.

Completeness None of the datasets we found were fully complete or free of defects. In the case of DSM and n-DSM, the received data included unwanted tiles covering areas outside our region of interest. For the Land Cover and Land Use Map, we identified instances of incorrect data. The Building Objects and Traffic Objects have mostly correct shapes but contain some empty attributes. The weather dataset, while technically complete, consists of only a single numerical value, making incompleteness a non-issue in this specific case.

Needless to say, the developers expect higher-quality datasets with fewer defects. This is a common issue worldwide, affecting datasets across different domains. Addressing these issues through better data validation and filtering mechanisms would greatly improve usability.

Other Suggestions The overall user experience is quite odd and unintuitive. There are four separate data portals for different categories, yet they are not well integrated with each other, making searching and navigating between them cumbersome. Additionally, many links are either broken or redirect users to unexpected pages, further complicating the experience. For services of this complexity, the lack of clear explanations can be frustrating. To tackle these issues, we recommend improving inter-portal connectivity, fixing broken links, and providing better guidance.

4.5 Governance Instruments to Improve the Croatian SDI

The evaluation criteria (Table 1) and suggestions for the Croatian SDI serve as the foundation for discussing governance instruments that can enhance its organizational development. Drawing from Crompvoets et al., 2018 and van Loenen, 2006, the following key components are identified:

- Leadership
- Vision
- Self-organization and collective decision-making
- Awareness
- Inter-organizational culture and knowledge management

While the challenges facing the Croatian SDI are common among intermediary stage SDIs, existing recommendations often lack long-term strategic planning. The intermediary context aligns with Boonstra's "desiring context," where organizations recognize the need for change, but bottlenecks persist in implementation. In this stage, support for transformation is high, yet effective communication is crucial to drive progress (van Loenen, 2006). The willingness of organizations to cooperate and the ability of top management to steer development are critical factors, as they can either accelerate or hinder SDI developments. By integrating these organizational components with Policy Windows framework (Kingdon, 1995), we can identify gaps and propose targeted improvements within the problem, solution, and political process.

According to Policy Windows concept, strategic timing is crucial for SDI reforms. The increasing severity of summer urban overheating and its impact on tourism create a pressing need for improved spatial data infrastructure which, as has been demonstrated, can be key in finding alternatives for solutions. As Kingdon highlights, "the important thing is that a proposal comes at the right time"—meaning that policy recommendations must be well-prepared in advance and actively promoted when political opportunities arise. By creating high-value thematic datasets that resonate with public interest, SDI initiatives can gain momentum and drive broader policy changes. Moreover, success in one policy area often increases the likelihood of success in adjacent domains, reinforcing the need for a long-term, integrated approach to SDI development in Croatia.

Although governing bodies generally aim to improve national infrastructure, they often lack the specialized knowledge required for effective SDI implementation. Developing thematic maps and indicators, such as the UHI model used in this case study, provides a practical, visual tool that raises awareness at both local and national levels. The lack of a coherent SDI means that researchers, by assuming the role of end-users, should aim to identify deficiencies and propose enhancements in self-organization and collective decision-making. Furthermore, by aligning with ongoing political initiatives that have the capacity to fund SDI improvements, such as European Commission, 2025 targeted strategies can be formulated to develop thematic maps that generate value and public interest.

Building upon key governance models, the following instruments are proposed to enhance the Croatian SDI:

1. Institutional and Organizational Instruments - Foster collaboration with private institutions and international GIS agencies. - Establish a centralized entity to coordinate inter-agency data sharing and SDI governance.

2. Financial and Economic Instruments - Leverage Croatia's Green Transition Fund to support SDI infrastructure. - Introduce incentives for private-sector contributions and SDI-driven innovation.

3. Capacity-Building and Knowledge Instruments - Improve public accessibility to datasets such as the nDSM. - Support grassroots movements that utilize thematic maps to advocate for policy change.

5. Conclusions and Recommendations

Our evaluation of the Croatian SDI by means of carrying out an Urban Heat Island mapping case study, has provided valuable insights into both the capabilities and limitations of the current system, and possibilities for improvement based on the results. Through performing the case study as non-government aligned researchers and being open to using datasets from various sources, we identified key challenges in data accessibility, interoperability, and usability within the NSDI. The study further demonstrated that access to high-quality derivative datasets or thematic maps can improve the quality of decision making, and can increase the scope of their results. This section synthesizes our findings and offers strategic recommendations for improving Croatia's spatial data infrastructure.

5.1 Key Findings

The Croatian SDI demonstrates several strengths, particularly in its commitment to INSPIRE standards and the provision of free, downloadable datasets. However, significant gaps exist that limit its effectiveness for specialized applications. The fragmented data access across multiple portals, insufficient update cycles, unclear licensing terms, and quality issues in some datasets present barriers to our use. The current system appears to be designed primarily for basic compliance rather than optimized for practical applications by researchers, planners, and developers.

Our case study demonstrates that an effective UHI model can be developed to identify high-risk urban areas suitable for tree planting. The results align spatially with datasets from the European Environment Agency (European Environment Agency, 2020) and Croatian-funded research (EBRD and DG Reform, 2024b) but offer significantly higher resolution, which is essential for selecting optimal planting locations. However, the reliance on international SDIs underscores gaps in the Croatian NSDI.

5.2 Strategic Recommendations

Based on our evaluation, we propose the following recommendations to enhance the Croatian SDI:

1. **Enhanced Update Cycles**: Implement a more frequent, phased update cycle for critical datasets like Land Cover and Land Use, shifting from the current six-year cycle to a two-year approach while maintaining INSPIRE compliance.
2. **Advanced Data Processing Services**: Introduce server-side processing capabilities that allow users to request specific data subsets, transformations, or derivative products without downloading entire datasets.
3. **Clear Licensing**: Establish and communicate a transparent licensing framework for all datasets, with functional links to detailed terms and conditions to facilitate proper use.
4. **High-Value Datasets**: Expand the available portfolio to include ready-to-use derivative datasets (e.g., Vegetation Fraction, Sky View Factor, Solar Irradiation, UHI index) that would support specialized applications without requiring users to process raw data.
5. **Multilingual Support**: Extend true multilingual support to all aspects of the SDI, including dataset descriptions, metadata, and documentation, to improve accessibility for international users.
6. **Quality Assurance Framework**: Implement a comprehensive quality assurance process or test functions to address incompleteness and inaccuracies in datasets.
7. **User-Centered Design**: Redesign the user interface with a focus on intuitive navigation, clear instructions, and consistent functionalities across all data services. Develop a unified portal or link those existing data services (NIPP, DGU, POP, DHMZ) to provide better navigation. This would eliminate the current fragmentation and improve overall user experience.

5.3 Future Research

Further research is needed to quantify the economic and social benefits of an enhanced SDI for Croatia, particularly in the context of climate change adaptation and urban planning. Additionally, comparative studies with other European SDIs could provide valuable benchmarks and identify best practices for implementation.

While one of the main focuses of this paper was the development of a model to analyse the Urban Heat Island effect, which was presumed to be valuable in identifying target zones for planting trees, further research could be made into identifying such high value, derivative datasets for end users. This could be done in conjunction between both government ministries and private sector, and could be an opportunity to further develop markets.

By addressing these recommendations, Croatia has the opportunity to transform its SDI from a basic compliance tool into a powerful enabler for innovation, research, and evidence-based decision-making in spatial planning and environmental management.

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