GreenCityLabHuế

Deliverable D1

Modelling the implementation of land-use changes and nature-based solutions

Land-use change modelling at city-level

Sebastian Scheuer[1], Jessica Jache[1], Dagmar Haase[1]

[1] Humboldt-Universität zu Berlin, Geography Department, Landscape Ecology Lab

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The joint research project GreenCityLabHuế – Strengthening climate resilience of urban regions in Central Vietnam through nature-based solutions for heat adaptation and air quality improvement, funded by Federal Ministry of Education and Research (BMBF) as part of the funding measure „Sustainable Development of Urban Regions" within the framework of the Strategy „Research for Sustainability" (FONA), started its Research and Development (R&D) phase in April 2021, following completion of the preceding definition phase. In the R&D-phase the project aims to strengthen the climate resilience of the city of Huế (Thừa Thiên Huế Province, Central Vietnam) through nature-based solutions (NBS) with a focus on heat adaptation and air quality improvement. To this end, a multidisciplinary research and experimental space will be created to develop, test, visualise, discuss, and implement ideas and concepts on the restoration and expansion of green-blue infrastructure (GBI), and thus for the promotion and implementation of NBS, in the urban area of Huế. In cooperation with stakeholders from science, politics, administration, and civil society, the international project consortium of Independent Institute for Environmental Issues (UfU), Humboldt-Universität zu Berlin (HUB), Mientrung Institute for Scientific Research (MISR), Thừa Thiên Huế Institute for Development Studies (HuếIDS), and the Faculty of Architecture of the University of Sciences/Huế University (HUSC) will generate joint knowledge for stakeholders and decision-makers on NBS, resulting in a city-wide vision – a strategy containing guiding principles and best-practice recommendations for a greener, more resilient, and sustainable urban development of Huế, including proposals for specific measures of GBI implementation.

Project website: www.greencitylabHuế.com

UfU Independent Institute for Environmental Issues

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REVISION	07/09/2022	Scheuer, S., Jache, J., Haase, D.	HUB	Revision of numerical simulation
REVISION	23/02/2023	Scheuer, S., Jache, J., Haase, D.	HUB	Revision of scenario reference frame: Rebasing status-quo assessment on corrected statistics. Revision of scenario evaluation on the basis of this change of the reference frame.

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TABLE OF CONTENTS

The Federal Ministry of Education and Research (BMBF) is funding this project within the framework of the Strategy „Research for Sustainability" (FONA) www.fona.de/en – BMBF funding code: GreenCityLabHuế (01LE1910A1). The content of this document does not reflect the official opinion of the Federal Ministry of Education and Research. Responsibility for the information and views expressed lies entirely with the author(s).

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EXECUTIVE SUMMARY

This report describes the modelling of narrative-based scenarios for green-blue interventions, e.g., construction of urban parks, or the planting of street trees, in Huế. The modelling work is conducted at the spatial scale of the city level. The methodology used for modelling interventions corresponds to a multilayer GIS-based approach, that is put into operation through a specifically developed toolbox. The devised tools form a toolchain to express the suitability of spatial entities for given interventions, and to model the allocation of space for implementing green-blue entities, based on a set of comparatively simple rules to reflect on scenario-specific assumptions and (green-blue element design) parameters. The outputs produced allow a reflection of potential pathways for a greener Huế, including a discussion on the feasibility of policy goals and on ways to achieve such goals. In so doing, the described work provides means of exploring different greening strategies, e.g., in the context of policy development and the support of planning and decision-making. It also provides the basis for further modelling, i.e., the subsequent assessment of impacts and ecosystem services delivered, and accordingly, the modelling of ecosystem services supply-and-demand.

KEYWORDS

narrative; scenario; greening interventions; city-scale; multilayer GIS approach; toolbox; virtual allocation of intervention

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LIST OF FIGURES

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LIST OF TABLES

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1 Introduction

The work described in this deliverable elaborates the modelling of green-blue infrastructure (GBI) interventions in Huế city as a form of nature-based solutions (NBS). Green-blue interventions include, e.g., the construction of (pocket) parks or afforestation action (so-called *path-level interventions*), the planting of street trees or the construction of green verges or bioswales (so-called *interventions at the street-level*), or so-called *selective actions* such as the greening of balconies, facades and roofs, the creation of house gardens, or the improvement of amenities in existing green spaces, i.e., interventions that represent very local actions, or actions that may be represented rather as an a-spatial, qualitative characteristic, instead of a spatial outcome.

The modelling of interventions is conducted at the spatial scale of the city-level, i.e., for the complete case study area, and is, first, intended to allow an *exploration and discussion of different pathways* for a greener city of Huế. Second, results of the modelling process provide the *basis for an assessment of benefits* provided by the proposed interventions (impact assessment), and subsequently, an *assessment of ecosystem services supply-and-demand*. Third, findings may be fed into the Green City Lab Huế for discussion amongst and obtaining feedback from local stakeholders and the public and are intended to *support the development of the Green City Vision Huế*.

The described work is based on various findings from the project's definition phase, including the devised GBI typology, the narratives, and the tentative scenarios developed previously. Various data used for the modelling has also been acquired and initially processed during the definition phase (Figure 1).

The scenarios considered in this report include a business-as-usual scenario for determining status-quo (2019) and baseline/business-as-usual conditions (scenario A); a scenario describing comparatively small-scale improvements (scenario B); a scenario detailing more ambitious, moderate to larger-scale improvements (scenario C); and a scenario with extensive, large-scale interventions as a sort of utopia (scenario D). These scenarios form a gradient of an increasing "degree of intervention", i.e., from scenario B to D, increasingly larger interventions that are reflective of increasingly ambitious policy goals—e.g., regarding desired land-use conversions/greening interventions to be achieved—are being proposed. Due to preferences of local partners and stakeholders, the modelling of interventions is closely aligned with Huế's land-use plan for 2030. Therefore, the proposed modelling process carefully considers the changes in land-cover and/or land-use that result from foreseen urban development, or that may result from a re-development of urban areas, as expressed in the urban plan for 2030. In this regard, the proposed scenarios consider certain changes, such as the development of new built-up land, as particularly providing opportunities for the implementation of NBS. Moreover, the various GBI elements proposed in the different scenarios consider the perceived popularity of certain green or blue spaces, as laid out by stakeholders in the definition phase.

In the following, the methodology developed and its implementation to put the modelling of interventions into operation is described in more detail. Subsequently, the application of this methodology, i.e., the translation of the proposed scenarios A–D into quantitative models is presented, and the modelling results examined and discussed.

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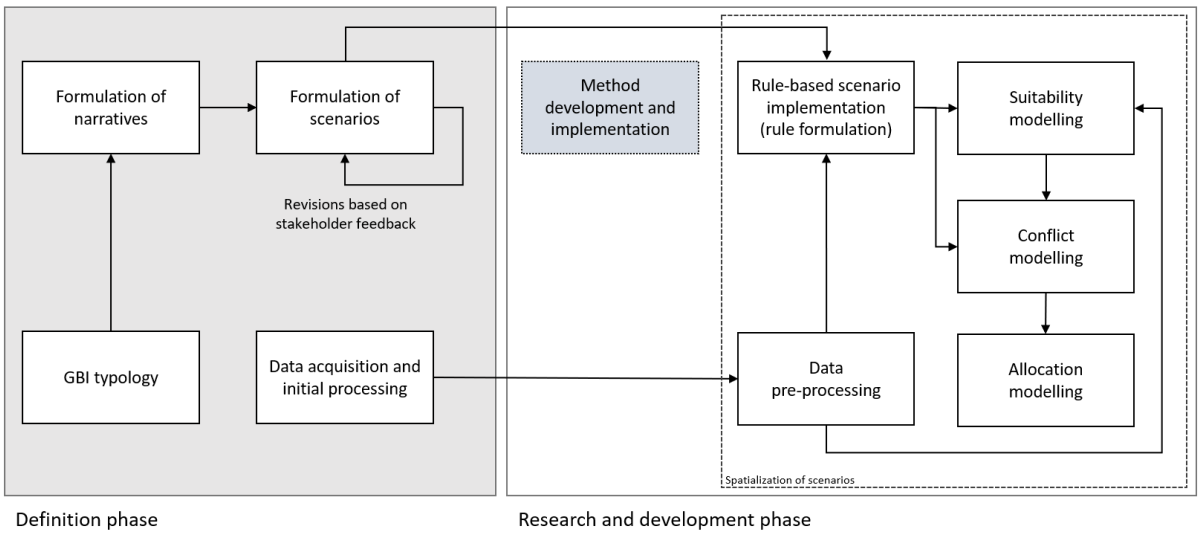

Figure 1. Overview of the work conducted in WP1 during the research and development phase, and relationship to work conducted previously in the definition phase.

2 Methodology development and implementation

There are various approaches to the modelling of land-use change, and for translating narratives into quantitative models (Mallampalli et al., 2016). Probabilistic land-use change models, e.g., implemented through grid-based cellular automata (Santé et al., 2010), and employing, e.g., random forests, artificial neural networks, Markov Chains or support vector machines, are adopted to assess and predict land-use transitions (Bielecka, 2020). Generally, such approaches require land-use data for several time steps as training data and for calibration and validation, and predict land-uses as a function of observed land-use changes as part of training. Often though, trained or predicted land-use classes are comparatively coarse both spatially and thematically, i.e., differentiating only between few types of built-up land and (semi-)natural vegetation such as green spaces or forests. Such coarse classifications of simple grid-based models are sufficient to analyse and predict urbanization patterns at urban or regional scales, and may suitably represent the patch-level interventions proposed here. However, more local interventions such as the proposed selective actions, or street-level interventions, may not be well-represented or reproducible, particularly due to spatial resolution and/or a mismatch of the spatial resolution of model, training/validation data, and type of proposed intervention, or an overall scarcity of suitable data. Such data scarcity is also prohibitive for the adoption of advanced models that determine land-use changes based also on driving forces, e.g., SLEUTH (Liu et al., 2019).

Therefore, a modelling approach is required that allows for a more fine-grained representation of land-uses/land-use changes across differing spatial scales also under comparatively limited data availability. GIS-based modelling approaches allow such more-detailed assessments, typically based on land-use change rules that translate verbal, qualitative information into (*if-then-else*) *instructions* or *rules* for the actual modelling, governing land-use changes (often) deterministically, but also probabilistically, or at random (Kain et al., 2016; Larondelle et al., 2016). Rules may be adapted to the level of available information/data, as needed. In addition, multilayer GIS approaches facilitate incorporating different types of ancillary data, e.g., planning zones, into the modelling process.

Here, such a rule-based, multilayer GIS approach is implemented (Figure 1). In so doing, a methodology is tailored to meet the following needs: (i) align closely to the urban plan for 2030;

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(ii) allow for limited availability and accuracy of data; (iii) model NBS interventions at differing spatial scales; and, simultaneously, (iv) model NBS interventions in a quantitatively manner, i.e., as spatial entities, or rather qualitatively, based on a set of rules. These rules reflect on characteristics, assumptions and traits of interventions, considering: (i) attributes related to the GBI elements proposed for implementation, i.e., related to the type of action to be taken, including, e.g., physical properties (size/*spatial footprint*); (ii) spatial attributes, e.g., to define target zones for interventions, or to rank/prioritise areas for intervention as a function of, e.g., local environmental or spatial conditions; and (iii) policy goals, that define, e.g., greening rates to be achieved, and that thus indicate conditions of success, or, respectively, failure. For ease of use, rules are provided in the form of spreadsheets.

Consequently, using such rules, the qualitative, narrative-related scenarios are translated into instructions for the quantitative or qualitative modelling of NBS actions (Figure 2). Similar to established approaches, the proposed methodology seeks to model the *suitability* of spatial entities (features) to accommodate certain NBS interventions, and subsequently, proposes areas for intervention as part of what is referred to as *allocation modelling*. Here, allocation may refer to a land-use change of certain extent as the result of a specific intervention, e.g., afforestation, thus denoting a quantitative outcome (Figure 2). However, an outcome of allocation modelling may also be to designate target zones for improvements such as the greening of balconies, and therefore, spatially indicating “search spaces” for implementing certain NBS actions to inform decision-making and planning in a more qualitative manner. Overall, allocation modelling informs on the types of interventions considered, their quality, number, location, and, whenever feasible, extent (size/area, length).

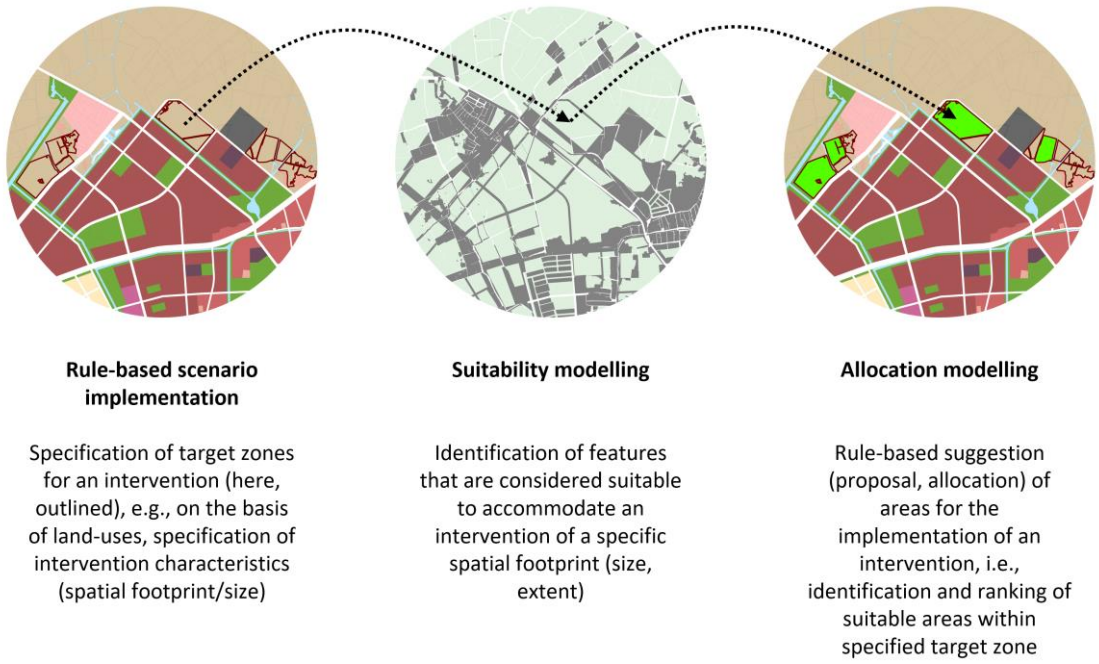

Figure 2. Modelling process example. Rules translate scenarios into modelling instructions, e.g., defining target zones for interventions, and the interventions themselves (left). Based on these rules, the suitability of spatial entities is modelled (middle), and subsequently, suitable features from the target zones are identified, ranked, and areas for the implementation of interventions proposed, i.e., allocated (right).

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The proposed methodology to spatialize scenarios is put into operation in the form of a Python toolbox for ArcGIS Pro version 2.8[1]. The various methodological steps as shown in Figure 1 are described below in more detail.

2.1 Data pre-processing

As outlined previously, the proposed methodology is designed to allow for scarce data, with potentially limited data accuracy. Therefore, the minimum data required is only two land-use datasets (of polygon geometry type) for two individual points in time. There is no strict requirement regarding the level of detail of the included land-use categories, or land cover, respectively, however, the highest level of differentiation between types of built-up land, including transportation, and (semi-)natural areas, is desirable. In addition to these datasets required at minimum, further ancillary data may be included when available, or as deemed necessary.

In a two-step process, the required two land-use datasets are combined into an integrated, synoptic dataset for the further modelling as follows (Figure 3): First, through the spatial intersection of both datasets, a matrix of observed land-use changes is compiled in the form of an Excel spreadsheet. In the spreadsheet, land-uses, and land-use changes, respectively, may be edited/recategorized, or grouped by the modeller as needed. In so doing, also restrictions on land-use changes may be imposed as needed. Second, based on this land-use change matrix, an integrated dataset, i.e., a change layer, is generated, that depicts the observed land-use changes between the two different time steps. If ancillary data is included by the modeller, it is intersected with the change layer to obtain the augmented change layer.

Importantly, regarding the implementation of NBS, it is precisely these changes in land-use that are considered to provide certain opportunities for NBS action, but that may also pose barriers. For example, the re-development of built-up land to new uses is considered to provide ample potential for the realization of NBS. However, in contrast, the absence of change may be a limiting factor and/or hindrance for the realization of particularly larger NBS.

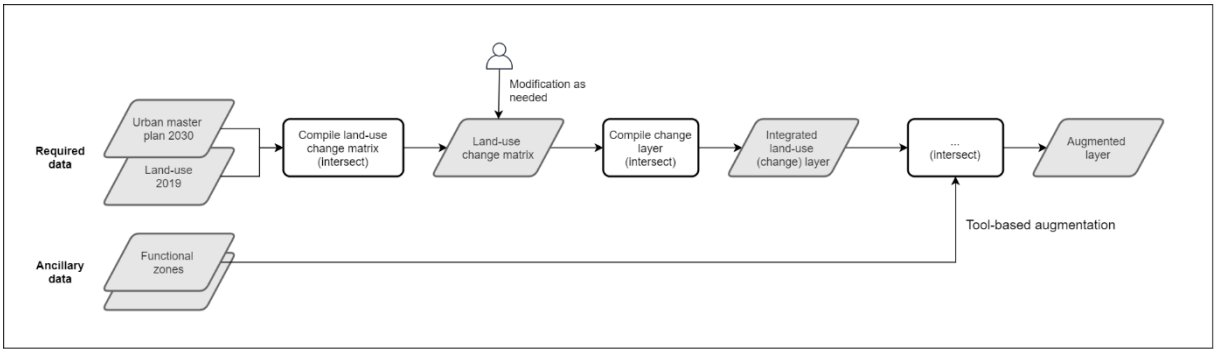

Figure 3. Initial pre-processing of land-use (patch-level) data to obtain an integrated patch-level dataset for modelling and analysis. The integrated dataset holds anticipated land-uses for the second time step and designates land-use changes likely to occur between the former and the latter time steps.

The (augmented) change layer provides the basis for the modelling of patch-level interventions or selective actions bound to certain land-uses, or target zones, respectively. Additionally, a

[1] Most recent version at the time of writing of this report.

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road layer (of line geometry type) may be generated from the integrated change layer for the modelling of interventions at the street level, in case no dedicated road layer is available for the case study area. The corresponding algorithm implemented to derive such road features from the polygon land-use data is shown in Figure 4.

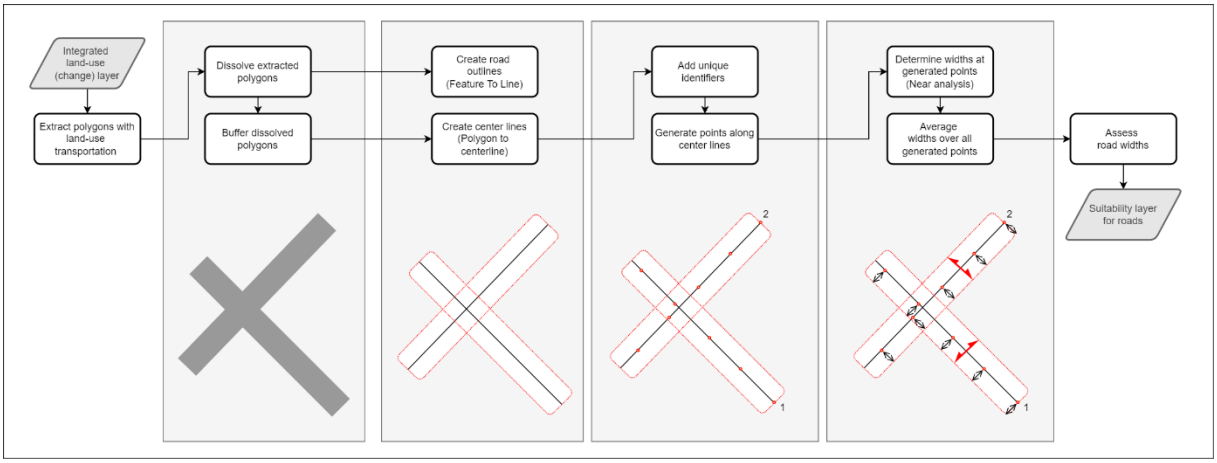

Figure 4. Workflow for the classification of roads based on modelled road with. Polygon data comprising transportation land (transportation infrastructure) is extracted from the integrated land-use (change) layer, and subsequently processed so that a center line of road polygons is created, as well as their outline. Unique identifiers are assigned to each center line. Subsequently, points are generated along each center line, and at each point location, the half width of each road is determined as the (perpendicular) distance between the center line point and road outline. The road width is then determined as the average of half widths for all center points of a road segment, multiplied by two to get the full width.

2.2 Rule-based scenario implementation (rule formulation)

As described earlier, rules are used to translate narrative scenarios into modelling parameters/instructions and input values, thereby also reflecting on intervention characteristics, local conditions, and policy goals. In so doing, rules formulation also reflects on certain opportunities or barriers to NBS implementation, and may consider the popularity of GBI elements through choice and order or rule specification.

The set of rules for the proposed methodology requires the following information and/or rules to be specified for each proposed NBS intervention: (i) designation; (ii) a so-called spatial footprint, reflecting on the intended size or spatial constraints of the proposed NBS action; (iii) a prioritization rule; and (iv) a stop (success) condition.

The *designation* is a brief label or identifier that is used to refer to the intervention in question. It is also used to establish a link between the modelled intervention with descriptive texts that narrate the intervention qualitatively. *Spatial footprint* conceptually denotes the applicable spatial scale of a given intervention, ranging, e.g., from local interventions or selective actions to small interventions such as pocket park, to larger actions such as creating large urban parks or afforestation. Consequently, spatial footprint is an indication of the desired size of the intervention, thus injecting a quantitative metric, or conversely, it is an indication of the patch space needed for a given NBS implementation, thus injecting a means to express spatial constraints to determine suitability. In case of patch-level interventions, spatial footprint conceptually refers to feature area, i.e., patch size, whereas for street-level interventions, it

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conceptually refers to road width. As part of the modelling process, the conceptual notion of spatial footprint needs to be linked to more specific patch sizes (feature area).

The *spatial selection rule* denotes spatially the desired *target zones* for a given intervention, i.e., they result in a *search space* within which suitable locations for the implementation of NBS shall be identified. This target zone, or search space, is expressed on the basis of spatial attributes, as generated during data pre-processing. I.e., the spatial selection rule may refer to land-uses or land-use changes, as contained in the integrated change layer, or may additionally refer to attributes of ancillary data used to augment this change layer. Hence, through the specification of a combination of land-uses, and/or land-use changes, and/or ancillary attributes, the desired target zones for interventions are spatially defined. The spatial selection rule corresponds to a SQL query string, i.e., simple value expressions in the form `variable = value` (equality) or `variable <> value` (inequality). Logical operators (i.e., `AND`, or `OR`) may be used to combine several expressions.

Third, through a *prioritization rule*, features located within a target zone may be ranked, and thus, priority areas for NBS action may be specified, e.g., also based on previous multi-criteria evaluation or other methods (Meerow and Newell, 2017). Ranking may be based on a variety of criteria, e.g., site-specific and/or patch-level metrics such as patch size, or patch shape. The latter reflects on development potentials and opportunities for NBS development, as particularly irregular shapes are considered more difficult for the development of built-up land and may therefore provide better opportunities for implementing NBS (Kremer et al., 2013; Miyawaki, 1998). In addition to development potential, the ranking of features may also be based on ancillary attributes, e.g., distance to residential land (or other land-uses, therefore), and/or the amount of available greenery. Supported prioritization rules are listed in Table 1. Several rules may be combined in order as a list of rules, separated by semicolon, e.g., `<rule1>;<rule2>;<rule3>`, with *rule1* taking precedence over *rule2*, *rule2* over *rule3*, etc.

Table 1. Overview of supported prioritization rules for the ranking of features.

Prioritization rule	Format	Description
No prioritization	select:none	Do not prioritize features. Iterate over the complete set of patches (features) as defined by the spatial selection rule, in the order of digitization of features, until a stop condition (if any) is met.
Random order	select:random	Iterate over patches (features) as defined by the spatial selection rule until a stop condition (if any) is met in a random order, i.e., order features randomly.
Ascending order	ascending:<variable>	Order patches (features) in ascending order of the values of the specified variable (shapefile field name), for iterating over the set until a stop condition (if any) is met.
Descending order	descending:<variable>	Order patches (features) in descending order of the values of the specified variable (shapefile field name), for iterating over the set until a stop condition (if any) is met.

Fourth, reflecting on policy goals and planning objectives, a *stop (success) condition* is required. Stop conditions include, e.g., that a given share of land of the spatial target zone has been “allocated” for NBS, that a given number of NBS have been reached, or that certain area thresholds are exceeded, e.g., a minimum area has been allocated to NBS. Supported stop conditions are listed in Table 2. At the moment, only a single stop condition per intervention is supported.

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Table 2. Overview of supported stop conditions.

Stop condition	Format	Description
Feature number reached	feature_count:<value>	Stop after a pre-defined number (total number) of patches (features) has been suggested for the implementation of NBS, when iterating over the ranked feature subset as defined through the spatial selection rule.
Feature percentage reached	feature_percentage:<value>	Stop after a pre-defined share (percentage) of patches (features) has been suggested for the implementation of NBS, when iterating over the ranked feature subset as defined through the spatial selection rule.
Lower area threshold reached	area_lower_total:<value>	Stop after a pre-defined area threshold has been reached. The area is computed through aggregating the areas of proposed NBS implementations, when iterating over the patches (features) as defined through the spatial selection rule. I.e., the corresponding spatial footprints of NBS are aggregated, here, using the lower boundary of the spatial footprint (cf. Figure 13).
Mean area threshold reached	area_mean_total:<value>	Similar to the lower area threshold stop condition, but using a mean value derived from the spatial footprint. This mean value is computed: (i) as the mean value of both, the lower (f_{low}) and the upper (f_{up}) boundary of a given spatial footprint f; or (ii) in the case where only a lower boundary f_{low} is defined for a spatial footprint, but no upper boundary, then the mean spatial footprint is derived from the average size of all patches with a feature area ≥ f_{low}.
Upper area threshold reached	area_upper_total:<value>	Similar to the lower area threshold stop condition, but using the upper boundary of the spatial footprint.
Lower area share threshold reached	area_lower_percentage: <value>	Stop after a pre-defined area share threshold has been reached. The threshold is computed through aggregating the areas of proposed NBS implementations, when iterating over the patches (features) as defined through the spatial selection rule, relative to the total area as defined through the spatial selection rule. The lower boundary of the spatial footprint is used for this computation.
Mean area share threshold reached	area_mean_percentage: <value>	Similar to the lower area share threshold stop condition, but using mean of spatial footprints.
Upper area share threshold reached	area_upper_percentage: <value>	Similar to the lower area share threshold stop condition, but using upper boundary of spatial footprints.
Threshold value reached	threshold:<variable>=<value>	Stop after a certain threshold has been reached. This threshold is computed by aggregating variable's values (shapefile field values) of patches (features) considered for NBS implementation, when iterating over the ranked patches (features) as defined through the spatial selection rule. Using this rule, e.g., street segment lengths can be used in contrast to area.

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2.3 Suitability modelling

The modelling, i.e., the determination of suitability, involves the evaluation of certain feature properties. Suitability assessment is conducted on the basis of the integrated change layer for patch-level interventions or for selective actions, and on the road layer for street-level interventions.

As part of suitability modelling, the conceptual notion of spatial footprints must be linked to more specific spatial thresholds. These thresholds may be chosen as a function of local policies (e.g., policies stating that newly constructed urban green spaces shall have a certain minimum size), design codes/building codes, however, thresholds may also be chosen based on the analysis of previous land-use changes or planned land-use changes.

Patch suitability is determined by comparing specified spatial footprint thresholds (lower threshold, and/or upper threshold, if any) with the size (feature area) of a given patch. The suitability may be compared either close-ended (as a function of upper and lower threshold) or open-ended (as a function of lower threshold only). An open-ended assessment is considered most feasible, as features that meet the minimum size constraints of larger patches are generally considered to also meet the size constraints of smaller patches (Figure 5). As indicated in Figure 5, suitability may also be tied to land-use—or land-use changes, respectively—, therefore reflecting on opportunities and barriers for NBS implementation. Consequently, certain land-uses or changes thereof may be deemed unsuitable, and thus be excluded from further analysis by the modeller a-priori.

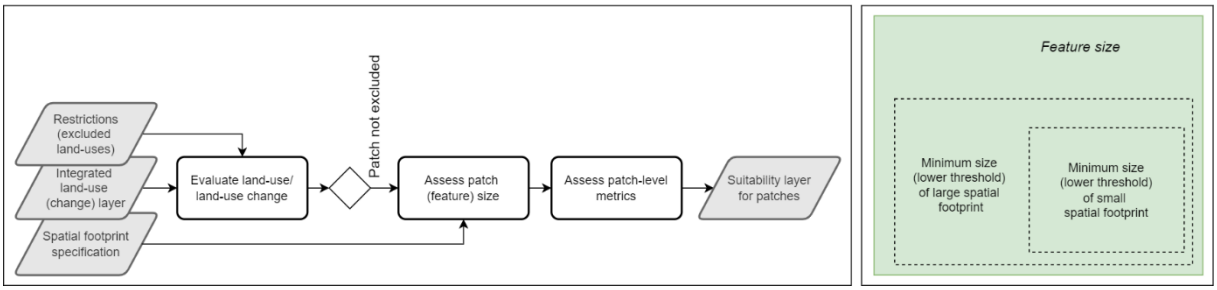

Figure 5. Workflow for the determination of feature (here, patch-level) suitability (left). On the right, the subsumption of smaller footprints by larger ones is illustrated, i.e., patches meeting the suitability criteria (minimum feature size constraints) of a large spatial footprint are considered to also meet the minimal criteria to accommodate smaller spatial footprints.

For street-level interventions, suitability is assessed as a function of road/road segment width (or possibly, length), as total road area is considered a less decisive factor in the evaluation of suitability for actions such as tree planting etc.

For each assessed spatial footprint, suitability is then denoted in the shapefile attribute table through a corresponding attribute, that is of Boolean type, indicating suitable (value=1) or not suitable (value=0) features. Additionally, in case of patches, patch-level metrics may be computed and stored to the output dataset, e.g., to enable prioritization rules to be based on such metrics. The available metrics include the Perimeter-Area Ratio (PARA), the Shape Index (SHAPE), and the Fractal Dimension Index (FRAC), and are computed as follows, where p_{ij} is equal to the perimeter (m) of patch *ij*, and where a_{ij} is equal to the area (m²) of the given patch (MacGarigal and Marks, 1995):

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$$PARA = \frac{p_{ij}}{a_{ij}} \quad \text{(Eq. 1)}$$

$$SHAPE = \frac{p_{ij}}{2\sqrt{\pi\, a_{ij}}} \quad \text{(Eq. 2)}$$

$$FRAC = \frac{2 \ln p_{ij}}{\ln a_{ij}} \quad \text{(Eq. 3)}$$

PARA is a relatively simple measure of shape. SHAPE is equal to 1 for circular patches, with SHAPE increasing for more irregular shapes, i.e., an increasing departure from the circular form. FRAC approaches a value of 1 for comparatively regular shapes (circular, square), and approaches a value of 2 for more irregular shapes (ibid.). Like above, for each computed metric, an attribute is added to the shapefile attribute table.

2.4 Conflict modelling

Conflict modelling is an aspect sought to express conflicts/barriers, however, on a conceptual level that is different from and additional to suitability as described above. Here, conflicts refer to barriers to NBS implementation emerging from, or being imposed by the earlier implementation of certain GBI elements at a given location. For example, proposing afforestation action in a certain patch may result in the patch to be considered unsuitable to accommodate subsequent types of interventions. Here, the order of modelling implementations (in terms of earlier/former vs. later/subsequent) is a function of the order of rules, thereby considering, e.g., feasibility or popularity of interventions. In the case that restrictions and barriers emerging from imposing such order shall be considered, such conflicts may be denoted in the form of a conflict matrix, as shown in Figure 6. However, conflict modelling is entirely optional.

	Intervention 1	Intervention 2	Intervention 3	Intervention ...
Intervention 1			C	
Intervention 2			C	
Intervention 3				
Intervention ...				

Figure 6. Exemplary conflict matrix. As shown, perceived conflicts between distinct interventions are denoted by the letter "C".

2.5 Allocation modelling

Allocation modelling refers to the process of identifying suitable patches, or roads, respectively, their ranking, and proposing NBS implementations until a stop condition, if any, is met (Figure 7). Typically, proposing, suggesting, considering or allocating[2] a feature for the implementation of GBI element(s) would result in changing of land-uses or land-cover in the result dataset, or

[2] These terms are used synonymously

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new geometries be constructed, and the total area of changes would quantitatively summarize achieved conversion rates/total area of land converted to green space etc.

Here, due to the fact that interventions may be quantitative or more qualitative in nature, and due to scale issues as described previously, a "*virtual bookkeeping"* is implemented instead of an actual re-classification of land-uses. In the case of patch-level interventions, this virtual bookkeeping refers to tracking the total area of NBS "implemented", as a function of spatial footprint. In case of selective actions, for example the number of areas suggested for the implementation of such actions may be tracked instead, and in case of street-level interventions, the virtual bookkeeping may also refer to the total length of roads considered for improvement. In so doing, the evaluation of proposed measures against policy goals, as defined through stop conditions, is enabled.

The allocation modelling process is implemented as shown in Figure 7. As input data, the layer created from suitability modelling must be provided. However, if needed, depending on attributes referred to in rule formulation, ancillary data may also be included. However, in that case, as geometries may change due to the underlying intersect operation, suitability will automatically be re-evaluated.

Then, the formulated spatial selection and prioritization rules are translated into GIS queries and filters/ordering instructions. Thereby, from all features of the input dataset, first, suitable features are identified. The set of suitable features is subsequently narrowed down according to the spatial selection rule, i.e., only features within the so-defined target zone are considered further. The resulting feature set is subsequently re-ordered, and thus ranked, in accordance with the stated prioritization rule (if any). In this ordered feature set, the top-most feature would be considered the first feature suggested to accommodate a given intervention, i.e., where action is suggested to be taken. If no prioritization rule is used, features may be processed in arbitrary order. As shown in Figure 7, the (un-)ordered set of features is being iterated, as follows:

(i) Evaluation of the stop condition;
(ii) Evaluation of conflicts that may emerge from previously allocated interventions, if the stop condition has not been met already;
(iii) Allocation in the absence of conflicts, i.e., virtual bookkeeping of NBS action, and updating of the stop condition;
(iv) Feature flagging, i.e., writing the result to the shapefile attribute table.

As result of allocation modelling, for each feature, i.e., patch or road segment assessed, a flag value is written to the shapefile attribute table that indicates the actual modelling result. As shown in Table 3, this flag value indicates whether a feature falls under the suitability and target zone criteria, has been prioritized, i.e., considered for NBS implementation, or whether a conflict has been identified, etc. (Figure 8).

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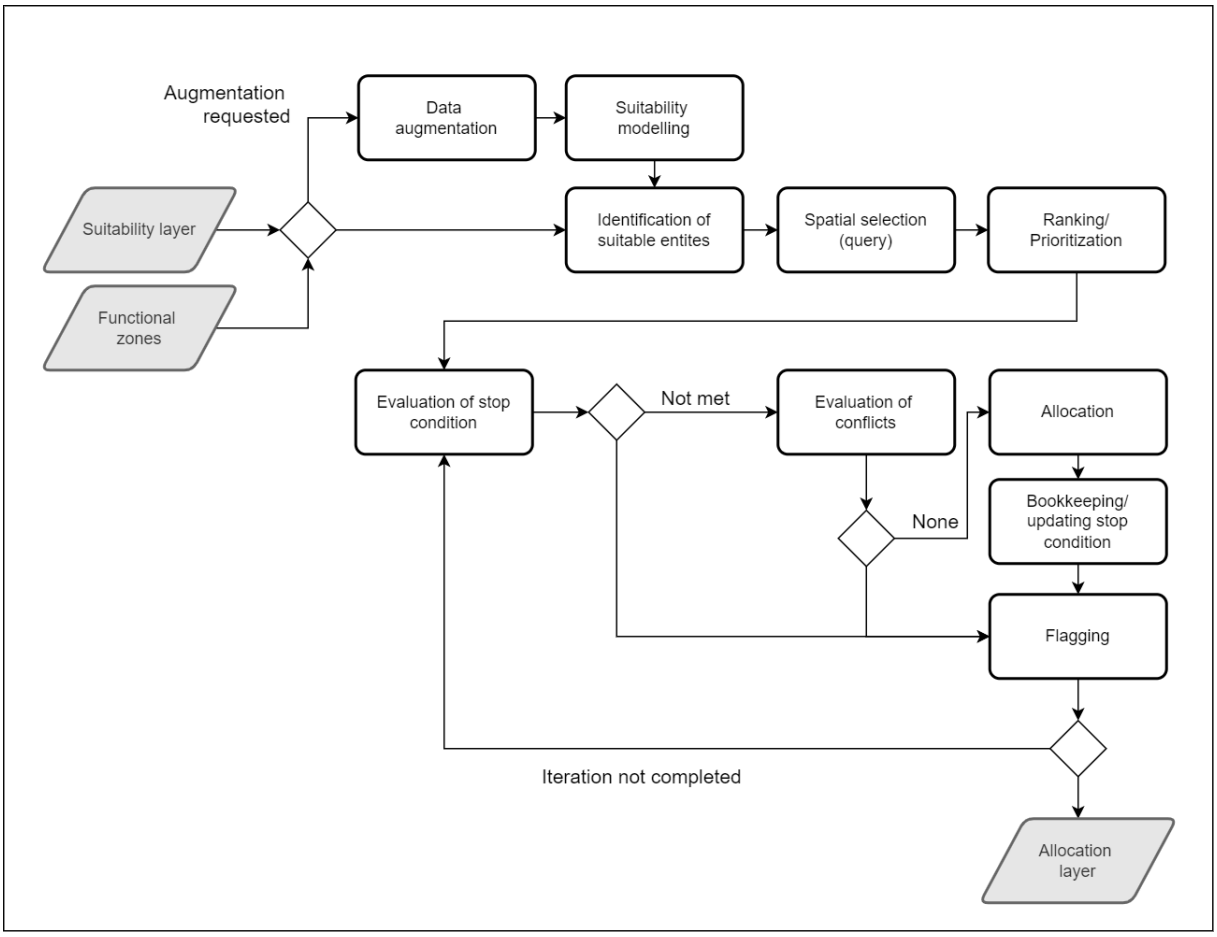

Figure 7. Allocation modelling algorithm, i.e., the modelling of interventions based on a previous suitability assessment.

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Table 3. Description of flag values indicating the result of allocation modelling at feature level.

Indication	Flag value	Description
Error condition	-1	The allocation algorithm failed. The feature could not be processed. Some error occurred in the script, possibly, input data was incorrect or missing.
Unsuitable entity	0	The feature has been evaluated as generally unsuitable for the given NBS intervention.
Suitable entity	1	The feature has been evaluated as generally suitable for the proposed intervention, e.g., as a function of spatial footprint. It is however not considered for the given NBS intervention.
Entity in accordance with the spatial selection rule	2	The feature has been evaluated to be generally suitable for the proposed intervention, and the feature is in accordance with the spatial selection rule, i.e., it is part of the target zone/search space.
Conflict emerged related to other intervention	30	The feature has been ranked, and was so ranked that it has generally been considered for NBS implementation. However, no action is proposed on the patch as testing for conflicts resulted in a conflict with a previously suggested intervention.
Conflict emerged related to available space	31	The feature has been ranked, and was so ranked that it has generally been considered for NBS implementation. However, no action is proposed on the patch as testing for conflicts resulted in a mismatch of available patch area due to previously suggested interventions.
Prioritized entity	4	The feature has been ranked, and was so ranked that it is considered (prioritized) for NBS intervention. In line with spatial footprint or other specified criteria, it is counted towards the stop condition. The feature should be inspected more closely for more-specific NBS planning.

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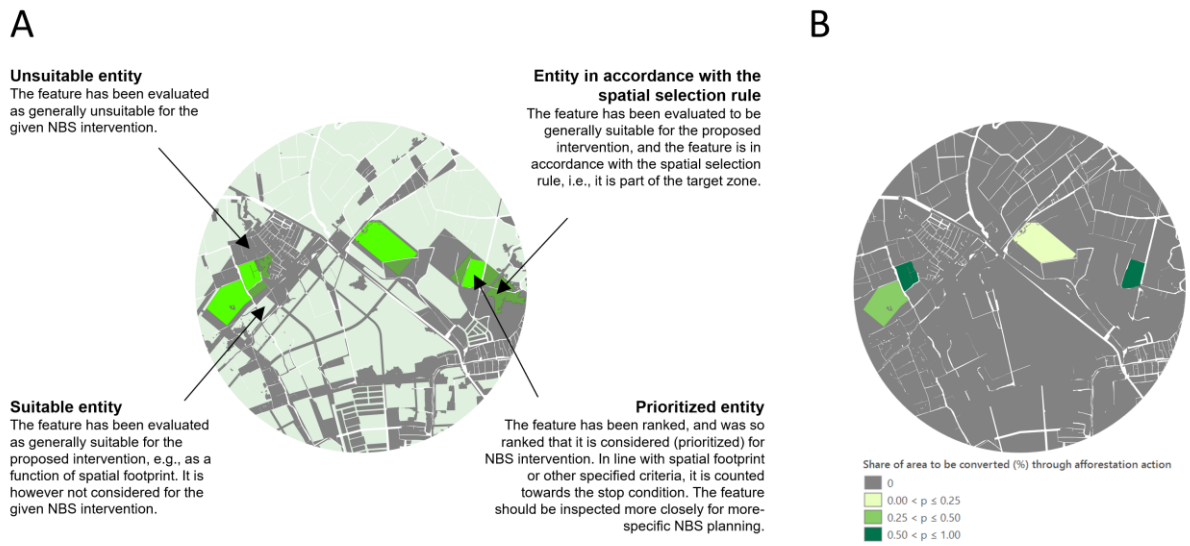

Figure 8. Visualization of exemplary outcomes of allocation modelling based on flag values. Features considered unsuitable for the proposed intervention are shown in dark grey (unsuitable entity with flag value 0). Features considered generally suitable, but being located outside of the target zone specified through the spatial selection rule are shown in pale green (suitable entity with flag value 1). Features evaluated as suitable that are located within the target zone are subsequently ranked and iterated, these are shown in either dark green or bright green colour. The latter, bright green features are prioritized for NBS action, i.e., ranked-so that they are suggested (proposed, allocated) for the implementation of a given intervention (prioritized entities with flag value 4). The former, dark green features were so ranked that they were *not* considered for an implementation (entities in accordance with the spatial selection rule with flag value 2), as the stop condition has already been met through previous allocations (A). For the prioritized features considered for NBS action, the (virtual) allocation of space results in a certain area of each feature to be considered for conversion, e.g., through afforestation action. This area is a function of designated spatial footprints as expressed in the set of rules. For prioritized features, the share (percentage) of feature area to be converted, i.e., used for the implementation of an intervention, can subsequently be determined, and visualized accordingly (B).

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3 Implementation of the modelling approach for the city of Huế

3.1 Data pre-processing

The integrated change layer for further analysis was derived from two land-use datasets, with the first being effective for the year 2019, and the second outlining the urban planning for the year 2030. Both land-use datasets were initially prepared during the definition phase and the early research and development phase of the project.

The land-use data for 2019 was compiled from land-use data for Huế, Huong Thuy, Huong Tra, and Phu Vang (DONRE Thua Thien Huế, 2019). It is used for representation of the status-quo. The latter land-use dataset for 2030 corresponds the ”*Land Use Plan And Functional Areas Plan 2030”* (cf. decision no. 649/QD-TTG[3]), that was last updated in 2019. Therefore, it represents intended future conditions, and is thus used to align scenario modelling to actual urban master planning. Moreover, as this plan already foresees the implementation of various GBI elements, it is also used to derive baseline/business-as-usual conditions (cf. scenario A).

In addition, as ancillary data, functional areas are considered. Functional areas indicate, e.g., the intentional preservation, renovation, or re-development of specific areas, or state areas restricted from development (Figure 9) and are therefore considered to support the identification of opportunities or prohibitive areas for NBS implementation (cf. decision no. 1271/QD-UBND from 13 June 2017[4]). The land-uses contained in the integrated change layer, augmented with ancillary data, and aligned with future planning, as well as the changes in land-use from 2019 to 2030, were determined based on the land-use change matrix shown in Table S 1 (cf. Figure 10).

[3] Promulgated attached to the decision number: 649/QD-TTG on 5 June 2014: APPROVAL FOR ADJUSTMENTS TO GENERAL PLANNING FOR HUE CITY TO 2030 AND A VISION TO 2050, The Socialist Republic of Vietnam, Thua Thien Hue.

[4] Decision number: 1271/QD-UBND on 13 June 2017: REGULATIONS FOR CONSTRUCTION MANAGEMENT ACCORDING TO THE ADJUSTMENT SCHEME OF THE GENERAL PLANNING OF HUE CITY TOWARDS 2030 AND VISION TO 2050. The Socialist Republic of Vietnam, Thua Thien Hue.

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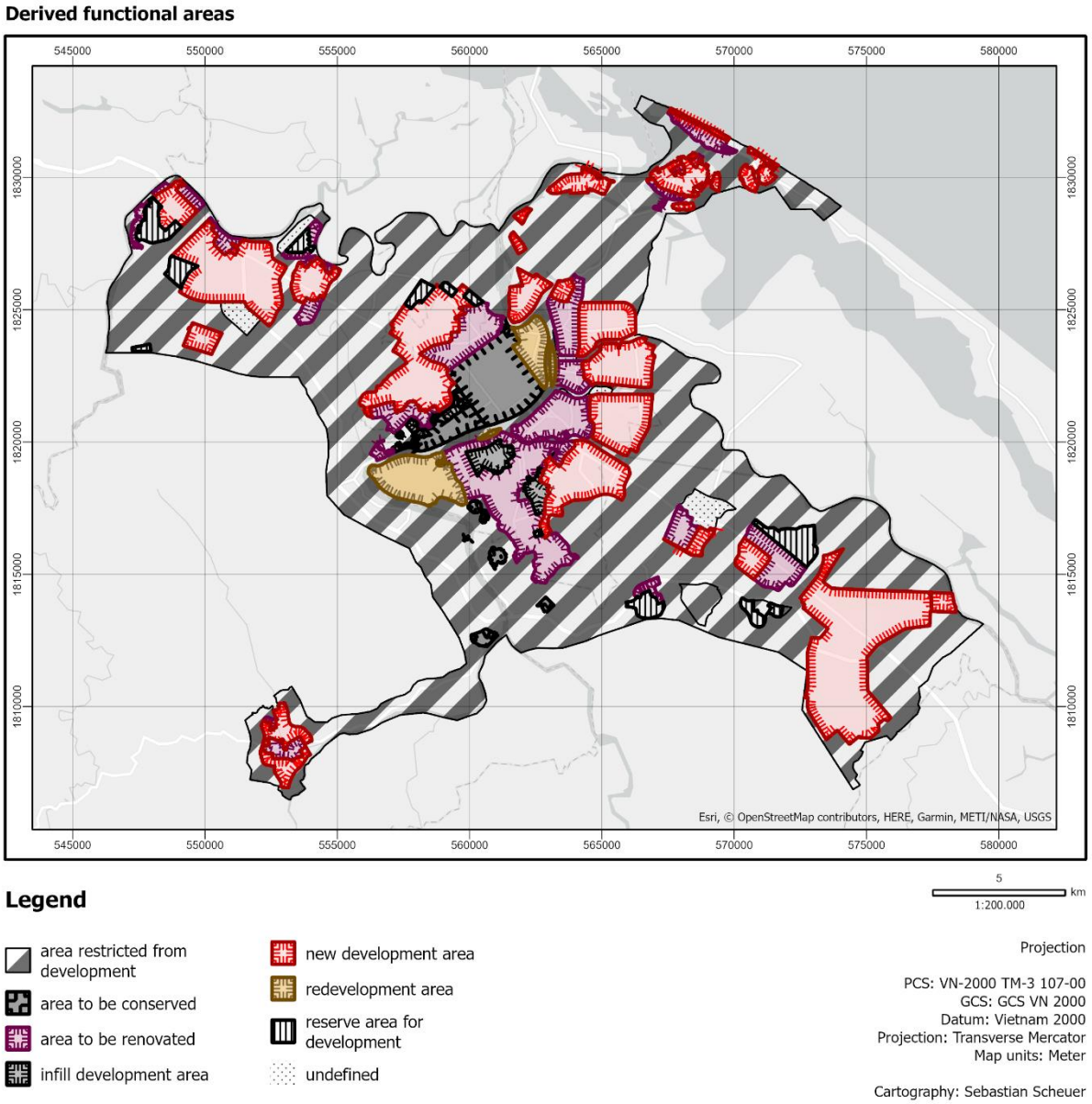

Figure 9. Functional areas ancillary data.

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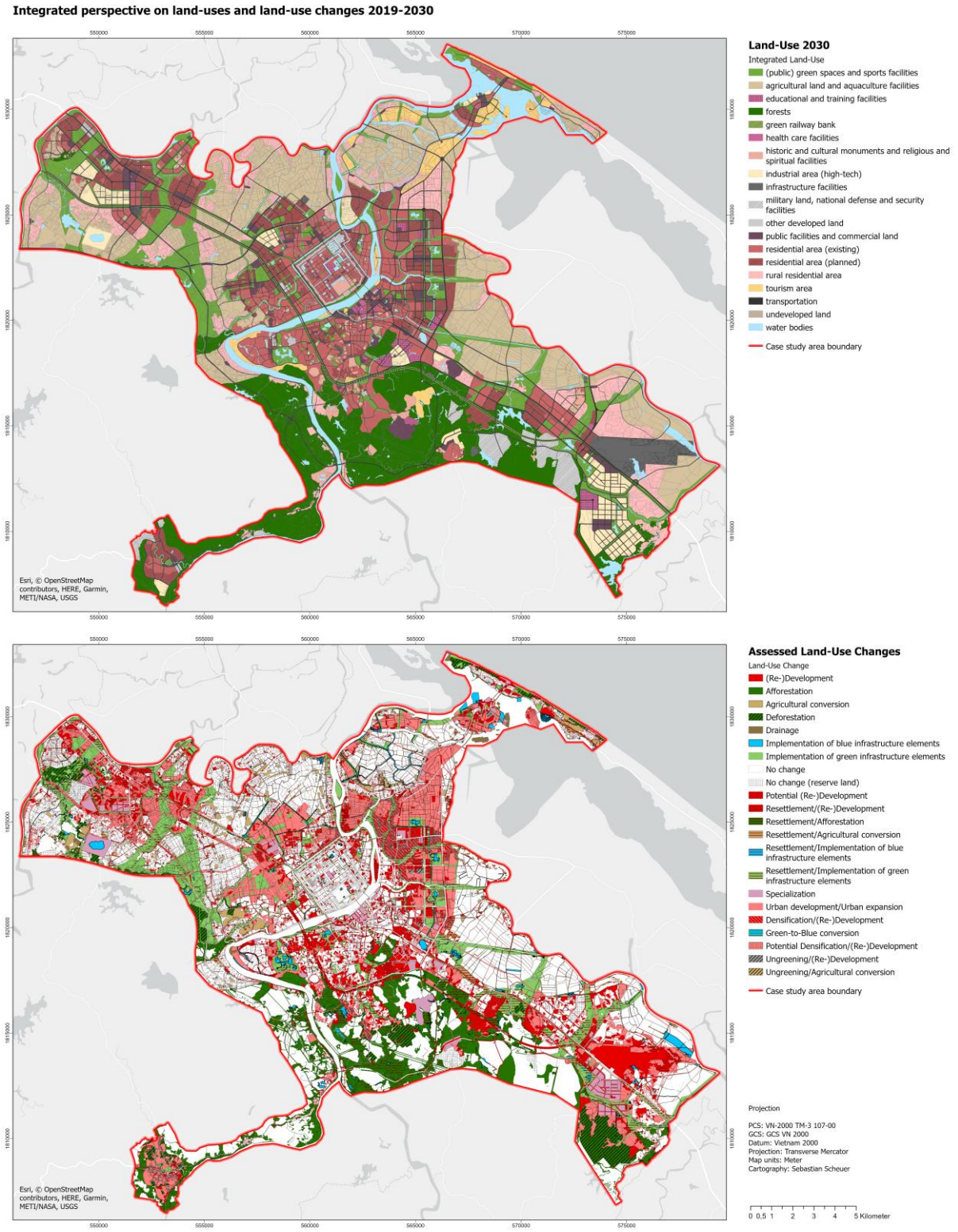

Figure 10. Integrated change layer with expected land-use in 2030 (top) and assessed land-use changes 2019-2030 (bottom).

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3.2 Rule-based scenario implementation (rule formulation)

3.2.1 Summary of scenarios

As described earlier, four narratives, and accordingly, scenarios, were tentatively developed/co-designed with local stakeholders in the definition phase of the GreenCityLabHuế project. The narratives and corresponding scenarios are summarized in Table 4. The scenarios include a status quo/business-as-usual scenario (designated scenario A), and three scenarios (designated scenario B to D) that describe various NBS interventions following a gradient of increasing degree of intervention. This degree of intervention reflects on increasing ambition for greening action and entails (for more details, cf. Jache et al., 2021 and Figure 11):

- As a qualitative dimension related to the choice of NBS interventions/GBI elements to be implemented, a higher number of types of GBI elements to be proposed. This also includes that, from scenario B to D, increasingly, also GBI elements currently considered less popular are proposed nonetheless , as well as GBI elements perceived as less feasible for implementation, e.g., by potentially requiring changes to building codes (e.g., green roofs);
- As a qualitative dimension related to the design of NBS interventions/GBI elements to be implemented, a higher “quality” of implementation. This refers to, e.g., tree density or similar, i.e., higher canopy covers to be achieved, and is thus referring to the desired “design” of measures. This qualitative dimension is primarily expressed through corresponding narratives;
- As a quantitative dimension related to the design of NBS interventions/GBI elements to be implemented, increasingly larger elements proposed, i.e., enlarging spatial footprints;
- As a quantitative dimension related to policy goals, higher conversion rates to be achieved, i.e., land converted to urban green space etc., or a higher number of interventions to be considered.

In the following, based on the narrative for each scenario, and following the gradient of degree of intervention as described above, NBS actions are further specified for modelling by translating them to sets of rules; Figure 12 depicts exemplarily the potential outcomes of the proposed interventions. In this translation, to additionally allow for an analysis of sensitivity of spatializations of interventions, for each scenario, different thresholds for spatial footprints are tested, i.e., lower, mean, or upper threshold/limit for area/feature percentages (cf. stop condition types in Table 2).

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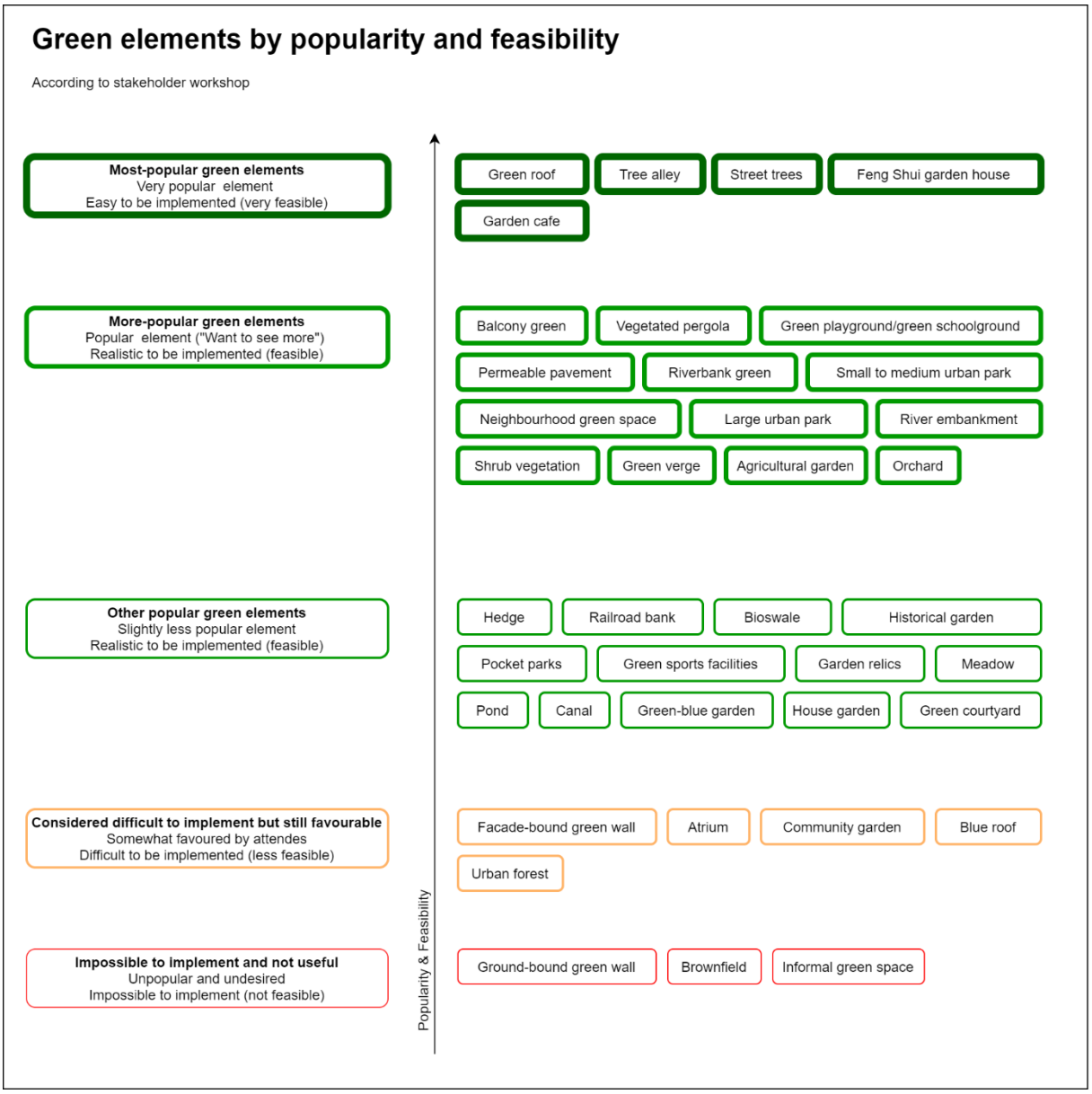

Figure 11. Perceived popularity of green infrastructure elements and the perceived feasibility of their implementation, as elicited through a stakeholder workshop (Jache et al., 2021).

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Table 4. Overview and narrative for the four considered scenarios A to D.

Designation	Scenario title	Narrative
A	Baseline/ business-as-usual	In comparison to the 2030 planning, no additional measures will be taken. This business-as-usual scenario is therefore characterized by the 2030 green space planning, as expressed in the 2030 Huế urban master plan. No additional interventions are considered in this scenario. This scenario serves as baseline scenario for scenarios B and D, in addition to the status-quo, that corresponds to 2019 conditions.
B	Smaller-scale improvements through traditional green elements	This scenario improves on the business-as-usual scenario through the implementation of additional actions/interventions. Actions will be taken in both existing and planned land-uses (across all relevant types of areas). Mostly, smaller-scale (selective and small-footprint) GBI elements/actions will be considered that are deemed traditional/popular, and that are therefore also (very) feasible for implementation. These GBI elements/actions include the planting of (street) trees, shrubs and hedges, the creation of tree alleys, the construction of green playgrounds and the greening/improvement of existing playgrounds, or the construction of small parks/pocket parks. Selective actions in existing land-uses include the greening of balconies and the construction of vegetated pergolas.
C	Moderate to large-scale improvements	This scenario improves on the small-scale interventions in scenario B through considering GBI elements/actions with larger spatial footprints (moderate- and large-footprint actions), as well as less traditional/not yet popular GBI elements. In existing land-uses, selective actions similar to B are anticipated; however, in addition to scenario B, also green courtyards, ponds, and house gardens will be considered, and community gardens will be proposed as well. Green spaces shall be improved, e.g., through the planting of trees, shrubs, or hedges, e.g., to construct woody playgrounds. Existing infrastructures may be improved further through permeable pavements, bioswales and green verges, especially in renovation and redevelopment areas. Newly constructed areas, represented by planned land-uses within in-fill areas, redevelopment areas and new development areas, provide the opportunity to implement GBI elements/actions with moderate and/or large spatial footprints, including, e.g., neighbourhood green spaces, riverbank green, medium-sized and/or large urban parks, orchards, green sports facilities, historical gardens, and meadows. It is anticipated that the 2030 urban planning may be revised if needed to spatially accommodate such larger-footprint actions. In so doing, the implementation of such actions/GBI elements, the green space per capita in planned land-uses shall be increased in comparison to the business-as-usual, or the smaller-scale improvements proposed in scenario B.
D	Eco-city	The eco-city narrative builds upon narrative C, and assumes that the green space per capita ratio shall be increased further. In addition to narrative C, it is proposed that urban forests and/or orchards may be planted, or large urban parks and (historical) gardens be constructed within land reserved for future development. Moreover, additional property-related selective actions are proposed, including green roofs, façade-bound green walls, and/or blue roofs. These actions should be implemented may be implemented where feasible within existing land-uses, and particularly in planned land-uses, their implementation may be increasingly accommodated through the adaptation of building codes.

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Figure 12. Exemplary depiction of potential outcomes of proposed interventions.

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3.2.2 Scenario A – Baseline/business as usual

Scenario A considers only those greening interventions that are explicitly foreseen in Huế's land-use planning for the year 2030. Thus, scenario A considers the business-as-usual, and provides a baseline against which additional measures foreseen in scenarios B and D can be evaluated against.

3.2.3 Scenario B – Smaller-scale improvements through traditional green elements

Following the corresponding narrative, scenario B considers some greening interventions in addition to the business-as-usual scenario, particularly selective and small-footprint interventions. Moreover, the scenario suggests rather popular GBI elements that, therefore, were also considered by stakeholders to be more feasible for implementation (Jache et al., 2021).

At the patch-level, scenario B foresees the construction of small pocket parks in various target areas. These target areas include primarily residential land (existing and planned) but also public facilities within new development areas, infill developments, and renovation areas. Minor interventions are foreseen within conservation areas. In line with ambitions of Huế to strengthen (eco-)tourism, an intervention proposes the construction of pocket parks within tourism areas to be newly developed until 2030. Selective measures consider balconies and pergolas to be greened in renovation and conservation areas. In addition, scenario B suggests the construction of playground areas within current public green spaces in near proximity to residential land. At street-level, scenario B proposes the planting of hedges and street trees.

The narrative description of the interventions proposed within scenario B are summarized in Table 5 at the level of patches, and in Table 6 at the street-level. The according rules for implementing scenario B are shown in Table S 2 for patch-level interventions, and in Table S 3 for street-level interventions.

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Table 5. Proposed interventions for scenario B at patch-level.

Designation	Spatial footprint	Description	Prioritization	Target
N_PLAY	Selective/ Local	Construction of new playgrounds within green infrastructures—i.e., (public) green spaces—to be implemented until 2030[5], within max. 1000m distance to existing, newly built or planned residential land.	Larger patch area, closer proximity to residential land	Proposing 15 features to be constructed
PARK_R1	Small	Construction of small parks (pocket parks) in residential areas to be developed/newly built until 2030[6], within new development areas or redevelopment areas.	Irregular patches	Proposing conversion of min. 10% of target area
PARK_R2	Small	Construction of small parks (pocket parks) in residential areas to be developed/newly built until 2030, within areas to be renovated, or infill areas.	Irregular patches	Proposing conversion of min. 7.5% of target area
PARK_R3	Small	Construction of small parks (pocket parks) in residential areas to be developed/newly built until 2030, within areas to be conserved.	Irregular patches	Proposing conversion of min. 5% of target area
PARK_P	Small	Construction of small parks (pocket parks) in public facilities, i.e., educational and training facilities, health care facilities, public and commercial land, that are to be developed/newly built or re-developed until 2030, within new development areas or areas to be renovated.	Irregular patches	Proposing conversion of min. 7.5% of target area
PARK_E	Small	Construction of small parks (pocket parks) to support eco-tourism, i.e., greening interventions in designated tourism areas within new development areas, and/or within areas to be redeveloped.	Irregular patches	Proposing conversion of min.

[5] Integrated land-use equal to (Public) green spaces and sports facilities, change state different from no change.
[6] Integrated land-use equal to residential area (existing or planned), change state equal to urban development/urban expansion.

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				7.5% of target area
SELECT_R	Selective/ Local	Selective greening actions in existing (current) residential areas, including the greening of balconies, the construction of vegetated pergolas, or of Feng-Shui elements, where feasible, within areas to be renovated, or areas to be conserved.	Regular patches	Proposing interventions considering 10% of features
SELECT_C	Selective/ Local	Selective greening actions in existing (current) public facilities and commercial land, including the construction of garden cafes, or vegetated pergolas, within areas to be renovated or areas to be conserved.	Regular patches	Proposing interventions considering 10% of features

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Table 6. Proposed interventions for scenario B at street-level.

Designation	Spatial footprint	Description	Prioritization	Target
HEDGES	WIDTH:S	Planting of (additional) hedges in residential streets (indicated by planned or existing residential land), within new development areas, that are otherwise considered unsuitable for an outfitting with trees.	Random	5% of residential streets improved, equal to 6342m in length
STR_TREE1	WIDTH:M	Planting of (additional) street trees in residential streets (indicated by planned or existing residential land), within new development areas	Random	5% of residential streets improved, equal to 6342m in length
STR_TREE2	WIDTH:M	Planting of (additional) street trees in residential streets (indicated by planned or existing residential land), within re-development areas	Random	5% of residential streets improved, equal to 1147m in length

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3.2.4 Scenario C – Moderate to large-scale improvements

Scenario C builds on scenario B, and suggests additional measures, as well as NBS actions with larger footprints. Moreover, reflecting upon more ambitions policy goals, scenario C also aims at converting larger shares of land to green or green-blue spaces.

Accordingly, at patch-level, when compared to scenario B, larger spatial footprints are proposed for urban green spaces (parks) to be constructed, and orchards and meadows are suggested as added types of green elements. Scenario C additionally proposes the creation of urban blue spaces in the form of ponds. Furthermore, as qualitative, selective-local measures, scenario C foresees the improvement of already existing urban green spaces, e.g., through planting of additional trees, by adding benches, etc., thereby aiming to achieve a better state of urban greenery with higher amenity values and improved ecosystem service delivery. Additional selective measures include the establishment of community gardens and the creation of house gardens. At the street-level, scenario C additionally proposes planting tree alleys/completing street tree ensembles to form tree alleys, construction of green verges, and the construction of bioswales to improve retention and infiltration capacities.

The narrative summary of patch-level interventions is shown in Table 7, and for street-level interventions in Table 8. The corresponding rules to implement scenario C are summarized in Table S 4 for the patch-level, and Table S 5 for the street-level.

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Table 7. Proposed interventions for scenario C at patch-level.

Designation	Spatial footprint	Description	Prioritization	Target
N_PLAY	Selective/ Local	Like scenario B, i.e., construction of new playgrounds within green infrastructures—i.e., (public) green spaces—to be implemented until 2030, within max. 1000m distance to existing, newly built or planned residential land, but proposing the realization of more features and in a higher quality, that includes planting of trees, shrubs, or hedges, i.e., construction in the form of woody playgrounds.	Larger patch area, closer proximity to residential land	Proposing 30 features to be constructed (+15 features compared to B)
IMP_GS	Selective/ Local, but using spatial condition for identification of areas	Improvement of existing green spaces throughout the study area, including planting trees, shrubs, and hedges, or construction of features such as benches etc., to improve amenity value and overall green space quality.	Irregular patches, closer proximity to residential land	Proposing conversion of min. 10% of target area
PARK_R1	Moderate	Like scenario B, i.e., construction of green spaces in residential areas to be developed/newly built until 2030, within new development areas or redevelopment areas, but proposing larger, i.e., moderate spatial footprints, thereby increasing the patch size of each individual park constructed.	Irregular patches	Proposing conversion of min. 15% of target area (+5% compared to B)
PARK_R2	Small-to-moderate	Like scenario B, i.e., construction of green spaces in residential areas to be developed/newly built until 2030, within areas to be renovated, or infill areas. but proposing larger, i.e., small-to-moderate spatial footprints, thereby increasing the patch size of each individual park constructed.	Irregular patches	Proposing conversion of min. 10% of target area (+2.5% compared to B)

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PARK_R3	Small	Like scenario B, i.e., construction of small parks (pocket parks) in residential areas to be developed/newly built until 2030, within areas to be conserved.	Irregular patches	Proposing conversion of min. 5% of target area (no change when compared to B)
PARK_P	Moderate-to-large	Like scenario B, i.e., construction of green spaces in public facilities, i.e., educational and training facilities, health care facilities, public and commercial land, that are to be developed/newly built or re-developed until 2030, within new development areas or areas to be renovated, but proposing larger, i.e., moderate-to-large spatial footprints, thereby increasing the patch size of each individual park constructed.	Irregular patches	Proposing conversion of min. 10% of target area (+2.5% compared to B)
PARK_E	Moderate	Like scenario B, i.e., construction of green spaces to support eco-tourism, i.e., greening interventions in tourism areas within new development areas, and/or within areas to be redeveloped, but proposing larger, i.e., moderate spatial footprints, thereby increasing the patch size of each individual park constructed.	Irregular patches	Proposing conversion of min. 15% of target area (+7.5% compared to B)
SELECT_R	Selective/ Local	Like scenario B, i.e., selective greening actions in existing (current) residential areas, including the greening of balconies, the construction of vegetated pergolas, or of Feng-Shui elements, where feasible, within areas to be renovated, or areas to be conserved.	Regular patches	Proposing interventions considering 15% of features (+5% of features compared to B)
SELECT_C	Selective/ Local	Like scenario B, i.e., selective greening actions in existing (current) public facilities and commercial land, including the construction of garden cafes, or vegetated pergolas, within areas to be renovated or areas to be conserved.	Regular patches	Proposing interventions considering 15% of features

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				(+5% of features compared to B)
ORCHARD	Moderate	Planting of moderately sized orchards on land foreseen to be converted to agricultural land until 2030.	Larger patch size, regular patches	Proposing conversion of min. 10% of target area
MEADOW	Moderate	Creation of moderately sized meadows on land foreseen to be converted to agricultural land until 2030. This measure is foreseen to be implemented in addition to orchards, allowing for a total conversion rate of 15% of foreseen agricultural land to NBS. The feature space for meadows is conceptualized to be different from orchards.	Larger patch size, regular patches	Proposing conversion of min. 5% of target area
PONDS	Small	Construction of small ponds within green infrastructures—i.e., (public) green spaces and green sports facilities—to be implemented until 2030, that are within max. 1000m distance to existing, newly built or planned residential land. Ponds should not be constructed where novel playgrounds are established.	Larger patch area, closer proximity to residential land, irregular patches	Proposing conversion of min. 1% of target area
CG	Selective/ Local	Establishment of community gardens on land foreseen to be re-developed into (public) green spaces (demolition land), within infill development areas.	Irregular patches	Proposing establishment of 5 community gardens
HG	Selective/ Local	Creation of house gardens, i.e., greening actions on private land as more diverse and adaptive greening, in rural residential land to be developed/newly built until 2030.	Larger patch area, irregular patches	Proposing interventions on 25% of features

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Table 8. Proposed interventions for scenario C at street-level.

Designation	Spatial footprint	Description	Prioritization	Target
HEDGES	WIDTH:S	Planting of (additional) hedges in residential streets (indicated by planned or existing residential land), within new development areas, that are otherwise considered unsuitable for an outfitting with trees.	Random	10% of residential streets improved, equal to 12684m in length
STR_TREE1	WIDTH:M	Planting of (additional) street trees in residential streets (indicated by planned or existing residential land), within new development areas	Random	10% of residential streets improved, equal to 12684m in length
STR_TREE2	WIDTH:M	Planting of (additional) street trees in residential streets (indicated by planned or existing residential land), within re-development areas	Random	10% of residential streets improved, equal to 2294m in length
ALLEY1	WIDTH:W	Planting of tree alleys, or completion of current tree layouts to tree alleys, in residential streets (indicated by planned or existing residential land), in new development areas	Random	10% of residential streets improved, equal to 12684m in length
ALLEY2	WIDTH:W	Planting of tree alleys, or completion of current tree layouts to tree alleys, in tourism land	Random	10% of streets connected to tourism areas, equal to 1522m in length

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Bioswales	WIDTH:W	Construction of bioswales associated to streets in industrial areas and infrastructure land, within new development areas	Random	5% of streets improved, equal to 3464m in length
GRN_AM1	WIDTH:B	Construction of green verges, and street furniture to increase amenity values, in residential streets (indicated by planned or existing residential land), in re-development areas	Random	5% of streets improved, equal to 1147m in length
GRN_AM2	WIDTH:B	Construction of green verges, and street furniture to increase amenity values, in residential streets (indicated by planned or existing residential land), in areas to be renovated	Random	5% of streets improved, equal to 6592m in length

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3.2.5 Scenario D – The eco-city

Scenario D is the scenario with the highest degree of intervention, i.e., it corresponds to a very ambitious and rather hypothetical scenario, a green utopia. Compared to scenario C, scenario D suggests implementing individual GBI elements as even larger entities, i.e., it further increases corresponding spatial footprints, as well as desired rates of land conversions, here, also considering additional target zones for certain interventions. Likewise, also in scenario D are further types of interventions proposed. At the patch-level, this includes large-scale afforestation action to increase the share of forest land in the case study area, and as selective-local measures, the greening of roofs and facades as types of interventions considered less feasible by stakeholders, as they possibly require an adaptation of building codes etc. for these green elements to be implemented. At the street-level, generally, stop conditions are increased accordingly, i.e., in total, scenario D foresees a larger share of roads (i.e., longer total length of roads) to be improved through the planting of hedges, street trees/tree alleys, and the construction of green verges or bioswales.
The narrative summary of patch-level interventions for scenario D is shown in Table 9, and in

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Table 10 for street-level interventions. The according rules to implement these interventions are shown in Table S 6 for the patch-level, and in Table S 7 for the street-level.

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Table 9. Proposed interventions for scenario D at patch-level.

Designation	Spatial footprint	Description	Prioritization	Target
N_PLAY	Selective/ Local	Like scenario C, i.e., construction of new, high-quality, woody playgrounds within green infrastructures—i.e., (public) green spaces—to be implemented until 2030, within max. 1000m distance to existing, newly built or planned residential land. Compared to scenario C, additional woody playgrounds will be constructed.	Larger patch area, closer proximity to residential land	Proposing 50 features to be constructed (+20 features compared to C)
IMP_GS	Selective/ Local, but using spatial condition for identification of areas	Like scenario C, i.e., improvement of existing green spaces throughout the study area, including planting trees, shrubs, and hedges, or construction of features such as benches etc., to improve amenity value and overall green space quality. In scenario D, a higher share of target zones will be considered for implementation.	Irregular patches, closer proximity to residential land	Proposing conversion of min. 15% of target area (+5% compared to C)
PARK_R1	Moderate-to-large	Like scenario B, i.e., construction of green spaces in residential areas to be developed/newly built until 2030, within new development areas or redevelopment areas, but proposing larger, i.e., moderate-to-large spatial footprint.	Irregular patches	Proposing conversion of min. 25% of target area (+10% compared to C)
PARK_R2	Moderate	Like scenario C, i.e., construction of green spaces in residential areas to be developed/newly built until 2030, within areas to be renovated, or infill areas, but proposing a larger, i.e., moderate spatial footprint.	Irregular patches	Proposing conversion of min. 15% of target area

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				(+5% compared to C)
PARK_R3	Small	Like scenario B, i.e., construction of small parks (pocket parks) in residential areas to be developed/newly built until 2030, within areas to be conserved.	Irregular patches	Proposing conversion of min. 5% of target area (no change when compared to C)
PARK_P	Moderate-to-large	Like scenario C, i.e., construction of green spaces in public facilities, i.e., educational and training facilities, health care facilities, public and commercial land, that are to be developed/newly built or re-developed until 2030, within new development areas or areas to be renovated, but proposing additional land to be converted.	Irregular patches	Proposing conversion of min. 15% of target area (+5% compared to C)
PARK_E	Moderate-to-large	Like scenario C, i.e., construction of green spaces to support eco-tourism, i.e., greening interventions in tourism areas within new development areas, and/or within areas to be redeveloped, but proposing larger, i.e., moderate-to-large spatial footprint, and additional land to be converted.	Irregular patches	Proposing conversion of min. 20% of target area (+5% compared to C)
PARK_E2	Large	Construction of large urban parks/green spaces to support eco-tourism, i.e., greening interventions in tourism areas, within areas restricted from development.	Irregular patches	Proposing conversion of min. 30% of target area

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SELECT_R	Selective/ Local	Like scenario C, i.e., selective greening actions in existing (current) residential areas, including the greening of balconies, the construction of vegetated pergolas, or of Feng-Shui elements, where feasible, within areas to be renovated, or areas to be conserved.	Regular patches	Proposing interventions considering 15% of features (no change when compared to C)
SELECT_R2	Selective/ Local	Consideration of construction codes that facilitate the implementation of green facades and green roofs in newly built residential land, i.e., existing or planned residential areas in new development areas.	Regular patches	Proposing such a consideration on 10% of features
SELECT_C	Selective/ Local	Like scenario C, i.e., selective greening actions in existing (current) public facilities and commercial land, including the construction of garden cafes, or vegetated pergolas, within areas to be renovated or areas to be conserved.	Regular patches	Proposing interventions considering 15% of features (no change when compared to C)
SELECT_C2	Selective/ Local	Consideration of construction codes that facilitate the implementation of green facades and green roofs in newly built educational and training facilities, health care facilities, and public and commercial land, within new development areas.	Regular patches	Proposing such a consideration on 10% of features
SELECT_I	Selective/ Local	Consideration of construction codes that facilitate the implementation of green facades and green roofs in newly built industrial (high-tech) areas or areas that specialize to accommodate industrial (high-tech) areas, within new development areas.	Regular patches	Proposing such a consideration on 10% of features
ORCHARD	Moderate-to-large	Like scenario C, i.e., planting of moderately sized orchards on land foreseen to be converted to agricultural land until 2030, but compared to scenario C, proposing a higher share of land to be converted.	Larger patch size, regular patches	Proposing conversion of min. 20% of target area

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				(+10% compared to C)
MEADOW	Moderate	Like scenario C, i.e., creation of moderately sized meadows on land foreseen to be converted to agricultural land until 2030, but it is proposed to convert a higher share of land. Meadows should be implemented on features that are not foreseen for the implementation of orchards.	Larger patch size, regular patches	Proposing conversion of min. 10% of target area (+5% compared to C)
MEADOW_2	Large	Conversion of parts of the industrial (high-tech) areas to be newly built or re-developed until 2030 to large meadows as actions for the compensation of sealing, within new development areas.	Larger patch size, regular patches	Proposing conversion of min. 15% of target area
PONDS	Small-to-moderate	Like scenario C, i.e., construction of small ponds within green infrastructures—i.e., (public) green spaces and green sports facilities—to be implemented until 2030, that are within max. 1000m distance to existing, newly built or planned residential land, but proposing larger, i.e., small-to-moderate spatial footprint. Ponds should not be constructed where novel playgrounds are foreseen to be established.	Larger patch area, closer proximity to residential land, irregular patches	Proposing conversion of min. 2.5% of target area (+1.5% compared to C)
CG	Selective/ Local	Like scenario C, i.e., establishment of community gardens on land foreseen to be re-developed into (public) green spaces (demolition land), within infill development areas.	Irregular patches	Proposing establishment of 5 community gardens (no change when compared to C)
CG_2	Selective/ Local	Establishment of community gardens on land foreseen to be re-developed into (public) green spaces (demolition land), within area to be renovated.	Irregular patches	Proposing establishment of

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				5 community gardens
HG	Selective/ Local	Like scenario C, i.e., creation of house gardens as greening actions on private land, as a form of more diverse and adaptive greening, foreseen in rural residential land to be developed/newly built until 2030.	Larger patch area, irregular patches	Proposing interventions on 25% of features (no change when compared to C)
AFFOR	Large	Afforestation of present agricultural land that is located within areas reserved for development.	Larger patch area, irregular patches	Proposing conversion of min. 30% of target area

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Table 10. Proposed interventions for scenario D at street-level.

Designation	Spatial footprint	Description	Prioritization	Target
HEDGES	WIDTH:S	Planting of (additional) hedges in residential streets (indicated by planned or existing residential land), within new development areas, that are otherwise considered unsuitable for an outfitting with trees.	Random	20% of residential streets improved, equal to 25368m in length
STR_TREE1	WIDTH:M	Planting of (additional) street trees in residential streets (indicated by planned or existing residential land), within new development areas	Random	20% of residential streets improved, equal to 25368m in length
STR_TREE2	WIDTH:M	Planting of (additional) street trees in residential streets (indicated by planned or existing residential land), within re-development areas	Random	20% of residential streets improved, equal to 4588m in length
ALLEY1	WIDTH:W	Planting of tree alleys, or completion of current tree layouts to tree alleys, in residential streets (indicated by planned or existing residential land), in new development areas	Random	20% of residential streets improved, equal to 25368m in length
ALLEY2	WIDTH:W	Planting of tree alleys, or completion of current tree layouts to tree alleys, in tourism land	Random	50% of streets connected to tourism areas, equal to 1522m in length

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BIOSWALE	WIDTH:W	Construction of bioswales associated to streets in industrial areas and infrastructure land, within new development areas	Random	15% of streets improved, equal to 3464m in length
GRN_AM1	WIDTH:B	Construction of green verges, and street furniture to increase amenity values, in residential streets (indicated by planned or existing residential land), in re-development areas	Random	15% of streets improved, equal to 3441m in length
GRN_AM2	WIDTH:B	Construction of green verges, and street furniture to increase amenity values, in residential streets (indicated by planned or existing residential land), in areas to be renovated	Random	15% of streets improved, equal to 6592m in length
HEDGES2	WIDTH:S	Planting of (additional) hedges in streets near health care and other public facilities, within areas to be renovated	Random	10% of streets improved, equal to 2756m
BIOSWALE	WIDTH:W	Construction of bioswales in streets near health care and other public facilities, within areas to be renovated	Random	10% of streets improved, equal to 2756m

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3.3 Suitability modelling

The determination of feature suitability requires size thresholds for spatial footprints to be defined. As described previously, these spatial footprints refer to feature area (feature size) at the patch-level, and to road (segment) width at street-level.

In this case study, at the patch-level, the suggested spatial footprints shall be aligned to actually planned measures, i.e., the footprint thresholds are to be derived from the greening interventions considered in the land-use planning for 2030. To do so, an analysis of corresponding patch sizes of urban green spaces, blue spaces, and forests was conducted, first, by dissolving relevant spatial entities based on changes in land-use identified in the integrated change layer, including greening and bluing interventions, afforestation, and the demolition of built-up land for the implementation of green/blue spaces. Second, for the dissolved (single-part) features, feature areas have been summarized using the following statistical metrics: Q1 and Q3 (i.e., first and third quartile), Median, Maximum, Mean, as well as the terciles T1 and T2 (i.e., the 33% and 66% percentile). The terciles values have been chosen as representative mid-points in the ranges Q1-Median and Median-Q3 (Table 11).

Table 11. Assessment of feature area (m²) for selected interventions proposed in the 2030 urban master plan for Huế city.

	All greening	All blueing	Afforestation	Green to Blue	Resettle/ Greening	Resettle/ Blueing
Minimum	1002	1001	1001	1438	1001	1008
Q1	2280	1555	3282	1534	1704	1354
Median	5897	2764	10282	1925	2924	1702
Q3	17721	5948	50668	2698	6243	2428
Maximum	695406	284452	1260808	82748	193906	17682
Mean	20773	7958	66565	11575	5741	2576
T1	2979	1880	4920	1780	1943	1476
T2	12108	4480	26872	2410	4589	2026

Subsequently, the assessed metrics are considered to derive spatial footprints/spatial footprint thresholds. Proposed spatial footprints range from selective, local (point) interventions to small, small-to-moderate, moderate, moderate-to-large, and large areas.

Selective, local (point-based) interventions, e.g., greening of balconies, of roofs, or construction of vegetated pergolas, are not considered to be constrained by patch size. This is due to their nature of being very local, small-scale, and often being related to feature types such as buildings that are typically not representable using land-use data. Therefore, the spatial footprint for these selective-local measures does not apply thresholds, and these measures are thus considered to be independent of actual feature size. For small footprints, a minimum shape area of 1000m² was considered to remove (at least parts of) likely intersection artifacts that result from a misalignment of spatial data sources. The upper threshold for small interventions is aligned to the first tercile. Small-to-moderate interventions are modelled in the range from first quartile to median. Moderate interventions are considered as covering an area ranging from the first to second tercile. Moderate-to-large interventions are conceptualized in the range from median to third quartile, and large interventions are bound to a minimum area

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corresponding to the second tercile, without upper threshold. Hence, a certain overlap between classes is suggested to allow for more fine-grained variations of patch sizes (Figure 13). The actual threshold value used are then derived from the statistical parameters listed in Table 11, and are shown for each spatial footprint in Table 12.

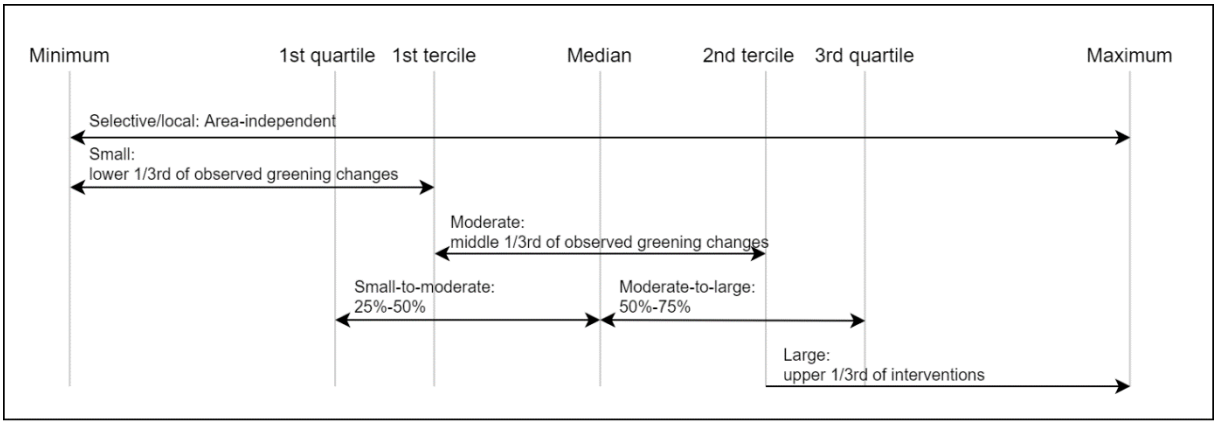

Figure 13. Conceptualization of spatial footprints based on statistical parameters of patch sizes of proposed greening interventions in the Huế 2030 urban master plan.

Table 12. Suggested thresholds for spatial footprints to determine patch-level suitability.

Designation	Description	Patch metric	Threshold value (V) (m²)
LOCAL:P	Selective, local (point) interventions	Shape Area	none[7]
AREA:S	Small interventions	Shape Area	1000 ≤ V < 2979
AREA:SM	Small-to-moderate interventions	Shape Area	2280 ≤ V < 5897
AREA:M	Moderate interventions	Shape Area	2979 ≤ V < 12108
AREA:ML	Moderate-to-large interventions	Shape Area	5897 ≤ V < 17721
AREA:L	Large interventions	Shape Area	V ≥ 12108

[7] Local interventions are not constrained by size of patch.

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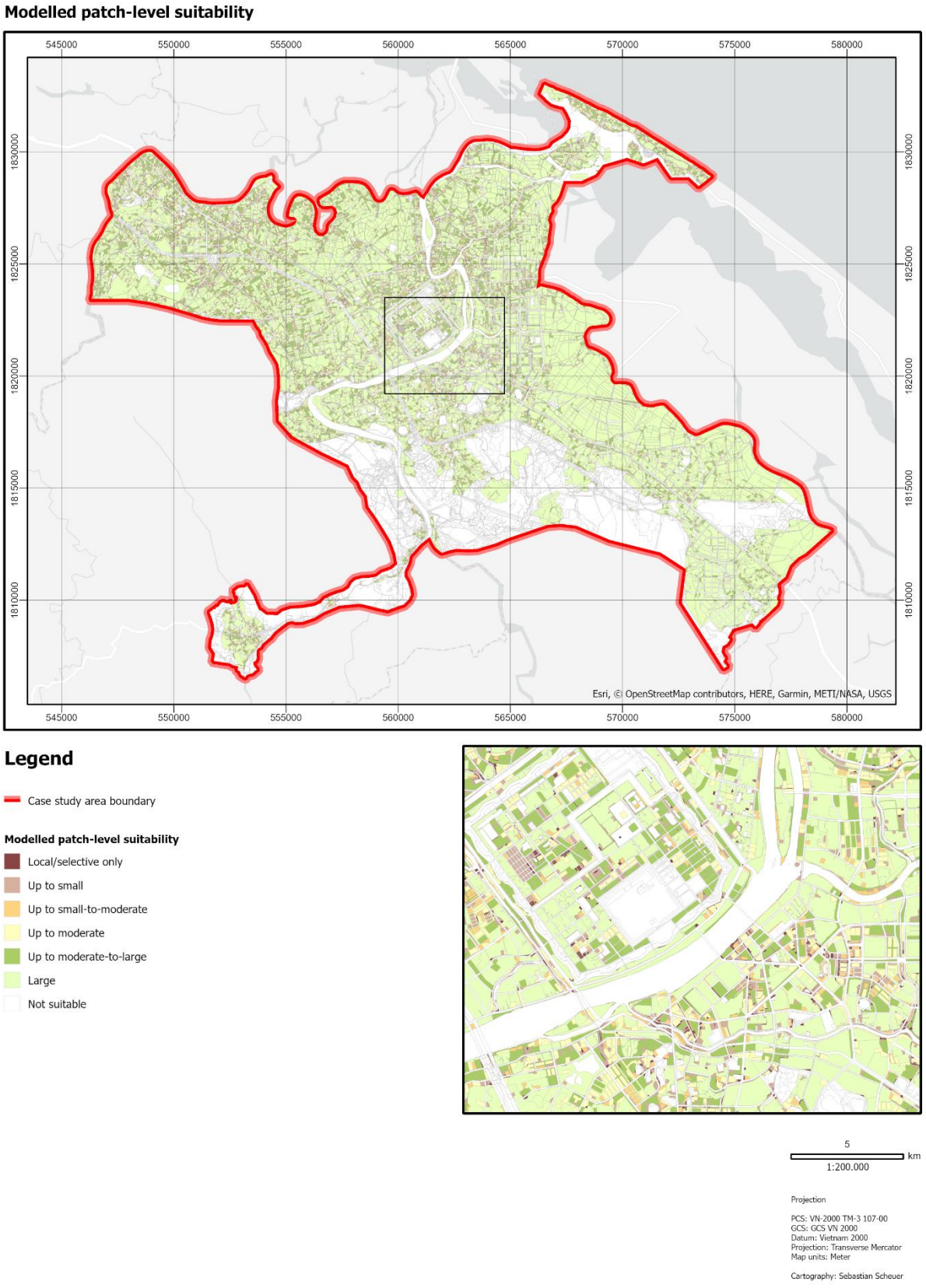

Figure 14. Modelled patch-level suitability based on conceptualized spatial footprints as a function of feature area.

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In addition to basing patch-level suitability on the shape area, the suitability of patches has also been evaluated based on land-use. Generally, water bodies, forests, infrastructure facilities—e.g., the airport areal—and military land, national defence, and security facilities were considered unsuitable a-priori for the implementation of NBS interventions and were thus excluded from the further modelling process. Green railway banks were specifically proposed in the 2030 land-use plan, and were thus also excluded from further development. As transportation land, and thus interventions at street-level are modelled separately, the transportation land-use category has also been excluded from the further modelling accordingly. The resulting modelled/evaluated suitability for patch-level interventions is shown in Figure 14.

As described earlier, for street-level interventions, suitability to accommodate different types of NBS is considered to be more related to the width (and/or, respectively, length) of a given road segment, instead of total road area. Consequently, for the modelling of NBS interventions within the transportation land, road width is used as parameter to determine feature suitability, and similarly to patch area, the road network has been categorized accordingly based on modelled width, using the road layer derived as part of data pre-processing.

Modelling of road suitability is conceptualized around simplified minimum width thresholds needed to provide for different road elements, including carriageways, pedestrian surfaces, tree pits for planting of street trees, or further allowances to construct green verges or provide street furniture/amenities. Here, also due to lack of necessary information, these minimum widths are derived from recommendations by the (German) Road and Transportation Research Association (2012), however, in subsequent revisions, the corresponding codes may be adapted to local Vietnamese provisions. Minimum widths are determined as follows (Road and Transportation Research Association, 2012):

- The width of a footway (pedestrian surface) should be designed so that two oncoming individuals can pass, requiring a pedestrian envelope width of ca. 1.80m. Additional safety clearances of at least 0.50m to the kerb, and 0.20m to buildings, hedgerows, or trees etc. shall be added, resulting in a typical footway width of 2.50m (one-sided) or 5.00m (total, double-sided).
- Widths of carriageways vary considerably, depending on the type of road (rural vs. urban main road, dual-lane vs. four-lane layout, etc.), and may need further adaption in width to accommodate public transport, trucks, wide loads, parking, protected cycling lanes etc. However, for main arterial roads or access roads, standard carriageway widths ranging from 4.50m to 6.50m are given, here, assuming an average width of 5.50m;

The assumed minimum widths of footways and carriageway result in a minimum road width of approximately 10.50m. Roads up to that width are considered unsuitable for the accommodation of additional elements such as roadside greenery. However, to identify the potential of roads to accommodate certain green elements, the following directions given by Road and Transportation Research Association (2012) are further considered:

- An additional envelope of 1m in width is considered suitable for including benches, as well as green strips without trees;
- An additional envelope of 2m in width is considered suitable for including tree pits/street trees (see also, e.g., Bloomberg and Benepe, 2009), or to accommodate certain children play area elements.

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Consequently, differing “road profiles” may be obtained from the permutation and combination of minimum road width with additional feature envelopes as needed for the accommodation of green elements, amenity features, or play elements (Figure 15). It becomes clear that roads of equal width, thus, common spatial footprint, may host different combinations of features, depending on the chosen features’ envelopes that are being combined, with corresponding spatial footprints being summarized in Table 13:

- A width of at least 11.50m is considered suitable to accommodate one-sided green margins, or amenity value features, or a mixture thereof;
- A width of at least 12.50m is considered suitable to accommodate two-sided green margins, or amenity value features such as benches, or a one-sided accommodation of (green margins with) street trees;
- A width of at least 13.50m is considered suitable to accommodate street margins with street trees on one side, and has sufficient width to additionally accommodate street margins without trees or amenity features on the other;
- A width of at least 14.50m or more has the potential to accommodate a wide array of green elements, including street trees on both sides of the carriageway. Alternatively, amenity features may be hosted.

Table 13. Suggested minimum road width (threshold) per road class for modelling road suitability.

Designation	Description	Patch metric	Threshold value (V) (m)
WIDTH:N	Narrow road, considered unsuitable for the planting of street trees.	Width	V < 11.50
WIDTH:S	Small road	Width	V ≥11.50
WIDTH:M	Road of moderate width	Width	V ≥ 12.50
WIDTH:B	Broad road	Width	V ≥ 13.50
WIDTH:W	Wide road	Width	V ≥ 14.50

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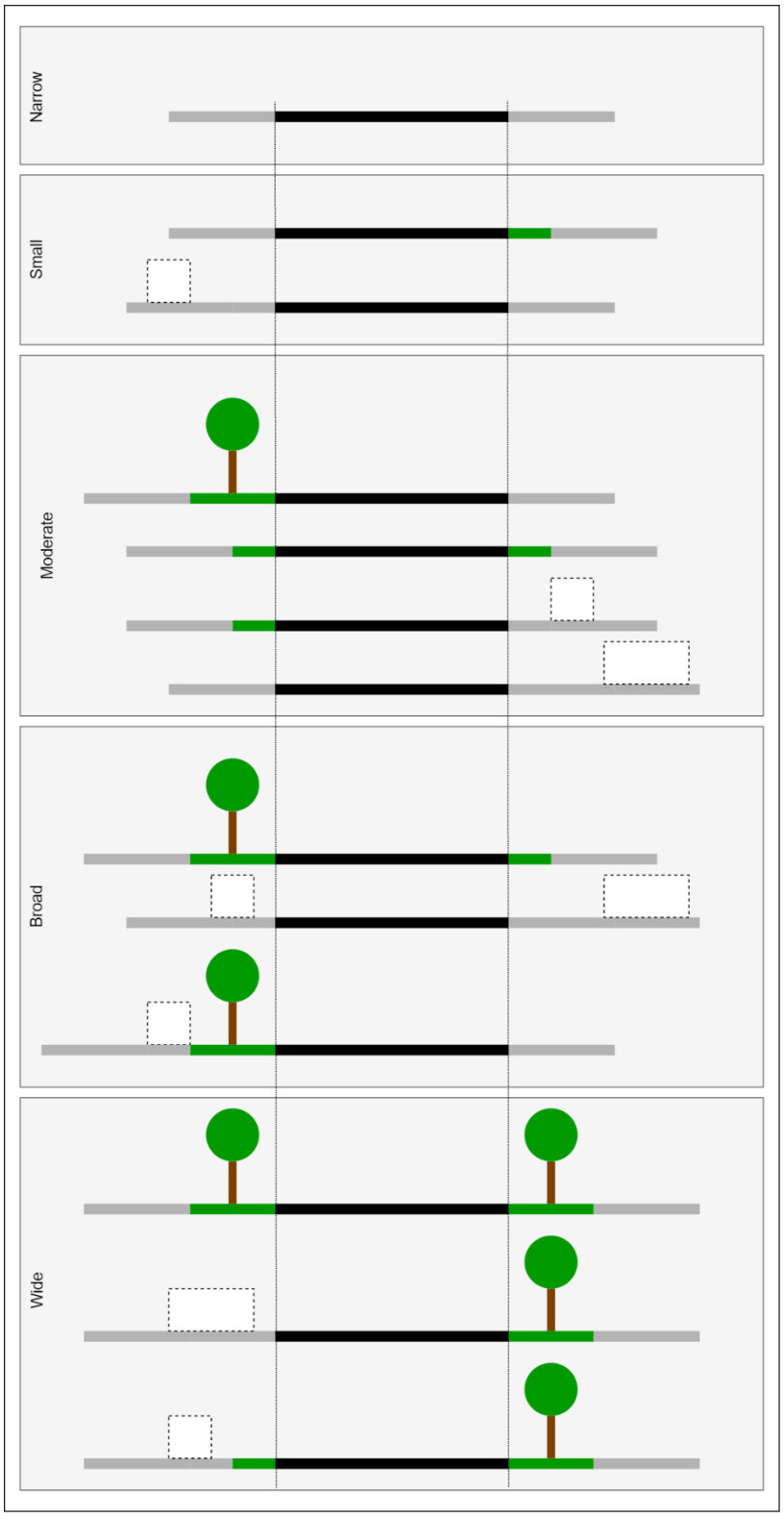

Figure 15. Road profiles per spatial footprint to determine suitability for the implementation of NBS at street-level. Based on recommended Carriageways are shown in black, footways in grey, and in green, green verges and/or tree pits. Amenity features are shown as dashed outlines, e.g., benches (dashed square), or play elements (dashed rectangle). It becomes clear that streets of equal width may accommodate a variety of features in differing combinations, depending on feature envelopes.

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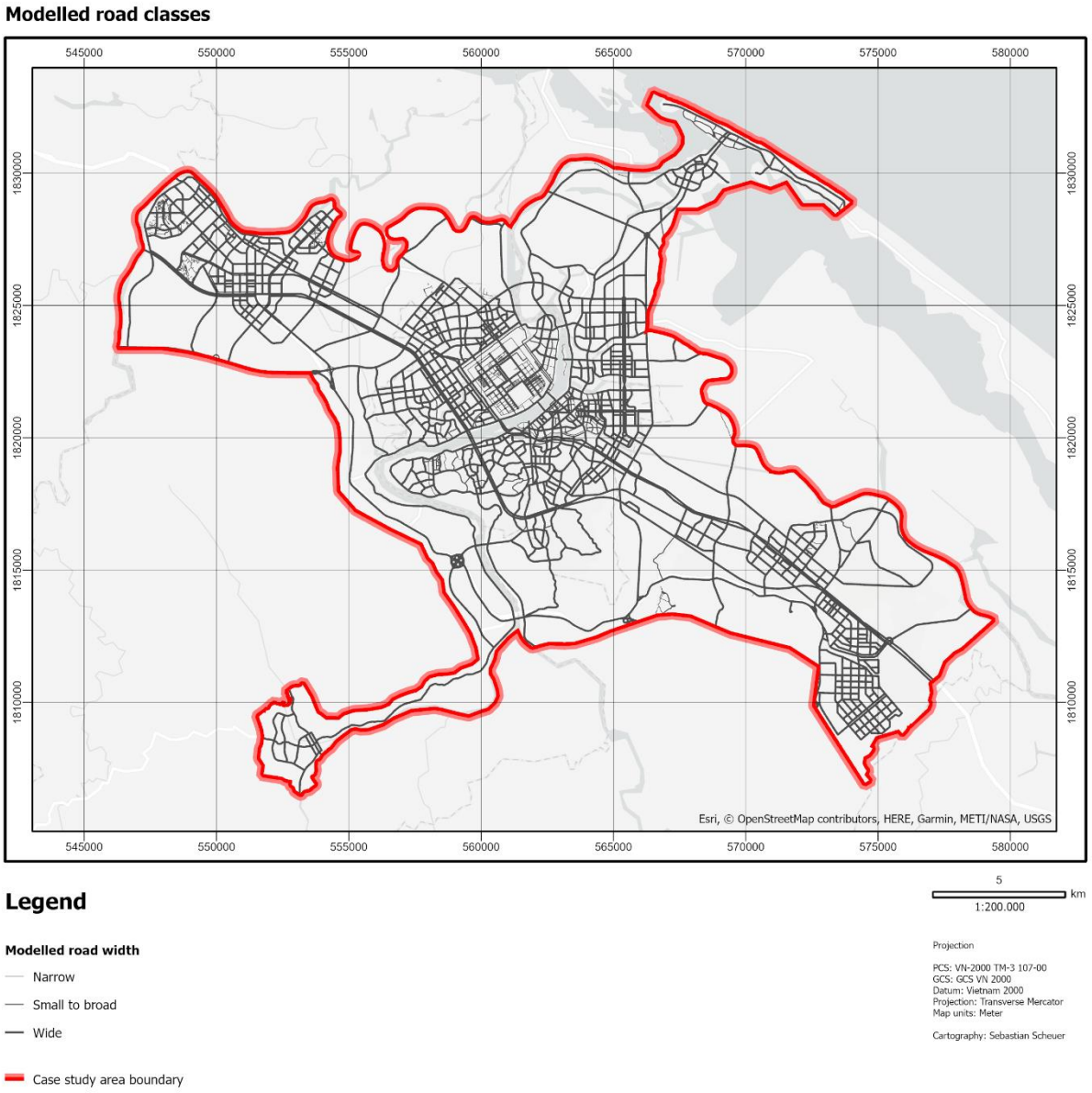

Figure 16. Modelled street-level suitability based on conceptualized spatial footprints as a function of feature width.

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3.4 Conflict modelling

Generally, also due to the inherent uncertainty of the assumptions for modelling of conflicts, only few such conflicts are suggested. For scenario B, there are no conflicts assumed between the proposed measures. For scenario C, conflicts have been defined so that on a given patch, no novel playgrounds may be established simultaneously with ponds, or with a foreseen improvement of amenity values of existing green spaces. Similarly, it has been defined that no meadow and orchard may be implemented on a common patch. The same restrictions have been imposed for scenario D. Generally, the reasoning for these restrictions is the goal to achieve a large spatial spread of NBS interventions, i.e., to avoid a spatial concentration of multiple, or somewhat similar measures on a common patch.

3.5 Allocation modelling

Following the formulation of scenario-specific rules (cf. Table S 2 to Table S 7), the modelling of NBS interventions is conducted based on these rules, and following the respective allocation modelling algorithm as shown in Figure 7. The results obtained from this process, per scenario, are shown in Figure 17 to Figure 20 (here, only the mean stop condition is shown). An evaluation and discussion of the results obtained follows accordingly.

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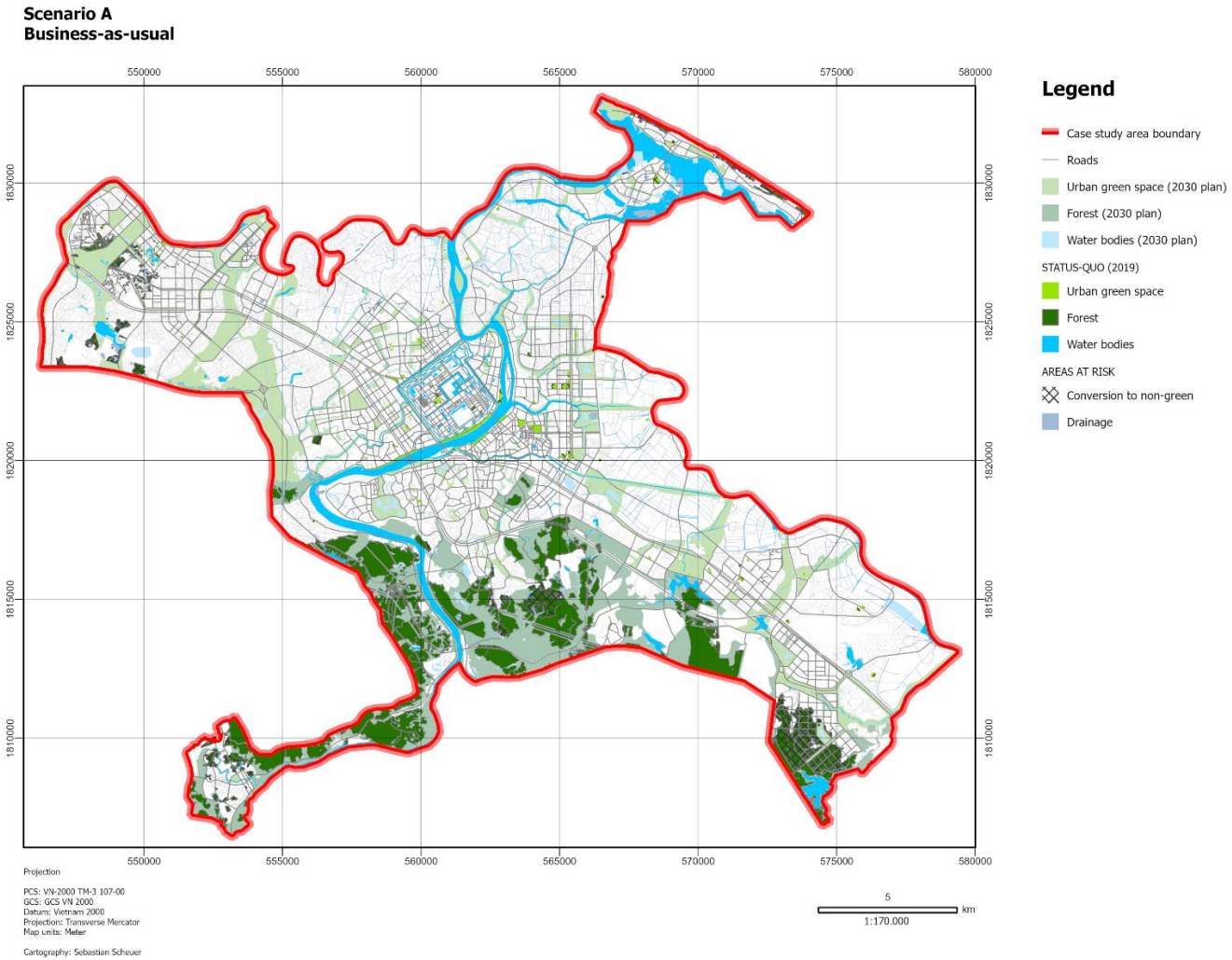

Figure 17. Map of urban green spaces, blue spaces, and forests for the status-quo (2019 land-use), and for the 2030 urban master plan. This plan corresponds to the baseline conditions, i.e., scenario A, (baseline/business-as-usual). Areas at risk denote green areas, forests, and water bodies areas that may potentially be lost due to conversion or drainage.

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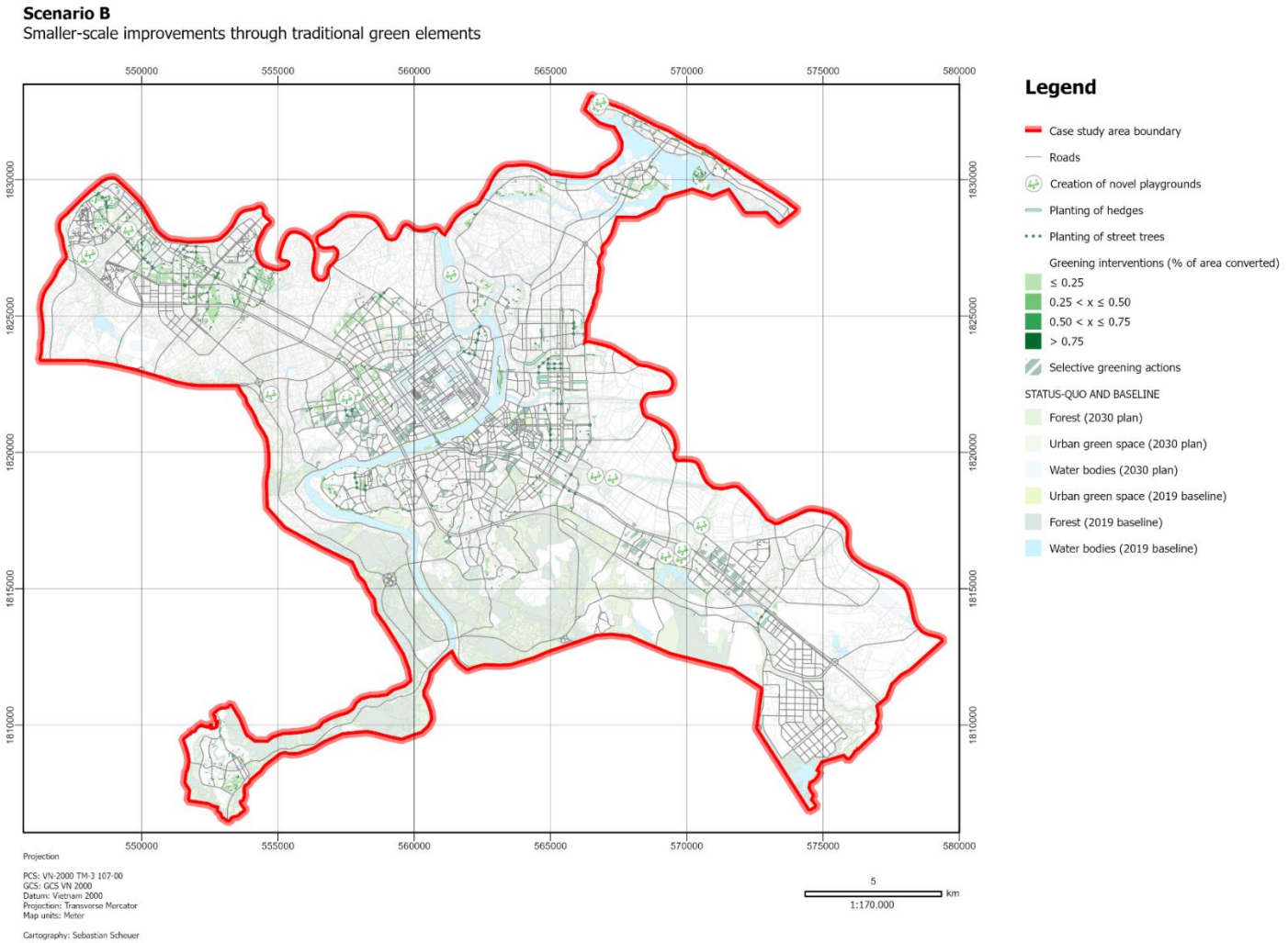

Figure 18. Map of selective actions, greening interventions (% of area converted) at patch-level, and interventions at street-level, for scenario B.

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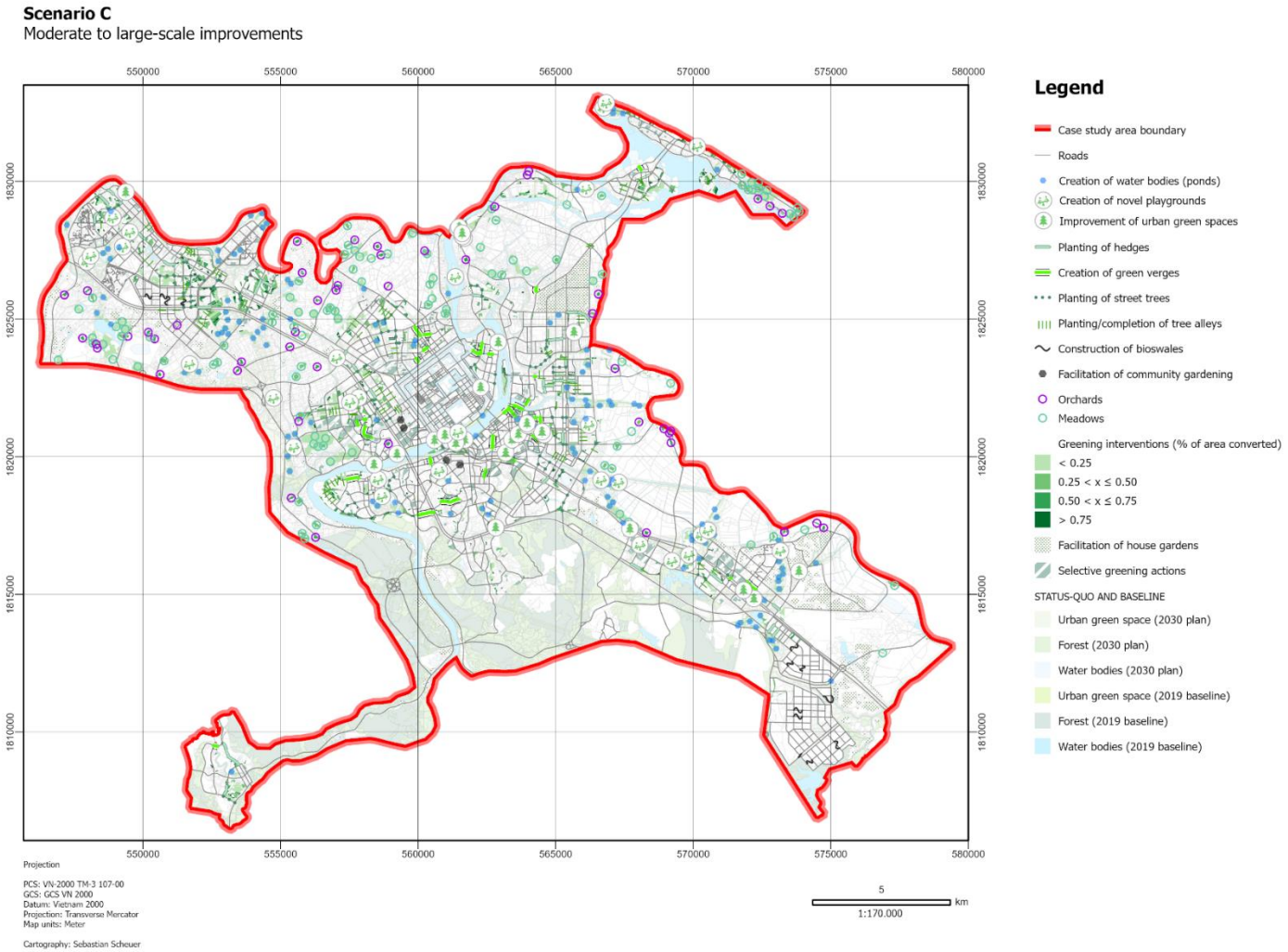

Figure 19. Map of selective actions, blue interventions, greening interventions (% of area converted) at patch-level, and interventions at street-level, for scenario C.

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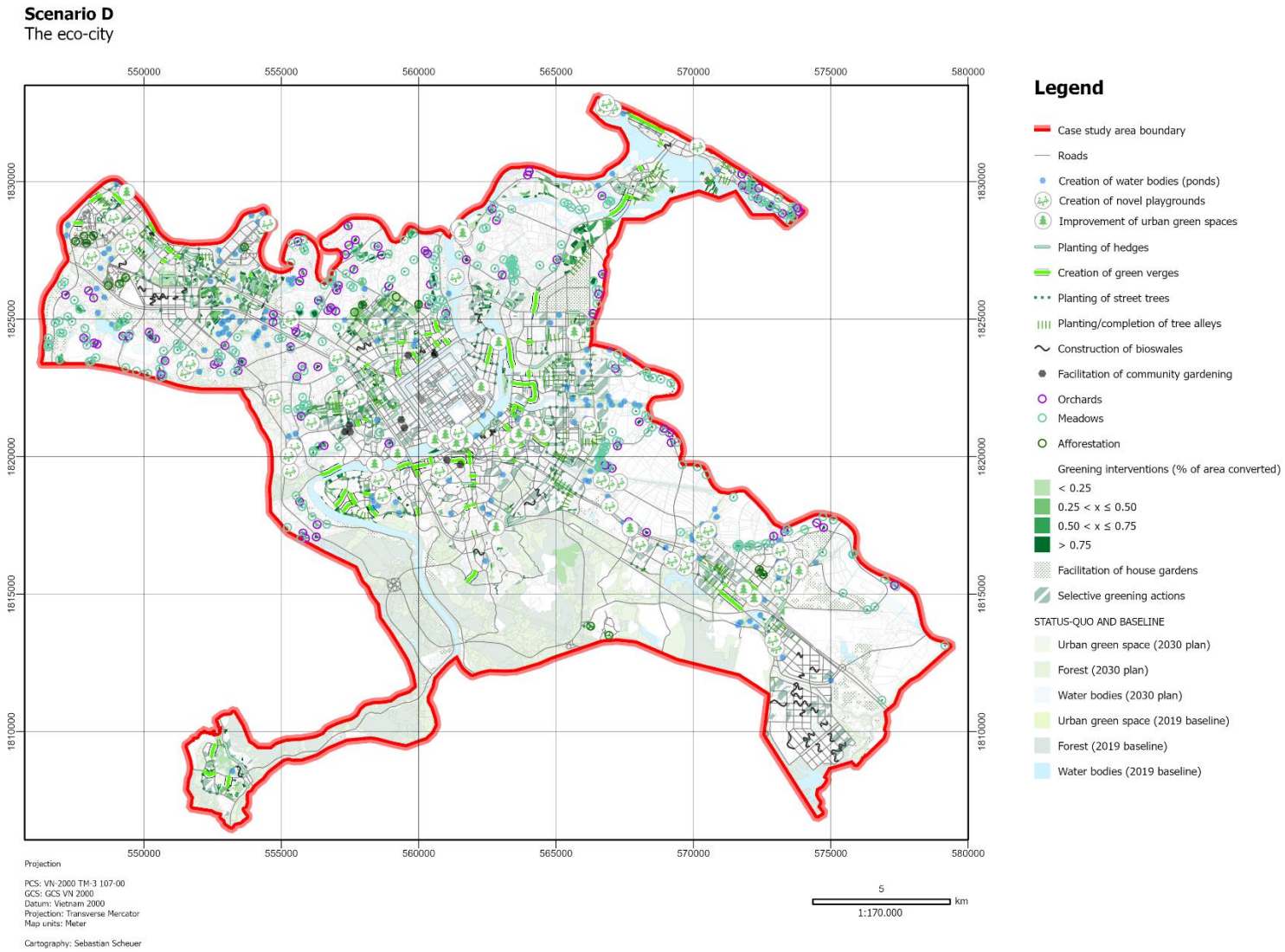

Figure 20. Map of selective actions, blue interventions, greening interventions (% of area converted) at patch-level, and interventions at street-level, for scenario D.

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4 Evaluation of scenarios

4.1 Status-quo conditions in 2019

From the analysis of spatial data corresponding to 2019 conditions, the status-quo situation is inferred. From this analysis, it is concluded based on available data, that in 2019, there is a total of about 200 ha of designated (public) green spaces (including recreation and sports facilities) in Huế. The total area of water bodies in 2019 is estimated at 3377 ha in 2019[8]. Forest cover, that can mainly be found in the southern and south-western parts of the study area, covers an area of about 3509 ha (cf. Figure 17 and Figure 21).

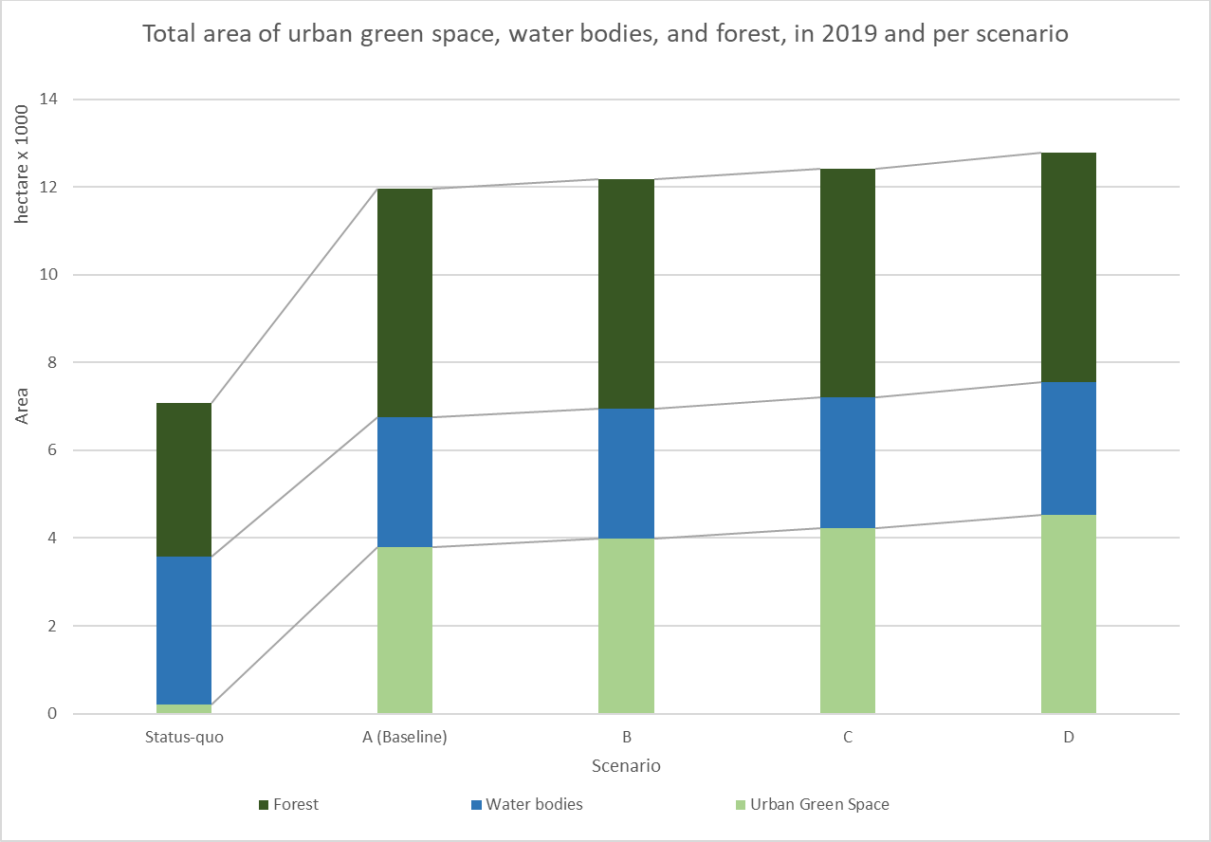

Figure 21. Total area (ha) of selected green-blue infrastructure (urban green space, water bodies, forest) in 2019 (status-quo), and per scenario. Evident is the significant increase of urban green space under scenario A.

4.2 Scenario A – Baseline/business-as-usual

As reported, the baseline/business-as-usual scenario reflects on the areas foreseen for the implementation of green or blue spaces until 2030 in accordance with the 2030 land-use plan (equating to the business-as-usual scenario, or baseline, respectively).

Under this scenario, changes to the green-blue infrastructure within the case study area are resultant of both losses and gains of green-blue elements. Regarding urban green spaces, the urban master plan 2030 proposes the creation of a green space network, with green corridors

[8] Please note that this figure considers all water bodies within the study region, i.e., including bodies of flowing water such as the Perfume River, but excludes aquaculture.

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created throughout the northern, central, and south-eastern parts of the study region (Figure 17). In so doing, a total of 3721 ha of urban green spaces is newly designated. However, simultaneously, about 136 ha of urban green spaces (here, including recreation and sports facilities) are apparently lost to other uses. Therefore, under scenario A, the net change in urban green space is equal to about 3585 ha (Figure 21 and Figure 22), with the total green space area for 2030 estimated at about 3786 ha[9]. This corresponds to an increase of urban green space by about 1792% when compared to the status-quo.

Regarding blue spaces, excluding aquaculture facilities, the total area of water bodies in scenario A for 2030 is estimated at 2963 ha, corresponding to a net loss of about 414 ha of water bodies compared to 2019 (Figure 22), a decrease of ca. 12.3%. This is mainly due to loss of about 1014 ha to other uses, e.g., conversion to agricultural land (including aquacultures), industrial areas, infrastructure facilities, and residential built-up. These losses are not compensated by proposed implementation of about 599 ha of blue features, e.g., various lakes and canals throughout the study area that are specifically proposed as part of the designated green space network. However, the exact nature of these conversions remains unknown, resulting in considerable uncertainties. For example, it remains unclear if water bodies will be drained when converted to green spaces or when located on afforestation land.

Regarding forest land, the total area in 2030 is estimated at 5214 ha under this scenario, equal to a net gain of 1705 ha of forest (Figure 22), an increase in forest land by 48.6% compared to 2019. However, concluding from available data, there is considerable turn-over in forest land. For example, the actual area foreseen for afforestation under scenario A is equal to 2743 ha, whereas 1039 ha of forest may be lost due to deforestation and conversion to other uses.

No specific interventions in transportation land, i.e., such as street tree planting at street-level, can be derived from the 2030 urban master plan. Therefore, any such interventions are not considered in this report.

4.3 Scenario B – Smaller-scale improvements through traditional green elements

Scenario B proposes small-scale patch-level improvements, primarily in residential land, but to a lesser extent also in public and commercial land (Figure 18). Regarding patch-level interventions, the suggested conversion rates as shown in Table 5 and Table 14, overall, amount to the conversion of approximately 208 ha (mean boundary constraint; Figure 23) of land in the designated target zones (Table 14), in addition to baseline. The proposed interventions in this scenario are therefore equivalent to approx. 291 soccer fields in size, and would correspond to about the amount of green space area available in 2019 (104%). When compared to the greening interventions according to the baseline scenario A, the suggested measures equate to an additional 5.8% of land to be greened. The total area of urban green space under scenario B would be equal to 3993 ha (mean boundary constraint; Figure 21 and Figure 22); that is an increase of about 1895.7% compared to 2019.

In this scenario, no blueing or afforestation action was proposed in addition to baseline scenario A. At street-level, interventions in transportation land amount to a length of 15,058 m of roads to be converted/improved (Table 15 and Figure 23).

[9] There is some uncertainty when assessing these areas due to potential issues in the designation of land-use categories in the 2019 and 2030 land-use data.

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Looking at the allocated lands as shown in Table 14, it becomes clear that the design of the proposed interventions, with respect to their intended size/spatial footprint, is a crucial factor for achieving the abovementioned greening goals. This is mainly due to the small spatial footprints proposed in relation to the comparatively large area that needs to be converted to meet the stated targets. Here, choosing small footprints clearly results in a considerable number of local interventions needed for achieving the set goals. This is further exacerbated when considering the lower end (lower boundary) of the suggested small spatial footprints. It also becomes clear that the choice of small spatial footprints impacts the achievability of the stated goals. As shown in Table 14, for PARK_R1, the intended conversion rate cannot be met through the designated lower-end small footprint size.

In addition to these interventions, several selective actions are proposed as part of scenario B. These include the greening of balconies, or the construction of vegetated pergolas to achieve greener spaces, as well as the construction of novel playgrounds. However, due to the very local nature of these interventions, they are not evaluated in terms of their spatial impact.

Table 14. Summary of patch-level intervention allocation modelling following scenario B.

Designation	Stop condition/ target (%)	Target zone (total, m²)	Stop condition type (boundary considered)	Number of interventions needed to achieve target	Total area allocated for conversion (m²)
PARK_R1	10.0	12821033	Lower	Not achievable	
			Mean	774	1281614
			Upper	430	1280970
PARK_R2	7.5	2714651	Lower	203	203000
			Mean	137	202307
			Upper	68	202572
PARK_R3	5.0	136585	Lower	7	7000
			Mean	6	7979
			Upper	3	8937
PARK_P	7.5	3448826	Lower	265	265000
			Mean	162	265878
			Upper	89	265131
PARK_E	7.5	4097477	Lower	317	317000
			Mean	192	317667
			Upper	107	318753

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Table 15. Summary of interventions in transportation land under scenario B.

Designation	Stop condition/ target (%)	Target length (total, m)	Stop condition type	Number of interventions needed to achieve target	Total allocated length (m)
HEDGES	5.0	126,840	Threshold	21	7030
STR_TREE1	5.0	126,840	Threshold	21	6406
STR_TREE2	5.0	22,940	Threshold	5	1622

4.4 Scenario C – Moderate to large-scale improvements

Scenario C builds on scenario B, but suggests, to a large extent, higher rates of converting land to green or blue infrastructure elements. To achieve these higher conversion rates, and to simultaneously increase the individual size of suggested green spaces in order to support recreation and restoration, it is also proposed that interventions have a larger spatial footprint. In addition, more types of green-blue infrastructure are considered in this scenario; this particularly refers to ponds as blue spaces to facilitate cooling (Figure 19).

Overall, suggested patch-level interventions in this scenario amount to a total area of approximately 431 ha (mean boundary constraint; Figure 23) of green space in addition to baseline (no afforestation action has been suggested in this scenario). This additional area is equal to about 604 soccer fields in size, and corresponds to an additional 12% of land to be greened compared to baseline. Compared to the status-quo, the suggested interventions would correspond to an area about double the amount of urban green space in 2019 (215%). The proposed measures would increase the area of urban green space to 4217 ha (mean boundary constraint; Figure 21 and Figure 22), an increase of 2007% compared to 2019.

In contrast to scenario B, scenario C suggests the creation of ponds to facilitate cooling. Therefore, from this area foreseen for greening, about 26 ha (mean boundary constraint; Figure 23) are allocated for blue infrastructure elements. So doing results in a slight reduction of water bodies net loss, with a total area of water bodies equal to about 2989 ha (mean boundary constraint, Figure 22), that corresponds to a decrease of about 11.5% compared to 2019.

Furthermore, actions to improve existing green spaces (intervention IMP_GS) are suggested on a total area of 6.5 ha (mean boundary constraint). This intervention aims at increasing provided ecosystem services and thus local benefits as well as amenity values through the planting of additional shrubs or trees, equipment, etc.

The total length of interventions at street-level is equal to 56,136 m (Table 17 and Figure 23).

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Table 16. Summary of patch-level intervention allocation modelling following scenario C.

Designation	Stop condition/ target (%)	Target zone (total, m²)	Stop condition type (boundary constraint)	Number of interventions needed to achieve target	Total area allocated for conversion (m²)
PARK_R1	15.0	12111642	Lower	606	1805274
			Mean	376	1804779
			Upper	149	1804092
PARK_R2	10.0	2434684	Lower	106	241680
			Mean	76	243812
			Upper	41	241777
PARK_R3	5.0	136585	Lower	7	7000
			Mean	6	7969
			Upper	3	8937
PARK_P	10.0	2780691	Lower	47	277159
			Mean	36	277324
			Upper	16	283536
PARK_E	15.0	3877651	Lower	200	595800
			Mean	130	597237
			Upper	50	605400
IMP_GS	10.0	631756	Lower	37	65778
			Mean	37	65778
			Upper	37	65778
ORCHARD	10.0	7355535	Lower	309	920511
			Mean	122	920307
			Upper	76	920208
MEADOW	5.0	7355535	Lower	155	461745
			Mean	61	460154
			Upper	38	460104
PONDS	1.0	25209134	Lower	261	261000
			Mean	132	262614
			Upper	88	262152

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Table 17. Summary of interventions in transportation land under scenario C.

Designation	Stop condition/ target (%)	Target length (total, m)	Stop condition type	Number of interventions needed to achieve target	Total allocated length (m)
HEDGES	10.0	126,840	Threshold	36	13020
STR_TREE1	10.0	126,840	Threshold	41	12781
STR_TREE2	10.0	22,940	Threshold	7	2458
ALLEY1	10.0	126,840	Threshold	45	12934
ALLEY2	10.0	15,220	Threshold	7	3133
BIOSWALE	5.0	69,280	Threshold	13	3613
GRN_AM1	5.0	22,940	Threshold	4	1193
GRN_AM2	5.0	131,840	Threshold	31	7004

4.5 Scenario D – The eco-city

In scenario D, in comparison to scenarios B and C, even higher rates of conversion are suggested for most proposed interventions. Accordingly, also the spatial footprints foreseen in this scenario are increased in size. Like scenario C, this aims at achieving the higher rates of land conversion to green-blue spaces, but again strives to achieve the construction of individually larger green-blue spaces. As summarized in Table 9, additional interventions considered include the afforestation of selected areas. Additional selective actions include the greening of facades or roofs, with the latter measures being tied specifically to newly constructed built-up land to allow for an evaluation or, possibly, change in building codes to support these green elements (Figure 20).

At the patch-level, the suggested interventions result in a total area of about 769 ha (mean boundary constraint) to be greened, here, including afforestation, i.e., about 1078 soccer fields in size (Table 18). This includes about 736 ha (mean boundary constraint) for the implementation of urban green space (resulting in an additional 20.5% of urban green space compared to baseline), and about 34 ha (mean boundary constraint) for afforestation (resulting in an additional 2% of land to be afforested compared to baseline; cf. Figure 23). Under scenario D, the total green space area would be equal to 4521 ha (an 2160% increase compared to 2019; Figure 21 and Figure 22), and the area proposed for greening would already correspond to about 3.6 times the status-quo green space (368%). Forest land would be equal to about 5248 ha (an increase by 49.5% compared to the status-quo).

Similar to scenario C, also scenario D proposes the creation of ponds as blue features in new urban green spaces. Hence, from the land allocated for greening, about 60 ha (mean boundary constraint; Figure 23) are foreseen for the implementation of water bodies. This would correspond to a net loss in water bodies of about 10.5% compared to 2019, with the total area of water bodies estimated at 3023 ha (mean boundary constraint; Figure 22) under this scenario.

The improvement of existing green spaces (intervention IMPG_GS) is considered for an area of about 12 ha (mean boundary constraint).

Finally, interventions at street-level amount to a total length of 128,951 m under this scenario (Table 19 and Figure 23).

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Table 18. Summary of patch-level intervention allocation modelling following scenario D.

Designation	Stop condition (%)	Target zone (total, m²)	Stop condition type (boundary considered)	Required number of interventions	Allocated area (m²)
PARK_R1	25.0	10978862	Lower	462	2724414
			Mean	320	2726544
			Upper	154	2729034
PARK_R2	15.0	2285221	Lower	114	339606
			Mean	76	340517
			Upper	28	339024
PARK_R3	5.0	136585	Lower	7	7000
			Mean	6	7979
			Upper	3	8937
PARK_P	15.0	2780691	Lower	71	418687
			Mean	53	418957
			Upper	24	425304
PARK_E	20.0	3569948	Lower	122	719434
			Mean	87	719959
			Upper	41	726561
IMP_GS	15.0	631756	Lower	43	121099
			Mean	43	121099
			Upper	27	108937
ORCHARD	20.0	5393077	Lower	88	1065504
			Mean	88	1065504
			Upper	66	1062873
MEADOW	10.0	7168135	Lower	240	714960
			Mean	240	714960
			Upper	59	714372
PONDS	2.5	23462858	Lower	264	601920
			Mean	147	601010
			Upper	102	601494

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PARK_E2	**30.0**	1769156	Lower	Not achievable	
			Mean	35	560672
			Upper	17	1086189
MEADOW_2	15.0	5393077	Lower	Not achievable	
			Mean	28	801916
			Upper	6	900885
AFFOR	30.0	1140221	Lower	28	339024
			Mean	15	337669
			Upper	5	359348

Table 19. Summary of interventions in transportation land under scenario D.

Designation	**Stop condition/ target (%)**	**Target length (total, m)**	**Stop condition type**	**Number of interventions needed to achieve target**	**Total allocated length (m)**
HEDGES	20.0	126,840	Threshold	74	25753
STR_TREE1	20.0	126,840	Threshold	77	25691
STR_TREE2	20.0	22,940	Threshold	15	4791
ALLEY1	20.0	126,840	Threshold	75	25817
ALLEY2	50.0	15,220	Threshold	27	7692
BIOSWALE	15.0	69,280	Threshold	36	10415
GRN_AM1	15.0	22,940	Threshold	10	3441
GRN_AM2	15.0	131,840	Threshold	71	19818
HEDGES2	10.0	27,560	Threshold	20	2775
BIOSWALE2	10.0	27,560	Threshold	15	2758

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4.6 Summary

When comparing baseline conditions for 2030 in scenario A with the status-quo in 2019, it becomes clear that overall, the share of urban green spaces and of forest is sought to be significantly increased (Figure 22). For urban green spaces, this particularly refers to the suggested green network, whilst afforestation is proposed primarily in the southern part of the case study area. However, as previously mentioned, there is a considerable turn-over in land-uses. Therefore, considerable shares of 2019 area of both types of GBI are also lost due to conversion/deforestation. For forest, this is primarily the case in the south-eastern part of the case study area, where large parts of forest are proposed for conversion to industrial/high-tech land, as well as in the southern-central part, where forest is lost to public facilities and/or commercial land. Smaller portions of forest land are lost, e.g., due to conversion to residential land, e.g., in the south-west and to the north of case study area. Similarly, comparatively large parts of existing urban green spaces, including recreational and sports facilities, are potentially lost, e.g., due to their conversion to residential land or other uses. This includes urban green space within the citadel, as well as along the Perfume River. As described previously, at the city scale, these losses are compensated by the foreseen implementation of new urban green spaces, and by afforestation, accordingly. However, risks may remain if the proposed greening/afforestation actions under scenario A fail or remain incomplete. Moreover, accessibility to GBI may be negatively affected in the respective parts of the case study area. Furthermore, impacts on biodiversity need to be considered, particularly of vegetation structure of green spaces is natural, or if comparatively old forest stands are converted. However, data quality issues may affect the accuracy of this assessment, i.e., particularly small green spaces or recreational and sports facilities may (not) be properly depicted in the 2030 urban master plan and may therefore not be foreseen for conversion.

Furthermore, for blue features, a net loss is anticipated until 2030 at the case study level (Figure 22). It has been discussed that although the 2030 urban master planning stipulates the creation of water bodies, e.g., within urban green spaces, it is simultaneously proposed to drain water bodies, that correspond, to a large extent, to canals on agricultural land. However, as before, uncertainties remain in the actual extent and nature of these measures, making it difficult to accurately assess changes.

Subsequently, as described, the interventions proposed in scenarios B, C, and D build on the baseline scenario, aligned to a gradient of an increasing degree of intervention. Hence, each of these scenarios proposes selected types of interventions for the implementation of green or blue infrastructure elements in addition to baseline, i.e., the actions derived from the Huế's 2030 land-use plan (Figure 23). However, a further examination of findings and their incorporation into more-specific urban planning will be needed for the realization of any scenario. When compared to baseline, the measures suggested in scenarios B to D result in an additional greening, i.e., urban green space area, of 5.8% (scenario B) to about 20.5% (scenario D). Although comparatively low, these figures must be contrasted with the comparatively high share of land foreseen for greening already under the baseline scenario. When viewed against the actual designated green space area in 2019 (status-quo), the measures proposed in scenarios B to D would result in the implementation of greening actions equal to an area of 104% (scenario B) to 368% (scenario D) of the status-quo green space total area. I.e., disregarding proposed greening interventions under the business-as-usual scenario (baseline), scenario B on its own would roughly double the green space in Huế city, whereas scenario D would result in 3.6fold increase in urban green space area.

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Regarding the blue infrastructure, the creation of ponds as proposed in scenarios B to D (Figure 23) may reduce net loss in water bodies slightly, but are not enough to compensate for drainage under baseline conditions (Figure 22). Regarding forest, forest cover is only slightly reduced in scenario D (Figure 22, Figure 23).

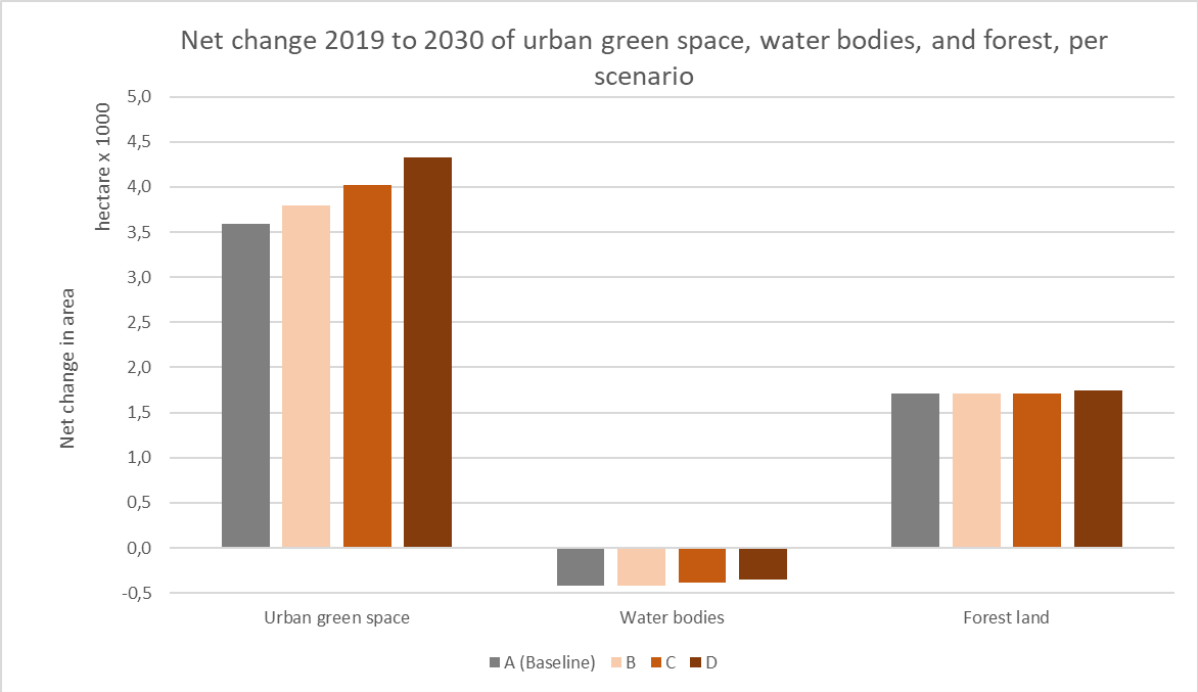

Figure 22. Net change 2019 to 2030 in area for urban green spaces, water bodies, and forests, per scenario.

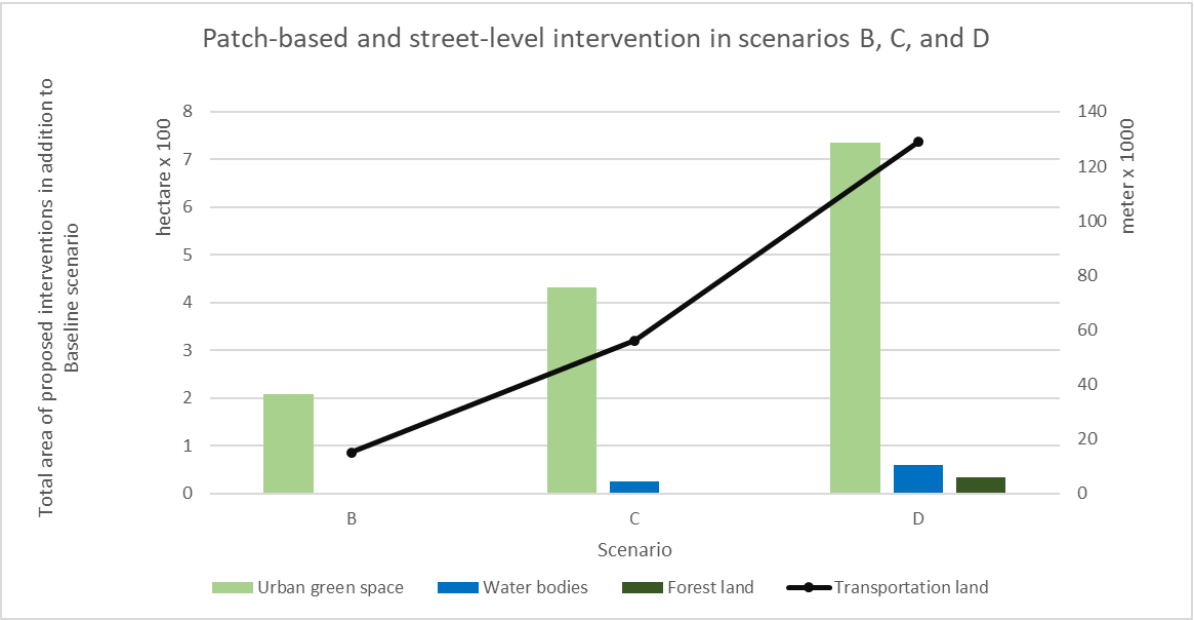

Figure 23. Proposed patch-based (ha) and street-level (m) interventions in scenarios B, C, and D. These interventions are proposed in addition to baseline.

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5 Discussion

The objective of this work package is the modelling of green-blue NBS interventions at the spatial scale of the whole city of Huế. In this context, it has been described how four scenarios are elaborated for the case study area, with each scenario representing a potential pathway to a greener city through the implementation of different types of green-blue interventions as forms of NBS action. It has also been outlined that the scenarios form a gradient of different degrees of intervention, with an increasing number of types of green or green-blue infrastructures as forms of NBS being considered, as well as being associated with higher ambitions with respect to the amount of greening to be achieved (i.e., land converted/conversion rates). Moreover, also an alignment of the chosen types per scenario with the perceived local popularity of these green-blue elements, as stated by local stakeholders, has been considered, with scenarios C and D increasingly proposing GBI elements for implementation that are perceived as less feasible/popular by local stakeholders. A key requirement of project partners has furthermore been the alignment of the modelling, and therefore, of the measures proposed for each scenario, with Huế's ambitions and visions (e.g., regarding the promotion of eco-tourism), as well as with the actual urban planning for 2030. The modelling of these scenarios is crucial to subsequently enable an assessment and evaluation of socio-environmental-economic impacts of the proposed interventions. Besides the type of intervention to be modelled, such as the construction of parks or afforestation action, the specific location of these interventions and their spatial extent, as in size (therefore, the spatial expression of the proposed intervention) is needed to conduct such impact assessment.

The research in this work package is conducted under several constraints, related to proposed interventions, and with data availability being a key issue. In this regard, it has been described how land-use changes from 2019 to 2030 are identified by the comparison of the status-quo land-use dataset (2019) with the 2030 land-use plan, with certain land-use changes being considered as key opportunities for the implementation of certain green-blue interventions. However, the level of detail of the acquired land-use datasets matches only partially, where, e.g., in areas to be developed, more detailed networks of roads and resulting city block structures are not always properly depicted in the 2030 land-use plan. Moreover, there are significant spatial mismatches between both datasets, i.e., a non-overlap of spatial data, that could not entirely be addressed in the initial data preparation or in data pre-processing. These spatial mismatches result in numerous spatial artifacts and, accordingly, uncertainties regarding the properties and state of affected spatial patches, with respect to their actual existence/size, desired land-use, and resulting land-use changes. To address these uncertainties resulting from spatial data inaccuracies, first, only patches were considered in the modelling process with an area larger than 1000m², thereby removing likely sliver polygons. Second, numerous polygons with invalid or implausible geometries were identified in the pre-processed data. Using patch metrics, i.e., FRAC index, these artifacts could be identified and subsequently removed from spatial data by removing polygons whose FRAC index was outside of the numeric range as defined for this index.

Moreover, it has been described previously that there is a certain disparity or disconnect in spatial scales between available spatial data on the one hand, and certain proposed interventions on the other. For example, based on the available land-use data, interventions such as afforestation or the construction of comparatively large urban parks can be depicted spatially, and thus modelled in a spatially explicit manner, in line with established modelling

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approaches such as cellular automata. In contrast to that, selective-local actions as comparatively small-scale greening actions such as the construction of pergolas (a very popular measure), the construction or improvement of playgrounds, the greening of balconies, or the greening of facades and roofs cannot, or can only hardly be modelled spatially explicitly. For the former example of pergolas, this is simply due to the type of intervention when compared to the spatial scale of modelling and analysis, rendering a spatial modelling unfeasible. Similarly, in case of playgrounds, no data had been made available that, e.g., inventories or locates playgrounds. For the latter examples of building-related greening interventions, this is due to the lack of required data, e.g., building footprints or detailed information on building codes to determine structural support for greening measures, so that ultimately, also these kinds of interventions cannot be modelled spatially explicit. However, in this context, it also needs to be noted that, e.g., building footprints would only rarely be available for areas to be built/developed until 2030, due to lack of more-detailed urban planning. The latter aspect also hampers a more explicit modelling of actions such as the construction of urban parks, as the data required for a detailed modelling of green space location, size, design, orientation within city structures etc. is not yet available. It also affects the modelling of interventions at street-level, as road presence and thus road lengths may be inaccurate or under-reported. Furthermore, there is an uncertainty in modelled road widths, as they have been derived from polygonal land-use data.

Consequently, the proposed methodology must consider and adapt to these data constraints. To do so, as described, the proposed methodology does not model implementation of green-blue elements in a spatially explicit manner. Instead, a virtual bookkeeping is proposed, where proposed interventions are tracked regarding type, size/land converted, and location on a basis of simple assumptions and rules. In so doing, the “virtualization” of modelling interventions addresses potential disconnects in spatial scale, as well as data deficiencies, as it foregoes a true spatialization of results, i.e., land-use conversions, and replaces such spatially explicit outputs with “search spaces”. Here, “search space” corresponds to urban areas which, according to formulated rules and thus assumptions or stakeholder perceptions, are considered suitable for the implementation of certain types of GBI. The virtual bookkeeping then informs on the area to be converted, in relation to a given search space and to the type of GBI in question, as well as keeping track of total land converted in relation to set policy goals.

However, the differing allocating of space in each scenario through considering lower spatial footprint thresholds, mean thresholds, or upper thresholds of spatial footprints, respectively, when evaluating a stop condition shows that despite the comparatively simple rules used, and the simple mechanism of spatial footprint per-se, comparatively complex spatial patterns of green-blue elements may emerge. As shown in Figure 24, varying the stop condition to use upper thresholds results in spatial configurations of green-blue spaces where less patches are considered for NBS action, thereby, e.g., possibly impacting ecological connectivity. However, the green-blue spaces proposed are larger individually, as the share of each patch foreseen for a conversion to urban green space increases, thereby possibly benefitting biodiversity as well as restorative and recreative potential. The same observations hold true when larger footprints are proposed instead of smaller ones.

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Figure 24. Exemplary configurations of green corridors as outcomes of allocation modelling, resulting from the specification of different thresholds. On the left, lower thresholds are used to evaluate the stop condition; in the middle, mean thresholds are used, and on the right, upper thresholds. In all cases, the underlying spatial footprint is of size “small”. It can be seen that from left to right, the number of patches considered for greening action decreases, however, the share of each patch to be converted to green space increases (as indicated by darker green color; see legend of Figure 18 for a more-detailed explanation).

The proposed approach, in conjunction with the realized toolbox, allows to map potential outcomes of greening strategies (scenarios) relatively straightforwardly, with these strategies differing, e.g., in the types of GBI elements considered; in the size of proposed interventions, reflecting, e.g., on constructing smaller (pocket) parks vs. larger (urban) parks; in the quality or design of proposed interventions, as reflected upon in the narrative; or in underlying policy goals, such as the additional greening of a given relative (%) or absolute (m²) area of land. The modelling outputs, as visualized in Figure 18 to Figure 20, then depict, on the one hand, if a goal is achievable at all, under consideration of the suggested actions considered for its achievement, and furthermore reflect on the actual effort needed for goal achievement.

Here, considering, e.g., scenario B, model outcomes indicate that, based on the scenario-specific assumptions of realizing greening goals through comparatively small actions such as pocket park construction (designated PARK_R1), just for this single type of intervention up to 764 individual actions across almost the whole study area would need to be taken in order to be able to achieve the assumed policy goal of converting 10% of corresponding target zone land to green spaces. It is obviously questionable if such a high number of measures is realistic, feasible, or achievable. However, such findings are seen to spark a debate amongst stakeholders, planners, and/or the public on which goals should be set, and on how they may be achieved. With respect to the example given, an alteration of goals, or changes in (design-related) assumptions (e.g., opting to create fewer larger green spaces instead or many smaller ones) may result in more realistic, more feasible, and better achievable greening strategies.

Furthermore, by providing only “search spaces” and, respectively, guidance on the type and size of GBI elements to be implemented within each these “search spaces”, the proposed methodology provides an opportunity for participative and collaborative urban planning, as clearly, in subsequent steps, proposed interventions must be evaluated and adapted to each respective “search space”, as part of more specific urban planning when developing newly built-up land, providing opportunities for local stakeholders to be involved, fostering communication, knowledge-exchange, and participation.

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Consequently, by allowing to express:

- Where should something happen (e.g., in current residential built-up);
- What should happen there (e.g., construction of parks);
- How should it be done (e.g., implementing comparatively small pocket parks);
- Where should it be done first (defining prioritization criteria, as described);
- What do we want to achieve in the end (e.g., converting 5% of the corresponding area to green space),

the proposed methodology is considered more a tool to explore potential pathways to support planning, by allowing to evaluate and compare outcomes of different assumptions, policies, or policy goals related to these questions. Clearly, the proposed approach is less a tool to provide "final outcomes" for planning, as it is not intended to substitute more-specific (participatory) urban planning.

6 Relationship of the work described with other tasks and work packages

The results of scenario modelling provide the basis for further work to be conducted in WP2, i.e., the assessment of impacts of proposed interventions on ecosystem conditions, or consequently, ecosystem services provided. In this context, likely impacts are governed by the type as well as number of interventions proposed; the areas converted to urban green-blue spaces; or the spatial distribution of these interventions across the study region. Although, as described previously, a virtual spatial allocation approach has been proposed for the city-wide modelling of GBI interventions, more more-essential parameters to inform impact assessment are provided also by the chosen approach.

Moreover, also in WP2, ecosystem service supply is also intended to be contrasted with ecosystem service demand (supply-and-demand modelling). To do so, the work described in this report provides a suitable basis, e.g., for a required spatial disaggregation of current or future population as the beneficiaries of ecosystem service supply.

Furthermore, the spatialized scenarios depict potential pathways to achieve certain policy goals, as expressed through the narratives and subsequent scenarios. They may therefore foster discussion and inform the co-design and co-learning process established in the Green City Lab (WP3), the development of decision support and policy (WP4), and the development of the Green City Vision Huế (WP5).

Finally, the provided toolbox implementing the city-wide modelling approach also facilitates reflections, i.e., discussions and findings from co-design and co-learning may be fed back into the toolbox through making changes to the comparatively simple set of required rules, to subsequently obtain an updated perspective on potential pathways towards a greener city.

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CONCLUSION

A GIS-based approach to model nature-based solutions has been introduced in this report. As described, the methodology uses a comparatively simple set of rules, fed into the modelling process through Excel spreadsheets, that translate qualitative narratives and scenarios based thereupon to modelling instructions, and in so-doing governing the identification of spatial entities considered suitable for selected interventions, and their subsequent allocation for NBS implementation. The resulting models allow a discussion on the feasibility of proposed interventions, and accordingly, associated policy goals, and thereby, enable stakeholders to explore potential pathways for, and potential outcomes of NBS action. Through the implementation of the approach as GIS toolbox, reproducibility of findings and transferability of method shall be facilitated.

To a certain extent, the presented findings are considered rather tentative in nature, i.e., being based on a first set of initial assumptions and suggestions as formulated in the set of rules. It is envisioned that with feedback from stakeholders or the public—e.g., as collected in the GreenCityLabHuế going forward—and with findings of other work packages becoming available, proposed interventions and rules may be revisited in related work packages to produce updated scenarios that support further discussion and the development of the Green Vision Huế.

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BIBLIOGRAPHY

Bielecka, E., 2020. GIS Spatial Analysis Modeling for Land Use Change. A Bibliometric Analysis of the Intellectual Base and Trends. Geosciences, 10, 421.

Bloomberg, M., Benepe, A., 2009. Tree Planting Standards. City of New York Parks & Recreation. New York City.

Jache, J., Scheuer, S., Stolpe, F., Sumfleth, L., Minh, T., Minh, T. B., Hoang, Y., Long Nguyen, D., Zschiesche, M., Haase, D., 2021. GreenCityLabHuế: Nature-based Solutions to Strengthen Climate Resilience of Urban Regions in Central Vietnam. Final report for the definition phase of the joint research project. Available online: https://www.greencitylabHuế.com/final-report-of-the-definition-phase-published/.

Kain, J.-H., Larondelle, N., Haase, D., Kaczorowska, A., 2016. Exploring local consequences of two land-use alternatives for the supply of urban ecosystem services in Stockholm year 2050. Ecological Indicators, 70, 615-629.

Kremer, P., Hamstead, Z. A., McPhearson, T., 2013. A social–ecological assessment of vacant lots in New York City. Landscape and Urban Planning, 120, 218-233.

Larondelle, N., Frantzeskaki, N., Haase, D., 2016. Mapping transition potential with stakeholder- and policy-driven scenarios in Rotterdam City. Ecological Indicators, 70, 630-643.

Liu, Y., Li, L., Chen, L., Cheng, L., Zhou, X., Cui, Y., Li, H., Liu, W., 2019. Urban growth simulation in different scenarios using the SLEUTH model: A case study of Hefei, East China. PLoS ONE, 14(11), e0224998.

MacGarigal, K., Marks, B.J., 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. Gen. Tech. Rep. PNW-GTR-351. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, Oregon, USA.

Mallampalli, V., Mavrommati, G., Thompson, J., Duveneck, M., Meyer, S., Ligmann-Zielinska, A., Gottschalk Druschke, C., Hychka, K., Kenney, M., Kok, K., Borsuk, M., 2016. Methods for translating narrative scenarios into quantitative assessments of land use change. Environmental Modelling and Software, 82, 7-20.

Meerow, S., Newell, J., 2017. Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit. Landscape and Urban Planning, 159, 62-75.

Miyawaki, A., 1998. Restoration of urban green environments based on the theories of vegetation ecology. Ecological Engineering, 11(1), 157-165.

Road and Transportation Research Association, 2012. Directives for the Design of Urban Roads (RASt06). Cologne.

Santé, I., García, A.M., Miranda, D., Crecente, R., 2010. Cellular automata models for the simulation of real-world urban processes: A review and analysis. Landscape and Urban Planning, 96(2), 108–122.

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APPENDIX

LAND-USE CHANGE MATRIX

Table S 1. Land-use change matrix compiled from the 2019 land-use dataset (column LU_2019_A) and the 2030 urban master plan (column LU_2030), the desired (integrated) land-use as a function of the observed land-use 2019 and the urban master plan 2030 (column Desired land-use), and the underlying, assumed land-use change (column Desired change state).

LU_2019_A	LU_2030	Desired land-use	Desired change state
aquaculture facilities	residential area (planned)	residential area (planned)	Urban development/Urban expansion
aquaculture facilities	residential area (existing)	residential area (existing)	Urban development/Urban expansion
aquaculture facilities	transportation	transportation	Urban development/Urban expansion
aquaculture facilities	forests	forests	Afforestation
aquaculture facilities	(public) green spaces and sports facilities	(Public) green spaces and sports facilities	Implementation of green infrastructure elements
aquaculture facilities	suburban village area	rural residential area	Urban development/Urban expansion
aquaculture facilities	military land, national defence and security facilities	military land, national defense and security facilities	Urban development/Urban expansion
aquaculture facilities	industrial area (high tech)	industrial area (high-tech)	Urban development/Urban expansion
aquaculture facilities	educational and training facilities	educational and training facilities	Urban development/Urban expansion
aquaculture facilities	water bodies	water bodies	Implementation of blue infrastructure elements
aquaculture facilities	agricultural land and aquaculture facilities	agricultural land and aquaculture facilities	No change
aquaculture facilities	infrastructure facilities	infrastructure facilities	Urban development/Urban expansion
aquaculture facilities	green railway bank	green railway bank	Urban development/Urban expansion
aquaculture facilities	public facilities and commercial land	public facilities and commercial land	Urban development/Urban expansion
aquaculture facilities	monuments and religious facilities	historic and cultural monuments and religious and spiritual facilities	Urban development/Urban expansion
aquaculture facilities	tourism area	tourism area	Urban development/Urban expansion
aquaculture facilities	other developed land	other developed land	Urban development/Urban expansion
aquaculture facilities	reserved area	agricultural land and aquaculture facilities	No change (reserve land)
aquaculture facilities	na	agricultural land and aquaculture facilities	No change

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LU_2019_A	LU_2030	Desired land-use	Desired change state
aquaculture facilities	health care facilities	health care facilities	Urban development/Urban expansion
cemeteries	industrial area (high tech)	industrial area (high-tech)	(Re-)Development
cemeteries	forests	forests	Afforestation
cemeteries	residential area (planned)	residential area (planned)	(Re-)Development
cemeteries	transportation	transportation	(Re-)Development
cemeteries	residential area (existing)	residential area (existing)	(Re-)Development
cemeteries	public facilities and commercial land	public facilities and commercial land	(Re-)Development
cemeteries	water bodies	water bodies	Implementation of blue infrastructure elements
cemeteries	suburban village area	rural residential area	(Re-)Development
cemeteries	(public) green spaces and sports facilities	(Public) green spaces and sports facilities	Implementation of green infrastructure elements
cemeteries	monuments and religious facilities	historic and cultural monuments and religious and spiritual facilities	No change
cemeteries	infrastructure facilities	infrastructure facilities	(Re-)Development
cemeteries	reserved area	historic and cultural monuments and religious and spiritual facilities	No change (reserve land)
cemeteries	green railway bank	green railway bank	(Re-)Development
cemeteries	military land, national defence and security facilities	military land, national defense and security facilities	(Re-)Development
cemeteries	health care facilities	health care facilities	(Re-)Development
cemeteries	agricultural land and aquaculture facilities	agricultural land and aquaculture facilities	Agricultural conversion
cemeteries	tourism area	tourism area	(Re-)Development
cemeteries	educational and training facilities	educational and training facilities	(Re-)Development
cemeteries	other developed land	other developed land	(Re-)Development
cemeteries	na	historic and cultural monuments and religious and spiritual facilities	No change
commercial and industrial area	other developed land	other developed land	(Re-)Development
commercial and industrial area	transportation	transportation	(Re-)Development
commercial and industrial area	forests	forests	Afforestation
commercial and industrial area	residential area (planned)	residential area (planned)	(Re-)Development
commercial and industrial area	suburban village area	rural residential area	(Re-)Development
commercial and industrial area	(public) green spaces and sports facilities	(Public) green spaces and sports facilities	Implementation of green infrastructure elements

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LU_2019_A	LU_2030	Desired land-use	Desired change state
commercial and industrial area	water bodies	water bodies	Implementation of blue infrastructure elements
commercial and industrial area	agricultural land and aquaculture facilities	agricultural land and aquaculture facilities	Agricultural conversion
commercial and industrial area	educational and training facilities	educational and training facilities	(Re-)Development
commercial and industrial area	industrial area (high tech)	industrial area (high-tech)	Specialization
commercial and industrial area	infrastructure facilities	infrastructure facilities	(Re-)Development
commercial and industrial area	public facilities and commercial land	public facilities and commercial land	No change
commercial and industrial area	reserved area	public facilities and commercial land	No change (reserve land)
commercial and industrial area	green railway bank	green railway bank	(Re-)Development
commercial and industrial area	residential area (existing)	residential area (existing)	(Re-)Development
commercial and industrial area	health care facilities	health care facilities	(Re-)Development
commercial and industrial area	monuments and religious facilities	historic and cultural monuments and religious and spiritual facilities	(Re-)Development
commercial and industrial area	tourism area	tourism area	Specialization
commercial and industrial area	military land, national defence and security facilities	military land, national defense and security facilities	(Re-)Development
commercial and industrial area	na	public facilities and commercial land	No change
dump sites	forests	forests	Afforestation
dump sites	infrastructure facilities	infrastructure facilities	No change
dump sites	reserved area	infrastructure facilities	No change (reserve land)
dump sites	water bodies	water bodies	Implementation of blue infrastructure elements
forests	forests	forests	No change
forests	water bodies	water bodies	Deforestation
forests	transportation	transportation	Deforestation
forests	industrial area (high tech)	industrial area (high-tech)	Deforestation
forests	residential area (planned)	residential area (planned)	Deforestation
forests	residential area (existing)	residential area (existing)	Deforestation
forests	military land, national defence and security facilities	military land, national defense and security facilities	Deforestation
forests	(public) green spaces and sports facilities	(Public) green spaces and sports facilities	Deforestation
forests	suburban village area	rural residential area	Deforestation

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LU_2019_A	LU_2030	Desired land-use	Desired change state
forests	public facilities and commercial land	public facilities and commercial land	Deforestation
forests	educational and training facilities	educational and training facilities	Deforestation
forests	infrastructure facilities	infrastructure facilities	Deforestation
forests	reserved area	forests	No change (reserve land)
forests	monuments and religious facilities	historic and cultural monuments and religious and spiritual facilities	Deforestation
forests	green railway bank	green railway bank	Deforestation
forests	tourism area	tourism area	Deforestation
forests	agricultural land and aquaculture facilities	agricultural land and aquaculture facilities	Deforestation
historic and cultural monuments	forests	forests	Afforestation
historic and cultural monuments	industrial area (high tech)	industrial area (high-tech)	(Re-)Development
historic and cultural monuments	transportation	transportation	(Re-)Development
historic and cultural monuments	suburban village area	rural residential area	(Re-)Development
historic and cultural monuments	monuments and religious facilities	historic and cultural monuments and religious and spiritual facilities	No change
historic and cultural monuments	water bodies	water bodies	Implementation of blue infrastructure elements
historic and cultural monuments	educational and training facilities	educational and training facilities	(Re-)Development
historic and cultural monuments	residential area (existing)	residential area (existing)	(Re-)Development
historic and cultural monuments	(public) green spaces and sports facilities	(Public) green spaces and sports facilities	Implementation of green infrastructure elements
historic and cultural monuments	public facilities and commercial land	public facilities and commercial land	(Re-)Development
historic and cultural monuments	other developed land	other developed land	(Re-)Development
historic and cultural monuments	residential area (planned)	residential area (planned)	(Re-)Development
historic and cultural monuments	agricultural land and aquaculture facilities	agricultural land and aquaculture facilities	Agricultural conversion
historic and cultural monuments	military land, national defence and security facilities	military land, national defense and security facilities	(Re-)Development
mineral extraction sites	suburban village area	rural residential area	Urban development/Urban expansion
mineral extraction sites	transportation	transportation	Urban development/Urban expansion
mineral extraction sites	forests	forests	Afforestation

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LU_2019_A	LU_2030	Desired land-use	Desired change state
mineral extraction sites	water bodies	water bodies	Implementation of blue infrastructure elements
mineral extraction sites	residential area (existing)	residential area (existing)	Urban development/Urban expansion
mineral extraction sites	public facilities and commercial land	public facilities and commercial land	Urban development/Urban expansion
n.a.	suburban village area	rural residential area	No change
n.a.	public facilities and commercial land	public facilities and commercial land	No change
n.a.	transportation	transportation	No change
n.a.	forests	forests	No change
n.a.	(public) green spaces and sports facilities	(Public) green spaces and sports facilities	No change
other agricultural land	forests	forests	Afforestation
other agricultural land	transportation	transportation	Urban development/Urban expansion
other agricultural land	water bodies	water bodies	Implementation of blue infrastructure elements
other agricultural land	industrial area (high tech)	industrial area (high-tech)	Urban development/Urban expansion
other agricultural land	residential area (planned)	residential area (planned)	Urban development/Urban expansion
other agricultural land	residential area (existing)	residential area (existing)	Urban development/Urban expansion
other agricultural land	other developed land	other developed land	Urban development/Urban expansion
other agricultural land	public facilities and commercial land	public facilities and commercial land	Urban development/Urban expansion
other agricultural land	infrastructure facilities	infrastructure facilities	Urban development/Urban expansion
other agricultural land	military land, national defence and security facilities	military land, national defense and security facilities	Urban development/Urban expansion
other agricultural land	(public) green spaces and sports facilities	(Public) green spaces and sports facilities	Implementation of green infrastructure elements
other agricultural land	suburban village area	rural residential area	Urban development/Urban expansion
other agricultural land	educational and training facilities	educational and training facilities	Urban development/Urban expansion
other agricultural land	monuments and religious facilities	historic and cultural monuments and religious and spiritual facilities	Urban development/Urban expansion
other agricultural land	reserved area	agricultural land and aquaculture facilities	No change (reserve land)
other agricultural land	green railway bank	green railway bank	Urban development/Urban expansion
other agricultural land	tourism area	tourism area	Urban development/Urban expansion

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LU_2019_A	LU_2030	Desired land-use	Desired change state
other agricultural land	agricultural land and aquaculture facilities	agricultural land and aquaculture facilities	No change
other agricultural land	health care facilities	health care facilities	Urban development/Urban expansion
other agricultural land	na	agricultural land and aquaculture facilities	No change
public and special use facilities	forests	forests	Afforestation
public and special use facilities	industrial area (high tech)	industrial area (high-tech)	(Re-)Development
public and special use facilities	transportation	transportation	(Re-)Development
public and special use facilities	residential area (planned)	residential area (planned)	(Re-)Development
public and special use facilities	residential area (existing)	residential area (existing)	(Re-)Development
public and special use facilities	other developed land	other developed land	(Re-)Development
public and special use facilities	public facilities and commercial land	public facilities and commercial land	No change
public and special use facilities	infrastructure facilities	infrastructure facilities	No change
public and special use facilities	military land, national defence and security facilities	military land, national defense and security facilities	(Re-)Development
public and special use facilities	suburban village area	rural residential area	(Re-)Development
public and special use facilities	(public) green spaces and sports facilities	(Public) green spaces and sports facilities	Implementation of green infrastructure elements
public and special use facilities	water bodies	water bodies	Implementation of blue infrastructure elements
public and special use facilities	monuments and religious facilities	historic and cultural monuments and religious and spiritual facilities	(Re-)Development
public and special use facilities	reserved area	public facilities and commercial land	No change
public and special use facilities	green railway bank	green railway bank	(Re-)Development
public and special use facilities	health care facilities	health care facilities	Specialization
public and special use facilities	agricultural land and aquaculture facilities	agricultural land and aquaculture facilities	Agricultural conversion
public and special use facilities	tourism area	tourism area	(Re-)Development
public and special use facilities	educational and training facilities	educational and training facilities	Specialization
public and special use facilities	na	public facilities and commercial land	No change
public green spaces	(public) green spaces and sports facilities	(Public) green spaces and sports facilities	No change

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LU_2019_A	LU_2030	Desired land-use	Desired change state
public green spaces	transportation	transportation	Ungreening/(Re-)Development
public green spaces	forests	forests	Afforestation
public green spaces	residential area (existing)	residential area (existing)	(Re-)Development
public green spaces	water bodies	water bodies	Green-to-Blue conversion
public green spaces	suburban village area	rural residential area	Ungreening/(Re-)Development
public green spaces	monuments and religious facilities	historic and cultural monuments and religious and spiritual facilities	Ungreening/(Re-)Development
public green spaces	public facilities and commercial land	public facilities and commercial land	Ungreening/(Re-)Development
public green spaces	residential area (planned)	residential area (planned)	Ungreening/(Re-)Development
public green spaces	agricultural land and aquaculture facilities	agricultural land and aquaculture facilities	Ungreening/Agricultural conversion
public green spaces	educational and training facilities	educational and training facilities	Ungreening/(Re-)Development
public green spaces	infrastructure facilities	infrastructure facilities	Ungreening/(Re-)Development
religious and spiritual facilities	forests	forests	Afforestation
religious and spiritual facilities	residential area (planned)	residential area (planned)	(Re-)Development
religious and spiritual facilities	residential area (existing)	residential area (existing)	(Re-)Development
religious and spiritual facilities	transportation	transportation	(Re-)Development
religious and spiritual facilities	water bodies	water bodies	Implementation of blue infrastructure elements
religious and spiritual facilities	suburban village area	rural residential area	(Re-)Development
religious and spiritual facilities	industrial area (high tech)	industrial area (high-tech)	(Re-)Development
religious and spiritual facilities	(public) green spaces and sports facilities	(Public) green spaces and sports facilities	Implementation of green infrastructure elements
religious and spiritual facilities	monuments and religious facilities	historic and cultural monuments and religious and spiritual facilities	No change
religious and spiritual facilities	infrastructure facilities	infrastructure facilities	(Re-)Development
religious and spiritual facilities	reserved area	historic and cultural monuments and religious and spiritual facilities	No change (reserve land)
religious and spiritual facilities	agricultural land and aquaculture facilities	agricultural land and aquaculture facilities	Agricultural conversion
religious and spiritual facilities	educational and training facilities	educational and training facilities	(Re-)Development
religious and spiritual facilities	public facilities and commercial land	public facilities and commercial land	(Re-)Development
religious and spiritual facilities	green railway bank	green railway bank	(Re-)Development

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LU_2019_A	LU_2030	Desired land-use	Desired change state
religious and spiritual facilities	tourism area	tourism area	(Re-)Development
religious and spiritual facilities	health care facilities	health care facilities	(Re-)Development
religious and spiritual facilities	na	historic and cultural monuments and religious and spiritual facilities	No change
religious and spiritual facilities	other developed land	other developed land	(Re-)Development
rice-growing areas	industrial area (high tech)	industrial area (high-tech)	Urban development/Urban expansion
rice-growing areas	forests	forests	Afforestation
rice-growing areas	residential area (planned)	residential area (planned)	Urban development/Urban expansion
rice-growing areas	transportation	transportation	Urban development/Urban expansion
rice-growing areas	residential area (existing)	residential area (existing)	Urban development/Urban expansion
rice-growing areas	military land, national defence and security facilities	military land, national defense and security facilities	Urban development/Urban expansion
rice-growing areas	water bodies	water bodies	Implementation of blue infrastructure elements
rice-growing areas	suburban village area	rural residential area	Urban development/Urban expansion
rice-growing areas	(public) green spaces and sports facilities	(Public) green spaces and sports facilities	Implementation of green infrastructure elements
rice-growing areas	agricultural land and aquaculture facilities	agricultural land and aquaculture facilities	No change
rice-growing areas	monuments and religious facilities	historic and cultural monuments and religious and spiritual facilities	Urban development/Urban expansion
rice-growing areas	infrastructure facilities	infrastructure facilities	Urban development/Urban expansion
rice-growing areas	reserved area	agricultural land and aquaculture facilities	No change (reserve land)
rice-growing areas	green railway bank	green railway bank	Urban development/Urban expansion
rice-growing areas	tourism area	tourism area	Urban development/Urban expansion
rice-growing areas	public facilities and commercial land	public facilities and commercial land	Urban development/Urban expansion
rice-growing areas	educational and training facilities	educational and training facilities	Urban development/Urban expansion
rice-growing areas	other developed land	other developed land	Urban development/Urban expansion
rice-growing areas	health care facilities	health care facilities	Urban development/Urban expansion
rice-growing areas	na	agricultural land and aquaculture facilities	No change

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LU_2019_A	LU_2030	Desired land-use	Desired change state
rural residential area	forests	forests	Resettlement/Afforestation
rural residential area	transportation	transportation	Resettlement/(Re-)Development
rural residential area	industrial area (high tech)	industrial area (high-tech)	Resettlement/(Re-)Development
rural residential area	residential area (planned)	residential area (planned)	Potential Densification/(Re-)Development
rural residential area	residential area (existing)	residential area (existing)	Densification/(Re-)Development
rural residential area	other developed land	other developed land	Resettlement/(Re-)Development
rural residential area	public facilities and commercial land	public facilities and commercial land	Resettlement/(Re-)Development
rural residential area	infrastructure facilities	infrastructure facilities	Resettlement/(Re-)Development
rural residential area	military land, national defence and security facilities	military land, national defense and security facilities	Resettlement/(Re-)Development
rural residential area	(public) green spaces and sports facilities	(Public) green spaces and sports facilities	Resettlement/Implementation of green infrastructure elements
rural residential area	water bodies	water bodies	Resettlement/Implementation of blue infrastructure elements
rural residential area	suburban village area	rural residential area	No change
rural residential area	agricultural land and aquaculture facilities	agricultural land and aquaculture facilities	Resettlement/Agricultural conversion
rural residential area	monuments and religious facilities	historic and cultural monuments and religious and spiritual facilities	Resettlement/(Re-)Development
rural residential area	health care facilities	health care facilities	Resettlement/(Re-)Development
rural residential area	educational and training facilities	educational and training facilities	Resettlement/(Re-)Development
rural residential area	reserved area	rural residential area	No change (reserve land)
rural residential area	tourism area	tourism area	Resettlement/(Re-)Development
rural residential area	na	rural residential area	No change
security and national defense	forests	forests	Afforestation
security and national defense	transportation	transportation	(Re-)Development
security and national defense	military land, national defence and security facilities	military land, national defense and security facilities	No change
security and national defense	water bodies	water bodies	Implementation of blue infrastructure elements
security and national defense	(public) green spaces and sports facilities	(Public) green spaces and sports facilities	Implementation of green infrastructure elements
security and national defense	infrastructure facilities	infrastructure facilities	(Re-)Development
security and national defense	educational and training facilities	educational and training facilities	(Re-)Development
security and national defense	reserved area	military land, national defense and security facilities	No change

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LU_2019_A	LU_2030	Desired land-use	Desired change state
security and national defense	industrial area (high tech)	industrial area (high-tech)	(Re-)Development
security and national defense	green railway bank	green railway bank	(Re-)Development
security and national defense	residential area (existing)	residential area (existing)	(Re-)Development
security and national defense	suburban village area	rural residential area	(Re-)Development
security and national defense	residential area (planned)	residential area (planned)	(Re-)Development
security and national defense	public facilities and commercial land	public facilities and commercial land	(Re-)Development
security and national defense	monuments and religious facilities	historic and cultural monuments and religious and spiritual facilities	(Re-)Development
security and national defense	agricultural land and aquaculture facilities	agricultural land and aquaculture facilities	Agricultural conversion
security and national defense	tourism area	tourism area	(Re-)Development
sports and recreation facilities	other developed land	other developed land	Ungreening/(Re-)Development
sports and recreation facilities	residential area (existing)	residential area (existing)	Ungreening/(Re-)Development
sports and recreation facilities	transportation	transportation	Ungreening/(Re-)Development
sports and recreation facilities	industrial area (high tech)	industrial area (high-tech)	Ungreening/(Re-)Development
sports and recreation facilities	suburban village area	rural residential area	Ungreening/(Re-)Development
sports and recreation facilities	forests	forests	Afforestation
sports and recreation facilities	reserved area	(Public) green spaces and sports facilities	No change
sports and recreation facilities	infrastructure facilities	infrastructure facilities	Ungreening/(Re-)Development
sports and recreation facilities	residential area (planned)	residential area (planned)	Ungreening/(Re-)Development
sports and recreation facilities	(public) green spaces and sports facilities	(Public) green spaces and sports facilities	No change
sports and recreation facilities	agricultural land and aquaculture facilities	agricultural land and aquaculture facilities	Ungreening/Agricultural conversion
sports and recreation facilities	public facilities and commercial land	public facilities and commercial land	Ungreening/(Re-)Development
sports and recreation facilities	monuments and religious facilities	historic and cultural monuments and religious and spiritual facilities	Ungreening/(Re-)Development
sports and recreation facilities	water bodies	water bodies	Green-to-Blue conversion
sports and recreation facilities	tourism area	tourism area	Ungreening/(Re-)Development

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LU_2019_A	LU_2030	Desired land-use	Desired change state
transportation	residential area (planned)	residential area (planned)	(Re-)Development
transportation	forests	forests	Afforestation
transportation	transportation	transportation	No change
transportation	suburban village area	rural residential area	(Re-)Development
transportation	water bodies	water bodies	Implementation of blue infrastructure elements
transportation	(public) green spaces and sports facilities	(Public) green spaces and sports facilities	Implementation of green infrastructure elements
transportation	industrial area (high tech)	industrial area (high-tech)	(Re-)Development
transportation	monuments and religious facilities	historic and cultural monuments and religious and spiritual facilities	(Re-)Development
transportation	infrastructure facilities	infrastructure facilities	(Re-)Development
transportation	military land, national defence and security facilities	military land, national defense and security facilities	(Re-)Development
transportation	educational and training facilities	educational and training facilities	(Re-)Development
transportation	residential area (existing)	residential area (existing)	(Re-)Development
transportation	tourism area	tourism area	(Re-)Development
transportation	agricultural land and aquaculture facilities	agricultural land and aquaculture facilities	(Re-)Development
transportation	public facilities and commercial land	public facilities and commercial land	(Re-)Development
transportation	green railway bank	green railway bank	(Re-)Development
transportation	na	transportation	No change
transportation	reserved area	transportation	No change (reserve land)
transportation	health care facilities	health care facilities	(Re-)Development
transportation	other developed land	other developed land	(Re-)Development
undeveloped land	other developed land	other developed land	Urban development/Urban expansion
undeveloped land	transportation	transportation	Urban development/Urban expansion
undeveloped land	forests	forests	Afforestation
undeveloped land	water bodies	water bodies	Implementation of blue infrastructure elements
undeveloped land	infrastructure facilities	infrastructure facilities	Urban development/Urban expansion
undeveloped land	residential area (planned)	residential area (planned)	Urban development/Urban expansion
undeveloped land	suburban village area	rural residential area	Urban development/Urban expansion
undeveloped land	(public) green spaces and sports facilities	(Public) green spaces and sports facilities	Implementation of green infrastructure elements
undeveloped land	industrial area (high tech)	industrial area (high-tech)	Urban development/Urban expansion

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LU_2019_A	LU_2030	Desired land-use	Desired change state
undeveloped land	public facilities and commercial land	public facilities and commercial land	Urban development/Urban expansion
undeveloped land	monuments and religious facilities	historic and cultural monuments and religious and spiritual facilities	Urban development/Urban expansion
undeveloped land	military land, national defence and security facilities	military land, national defense and security facilities	Urban development/Urban expansion
undeveloped land	green railway bank	green railway bank	Urban development/Urban expansion
undeveloped land	residential area (existing)	residential area (existing)	Urban development/Urban expansion
undeveloped land	educational and training facilities	educational and training facilities	Urban development/Urban expansion
undeveloped land	reserved area	undeveloped land	No change (reserve land)
undeveloped land	agricultural land and aquaculture facilities	agricultural land and aquaculture facilities	Agricultural conversion
undeveloped land	tourism area	tourism area	Urban development/Urban expansion
undeveloped land	na	undeveloped land	No change
undeveloped land	health care facilities	health care facilities	Urban development/Urban expansion
urban residential area	(public) green spaces and sports facilities	(Public) green spaces and sports facilities	Resettlement/Implementation of green infrastructure elements
urban residential area	transportation	transportation	Resettlement/(Re-)Development
urban residential area	water bodies	water bodies	Resettlement/Implementation of blue infrastructure elements
urban residential area	infrastructure facilities	infrastructure facilities	Resettlement/(Re-)Development
urban residential area	forests	forests	Resettlement/Afforestation
urban residential area	industrial area (high tech)	industrial area (high-tech)	Resettlement/(Re-)Development
urban residential area	reserved area	residential area (existing)	No change (reserve land)
urban residential area	residential area (planned)	residential area (planned)	Potential (Re-)Development
urban residential area	military land, national defence and security facilities	military land, national defense and security facilities	Resettlement/(Re-)Development
urban residential area	green railway bank	green railway bank	Resettlement/(Re-)Development
urban residential area	residential area (existing)	residential area (existing)	No change
urban residential area	suburban village area	rural residential area	No change
urban residential area	health care facilities	health care facilities	Resettlement/(Re-)Development
urban residential area	public facilities and commercial land	public facilities and commercial land	Resettlement/(Re-)Development
urban residential area	agricultural land and aquaculture facilities	agricultural land and aquaculture facilities	Resettlement/Agricultural conversion
urban residential area	monuments and religious facilities	historic and cultural monuments and religious and spiritual facilities	Resettlement/(Re-)Development
urban residential area	tourism area	tourism area	Resettlement/(Re-)Development

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LU_2019_A	LU_2030	Desired land-use	Desired change state
urban residential area	educational and training facilities	educational and training facilities	Resettlement/(Re-)Development
urban residential area	other developed land	other developed land	Resettlement/(Re-)Development
urban residential area	na	residential area (existing)	No change
utilitiy area	industrial area (high tech)	industrial area (high-tech)	(Re-)Development
utilitiy area	forests	forests	Afforestation
utilitiy area	water bodies	water bodies	Implementation of blue infrastructure elements
utilitiy area	residential area (planned)	residential area (planned)	(Re-)Development
utilitiy area	transportation	transportation	(Re-)Development
utilitiy area	other developed land	other developed land	(Re-)Development
utilitiy area	infrastructure facilities	infrastructure facilities	No change
utilitiy area	suburban village area	rural residential area	(Re-)Development
utilitiy area	(public) green spaces and sports facilities	(Public) green spaces and sports facilities	Implementation of green infrastructure elements
utilitiy area	reserved area	infrastructure facilities	No change (reserve land)
utilitiy area	military land, national defence and security facilities	military land, national defense and security facilities	(Re-)Development
utilitiy area	public facilities and commercial land	public facilities and commercial land	(Re-)Development
utilitiy area	residential area (existing)	residential area (existing)	(Re-)Development
utilitiy area	green railway bank	green railway bank	(Re-)Development
utilitiy area	agricultural land and aquaculture facilities	agricultural land and aquaculture facilities	Agricultural conversion
utilitiy area	monuments and religious facilities	historic and cultural monuments and religious and spiritual facilities	(Re-)Development
utilitiy area	educational and training facilities	educational and training facilities	(Re-)Development
utilitiy area	na	infrastructure facilities	No change
utilitiy area	tourism area	tourism area	(Re-)Development
water bodies	forests	forests	Afforestation
water bodies	industrial area (high tech)	industrial area (high-tech)	Drainage
water bodies	water bodies	water bodies	No change
water bodies	transportation	transportation	Drainage
water bodies	residential area (planned)	residential area (planned)	Drainage
water bodies	residential area (existing)	residential area (existing)	Drainage
water bodies	other developed land	other developed land	Drainage
water bodies	public facilities and commercial land	public facilities and commercial land	Drainage
water bodies	military land, national defence and security facilities	military land, national defense and security facilities	Drainage
water bodies	infrastructure facilities	infrastructure facilities	Drainage

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LU_2019_A	LU_2030	Desired land-use	Desired change state
water bodies	suburban village area	rural residential area	Drainage
water bodies	(public) green spaces and sports facilities	(Public) green spaces and sports facilities	Drainage
water bodies	educational and training facilities	educational and training facilities	Drainage
water bodies	agricultural land and aquaculture facilities	agricultural land and aquaculture facilities	Drainage
water bodies	monuments and religious facilities	historic and cultural monuments and religious and spiritual facilities	Drainage
water bodies	reserved area	water bodies	No change (reserve land)
water bodies	green railway bank	green railway bank	Drainage
water bodies	tourism area	tourism area	Drainage
water bodies	health care facilities	health care facilities	Drainage
water bodies	na	water bodies	No change

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SCENARIO RULES

Table S 2. Rules for the implementation of patch-level interventions for scenario B. The mean spatial footprint is shown as stop condition.

Intervention type	Spatial footprint	Selection Rule	Priorization Rule	Stop condition
N_PLAY	LOCAL:P	Integrated_LU = '(Public) green spaces and sports facilities' And (ChangeState <> 'No change' Or ChangeState <> 'No change (reserve land)') AND D_RESPL < 1000	descending:Shape_Area; ascending:D_RES	feature_count:15
PARK_R1	AREA:S	(Integrated_LU = 'residential area (planned)' OR Integrated_LU = 'residential area (existing)') AND ChangeState = 'Urban development/Urban expansion' and (FuncArea = 'new development area' or FuncArea = 'redevelopment area')	descending:FRAC	area_mean_percentage:10
PARK_R2	AREA:S	(Integrated_LU = 'residential area (planned)' OR Integrated_LU = 'residential area (existing)') AND ChangeState = 'Urban development/Urban expansion' and (FuncArea = 'area to be renovated' or FuncArea = 'infill development area')	descending:FRAC	area_mean_percentage:7.5
PARK_R3	AREA:S	(Integrated_LU = 'residential area (planned)' OR Integrated_LU = 'residential area (existing)') AND ChangeState = 'Urban development/Urban expansion' and (FuncArea = 'area to be conserved')	descending:FRAC	area_mean_percentage:5
PARK_P	AREA:S	((Integrated_LU = 'educational and training facilities' OR Integrated_LU = 'health care facilities' OR Integrated_LU = 'public facilities and commercial land') AND (ChangeState = 'Urban development/Urban expansion' OR ChangeState = '(Re-)Development')) and (FuncArea = 'new development area' OR FuncArea = 'area to be renovated')	descending:FRAC	area_mean_percentage:7.5
PARK_E	AREA:S	Integrated_LU = 'tourism area' and (FuncArea = 'redevelopment area' OR FuncArea = 'new development area')	descending:FRAC	area_mean_percentage:7.5
SELECT_R	LOCAL:P	(Integrated_LU = 'residential area (existing)' OR Integrated_LU = 'residential area (planned)') AND (ChangeState = 'No change' or ChangeState = 'No change (reserve land)') AND (FuncArea = 'area to be renovated' or FuncArea = 'area to be conserved')	ascending:FRAC	feature_percentage:10
SELECT_C	LOCAL:P	(Integrated_LU = 'public facilities and commercial land') AND (ChangeState = 'No change' or ChangeState = 'No change (reserve land)') and (FuncArea = 'area to be renovated' or FuncArea = 'area to be conserved')	ascending:FRAC	feature_percentage:10

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Table S 3. Rules for the implementation of street-level interventions for scenario B.

Intervention type	Spatial footprint	Selection Rule	Priorization Rule	Stop condition
HEDGES	WIDTH:S	(Integrated_LU = 'residential area (existing)' Or Integrated_LU = 'residential area (planned)') And FuncArea = 'new development area'	select:random	threshold:Shape_Length=6342
STR_TREE1	WIDTH:M	(Integrated_LU = 'residential area (existing)' Or Integrated_LU = 'residential area (planned)') And FuncArea = 'new development area'	select:random	threshold:Shape_Length=6342
STR_TREE2	WIDTH:M	(Integrated_LU = 'residential area (existing)' Or Integrated_LU = 'residential area (planned)') And FuncArea = 'redevelopment area'	select:random	threshold:Shape_Length=1147

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Table S 4. Rules for the implementation of patch-level interventions for scenario C. The mean spatial footprint is shown as stop condition.

Intervention type	Spatial footprint	Selection Rule	Priorization Rule	Stop condition
N_PLAY	LOCAL:P	Integrated_LU = '(Public) green spaces and sports facilities' And (ChangeState <> 'No change' Or ChangeState <> 'No change (reserve land)') AND D_RESPL < 1000	descending:Shape_Area ;ascending:D_RES	feature_count:30
IMP_GS	LOCAL:P	Integrated_LU = '(Public) green spaces and sports facilities' And (ChangeState = 'No change' or ChangeState = 'No change (reserve land)')	descending:FRAC;asce nding:D_RES	area_mean_percentage:10
PARK_R1	AREA:M	(Integrated_LU = 'residential area (planned)' OR Integrated_LU = 'residential area (existing)') AND ChangeState = 'Urban development/Urban expansion' and (FuncArea = 'new development area' or FuncArea = 'redevelopment area')	descending:FRAC	area_mean_percentage:15
PARK_R2	AREA:SM	(Integrated_LU = 'residential area (planned)' OR Integrated_LU = 'residential area (existing)') AND ChangeState = 'Urban development/Urban expansion' and (FuncArea = 'area to be renovated' or FuncArea = 'infill development area')	descending:FRAC	area_mean_percentage:10
PARK_R3	AREA:S	(Integrated_LU = 'residential area (planned)' OR Integrated_LU = 'residential area (existing)') AND ChangeState = 'Urban development/Urban expansion' and (FuncArea = 'area to be conserved')	descending:FRAC	area_mean_percentage:5
PARK_P	AREA:ML	((Integrated_LU = 'educational and training facilities' OR Integrated_LU = 'health care facilities' OR Integrated_LU = 'public facilities and commercial land') AND (ChangeState = 'Urban development/Urban expansion' OR ChangeState = '(Re-)Development')) and (FuncArea = 'new development area' OR FuncArea = 'area to be renovated')	descending:FRAC	area_mean_percentage:10
PARK_E	AREA:M	Integrated_LU = 'tourism area' and (FuncArea = 'redevelopment area' OR FuncArea = 'new development area')	descending:FRAC	area_mean_percentage:15
SELECT_R	LOCAL:P	(Integrated_LU = 'residential area (existing)' OR Integrated_LU = 'residential area (planned)') AND (ChangeState = 'No change' or ChangeState = 'No change (reserve land)') AND (FuncArea = 'area to be renovated' or FuncArea = 'area to be conserved')	ascending:FRAC	feature_percentage:15
SELECT_C	LOCAL:P	(Integrated_LU = 'public facilities and commercial land') AND (ChangeState = 'No change' or ChangeState = 'No change (reserve land)') and (FuncArea = 'area to be renovated' or FuncArea = 'area to be conserved')	ascending:FRAC	feature_percentage:15

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ORCHARD	AREA:M	Integrated_LU = 'agricultural land and aquaculture facilities' And (ChangeState <> 'No change' And ChangeState <> 'No change (reserve land)')	descending:Shape_Area;ascending:FRAC	area_mean_percentage:10
MEADOW	AREA:M	Integrated_LU = 'agricultural land and aquaculture facilities' And (ChangeState <> 'No change' And ChangeState <> 'No change (reserve land)')	descending:Shape_Area;ascending:FRAC	area_mean_percentage:5
PONDS	AREA:S	Integrated_LU = '(Public) green spaces and sports facilities' And (ChangeState <> 'No change' Or ChangeState <> 'No change (reserve land)') AND D_RESPL < 1000	descending:Shape_Area;ascending:D_RES;descending:FRAC	area_mean_percentage:1
CG	LOCAL:P	ChangeState = 'Resettlement/Implementation of green infrastructure elements' AND FuncArea = 'infill development area'	descending:FRAC	feature_count:5
HG	LOCAL:P	Integrated_LU = 'rural residential area' AND (ChangeState <> 'No change' AND ChangeState <> 'No change (reserve land)')	descending:Shape_Area;descending:FRAC	feature_percentage:25

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Table S 5. Rules for the implementation of street-level interventions for scenario C.

Intervention type	Spatial footprint	Selection Rule	Priorization Rule	Stop condition
HEDGES	WIDTH:S	(Integrated_LU = 'residential area (existing)' Or Integrated_LU = 'residential area (planned)') And FuncArea = 'new development area'	select:random	threshold:Shape_Length=12684
STR_TREE1	WIDTH:M	(Integrated_LU = 'residential area (existing)' Or Integrated_LU = 'residential area (planned)') And FuncArea = 'new development area'	select:random	threshold:Shape_Length=12684
STR_TREE2	WIDTH:M	(Integrated_LU = 'residential area (existing)' Or Integrated_LU = 'residential area (planned)') And FuncArea = 'redevelopment area'	select:random	threshold:Shape_Length=2294
ALLEY1	WIDTH:W	(Integrated_LU = 'residential area (existing)' Or Integrated_LU = 'residential area (planned)') And FuncArea = 'new development area'	select:random	threshold:Shape_Length=12684
ALLEY2	WIDTH:W	Integrated_LU = 'tourism area'	select:random	threshold:Shape_Length=1522
BIOSWALE	WIDTH:W	(Integrated_LU = 'industrial area (high-tech)' Or Integrated_LU = 'infrastructure facilities') And FuncArea = 'new development area'	select:random	threshold:Shape_Length=3464
GRN_AM1	WIDTH:B	(Integrated_LU = 'residential area (existing)' Or Integrated_LU = 'residential area (planned)') And FuncArea = 'redevelopment area'	select:random	threshold:Shape_Length=1147
GRN_AM2	WIDTH:B	(Integrated_LU = 'residential area (existing)' Or Integrated_LU = 'residential area (planned)') And FuncArea = 'area to be renovated'	select:random	threshold:Shape_Length=6592

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Table S 6. Rules for the implementation of patch-level interventions for scenario D. The mean spatial footprint is shown as stop condition.

Intervention type	Spatial footprint	Selection Rule	Priorization Rule	Stop condition
N_PLAY	LOCAL:P	Integrated_LU = '(Public) green spaces and sports facilities' And (ChangeState <> 'No change' Or ChangeState <> 'No change (reserve land)') AND D_RESPL < 1000	descending:Shape_Area; ascending:D_RES	feature_count:50
IMP_GS	LOCAL:P	Integrated_LU = '(Public) green spaces and sports facilities' And (ChangeState = 'No change' or ChangeState = 'No change (reserve land)')	descending:FRAC; ascending:D_RES	area_mean_percentage:15
PARK_R1	AREA:ML	(Integrated_LU = 'residential area (planned)' OR Integrated_LU = 'residential area (existing)') AND ChangeState = 'Urban development/Urban expansion' and (FuncArea = 'new development area' or FuncArea = 'redevelopment area')	descending:FRAC	area_mean_percentage:25
PARK_R2	AREA:M	(Integrated_LU = 'residential area (planned)' OR Integrated_LU = 'residential area (existing)') AND ChangeState = 'Urban development/Urban expansion' and (FuncArea = 'area to be renovated' or FuncArea = 'infill development area')	descending:FRAC	area_mean_percentage:15
PARK_R3	AREA:S	(Integrated_LU = 'residential area (planned)' OR Integrated_LU = 'residential area (existing)') AND ChangeState = 'Urban development/Urban expansion' and (FuncArea = 'area to be conserved')	descending:FRAC	area_mean_percentage:5
PARK_P	AREA:ML	((Integrated_LU = 'educational and training facilities' OR Integrated_LU = 'health care facilities' OR Integrated_LU = 'public facilities and commercial land') AND (ChangeState = 'Urban development/Urban expansion' OR ChangeState = '(Re-)Development')) and (FuncArea = 'new development area' OR FuncArea = 'area to be renovated')	descending:FRAC	area_mean_percentage:15
PARK_E	AREA:ML	Integrated_LU = 'tourism area' and (FuncArea = 'redevelopment area' OR FuncArea = 'new development area')	descending:FRAC	area_mean_percentage:20
PARK_E2	AREA:L	Integrated_LU = 'tourism area' and (FuncArea = 'area restricted from development')	descending:FRAC	area_mean_percentage:30
SELECT_R	LOCAL:P	(Integrated_LU = 'residential area (existing)' OR Integrated_LU = 'residential area (planned)') AND (ChangeState = 'No change' or ChangeState = 'No change (reserve land)') AND (FuncArea = 'area to be renovated' or FuncArea = 'area to be conserved')	ascending:FRAC	feature_percentage:15
SELECT_R2	LOCAL:P	((Integrated_LU = 'residential area (planned)' OR Integrated_LU = 'residential area (existing)') AND (ChangeState = 'Urban development/Urban expansion' OR ChangeState = '(Re-)Development')) and (FuncArea = 'new development area')	ascending:FRAC	feature_percentage:10

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SELECT_C	LOCAL:P	(Integrated_LU = 'public facilities and commercial land') AND (ChangeState = 'No change' or ChangeState = 'No change (reserve land)') and (FuncArea = 'area to be renovated' or FuncArea = 'area to be conserved')	ascending:FRAC	feature_percentage:15
SELECT_C2	LOCAL:P	((Integrated_LU = 'educational and training facilities' OR Integrated_LU = 'health care facilities' OR Integrated_LU = 'public facilities and commercial land') AND (ChangeState = 'Urban development/Urban expansion' OR ChangeState = '(Re-)Development')) and (FuncArea = 'new development area')	ascending:FRAC	feature_percentage:10
SELECT_I	LOCAL:P	(Integrated_LU = 'industrial area (high-tech)' And (ChangeState = 'Urban development/Urban expansion' Or ChangeState = '(Re-)Development')) And FuncArea = 'new development area'	ascending:FRAC	feature_percentage:10
ORCHARD	AREA:L	Integrated_LU = 'agricultural land and aquaculture facilities' And (ChangeState <> 'No change' And ChangeState <> 'No change (reserve land)' And ChangeState <> '(Re-)Development')	ascending:Shape_Area;descending:FRAC	area_mean_percentage:20
MEADOW	AREA:M	Integrated_LU = 'agricultural land and aquaculture facilities' And (ChangeState <> 'No change' And ChangeState <> 'No change (reserve land)' And ChangeState <> '(Re-)Development')	ascending:Shape_Area;descending:FRAC	area_mean_percentage:10
MEADOW_2	AREA:L	Integrated_LU = 'agricultural land and aquaculture facilities' And (ChangeState <> 'No change' And ChangeState <> 'No change (reserve land)' And ChangeState <> '(Re-)Development')	ascending:Shape_Area;descending:FRAC	area_mean_percentage:15
PONDS	AREA:SM	Integrated_LU = '(Public) green spaces and sports facilities' And (ChangeState <> 'No change' Or ChangeState <> 'No change (reserve land)') AND D_RESPL < 1000	descending:Shape_Area;ascending:D_RES;descending:FRAC	area_mean_percentage:2.5
CG	LOCAL:P	ChangeState = 'Resettlement/Implementation of green infrastructure elements' AND FuncArea = 'infill development area'	descending:FRAC	feature_count:5
CG_2	LOCAL:P	ChangeState = 'Resettlement/Implementation of green infrastructure elements' AND FuncArea = 'area to be renovated'	descending:FRAC	feature_count:5
HG	LOCAL:P	Integrated_LU = 'rural residential area' AND (ChangeState <> 'No change' AND ChangeState <> 'No change (reserve land)')	descending:Shape_Area;descending:FRAC	feature_percentage:25
AFFOR	AREA:L	(Integrated_LU = 'agricultural land and aquaculture facilities' And (ChangeState = 'No change (reserve land)' Or ChangeState = 'No change')) And FuncArea = 'reserve area for development'	descending:Shape_Area;descending:FRAC	area_mean_percentage:30

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Table S 7. Rules for the implementation of street-level interventions for scenario D.

Intervention type	Spatial footprint	Selection Rule	Priorization Rule	Stop condition
HEDGES	WIDTH:S	(Integrated_LU = 'residential area (existing)' Or Integrated_LU = 'residential area (planned)') And FuncArea = 'new development area'	select:random	threshold:Shape_Length=25368
STR_TREE1	WIDTH:M	(Integrated_LU = 'residential area (existing)' Or Integrated_LU = 'residential area (planned)') And FuncArea = 'new development area'	select:random	threshold:Shape_Length=25368
STR_TREE2	WIDTH:M	(Integrated_LU = 'residential area (existing)' Or Integrated_LU = 'residential area (planned)') And FuncArea = 'redevelopment area'	select:random	threshold:Shape_Length=4588
ALLEY1	WIDTH:W	(Integrated_LU = 'residential area (existing)' Or Integrated_LU = 'residential area (planned)') And FuncArea = 'new development area'	select:random	threshold:Shape_Length=25368
ALLEY2	WIDTH:W	Integrated_LU = 'tourism area'	select:random	threshold:Shape_Length=7610
BIOSWALE	WIDTH:W	(Integrated_LU = 'industrial area (high-tech)' Or Integrated_LU = 'infrastructure facilities') And FuncArea = 'new development area'	select:random	threshold:Shape_Length=10392
GRN_AM1	WIDTH:B	(Integrated_LU = 'residential area (existing)' Or Integrated_LU = 'residential area (planned)') And FuncArea = 'redevelopment area'	select:random	threshold:Shape_Length=3441
GRN_AM2	WIDTH:B	(Integrated_LU = 'residential area (existing)' Or Integrated_LU = 'residential area (planned)') And FuncArea = 'area to be renovated'	select:random	threshold:Shape_Length=19776
HEDGES2	WIDTH:S	(Integrated_LU = 'health care facilities' Or Integrated_LU = 'public facilities and commercial land') And FuncArea = 'area to be renovated'	select:random	threshold:Shape_Length=2756
BIOSWALE2	WIDTH:W	(Integrated_LU = 'health care facilities' Or Integrated_LU = 'public facilities and commercial land') And FuncArea = 'area to be renovated'	select:random	threshold:Shape_Length=2756

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