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Spatial Impact Assessment and Classification (SIAC) tool for assessing UF-NBS scenarios

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Summary

The CLEARING HOUSE Spatial Impact Assessment and Classification (SIAC) tool is conceptualized as a prototypical implementation of the CLEARING HOUSE typology on UF-NBS. Aimed primarily at practitioners and academia, and proposed as a plugin for the freely available, open desktop Geographic Information System (GIS) QGIS, SIAC seeks to enable a rapid, trait-based and indicator-based assessment of UF-NBS, including an evaluation of spatial-morphological UF-NBS configurations and relationships, and an estimation of likely UF-NBS impacts and benefits. This document describes (the process of) the implementation of this tool. It outlines the intended scope and purpose of SIAC, and the intended tool impacts (i.e., outputs or products) with respect to user demands. Tool implementation is described, with a focus on key functionalities and required key data, as well as evaluation of the proposed tool.

Approval

Date	By
2024-04-12 15:06:47	Dr. Rik DE VREESE (EFI)
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Spatial Impact Assessment and Classification (SIAC) tool for assessing UF-NBS scenarios (Deliverable 4.2)

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REFERENCE

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STATUS AND REVISIONS

Version	Date	Author	Partner	Description
v1.0	14/11/2023	Sebastian Scheuer	HUB	Working draft for SIAC tool.
V1.1	18/11/2023	Rik De Vreese	EFI	Review of v1.0
V1.2	23/11/2023	Sebastian Scheuer	HUB	Final version

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EXECUTIVE SUMMARY

The CLEARING HOUSE Spatial Impact Assessment and Classification (SIAC) tool is conceptualized as a prototypical implementation of the CLEARING HOUSE typology on UF-NBS. Aimed primarily at practitioners and academia, and proposed as a plugin for the freely available, open desktop Geographic Information System (GIS) QGIS, SIAC seeks to enable a rapid, trait-based and indicator-based assessment of UF-NBS, including an evaluation of spatial-morphological UF-NBS configurations and relationships, and an estimation of likely UF-NBS impacts and benefits. This document describes (the process of) the implementation of this tool. It outlines the intended scope and purpose of SIAC, and the intended tool impacts (i.e., outputs or products) with respect to user demands. Tool implementation is described, with a focus on key functionalities and required key data, as well as evaluation of the proposed tool.

KEYWORDS

Decision support tool; Spatial Impact Assessment and Classification tool; UF-NBS; trait-based analysis; tool development; CLEARING HOUSE

ABBREVIATIONS

NBS: Nature-based solutions
UF-NBS: Urban forests as nature-based solutions
SIAC: Spatial Impact Assessment and Classification

KEY DEFINITIONS

Urban forests: tree-based urban ecosystems that address societal challenges, simultaneously providing ecosystem services for human well-being and biodiversity benefits. Urban forests include peri-urban and urban forests, forested parks, small woods in urban areas, and trees in public and private spaces.

Urban forestry: the practice of planning and management of urban forests to ensure their health, longevity and ability to provide ecosystem services now and in the future.

Nature-based Solutions (NBS): Nature-based Solutions (NBS) are defined as *"actions to protect, sustainably manage, and restore natural or modified ecosystems, which address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits"*. (IUCN, 2018)

Urban forests as nature-based solutions: UF-NBS are a subset of nature-based solutions, which build on tree-based urban ecosystems to address societal challenges, simultaneously providing ecosystem services for human well-being and biodiversity benefits. UF-NBS include peri-urban and urban forests, forested parks, small woods in urban areas, and trees in public and private spaces. UF-NBS comprise every measure a city can take to address urban development challenges by deploying tree-based ecosystems. (European Forest Institute, 2018)

Urban tree(s): usually long living woody organism including woody shrubs, usually single stemmed, with the potential to grow at a site in an urban or peri-urban area. This includes roadside trees, trees in squares, parking areas, or in parks and private gardens. Urban trees appear as individual trees, or as groups of trees.

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1 Introduction

This task has been concerned with the development of a tool for conducting UF-NBS impact assessment and classification (in the following, SIAC tool, or SIAC), in lieu of an online application and as outlined in the alternative workplan for CLEARING HOUSE as agreed upon by the project funder through the 2nd grant amendment. The development of SIAC is intended to serve as a trait-based, prototypical integrated toolbox for a first estimation of urban forest conditions and benefits at local level, based upon trait-based concepts and definitions developed and devised in the CLEARING HOUSE UF-NBS typology (Scheuer et al., 2022). Here, a **trait** is understood as an (aggregate) feature of a given UF-NBS, including spatial (e.g., area/extent), structural/morphological (i.e., aspects related to composition, such as including trees, shrubs, waterbodies, artificial features, etc.), contextual (i.e., related to the embedding in the urban matrix, and to spatial context including socio-demographic settings, etc.), functional (i.e., aspects related to biophysical processes or affordances resulting in ecosystem services/benefits provided at the UF-NBS level), sensory (e.g., regarding perceivable birdsong or noise) or institutional characteristics (e.g., regarding institutional accessibility or use entitlements; cf. Scheuer et al., 2022). Therefore, SIAC seeks to bring together formal, trait-based UF-NBS knowledge with UF-NBS-related (case-specific) challenges, research questions, and data (**Figure 1**). Regarding data, SIAC is intended to consume a minimum amount of data. On the one hand, this specific focus of SIAC is intended to avoid reproducing existing, well-established and more detailed applications such as i-Tree (USDA Forest Service et al., 2023). On the other hand, it should facilitate transferability of SIAC to other geographical, potentially data-sparse contexts.

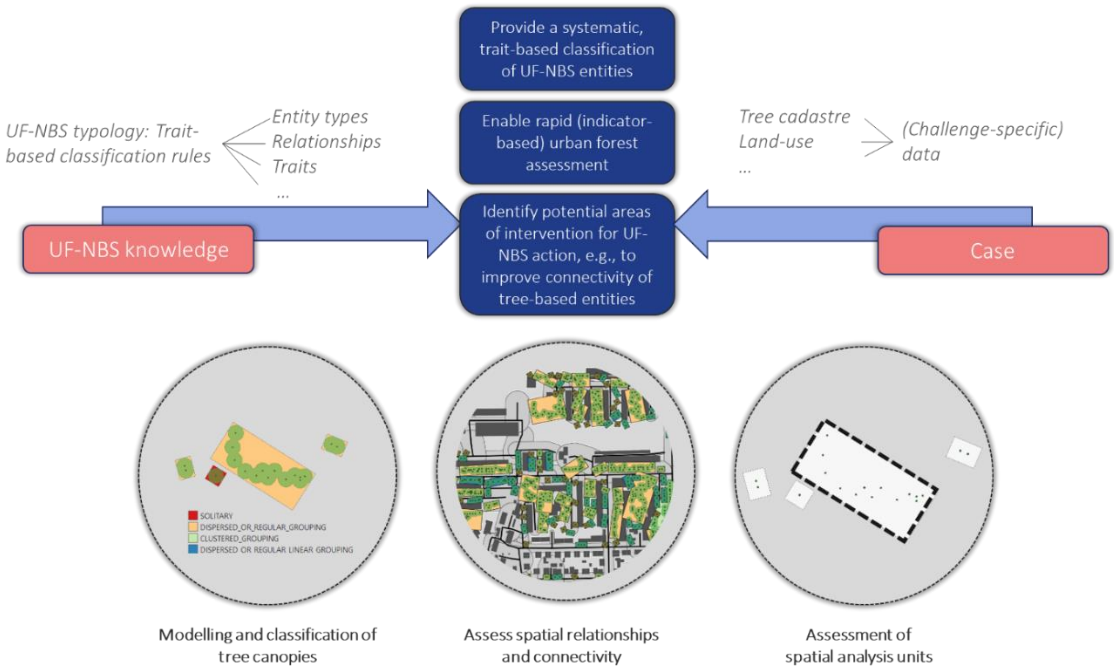

Figure 1. Conceptual outline of SIAC (taken from Scheuer et al., 2023a). The SIAC tool is sought to bring together UF-NBS knowledge, e.g., as captured in a formal way in the CLEARING HOUSE UF-NBS typology (Scheuer et al., 2022), with (case-specific) data and with respect to (case-specific or framing) user demands, interests, or challenges.

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By aligning SIAC with the CLEARING HOUSE UF-NBS typology, the tool also adoptions tree-based entities, and particularly the concepts of tree and tree cover (tree canopy), as core entities of the assessment. Here, tree-based UF-NBS entities refer to real-world objects that correspond to trees, or that are composed (that contain) one or more trees, such as urban green spaces or forest. For these entities, and more specifically of corresponding tree cover, first, certain spatial and morphological traits are modelled, i.e., area (extent) of tree cover as well as grouping of entities, e.g., into solitary trees or groups of trees. This modelling is conducted based on measured data or user assumptions, and it serves as basis for subsequent analysis. Second, spatial-topological relationships between tree cover and artificial features (streetscapes, built-up) are modelled and evaluated in a data- and trait-driven manner. I.e., in so-doing, trees may be classified as street trees, or as trees in close proximity to buildings, and furthermore, for user-defined areas of interest, traits such as share of tree cover and built-up may be aggregated. This knowledge may allow, e.g., first appraisals particularly of the 3 and 30 components of the 3-30-300 rule (Browning et al., 2024). Third, the spatial relationships between UF-NBS may also be assessed based on an approximation of graph-based connectivity (Urban and Keitt, 2001; Pascual-Horta and Saura, 2006; Petsas et al., 2021), considering also potential anthropogenic barriers to connectivity (here, primarily buildings) as suggested by Chan et al. (2021). This information may support maintaining (or improving) UF-NBS connectivity, e.g., through an identification of bridges and articulation points, which are important for preventing further fragmentation of the UF-NBS network. Fourth, benefits, i.e., contributions of UF-NBS to selected ecosystem services are estimated, primarily as a function of tree cover in line with Nowak et al. (2013), Kremer et al. (2016), or Ziter et al. (2019).

The overall process of SIAC development is summarized in **Figure 2**. As shown, an initial elicitation of user demands on April 30, 2021—thereby achieving Milestone M4.3—is followed by a screening of stated demands, and a screening of further (framing) challenges that support the further positioning and development of the tool. Based thereupon, SIAC has subsequently been conceptualized, i.e., an overall application concept has been devised and a mock-up in the form of a concept note (Scheuer et al., 2023a) has been prepared accordingly. The mock-up outlines the intended scope and purpose, data requirements, functionality, and impacts—i.e., outputs and products—of SIAC. It also drafts the foreseen technical implementation as QGIS plugin.

The mock-up has been evaluated in a mock-up evaluation online workshop on February 21, 2023. In the workshop, the SIAC concept has been presented to stakeholders and was subsequently evaluated, thereby achieving Milestone M4.4. The SIAC tool has then been further implemented. A testing phase of an early development version of SIAC further accompanied this further tool development. This testing phase started in July 2023 and has been concluded on September 21, 2023, with feedback of the testing phase being shared. As shown, feedback from the mock-up evaluation as well as from the testing phase were considered to refine the overall application concept, and to improve tool implementation and documentation, as deemed feasible.

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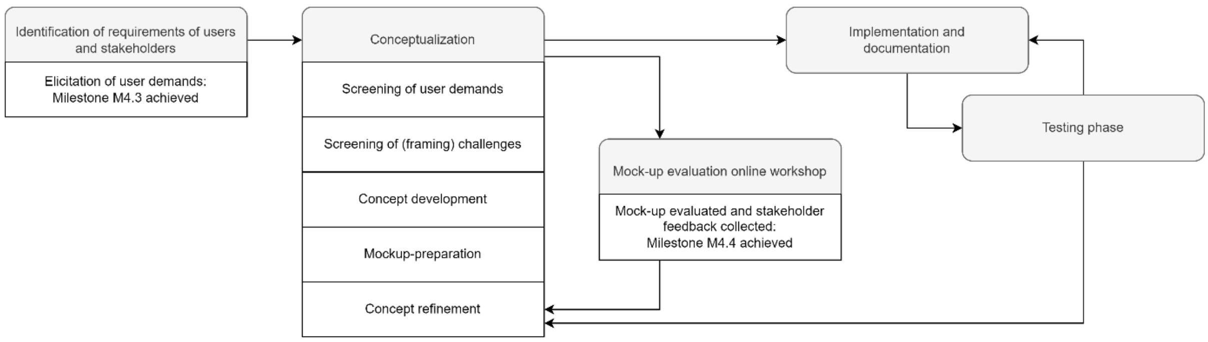

Figure 2. Tool development process overview.

In the following, conceptualization, mock-up evaluation, implementation and testing will be described further. The identification of requirements of users and stakeholders is described in the Milestone document M4.3 (Wolff et al., 2021).

2 Tool conceptualization

Against the background of elicited/screened user demands (framing) challenges, the conceptualization of the SIAC tool includes (i) detailing the tool's scope and purpose; (ii) outlining targeted user groups; (iii) summarizing intended key impacts with respect to anticipated tool outputs and products; and (iv) designating core functions deemed relevant to realize intended impacts. Each of the aforementioned aspects is summarized below.

2.1 Scope and purpose

Here, scope and purpose of SIAC refer to the tool's positioning towards the elicited/screened user demands and (framing) challenges. First, with respect to stated user demands (Wolff et al., 2021), SIAC is sought to address the following items: (i) model UF-NBS conditions; (ii) assess the relationship between urban grey buildings and green spaces; (iii) provide locally specific, operational indicators on UF-NBS; (iv) assess UF-NBS benefits/contributions of UF-NBS to selected ecosystem services; and (v) raise awareness towards UF-NBS.

Second, SIAC is intended to support the following (framing) challenges, that are aligned to the IUCN Urban Nature Index themes (cf. IUCN, 2023) as follows: (i) identification of (trends in) vegetation cover (theme 3.1); (ii) identification of (trends in) plant species diversity (theme 4.2); (iii) identification of (trends in) connectivity (theme 3.5); and (iv) human health (theme 5.3).

2.2 User groups

In line with SIAC being conceptualized as prototypical UF-NBS typology implementation for QGIS, the user groups targeted by SIAC focus more closely on potential users of QGIS and thus individuals generally trained the use of geographic information systems. Therefore, SIAC targets primarily research and academia, NGOs, and practitioners supporting decision-making, e.g., from local

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authorities, UF-NBS management, (environmental) planning, etc. Although the tool may in principle be used by citizens and the broader public, lack of needed skills may prevent such users from accessing/operating the tool. However, it is envisioned that assessment results may also be made accessible to this user group by feeding SIAC outputs into the more-accessible SIK-Hub tool[1].

2.3 Key impacts

Application of the SIAC tool, and thus, the outputs and products generated by SIAC shall support the following key impacts: (i) adoption of a trait-based approach that is aligned with the trait-based CLEARING HOUSE UF-NBS typology (Scheuer et al.; 2022); (ii) provide a systematic, trait-based assessment (classification) of UF-NBS in terms of their morphological and spatial-topological configuration; (iii) facilitate cross-case comparison studies through a consistent, data-driven UF-NBS assessment based on comparatively sparse data; (iv) enable a rapid, i.e., indicator-based UF-NBS assessment; (v) augment existing data, e.g., using Boolean indicators; and (vi) support the management of UF-NBS.

Directly reflecting on stated user demands, the indicator-based assessment shall express, first, current state and conditions of UF-NBS, for example, regarding (the share of) (non-)woody vegetation cover, tree canopy cover, or street tree density, i.e., implementing indicators, as suggested for example by the European Commission, Directorate-General for Research and Innovation (2021) or Bundesamt für Naturschutz (2023). Second, the indicator-based assessment shall estimate benefits of UF-NBS, i.e., potential contributions of UF-NBS entities to selected ecosystem services including carbon storage and sequestration, regulation of air quality, and regulation of air temperature. Third, in line with IUCN Urban Nature Index theme 3.5, connectivity of UF-NBS shall be assessed. Assessment results should augment provided data, and reports be generated. Findings should support the management of UF-NBS, for example, by identifying potential areas for conservation or intervention, e.g., to maintain or improve connectivity of tree-based entities.

2.4 Designated core functions

In line with intended impacts, the following functions are considered core functions for SIAC: (i) modelling of tree cover; (ii) modelling of spatial-morphological traits of UF-NBS entities and their according classification; (iii) modelling of spatial-topological relationships, e.g., to urban (grey) features such as streets and buildings, or to other green features; (iv) modelling of connectivity in a graph-based manner; (v) computation of suitable indicators for characterizing the current state and conditions of UF-NBS; and (vi) computation of suitable indicators for the estimation of potential benefits/contributions to selected ecosystem services.

Details on the tool concept are further described in the respective concept note (M4.4; cf. Scheuer et al., 2023a). As mentioned previously, this concept note has subsequently been evaluated by stakeholders.

[1] SIK-Hub is the second tool developed by CLEARING HOUSE as part of T4.2, and is described in Wolff (2023).

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3 Mock-up evaluation

The concept note devised as tool mock-up (Scheuer et al., 2023a) detailing the overall conceptualization has been evaluated by partners from the case study cities, and the CLEARING HOUSE stakeholder advisory group. The evaluation was conducted in form of an online workshop held on February 21, 2023. Stakeholders were subsequently invited to share feedback on the mock-up using an online questionnaire. So-doing aimed at structuring the evaluation, in order to obtain feedback along a set of evaluation criteria. Each of the following evaluation criteria has been evaluated along a four-point Likert scale (**Figure 3**); in addition, comments could be provided:

(i) Perceived *usefulness* of the tool, e.g., to fill knowledge gaps; and
(ii) Regarding *functionality* of the tool,

   a. Perceived ease of use;
   b. Suitability of intended functions to support decision-making;
   c. Suitability of intended impacts (outputs, products) to support decision-making.

As shown in **Figure 3**, stakeholders perceived the conceptualization of SIAC comparatively positively (with SIK-Hub apparently being perceived slightly more favourable than SIAC).

When additionally looking at the comments shared by stakeholders on these aspects (**Table 1**), stakeholder comments deemed the justification for embedding the tool in QGIS convincing. It has also been emphasized that biodiversity of urban areas must be expressed by the tool as well as UF-NBS impact on infrastructures would be considered useful. Major concerns expressed included the integration of diverse data and data sources, as well as a potentially limited ease of use. To address the former feedback, emphasis has been on including indicators typically considered for expressing tree genus/tree species richness and diversity, e.g., total richness, Menhinick's index, Margalef's index, Simpson’s Index, Shannon-Wiener Diversity Index, Pielou Index of Evenness (Fedor and Zvaríková, 2019; Roberts, 2019). Moreover, the assessment of spatial relationships within SIAC focuses on assessing spatial (topological) relationships between tree-based entities and streets as well as buildings. To address the latter concern, comprehensive documentation has been prepared for the SIAC tool. It however needs to be noted that the tool is primarily addressing experts or trained individuals, therefore, a higher degree of complexity may be considered acceptable.

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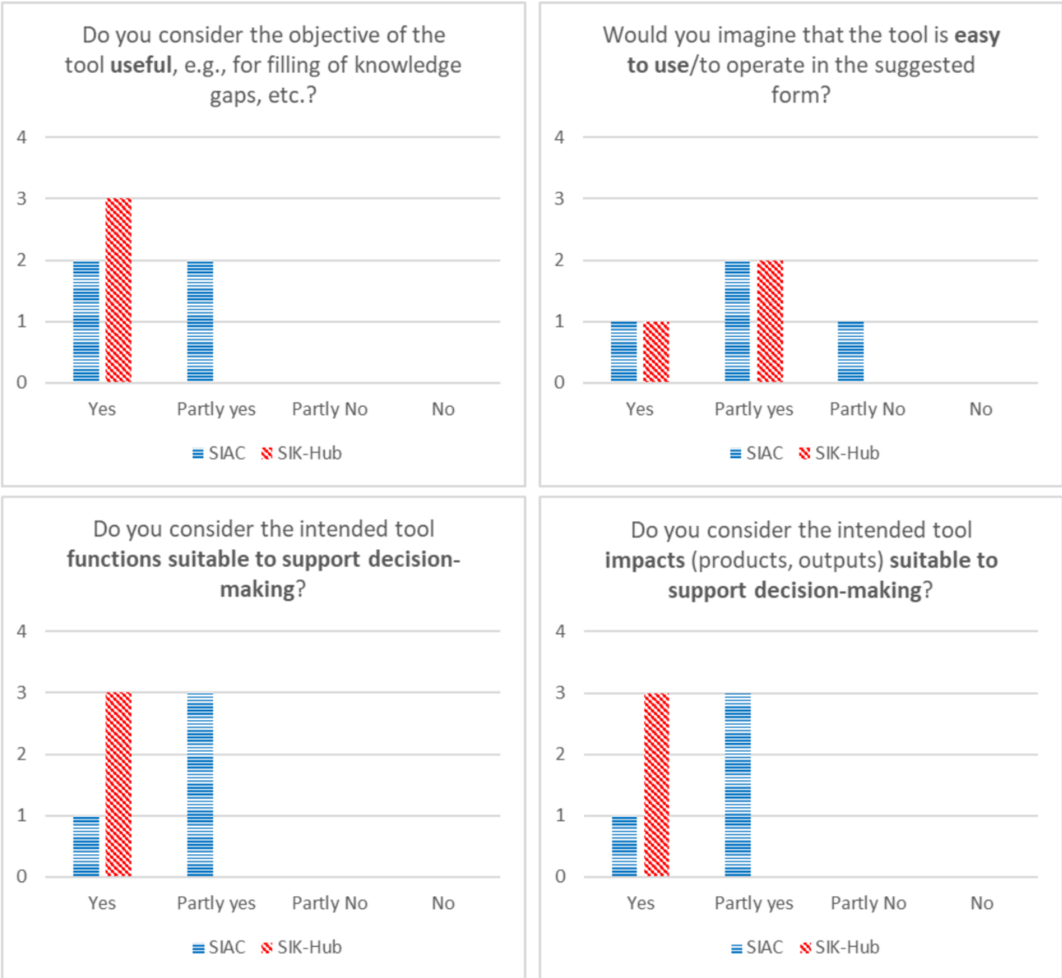

Figure 3. Results of the evaluation of tool mock-ups.

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Table 1. Comments made by stakeholders on the SIAC tool as part of mock-up evaluation.

Evaluation aspect	**Shared comments**
Usefulness	• The tool needs to reflect the biodiversity status of the urban areas and the impact of infrastructures. • The systematic assessment of NBS is of high importance. NBS are in the interlink between ecosystems (ES), management of ecosystems (governance) and uses of NBS. The assessment therefore should include a trait-based typology that covers all 3 dimensions.
Easy-to-operate	• Partly yes because I am not aware of and haven't used QGIS but the justification of this rather than an online application makes sense. • I see a very big challenge in including already existing data and plans into the conceptual framework. A key element may be the openness towards all kinds of existing data/plans/research.
Functionality to support decision-making	(No specific comments were given)
Impacts (outputs, products) to support decision-making	• The tool needs to reflect the biodiversity status of the urban areas and the impact of infrastructures.
General remarks	• This will be a very useful tool to have available

4 Tool implementation

4.1 Summary of the technical foundation

In accordance with the overall conceptualization and in line with the presented mock-up, SIAC has been developed as a QGIS plugin[2]. SIAC is thus developed in the Python programming language. Targeting QGIS and use of the Python programming language allow leveraging existing visualization and data processing/geoprocessing functionalities of QGIS, as well as making use of an extensive repository of Python packages providing a host of methods for the processing and analysis of data. Consequently, by adopting QGIS functions and/or Python packages as needed for the implementation of SIAC tool functions[3], a reproduction of pre-existing functional components could mostly be avoided.

With QGIS being an open and freely available desktop GIS, adoption of QGIS in lieu of the originally foreseen online application is not considered a significant barrier for tool adoption; instead, in

[2] The targeted minimum version of QGIS is 3.28.2

[3] SIAC imports the following Python packages as dependencies: pandas, geopandas, networkx, scikit-learn, matplotlib, seaborn, statsmodels, momepy, shapely, xlsxwriter (cf. Scheuer et al., 2023b)

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perspective, this may even facilitate adoption and dissemination, and may also facilitate an integration with third-party tools.

SIAC presents the user with a plugin window (a dialogue window), that allows managing data sources, setting assessment parameters, accessing tool functions and that provides the user with generated outputs (**Figure 4**). More details on the operation of SIAC are provided in the tool's documentation (Scheuer et al., 2023b).

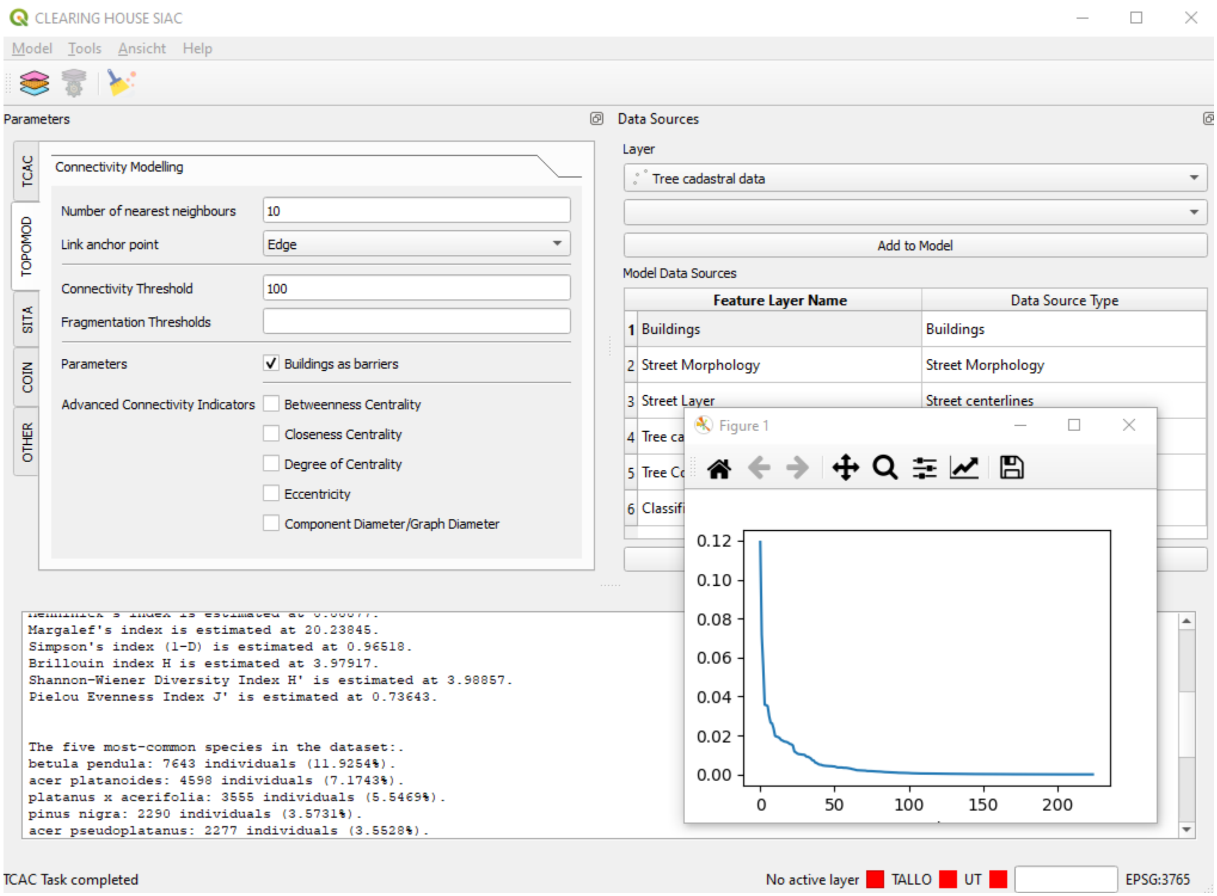

Figure 4. The SIAC plugin window. Through the provided dialogue window, data is managed, and tool outputs are provided (cf. Scheuer et al., 2023b for details).

4.2 Summary of tool architecture and functionality

The implementation of SIAC follows a modular pattern, i.e., specific tool functions are encapsulated in distinct modules. On the one hand, this modular design shall improve maintainability and facilitate extensibility. On the other hand, re-use of functions is facilitated across SIAC. These modules, as well as their intended purpose—i.e., the functionality implemented in each module's scope—are summarized in **Table 2**.

Table 2. Overview of included tool modules.

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Module	Module purpose (functionality)
TCAC (Tree Configuration Assessment and Classification)	The TCAC module is primarily concerned with the modelling of tree cover, and the assessment of the spatial-morphological configuration of tree features and of tree species richness and diversity. Further functions provided by the module include, e.g., tools to derive tree traits from supported tree databases.
TOPOMOD (Tools for the modelling of spatial relationships and topology)	The TOPOMOD module allows assessing spatial-topological relationships of trees or tree cover with anthropogenic urban features such as streets or buildings, and furthermore implements an assessment of connectivity and fragmentation based on tree-based entities.
SITA (Site assessment)	The SITA module is intended to derive traits for user-defined spatial units of analysis, i.e., patches/plots delineated by distinct polygon features.
COIN (Computation of Indicators)	The COIN module seeks to estimate indicators on urban forest conditions, e.g., tree cover or forest cover, and furthermore seeks to assess benefits, i.e., ecosystem services provided by the urban forest such as the regulation of air quality.
Pre-Processing	The Pre-Processing module includes functions for the generation of spatial urban-morphological data if no such data is available, including, e.g., the modelling of street morphology (ground area) and of plots.

Subsequently, potential use cases, i.e., exemplary research questions related to stated user demands and elicited (framing) challenges, and the SIAC functions that may be used to address respective research questions, are summarized in **Table 3**. An in-depth description of tool functionality, data requirements at the individual tool function level, and information flow across tool functions is provided in the SIAC tool Documentation (Scheuer et al., 2023b).

4.3 Summary of required data

It has been mentioned that SIAC is devised in such a way that provided functions require a minimum amount of data (**Table 4**). If available, a tree cadastre (i.e., a point feature layer) that characterizes the spatial configuration (i.e., planting locations) of trees as adopted UF-NBS core entities, and that may provide further levels of detail such as tree-specific traits (e.g., crown diameter, genus/species) is key input data. Based on this layer, tree cover and the spatial-morphological configuration of tree-based entities (i.e., grouping of trees) are then being modelled. However, alternatively, if no such tree cadastre is available for a case study area, a polygon layer representing tree cover, such as the Urban Atlas Street Tree Layer (Copernicus, 2018) or a layer derived from remote sensing data, may also be ingested by SIAC.

Other required data include building footprints as well as street centrelines and street morphologies. Combining such data with modelled tree cover allows assessing spatial relationships and an

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identification (classification) of likely instances of specific UF-NBS types (e.g., street trees). UF-NBS benefits and current conditions are subsequently evaluated using selected indicators either at the dataset level, or spatially explicitly at the level of so-called plots. For this assessment of UF-NBS conditions and benefits, modelled tree cover is again the key input data layer. Here, plots are understood as distinct polygon features representing specific areas of interest, i.e., spatial analysis units. They may represent actual land parcels, but may also correspond to other spatial entities such as administrative districts. Plots may also be derived from provided input data, e.g., by using enclosed tessellation (cf. Scheuer et al., 2023b for details).

4.4 Scenario-based UF-NBS assessment

The CLEARING HOUSE project initially proposed an online application for the assessment of impacts of different UF-NBS scenarios. Here, a scenario is understood as a distinct, spatially explicit configuration of trees and tree-based entities such as tree cover. Hence, a given scenario is denoted by the user-provided input data, i.e., a tree cadastre, or alternatively, a tree cover layer. Consequently, modifying or altering these respective input data, e.g., on the basis of narratives, allows representing different scenarios. Therefore, SIAC is considered to support the assessment of scenario-specific impacts within the tool's outlined scope and purpose.

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Table 3. Potential use cases of the SIAC tool, exemplified by exemplary research questions, with the corresponding functions of SIAC, and alignment of use case and function with (framing) challenges and stated user demands.

Use case (Exemplary research question)	Functional scope of SIAC[4]	Alignment to stated user demands and challenges								
		IUCN Urban Nature Index Theme				UF-NBS conditions	UF-NBS indicators	UF-NBS benefits	Spatial relationships	UF-NBS awareness
		3.1	3.5	4.2	5.3					
Determine the total tree cover for an area of interest	Modelling of tree cover	X				X	X			
Identification of solitary trees and rows of trees	Classification of spatial-morphological patterns	X	X			X				
Obtain the total abundance of tree features, the relative abundance of tree species, and identify tree entities of interest (e.g., urban food forest entities, or entities with specific allergenic potential)	Assessment of tree species richness and diversity	X	X	X		X	X	X		X
Identification of street trees and of trees adjacent to buildings	Assessment of spatial-topological relationships		X						X	
Assessment of tree cover connectivity, including connected components, and fragmentation	Modelling of connectivity and fragmentation		X			X	X			
Identification of tree cover features that are important for maintaining connectivity	Modelling of connectivity and fragmentation		X			X	X			
Determination of tree cover and impervious cover for spatial units of analysis	Assessment of (randomly sampled) plots	X				X			X	
Identify UF-NBS entities, e.g., (tiny) forests, based on formal rules	Assessment of total forest cover	X	X			X				X
Determine the amount of air pollutants removed by tree-based entities	Estimation of regulation of air quality				X			X		X
Determine the amount of carbon stored by tree-based entities	Estimation of carbon sequestration and storage				X			X		X
Determine the cooling effect of UF-NBS	Local OLS regression				X			X		X

[4] Please refer to the SIAC Documentation (Scheuer et al., 2023b) for a detailed description of SIAC functions.

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Table 4. Non-exhaustive list of required data.

Dataset	Format	Geometry Type	Remarks
Tree cadastre	Vector layer	Point	At a minimum, location of trees, or alternatively, polygon feature layer of tree cover.
Street centrelines	Vector layer	Line	
Street morphology	Vector layer	Polygon	Polygon features representing streetscapes.
Building footprints	Vector layer	Polygon	
Plots	Vector layer	Polygon	Polygon features representing areas of interest/spatial analysis units.

5 Testing and tentative tool evaluation

An early development version of the SIAC tool has undergone extensive testing as part of T4.4 (see Basnou et al., 2024). Similar to the evaluation of mock-ups, a set of testing criteria has been elaborated to support initial testing and tentative evaluation of the tool. These criteria include the quality and sufficiency of provided documentation (user guidance, level of detail, comprehensibility); tool deployment and functionality (difficulty of putting the tool into operation, impressions on the functions, technical readiness/problems and bugs); and usefulness of tool outputs and generated data.

Shared feedback suggests that the provided documentation is complex and sufficient, however, certain parts may require more detailed explanations. As a consequence, the provided documentation has been revised according to shared feedback. Tool deployment, that potentially requires setting up QGIS, and the subsequent installation of required Python package dependencies and of the SIAC plugin itself, has been described as difficult and not user-friendly, possibly requiring a GIS expert to conduct the installation. However, given the intended user groups, such complexity may somewhat be expected/accepted. Internal tests also suggested that a user with a certain level of GIS experience has been able to setup SIAC with comparative ease, following the provided documentation. Therefore, to ease potential installation issues, the documentation that details the deployment of SIAC has further been revised to provide more user guidance during this step. Outputs produced by the tool were considered relevant for the decision-making process, and overall meaningful, despite considerable uncertainties and limitations, e.g., in terms of underlying assumptions and accuracy of estimates.

This particularly referred to the assessment of UF-NBS contributions to the chosen ecosystem services, i.e., carbon storage and sequestration, air quality regulation, and regulation of air temperature. In this regard, SIAC has been positioned to provide first (rough) estimates on respective benefits, considering also required data at a broader scale. Therefore, the assessment of benefits towards either service is based primarily on (modelled) tree cover, and accordingly, on (averaged) ecosystem service potentials, e.g., carbon storage and carbon sequestration rates, removal rates of air pollutants SO_2, NO_2, PM10, O3, and CO (e.g., Nowak et al., 2013; Kremer et al., 2016). Whilst this presents a clear limitation of the tool in contrast to more-detailed methods such as the use of allometric equations that consider additional tree traits, the conceived implementation ensures though that functionality is maintained

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across all supported input data. Moreover, it allows application of SIAC in data-sparse settings, thereby possibly promoting transferability and tool adoption under such circumstances.

6 Availability of the SIAC tool

The SIAC tool (QGIS plugin) and the Documentation are available in the CLEARING HOUSE Community at Zendo: https://doi.org/10.5281/zenodo.10255287. The tool is open source, released under the modified 3-Clause BSD License.

CONCLUSION

This document summarized the conceptualization of the CLEARING HOUSE Spatial Impact Assessment and Classification (SIAC) tool against the background of previously elicited user demands and (framing) challenges in line with IUCN urban nature index themes. In line with the SIAC conceptualization and thus the tool mock-up, and further considering feedback from city partners and the CLEARING HOUSE stakeholder advisory group, the implementation of SIAC was conducted as plugin for the open, freely available desktop geographic information system QGIS. Details on provided functionality and required data, inclusive of schematic illustrations of data/information flow within the SIAC toolkit, is available in the provided tool documentation (Scheuer et al., 2023b).

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