



Portfolio Decision Analysis for Evaluating Stakeholder Conflicts in Land Use Planning

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Published online: 10 February 2020
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Abstract

Urban planning typically involves multiple actors and stakeholders with conflicting opinions and diverging preferences. The proposed development plans and actions greatly affect the quality of life of the local community at different spatial scales and time horizons. Consequently, it is important for decision-makers to understand and analyse the conflicting needs and priorities of the local community. This paper presents a decision analytic framework for evaluating stakeholder conflicts in urban planning. First, the stakeholders state their preferences regarding the actions in terms of a set of criteria and estimate the weight of each criterion. Then, a conflict index and overall value for each action is calculated. Next, a set of Pareto efficient portfolios of actions are generated by solving an optimization problem with different levels of conflict as a resource constraint. Finally, a sensitivity analysis of the actions is performed. The framework is demonstrated using real-world survey data collected in the municipality of Upplands Väsby, Sweden.

Keywords Multiple criteria decision analysis · Portfolio decision analysis · Conflict analysis · Optimization · Urban planning

1 Introduction

Land use and urban planning involve a wide range of stakeholders with a plurality of conflicting interests, goals, and activities that have impacts at different spatial scales and time horizons (Geertman and Stillwell 2003). A core task for planners is to analyse planning conflicts and take appropriate measures to ameliorate them so as to ensure that the uses of the land are sustainable, community resources are not wasted,

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and social conflict does not cause disruption among disparate interest groups. Urban planning conflicts are complex problems that lend themselves to multiple criteria decision analysis (MCDA) (Malczewski and Rinner 2015). MCDA is a collection of formal methods that offer a systematic way of analysing decision-making problems with multiple and often conflicting criteria or objectives that various decision-makers and stakeholders judge and value differently.

Conflicts can be studied formally using methods of conflict analysis. Drawing on Beinat (1998), we can specify 4 objectives for conflict analysis: (1) determine whether there is conflict between stakeholders, (2) identify which stakeholders are in conflict, (3) measure the degree of conflict, and (4) provide information to manage the conflicts and support negotiation. Various methods, techniques, and computer software for supporting conflict analysis have been reported in the literature. For example, Feick and Hall (2001) developed a spatial decision support system that united geographic information systems (GIS) technology with multiple criteria evaluation based on weighted summation and concordance analysis (a type of outranking) to explore issues of conflict and consensus regarding the selection of developable sites for tourism accommodations. Zhang and Fung (2013) proposed a conflict resolution model in a public participation GIS prototype designed for land use planning. In their model, the conflicts are resolved both by analysing the stakeholders' preferences (criteria weights) and by enabling stakeholders to find compromises by interacting through a Web-based discussion forum. Herrera-Viedma et al. (2002) presented a consensus model consisting of two parts: (i) a consensus measure used to evaluate the agreement within a group of experts, and (ii) a proximity measure used to evaluate the distance of each individual opinion from the collective opinion of the group. An underlying stakeholder conflict is typically measured using the stakeholder preferences as an input to the model, and can, e.g. be based on criteria weights (Luè and Colorni 2015; Ngwenyama et al. 1996), rankings (Cook et al. 1997; Ray and Triantaphyllou 1998) and values (Bana e Costa 2001).

Compared to standard MCDA, actions in urban planning are typically not mutually exclusive and realized in isolation; rather, they often complement each other and can be advantageously implemented in combination. The analysis of decision problems in which the goal is to select a combination or a *portfolio* of actions, i.e. a subset from a larger set of actions, is often referred to as portfolio decision analysis (PDA). In PDA, each action has a value and an associated consumable resource. The portfolio is a combination of actions constrained by an overall resource budget and possibly other constraints (Salo et al. 2011). In general, portfolios can be generated using mathematical optimization (Liesjö et al. 2007, 2008; Vilkkumaa et al. 2014; Lourenço et al. 2012) or a benefit-to-cost ratio approach (Kirkwood 1997; Phillips and Bana e Costa 2007). PDA has been used in a variety of contexts, ranging from ecosystem management (Convertino and Valverde 2013), participatory budget elaboration (Rios and Rios Insua 2008), development of shared action agendas (Vilkkumaa et al. 2014), and battleship design (Phillips 2011).

In this paper, we present a decision analytic framework for evaluating conflicts in urban planning between two stakeholder groups. The framework ties together multi-attribute value theory with previous research consisting of methods for eliciting stakeholder preferences (Danielson et al. 2014; Danielson and Ekenberg 2016; Fasth et al. 2018) and measuring conflict related to an action within one stakeholder

group and between two stakeholder groups (Fasth et al. 2018). The framework also contains a revised method for generating conflict constrained portfolios based on Lourenço et al. (2012); Fasth et al. (2016), and a method for sensitivity analysis which draws on the concept of core index (Liesjö et al. 2007, 2008). The revised optimization approach enables the generation of both productive and counterproductive portfolios, in which the latter has an overall negative impact on the attainment of the objectives. The aim of the framework is to support decision-makers, i.e. planners and politicians, with identifying and analysing conflict-prone actions that are potentially costly and time-consuming if not detected early and managed properly. We envision it as being used at various decision points in the urban planning process, making the process more data-driven, transparent, and accountable.

We demonstrate the framework using real-world survey data collected in conjunction with a comprehensive planning project in the municipality of Upplands Väsby, Sweden. First, we conducted a Web survey with the purpose of measuring citizen preferences regarding land use, urban development, and community services in Upplands Väsby, centred around 10 focus areas. In this study, we consider the citizens or the public the primary stakeholder group, although businesses, non-governmental organizations, etc., are important stakeholders as well. Next, we applied the decision analytic framework to the survey results with the aim of testing its applicability to empirical data. For demonstrative purposes in this paper, we defined the two stakeholder groups based on spatial segregation between Swedish citizens and non-Swedish citizens. The results include a set of portfolios of actions for each stakeholder group constrained by a within-group conflict index, and a third portfolio set of actions constrained by a between-group conflict index based on the difference between the two stakeholder groups. The sensitivity analysis indicated which actions were the most conflict-prone within and between the two stakeholder groups. We demonstrated the framework to the municipal office with positive feedback. The overall results suggest that the framework has potential for supporting decision-makers in analysing stakeholder conflicts at various decision-points in the urban planning process. This article proceeds as follows. The following section presents an overview of the decision analytic framework. The subsequent section demonstrates its use on real-world data collected in Upplands Väsby. We conclude with a discussion of the results, highlighting points of interest, and suggest directions for future research.

2 Decision Analytic Framework for Conflict Evaluation

The proposed framework has its theoretical foundation in multi-attribute value theory (MAVT). In MAVT, the performance of an action is evaluated in terms of criteria (preference scoring), and a weight is attributed to each criterion. The scores and the weights are then aggregated into an overall value for each action. A common method of aggregation used in MCDA is additive aggregation, in which the weights and the preference scores are multiplied for each criterion and summed to an overall value, see Eq. (1). In this equation, $V(a)$ is the overall value of action a , w_i is the weight of a criterion i , and $v_i(a)$ is the performance score of action a in terms of criterion i (Belton and Stewart 2002).

$$V(a) = \sum_{i=1}^m w_i v_i(a) \quad (1)$$

The framework consists of three separate but interdependent parts. In the first part, the stakeholders state their preferences regarding the actions under consideration in terms of a set of criteria, and then the weight of each criterion is estimated. In the second part, a conflict index and an overall value for each action is calculated, and a set of efficient portfolios of actions constrained by a conflict index is generated. In the third part, a sensitivity analysis of the actions is performed with respect to the degree of inclusion in the set of portfolios.

This section proceeds as follows. Section 2.1 presents two elicitation methods based on cardinal ranking: one for eliciting performance scores, and one for eliciting criteria weights. Section 2.2 presents (i) two stakeholder conflict indices, (ii) an algorithm for generating conflict constrained portfolios, and (iii) a procedure for performing sensitivity analyses on the results.

2.1 Elicitation of Cardinal Preferences

The framework uses two methods for the elicitation of preferences, based on cardinal ranking. In the traditional elicitation of ordinal preferences, the criteria under consideration are ranked on an ordinal scale, from the most to the least important criterion. The ordinal ranking is then converted to surrogate weights using methods such as rank-sum and rank-reciprocal (Stillwell et al. 1981) or rank order centroid (Barron 1992; Barron and Barrett 1996b). The simplicity of ordinal ranking comes with the benefit of being less cognitively demanding, since the stakeholders do not have to state and agree on specific values (Kirkwood and Sarin 1985; Barron and Barrett 1996a). A drawback of ordinal ranking is that it disregards more precise information about preferences, even if it exists (Jia et al. 1998). However, this aspect is taken into account in the elicitation methods used in the proposed framework: cardinal ranking (CAR) (Danielson et al. 2014; Danielson and Ekenberg 2016) and the application CAR for conflict evaluations (CAR-CE) (Fasth et al. 2018). In CAR, the ordinal ranking is refined by adding cardinal information regarding the strength of preference between each pair of elements in the ranking. Below, we briefly present these two methods. First, we present CAR and how it is used for eliciting criteria weights. Then, we present CAR-CE and explain how it is used for eliciting an action's performance in terms of a criterion and its performance relative to a *do nothing* action.

2.1.1 Cardinal Ranking of Weights

The CAR method (Danielson et al. 2014; Danielson and Ekenberg 2016) extends an ordinal ranking of criteria with information regarding the strengths of the preferences between two criteria. The strength of a preference is denoted by $>_i$ where i is the number of steps separating the pair of criteria. These steps can be expressed using semantic labels such as

- \sim_0 equally important, zero steps;
- \succ_1 slightly more important, one step;
- \succ_2 more important, two steps;
- \succ_3 much more important, three steps.

For example, let $G = \{G_1, \dots, G_4\}$ be a set of 4 criteria. A cardinal ranking of the criteria could be $G_1 \succ_1 G_2 \succ_3 G_3 \succ_2 G_4$, i.e. criterion G_1 is slightly more important than criterion G_2 , which is much more important than criterion G_3 , which in turn is more important than criterion G_4 . The preference statements are then transformed into weights by the following three-step procedure.

1. On the underlying importance scale an ordinal number is assigned to each position, where the first position is the most important.
2. The scale has Q positions, and the position of criterion i is denoted by $p(i) \in 1, \dots, Q$. For two adjacent criteria, c_i and c_j , the strength of the preference between them is $s_i = |p(i) - p(j)|$ for $c_i \succ_{s_i} c_j$.
3. Finally, the weights are calculated by Eq. (2), see (Danielson et al. 2014; Danielson and Ekenberg 2016) for further details.

$$w_i^{\text{CAR}} = \frac{1/p(i) + \frac{Q+1-p(i)}{Q}}{\sum_{j=1}^N (1/p(j) + \frac{Q+1-p(j)}{Q})} \quad (2)$$

Note that the elicitation of the weights should follow a swing-like procedure, as described in Von Winterfeldt and Edwards (1986) or Danielson and Ekenberg (2019).

2.1.2 Cardinal Ranking for Conflict Evaluations

The method of CAR for conflict evaluations (Fasth et al. 2018) is an application of CAR for values (Danielson et al. 2014; Danielson and Ekenberg 2016), in which a *do nothing* action A_α is added to the ranking. The purpose of the *do nothing* action is to enable making preference statements regarding an action's negative or positive performance in comparison to this action. CAR-CE uses the same notation and semantic labels for values as the CAR described above.

For example, let $A = \{A_1, \dots, A_4\}$ be a set of 4 actions evaluated in terms of criterion G_1 . Suppose that a stakeholder, using cardinal ranking, states that $A_1 \succ_2 A_2 \succ_2 A_3 \succ_3 A_4$. Then the stakeholder inserts the *do nothing* action A_α between A_2 and A_3 , resulting in the CAR-CE ranking $A_1 \succ_2 A_2 \succ_1 A_\alpha \succ_1 A_3 \succ_3 A_4$, i.e. A_1 is better than A_2 , which is better than A_3 , which is much better than A_4 . A_1 and A_2 are positive relative to A_α , and A_3 and A_4 are negative relative to A_α . CAR-CE extends the CAR method of eliciting scores with a step where the *do nothing* action is included in the ranking. The preference statements are transformed into scores using the following procedure:

1. On the underlying importance scale an ordinal number is assigned to each position where the first position is the most important.
2. The scale has Q positions, and the position of criterion i is denoted by $p(i) \in 1, \dots, Q$. For two adjacent criteria c_i and c_j , the strength of preference between them is $s_i = |p(i) - p(j)|$, whenever $c_i >_{s_i} c_j$.
3. Insert the *do nothing* alternative A_a into the ranking.
4. Normalize the ranking to a proportional $[0, 1]$ value scale using Eq. (3).

$$v_i^{\text{CAR}} = \frac{Q - p(i)}{Q - 1} \quad (3)$$

Note that Eq. (3) transforms the values to an underlying interval scale where the worst action is assigned the value of 0 and the best action the value of 1. However, de Almeida et al. (2014) argue that this transformation can lead to scaling issues in multi-attribute portfolio problems. Instead, they suggest using Eq. (4), which results in a ratio scale type transformation of the values, where the worst action may have a value less than 0 and the best action a value greater than 1.

$$v_i = \frac{(Q + 1) - p(i)}{Q}. \quad (4)$$

We therefore replace Eq. (3) by Eq. (4) in the last step of the CAR-CE procedure described above.

2.2 Analysis and Evaluation

We use three methods for analysing the stakeholder preferences. In this section, we briefly present (i) two conflict indices for measuring the conflict within a stakeholder group and between two stakeholder groups, (ii) a portfolio optimization approach that uses the conflict indices to analyse how a change in conflict affects portfolio composition, and (iii) a sensitivity analysis based on the concept of *core index*.

2.2.1 Conflict Indices

Several methods for investigating conflict between stakeholder preferences have been suggested in the literature. For example, Ngwenyama et al. (1996) and Luè and Colorni (2015) suggest analysing the weights of the criteria, Cook et al. (1997) and Ray and Triantaphyllou (1998) suggest investigating the rankings, whereas Bana e Costa (2001) and Fasth et al. (2018) suggest analysing the action's performance scores. The two latter approaches are similar in how the underlying conflicting stakeholder sets are defined. However, in Fasth et al. (2018) there are also defined two conflict indices: (i) a within-group conflict index, which measures the conflict within a single stakeholder group, and (ii) a between-group conflict index, which measures the conflict between two groups of stakeholders. Furthermore, the indices use a sum of squares approach similar to Ward's clustering method (Rencher 2003, p. 466) and use the *do nothing* action A_a to divide the stakeholders into two opposing stakeholder subsets.

Within-group conflict index This is a measure of the conflict within a stakeholder group. Let $A = \{A_1, A_2, \dots, A_n\}$ be a set of actions, $G = \{G_1, G_2, \dots, G_m\}$ a set of criteria, $S = \{S_1, S_2, \dots, S_o\}$ a set of stakeholders, and let the performance score of action A_j in terms of criterion G_i for stakeholder S_k be denoted by v_{ij}^k . For each criterion G_i and action A_j , the set of stakeholders S is divided into two sub-sets: the stakeholders who state that $v_{ij}^k < v_{i\alpha}^k$ are assigned to the con-group S_{ij}^- , and stakeholders who state that $v_{ij}^k \geq v_{i\alpha}^k$ are assigned to the pro-group S_{ij}^+ , see Eqs. (5) and (6).

$$S_{ij}^- = \{S_k \in S : v_{ij}^k < v_{i\alpha}^k\}_{k=1}^n \tag{5}$$

$$S_{ij}^+ = \{S_k \in S : v_{ij}^k \geq v_{i\alpha}^k\}_{k=1}^n \tag{6}$$

The within-group conflict index is based on the value difference d_{ij}^k between the part-worth value q_{ij}^k of an action A_j and the part-worth value $q_{i\alpha}^k$ of action A_α . The part-worth value q_{ij}^k of criterion G_i for action A_j for stakeholder S_k is given by $q_{ij}^k = w_i^k v_{ij}^k$, where w_i^k is the weight (scaling constant) of criterion G_i under the condition that $0 \leq w_i^k \leq 1$ and $\sum_i^m w_i^k = 1$. The value difference in part-worth values is then

$$d_{ij}^k = |q_{i\alpha}^k - q_{ij}^k|. \tag{7}$$

The within-group conflict index uses a sum of squares approach calculated for the con-group (9), the pro-group (10), and a third group which includes the members of both groups (11). In the equations, we use a stakeholder scaling constant λ_k (where $\lambda_k \geq 0$ and $\sum_k^o \lambda_k = 1$) to quantify the power of social influence, and for each stakeholder we calculate the sum of the squared differences between the value difference d_{ij}^k and the group's mean distance. The conflict index of a set of stakeholders S for criterion G_i and action A_j is then given by Equation (8), where β is a factor used to normalize the result to a [0,1] scale.

$$d_{ij}^S = \sqrt{\beta(T_{ij}^S - (C_{ij}^S + P_{ij}^S))} \tag{8}$$

where

$$\beta = \frac{1}{\sum_{S_k \in S} \lambda_k^2}$$

$$C_{ij}^S = \sum_{S_k \in S_{ij}^-} \lambda_k^2 \left(d_{ij}^k - \frac{\sum_{S_k \in S_{ij}^-} d_{ij}^k}{|S_{ij}^-|} \right)^2 \tag{9}$$

$$P_{ij}^S = \sum_{S_k \in S_{ij}^+} \lambda_k^2 \left(d_{ij}^k - \frac{\sum_{S_k \in S_{ij}^+} d_{ij}^k}{|S_{ij}^+|} \right)^2 \tag{10}$$

$$T_{ij}^S = \sum_{S_k \in S_{ij}} \lambda_k^2 \left(d_{ij}^k - \frac{\sum_{S_k \in S_{ij}} d_{ij}^k}{|S_{ij}|} \right)^2 \tag{11}$$

The conflict index d_{ij}^S in Eq. (8) is defined within the range [0, 1]. In Eq. (7), a maximum value of 1 is assigned when all members of the con-group state that $q_{i\alpha} = 1$ and $q_{ij} = 0$, all members of the pro-group state that $q_{i\alpha} = 0$ and $q_{ij} = 1$, and when the power balance of the two groups are equal, i.e. when the sum of the con-group’s and pro-group’s stakeholder scaling constants are equal, such that $\sum_{S_k \in S_{ij}^-} \lambda_k - \sum_{S_l \in S_{ij}^+} \lambda_l = 0$. Furthermore, in Eq. (7), a minimum of 0 is assigned when either the con-group or the pro-group is empty. The power balance between the two groups affects the result since an evenly distributed power balance produces a greater conflict (as seen above), and since stakeholders with less power and social influence are more likely to accept (what they consider) counterproductive actions (Torrance 1957). Expressed differently, if all stakeholders have the same scaling constant, then the number of stakeholders in each group affects the magnitude of the conflict.

Between-group conflict index This is a measure of the conflict between two stakeholder groups. Let D and E be two subsets of S , e.g. two stakeholder groups from two separate residential areas. As in the within-group conflict index, for each criterion G_i and action A_j , we partition each stakeholder group, D and E , into two subsets, such that stakeholders who stated that $v_{ij}^k < v_{i\alpha}^k$ are assigned to the con-groups S_{ij}^{D-} and S_{ij}^{E-} , and stakeholders who stated that $v_{ij}^k \geq v_{i\alpha}^k$ are assigned to the pro-groups S_{ij}^{D+} and S_{ij}^{E+} , see (12).

$$\begin{aligned} S_{ij}^{D-} &= \{S_k \in D : q_{ij}^k < q_{i\alpha}^k\}_{j=1}^n \\ S_{ij}^{D+} &= \{S_k \in D : q_{ij}^k \geq q_{i\alpha}^k\}_{j=1}^n \\ S_{ij}^{E-} &= \{S_k \in E : q_{ij}^k < q_{i\alpha}^k\}_{j=1}^n \\ S_{ij}^{E+} &= \{S_k \in E : q_{ij}^k \geq q_{i\alpha}^k\}_{j=1}^n \end{aligned} \tag{12}$$

As in the within-group conflict index, the between-group conflict index uses a sum of squares approach, here calculated for i) the con-groups C_{ij}^D, C_{ij}^E , and the combined con-group $C_{ij}^{D,E}$ (9), ii) the pro-groups P_{ij}^D, P_{ij}^E and the combined pro-group $P_{ij}^{D,E}$ (10), and iii) T_{ij}^D for stakeholder group D , T_{ij}^E for stakeholder group E , and $T_{ij}^{D,E}$ for the combined D and E group (11). The between-group conflict index $d_{ij}^{D,E}$ of stakeholder sets D and E regarding criterion G_i and alternative A_j is given by

$$d_{ij}^{D,E} = \sqrt{\frac{\beta \left| \left(T_{ij}^{D,E} - (T_{ij}^D + T_{ij}^E) \right) \right|}{\left((C_{ij}^{D,E} - (C_{ij}^D + C_{ij}^E)) + (P_{ij}^{D,E} - (P_{ij}^D + P_{ij}^E)) \right)}} \tag{13}$$

where $\beta = \frac{1}{\sum_{S_k \in S} \lambda_k^2}$.

2.2.2 Conflict Constrained Portfolio Optimization

The main idea of conflict constrained portfolios is to investigate how a change in overall conflict affects the composition of a portfolio. It is centred around solving a 0–1 knapsack optimization problem (Martello and Toth 1990) where the objective function maximizes the overall value of the portfolio using conflict as a resource constraint. The name is derived from the problem faced by a person who is interested in filling a knapsack (rucksack) of fixed size with items, each with a set of two attributes: a value that quantifies the level of desirability or importance of the item, and a volume. Since the knapsack is of fixed size, the problem is to figure out how to fill it with the optimal combination of items that yields the highest total value. The knapsack problem is formally described in Eq. (14), where x_j denotes a binary decision variable set to 1 if the item is included and 0 if it is not.

$$\begin{aligned} & \text{maximize } \sum_{j=1}^n W(A_j)x_j \\ & \text{subject to } \sum_{j=1}^n d_j x_j \leq B \\ & x \in \{0, 1\}, j = 1, \dots, n \end{aligned} \quad (14)$$

The stakeholders' aggregated value $W(A_j)$ of an action A_j is given by

$$W(A_j) = \sum_k \lambda_k \sum_i (q_{ij}^k - q_{i\alpha}^k). \quad (15)$$

An action's overall conflict index d_j , i.e. the sum of all criterion-specific conflict indices, is given by

$$d_j = \sum_i d_{ij}^S. \quad (16)$$

The resource constraint B is the sum of all actions' overall conflict indices, and is defined by

$$B = \sum_{j=1}^n d_j \quad (17)$$

Note that $W(A_j)$ becomes negative when the stakeholder group as a whole holds the opinion that action A_j is worse than the *do nothing* action. This means in practice that the action is deemed counterproductive.

The front of efficient portfolios is generated by following the procedure described in Fasth et al. (2016) and Lourenço et al. (2012), in which the problem is solved multiple times with different values set for the resource constraint B . The problem is first solved by setting B to the sum of all actions' conflict indices, then in the subsequent executions, B is reduced by a small number τ , e.g. $\tau = B/|S|^2$. A difference between our procedure and the aforementioned is that in addition to maximizing the objective

function, we also minimize it to find possible negative or counterproductive portfolios. The concept of counterproductive portfolios gives an additional insight into the decision problem, as it highlights actions that are especially bad and should be discarded or further investigated. The procedure is illustrated in Algorithm 1.

Algorithm 1: Conflict Constrained Portfolio Optimization

Input : A set of actions including the stakeholders' aggregated values (Equation 15), and the aggregated conflict indices (Equation 16).

Output: A set of efficient portfolios.

```

1 positive_portfolios_exist ← TRUE
2 negative_portfolios_exist ← TRUE
3  $P \leftarrow$  new set of portfolios
4  $B \leftarrow$  the sum of all actions' overall conflict indices (Equation 17)
  /* Generate the first positive portfolio */
5  $p \leftarrow$  the positive portfolio generated by maximizing the objective function when
  solving (Equation 14) and using  $B$  as a constraint.
6 if  $p$  has actions then
7   | insert  $p$  into  $P$ 
8 else
9   | positive_portfolios_exist ← FALSE
10 end
  /* Generate the following positive portfolios */
11 while positive_portfolios_exist do
12   |  $B \leftarrow$  the sum of the overall conflict indices (Equation 17) of the actions included
  | in the previous portfolio  $p$  subtracted by  $\tau$ 
13   |  $p \leftarrow$  the positive portfolio generated by maximizing the objective function when
  | solving (Equation 14) and using  $B$  as a constraint.
14   | if  $p$  has actions then
15     | insert  $p$  into  $P$ 
16   | else
17     | positive_portfolios_exist ← FALSE
18   | end
19 end
20  $B \leftarrow$  the sum of all actions' overall conflict indices (Equation 17)
  /* Generate the first negative portfolio */
21  $p \leftarrow$  the negative portfolio generated by minimizing the objective function when
  solving (Equation 14) and using  $B$  as a constraint.
22 if  $p$  has actions then
23   | insert  $p$  into  $P$ 
24 else
25   | negative_portfolios_exist ← FALSE
26 end
  /* Generate the following negative portfolios */
27 while negative_portfolios_exist do
28   |  $B \leftarrow$  the sum of the overall conflict indices (Equation 17) of the actions included
  | in the previous portfolio  $p$  subtracted by  $\tau$ 
29   |  $p \leftarrow$  the negative portfolio generated by minimizing the objective function when
  | solving (Equation 14) and using  $B$  as a constraint.
30   | if  $p$  has actions then
31     | insert  $p$  into  $P$ 
32   | else
33     | negative_portfolios_exist ← FALSE
34   | end
35 end
36 return  $P$ 

```

2.2.3 Sensitivity Analysis

The aim of a sensitivity analysis is to investigate how a change in some variable affects the stability of a solution. Kleinmuntz (2007) describes two methods of sensitivity analysis. In the first, the actions under consideration are forced to be either excluded or included in the portfolio. In the second, the budget constraint is varied to analyse how the portfolio composition changes. As described in the previous section, we use the latter method by solving the optimization problem with different levels of the budget constraint. A simple method for measuring an action's degree of inclusion in a set of optimal portfolios is to use the concept of the core index (Liesjö et al. 2007, 2008). A core index is defined by

$$CI(A_j) = \frac{|\{p \in P | A_j \in p\}|}{|P|} \quad (18)$$

where the denominator is equal to the number of portfolios p which are included in the set of non-dominated portfolios P , given that A_j is included in p , and the numerator is equal to the cardinality of the set of non-dominated portfolios P . The core index $CI(A_j)$ of an action A_j lies within $0 \leq CI(A_j) \leq 1$. Three semantic labels are used to distinguish between the core index of different actions. First, an action A_j included in all portfolios $CI(A_j) = 1$ is called a *core* action. Second, an action A_j included in no portfolios $CI(A_j) = 0$ is called an *exterior* action. Third, an action A_j included in more than one but not all portfolios $0 < CI(A_j) < 1$ is called a *borderline* action. In general, a decision-maker is advised to select core actions, discard exterior actions, and to focus on borderline actions. In the calculation of the core index we separate negative from positive portfolios, which results in negative and positive core indices.

To further distinguish between the borderline actions, we introduce the concept of borderline action *subtypes*. First, we denote by a the lower bound and by b the upper bound of the core index interval. Then, we define n points $\{x_1, x_2, x_3, \dots, x_n\}$ along the interval to divide it into $n + 1$ equal sized bins $[a, x_1], [x_2, x_3], \dots, [x_n, b]$. Next, to identify actions whose conflict index values between two stakeholder groups differ by more than a predefined threshold value, we introduce the concept of *core index slopes*. Let $CI(A_j^D)$ and $CI(A_j^E)$ be the core indices of action A_j for group D and E respectively. A core index slope exists if $|CI(A_j^D) - CI(A_j^E)| > \gamma$, where γ is a predefined threshold value in the range $(0, 1)$. For example, in the next section, where we demonstrate the framework, we divide the core index into three equal sized bins: a lower bin with the range $(0, 0.33]$, a middle bin with the range $(0.33, 0.66]$, and an upper bin with the range $(0.66, 1)$. We use a threshold value γ equal to one-half the borderline subtype range, i.e. $\gamma = 1/2 \cdot 1/3 = 1/6$. The exact number of bins is obviously a judgment call that depends on the context and purpose of the sensitivity analysis. A slope graph (Tufté 2001) can effectively support the analysis and communicate the results to stakeholders, see Fig. 3 in the next section.

3 Empirical Study: Conflict Analysis in Upplands Väsby

3.1 Background

The municipality of Upplands Väsby is a suburb municipality of Stockholm (the capital of Sweden). In 2012, the municipal office embarked on a process of establishing a new comprehensive plan towards 2040. Apart from providing thousands of new homes, a central theme of the new plan is to transform the image of central Upplands Väsby from a uniform and mono-functional dormitory suburb to a modern green town that offers a variety of housing choices, a dynamic businesses climate, vibrant gathering places, and recreational opportunities. This means increasing the construction of new homes while keeping residential proximity to green spaces, among many other trade-offs. Improving school performances and feelings of safety and security have also been matters of great concern. In developing the new comprehensive plan, community involvement was seen as central to its success. The municipal office therefore conducted a number of extensive community dialogues to reflect the values, collective vision, and development goals of the community. Also seen as important was the involvement of academics: people who could provide scientific input and act as a sounding board for ideas. In 2014, we therefore established a collaboration with the municipal office with the goal of developing new methods for analysing stakeholder conflicts in urban planning.

3.2 The Elicitation of Stakeholder Preferences

Together with the municipal office, we developed a Web survey form using the open source content management system Drupal¹ and the Drupal Webform module² to collect the preferences of citizens regarding land use, urban development, and community services in Upplands Väsby. A survey invitation letter was sent by paper mail to 10,000 persons based on a random sample of the municipal population registry consisting of 31,408 individuals aged 18 years or older. The survey was open between January and March 2015. In all, 1,032 respondents participated in the survey, which constitutes a response rate of 10.3 percent. Participation in the survey was voluntary and anonymous.

The form was composed of 20 items divided into 4 parts. The first part consisted of 10 items that concerned 10 focus areas, each associated with 5 actions, see Table A in the “Appendix”. For each focus area, the respondent was asked to estimate their preference regarding 5 actions using an interactive horizontal slider which implemented the CAR-CE method. For example, by dragging the slider handles, the respondent could express that “offer more residential building types” (action a) is much better than “offer more diverse apartment sizes” (action b). The CAR-CE slider had 5 handles, one for each action, that could be moved with the

¹ <https://www.drupal.org>.

² <https://www.drupal.org/project/webform>.

mouse along a 15-point Likert-type ranking scale consisting of a midpoint indicated by a tick mark and bipolar endpoints: 7 steps on the left side and 7 steps on the right side. When a handle is dragged away from the midpoint, a colour gradient—red to the left and green to the right—illustrates the strength of the preference for that particular action. The relative strength of preference for each action was indicated by a semantic expression below the slider axis.

The second part of the form consisted of one item, for which the respondent was asked to estimate the relative importance of each focus area using a second type of interactive slider that implemented the CAR method of eliciting preferences. For example, the respondent could state that “diversity in housing supply” is much more important than “communications”, which in turn is more important than “education”. The slider had 10 handles, each representing one of the 10 focus areas. When the respondent dragged a handle to the right, a blue colour gradient ranging from a weak to a strong hue illustrated its importance. Both sliders, the one that implemented CAR-CE and the one that implemented CAR, were based on the jQuery UI slider widget.³ The relative importance was elicited using a simplified method to reduce the cognitive burden on the part of the respondent, although a swing-like procedure would have been theoretically sounder. Furthermore, the suggested actions were also broad and tentative in nature, which made it difficult to estimate their consequences.

The third part consisted of three items not considered in the decision analytic framework, so it is not discussed further. In the fourth and last part of the form, we asked the respondent about their demographic background, including the geographical subarea in which they lived, highest level of educational attainment, occupation, length of residency, age, and gender.

3.3 Results

For demonstration purposes, we analyse the patterns of residential segregation. Sweden has experienced a large amount of immigration over the last decades, and segregation between natives and immigrants has become a permanent feature of Sweden’s largest cities, including Stockholm. Segregation is important to analyse because it is a cross-cutting factor that affects labour market opportunities, educational attainment, and health outcomes, just to give a few examples. Based on Swedish register data, we created two stakeholder groups by selecting geographical subareas in the municipality of Upplands Väsby with the highest (roughly 20 percent) and lowest (roughly 5 percent) proportion of non-Swedish citizens, denoted by group D and group E, respectively. We denote their union by group F. The subareas with a high proportion of non-Swedish citizens (group D) are characterized by public housing located in the city centre and near the highway and the railway, whereas the subareas with the lowest proportion of non-Swedish citizens (group E) are characterized by private housing located further away from the city centre and the heavy traffic.

³ <https://jqueryui.com/slider/>.

For convenience, we repeat the key steps of the framework below. First, a within-group conflict index and an overall value is calculated for each action and each group, using Eqs. (8) and (15), respectively. Then, a between-group conflict index (Eq. 13) is calculated between group D and group E for each action, and an overall value for group F (Eq. 15) for each action. Next, we apply Algorithm 1 to group D, group E, and group F to generate the front of efficient portfolios. Note that the resource constraint B (Eq. 17) used when solving the knapsack problem (Eq. 14) for group D and group E is based on the within-group conflict index (Eq. 8) but that the between-group conflict index (Eq. 13) is used for group F.

Figure 1 displays the Pareto efficient portfolios for all 10 focus areas for group D and group E. Fig. 2 displays the corresponding plots for group F. The focus area which includes the portfolio with the highest aggregated within-group conflict index is 9 “safety” for group D (conflict = 0.081) and 8 “school” for group E (conflict = 0.091). For group F, the focus area which includes the portfolio with the highest aggregated between-group conflict index is 8 “school” (conflict = 0.014). The focus area which includes the portfolio with the lowest aggregated within-group conflict index is 10 “ecological sustainability” for group D (conflict = 0.0057) and 3 “invest in public spaces” for group E (conflict = 0.004). The focus area which includes the portfolio with the lowest aggregated between-group conflict index for group F is 1 “parks and green spaces” (conflict = 0.0005). Note that both focus area 2 “diversity in housing supply” and focus area 3 “invest in public spaces” have negative portfolios, i.e. portfolios consisting of counterproductive actions. Actions such as these should either be further analysed or discarded.

3.3.1 Sensitivity Analysis

The slope graph in Fig. 3 displays the core index values of group D and group E for all 50 actions. Core index slopes, actions with a big core index difference between the two groups, are indicated with a red downward facing triangle. Actions with a small core index difference and a high core index value in both groups are indicated with a green upward facing triangle. The remaining actions are indicated with a light grey circle. Let us first focus on the red downward facing triangles, the core index slopes. As can be seen, action 8d, “more modern IT in education”, has the steepest slope, indicating the largest disagreement between the two groups. In group D, action 8d is found in the lower bin $[0, 33]$ with a core index of 0.14, whereas in group E it is found in the upper bin $[0.66, 1]$ with a core index of 0.77. This result suggests action 8d is a good candidate for further investigation, but not an action suitable for implementation. Other high conflict actions include 3e “build underground car parks in residential buildings” (core index difference 0.61), 10a “reduce energy consumption” (0.51), 4e “improve public transport to and from Stockholm” (0.48), and 6e “Improve the education in high schools” (0.34).

Turning to the actions that are indicated with a green upward triangle, we find good candidates for implementation:

- 10e Reduce toxins and hazardous chemicals in the environment.
- 9c Improve the lighting in the city centre.
- 8c More professional development for school teachers.
- 8b Raise the quality of teaching.
- 6d Improve the education in primary schools.
- 9a Increase safety around the train station.

The sensitivity analysis suggests several important insights and areas for further investigation. First, the city council should focus on improving the public education system: strengthening teachers' professional development, raising the quality of teaching, and improving primary school education. Second, the city council should improve the safety around the train station and in the city centre, for example by installing better street lighting since many people feel uneasy in inadequately lit outdoor urban environments. Action 10e, "Reduce toxins and hazardous chemicals in the environment" has, by far, the smallest core index difference among all considered actions. The municipal office can confidently implement this action in terms of stakeholder disagreement (as it is negligible), but it should probably prioritize other more pressing issues discussed above.

4 Conclusions

In this paper, we have presented a decision analytic framework for evaluating stakeholder conflicts in land use and urban planning. The framework brings together several established theoretical concepts with previous research consisting of methods for (i) eliciting stakeholder preferences (Danielson et al. 2014; Danielson and Ekenberg 2016; Fasth et al. 2018), (ii) measuring conflict related to an action within one stakeholder group and between two stakeholder groups (Fasth et al. 2018). We also presented (iii) a revised optimization method for generating conflict constrained portfolios based on Fasth et al. (2016) and Lourenço et al. (2012), and (iv) a sensitivity analysis which draws on the concept of the core index (Liesjö et al. 2007, 2008). The revised optimization enables generation of both positive and negative portfolios, in which the negative portfolios will have an overall negative impact on the attainment of the objectives.

In order to analyse the stakeholder conflicts, we used a conflict index as a resource constraint in the knapsack optimization problem. It was solved multiple times with different levels of the conflict index, resulting in a set of efficient portfolios. The portfolios can then be further analysed to investigate how a change in overall conflict affects the composition of a portfolio, and thereby analyse the sensitivity of the individual actions. The sensitivity analysis is based on the concept of a core index, which measures an action's degree of inclusion in a set of portfolios, defined as core, borderline, and exterior actions. To further distinguish between the borderline actions, we introduced the concept of sub-types of borderline actions, which divide the core index into n equally sized bins, and the concept of core index slopes to highlight actions of potential interest. Furthermore, our framework helps

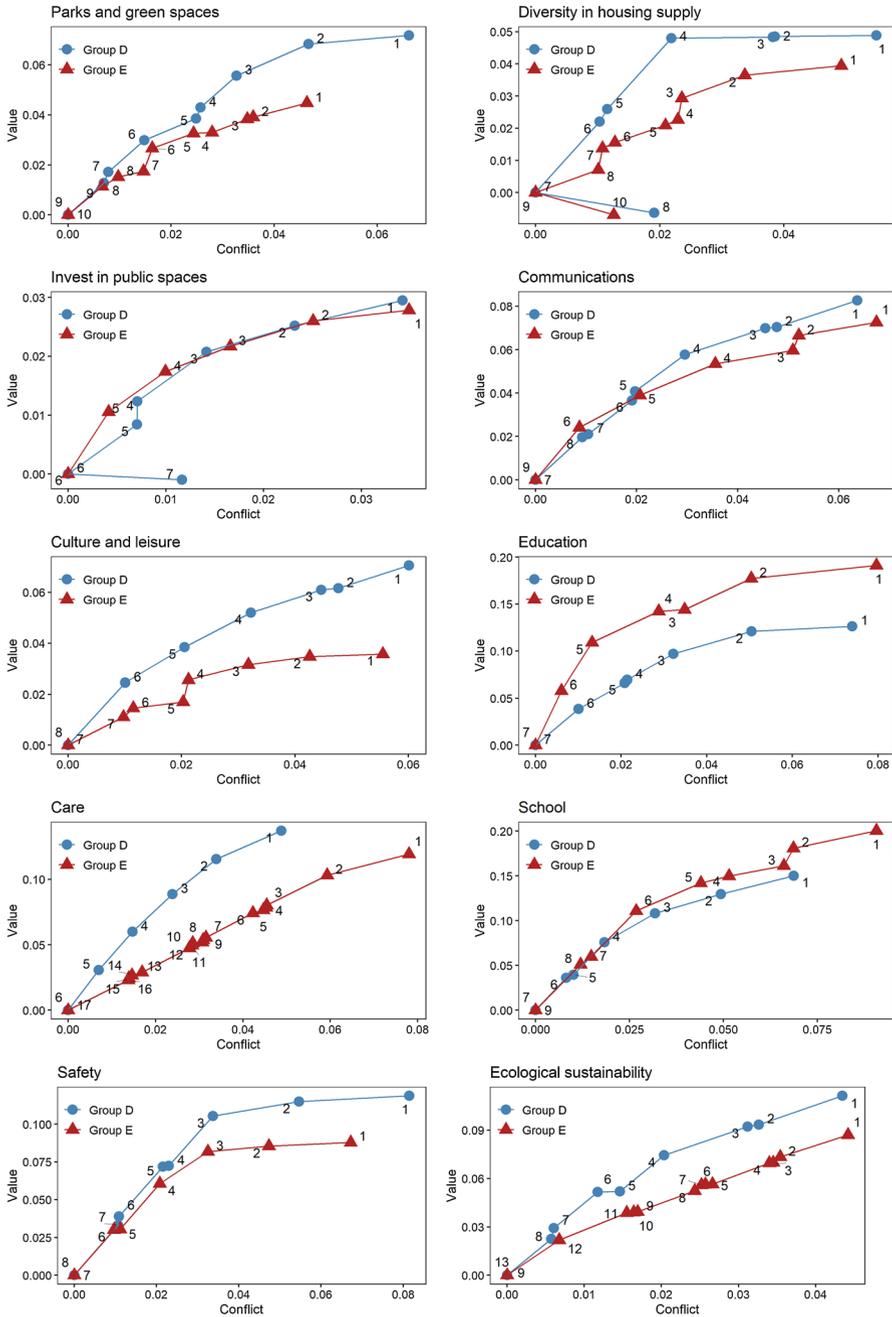


Fig. 1 Plots of Pareto efficient portfolios of group D and group E for all 10 focus areas

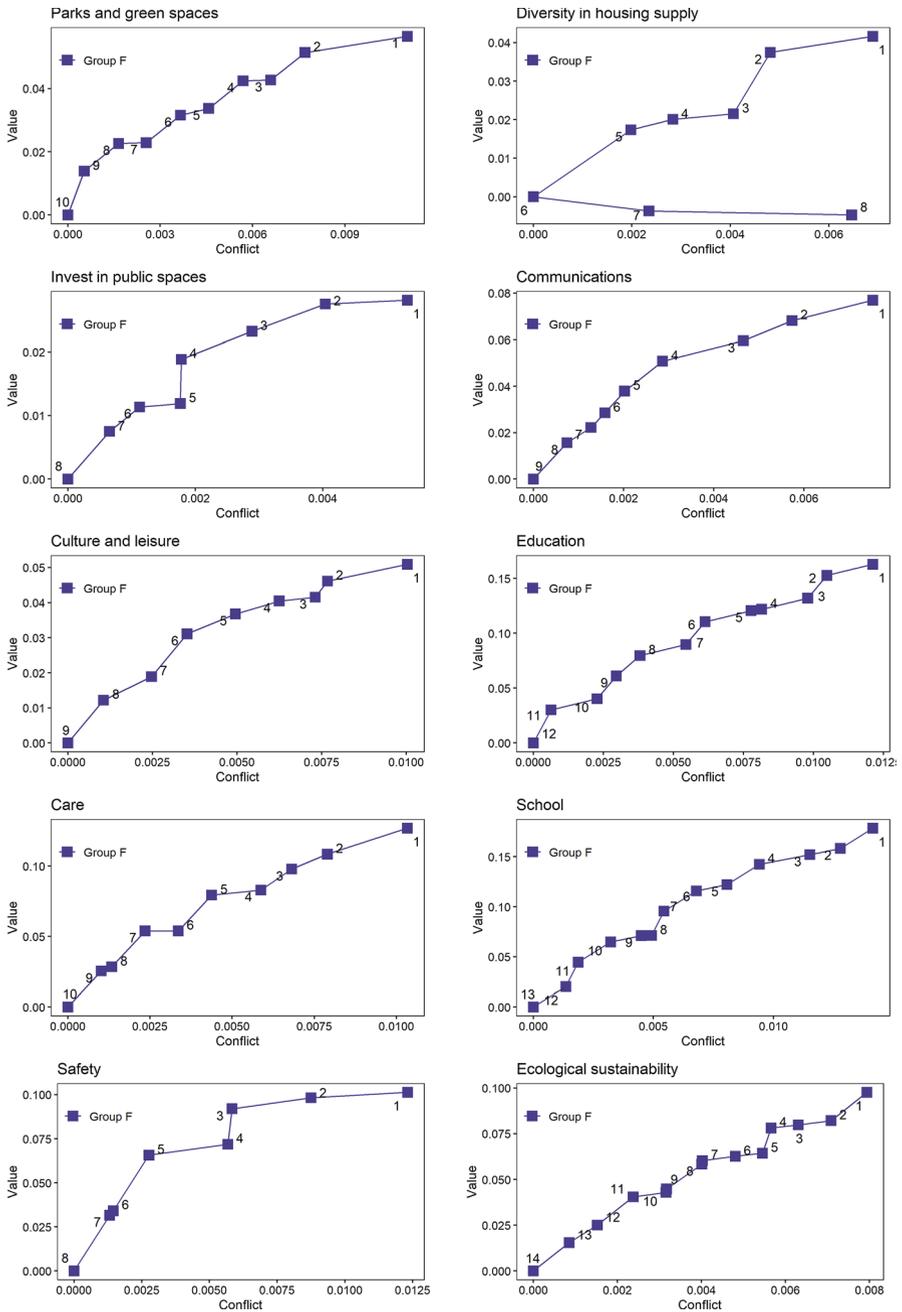


Fig. 2 Plots of Pareto efficient portfolios for group F for all 10 focus areas

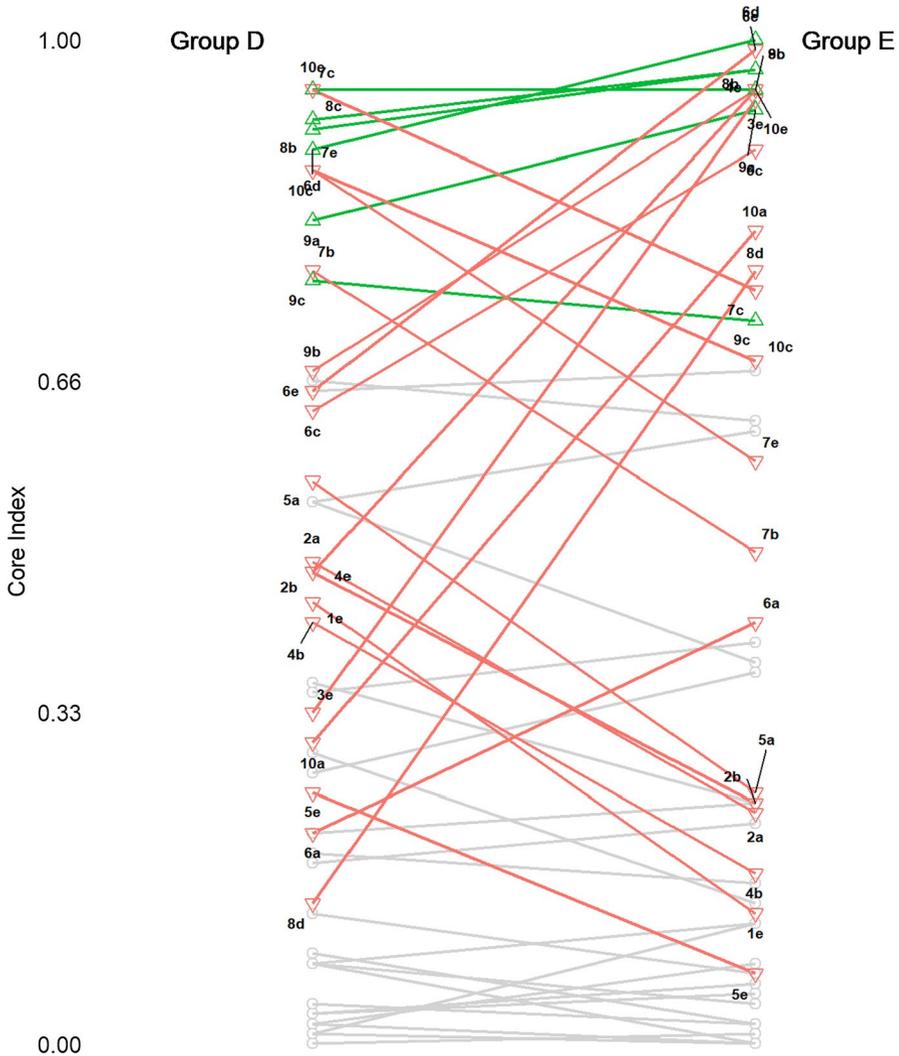


Fig. 3 Slope graph for comparing the core index values of group D and group E. Core index slopes, actions with a high core index difference between the two groups, are highlighted red. Actions with a low core index difference and high core index in both groups are highlighted green. Remaining actions are grey

in distinguishing productive actions from counterproductive actions with negative values. These actions can either be further investigated or discarded.

The use of two different conflict indices (within-group conflict index and between-group conflict index) as resource constraints applied to the same optimization problem provides valuable complementary views of the actions. For example, in the analysis of group D (or group E), which uses the within-group conflict index, the core index indicates which actions produce the greatest value for the group under

the constraint that there should be no more than a low level of conflict within the group. In the analysis using the between-group conflict index, the core index indicates which actions produce the greatest value for both groups, under the constraint that there should be little conflict between them.

The framework was demonstrated to the Upplands Väsby municipal office using real-world data with positive feedback. The overall outcome suggests that the framework is useful for the intended audience and we believe that the work is promising enough to warrant an in-depth case study. Investigation of alternative algorithms for generating portfolios are also of interest for future research.

Acknowledgements Open access funding provided by Stockholm University. We thank Kristina Sandberg, Johannes Wikman, Linnea Askling, Elisabeth Dahlqvist, Petra Lundqvist, Linda Corsvall, Helena Nyman, Marcus Ershammar, Sebastian Sjögren, Peter Mwaka, Gunnar Högberg, and Nils Munthe of the municipality of Upplands Väsby for their collaboration and provision of data. We thank Joakim Malmdin, Stefan Svanström, Stefan Palmelius, Andreas Persson, Birgitta Edberg, Teresia Dunér, Anna Nilheimer, Harriet Löfqvist, Elisabeth Blom, and Gunilla Sandberg at Statistics Sweden for helpful discussions. We also thank Erik Thuning for technical assistance with Drupal and Jonas Collin for producing the slider instructional video.

Funding Partially funded by Formas, the Swedish Research Council for Sustainable Development, Grant Number: 2011-3313-20412-31.

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Appendix: Focus Areas and Associated Actions

Parks and green spaces

- 1a. Preserve existing large green spaces
- 1b. Build parks in existing urban districts
- 1c. Build homes close to green spaces
- 1d. Renovate existing parks
- 1e. Improve accessibility to major green spaces

Diversity in housing supply

- 2a. Offer more types of residential buildings
- 2b. Offer more varied sizes of apartments
- 2c. Offer small-scale land ownership
- 2d. Preserve the conceptual foundations of the buildings from the 1970s
- 2e. Offer more waterfront residences

Investment in public spaces

3a.	Enable more diverse traffic
3b.	Enable car parking along the streets
3c.	Face residential entrances toward the streets
3d.	Make public ground floor premises transparent
3e.	Build underground car parks in residential buildings
<i>Communications</i>	
4a.	Strengthen the connection to adjacent neighbourhoods and reduce the barriers to transport
4b.	Improve late night public transport
4c.	Improve public transport to and from Uppsala
4d.	Improve the North–South and East–West routes through a fine-mesh transportation network
4e.	Improve public transport to and from Stockholm
<i>Culture and leisure</i>	
5a.	Expand the range of cultural, sporting, and recreational activities
5b.	Create better opportunities for festivals and concerts
5c.	Create better opportunities for outdoor recreation
5d.	Organize public and farmers' markets
5e.	Provide municipal grants for cultural and recreational projects
<i>Education</i>	
6a.	Renovate old schools
6b.	Build new schools
6c.	Refurbish school yards
6d.	Improve the education in primary schools
6e.	Improve the education in high schools
<i>Care</i>	
7a.	More cultural and recreational activities for the elderly
7b.	More cultural and recreational activities for children and young people
7c.	Improve care for the elderly
7d.	More youth centres and youth workers
7e.	Reduce preschool class sizes
<i>School</i>	
8a.	Reduce preschool class sizes
8b.	Raise the quality of teaching
8c.	More professional development for school teachers
8d.	More modern information technology (IT) in education
8e.	Involve caretakers more in school
<i>Safety</i>	
9a.	Increase safety around the train station
9b.	More police officers in the city centre
9c.	Improve the lighting in the city centre
9d.	Restrict the opening hours of bars and restaurants which serve alcohol in the city centre
9e.	Extend the opening hours of shops in the city centre
<i>Ecological sustainability</i>	

10a.	Reduce energy consumption
10b.	Reduce transport noise and sound pollution
10c.	Increase climate adaptation and recycling
10d.	Prioritize environmentally friendly modes of transport (walking, cycling, public transport)
10e.	Reduce toxins and hazardous chemicals in the environment

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Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

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