Introducing Spatial Variability to the Impact Significance Assessment

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Abstract The concept of Circular Economy has gained momentum during the last decade. Yet unsustainable circular systems can also create unintended social, economic and environmental damage. Sustainability is highly dependent on a system's geographical context, such as location of resources, cultural acceptance, economic, environmental and transport geography. While in some cases an impact of the proposed change may be considered equally significant under all circumstances (e.g. increase of carbon emissions as a main contributor to the global climate change), many impacts may change both their direction and the extent of significance dependent on their context (e.g. land consumption may be positively evaluated if applied to abandoned territories or negatively if a forest needs to be sacrificed). The geographical context, (i.e. its sensitivity, vulnerability or potential) is commonly assessed by Spatial Decision Support Systems. However, currently those systems typically do not perform an actual impact assessment as impact characteristics stay constant regardless of location. Likewise, relevant Impact Assessment methods, although gradually becoming more spatial, assume their context as invariable. As a consequence, impact significance so far is also a spatially unvarying concept. However, current technological developments allow to rapidly record, analyse and visualise spatial data. This article introduces the concept of spatially varying impact significance assessment, by reviewing its current definitions in literature, and analysing to what extent the concept is applied in existing assessment methods. It concludes with a formulation of spatially varying impact significance assessment for innovation in the field of impact assessment.

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1 Introduction

Resource scarcity and rapid urbanisation both in light of rapidly changing demographics, power shifts and climate change create a snowballing challenge for sustainability. Fortunately, another, more positive, megatrend is the accelerating technological innovation that could provide important contributions to human well-being, improve labour efficiency, communication and education, and in that way rise society to the aforementioned challenges (Retief et al. 2016). Indeed the rapidly increasing computational power, means of sharing data and information, and digital literacy, are key drivers in the pursuit of sustainability.

In the past decade the concept of Circular Economy (CE), as a response to the aforementioned trends, has gained momentum with a rapidly increasing number of publications each year (Geissdoerfer et al. 2017). CE is an economic model based on renewability of all resources energy, materials, water, topsoil, land and air while retaining or creating value, promoting positive systemic impacts on ecology, economy and society, and preventing negative impacts (REPAiR D6.1 2017).

However, it is important to realise that the ultimate goal is not achieving circularity but sustainability. While these two terms tend to appear hand in hand, unsustainable circular systems also exist, which can cause unintended negative consequences (e.g., due to excessive use of transport and energy, unattractive working conditions or business abandonment due to failed adoption) (van Buren et al. 2016). Some previous studies upon conducting Life Cycle Assessment (LCA) have shown that closed loops are not always favourable from an environmental point of view (Haupt and Zschokke 2017). Therefore complex highly interdependent systems require a systems approach (Williams et al. 2017).

The shift towards circularity is going to require changes in design, production, logistics and consumer behaviour. The sustainability of these systems is highly dependent on their geographical contexts, such as location and availability of resources, presence of skilled labour force, economic, environmental and transport geography (Accorsi et al. 2015). Policies and shift supporting tools cannot be applied uniformly across the territory because the economic, social, environmental and institutional situations differ not only on a national level but also locally, on a community level. These instruments need to include place-based contextualised significance assessments of probable impacts, with Geographic Information Systems (GIS) as their basis.

This paper is linked with the H2020 Research and Innovation Action project REPAiR (Resource Management in Peri-urban Areas). The project aims to provide a Geodesign Decision Support Environment (GDSE) as a tool to assist local and regional authorities in creating and evaluating integrated spatial development strategies for Circular Economy. The strategies need to be specific for the place at hand, transdisciplinary, eco-innovative and promote the use of waste as a resource.

In the context of sustainability pursuit and transition towards CE, this paper proposes that both impact and its context assessments cannot be applied uniformly, and that the significance of impacts is a spatially varying measure. The paper is organised as follows. First, the general concept of impact significance is reviewed setting the theoretical framework of this study. Then, the need for spatial differentiation is discussed, defining the analytical framework that is later applied to four methods of impact assessment considered the most relevant in the context of this research. Recommendations for spatially differentiated impact significance assessment are given in the fifth section. Finally, conclusions are drawn followed by discussion on future work.

2 Theoretical Framework

"Impact Significance Assessment" or "Impact Significance Determination" is not commonly explored as a separate subject as a combined query in Scopus returns merely 11 distinct results (Query 1, Table 1). Reducing the query into "Impact Significance" results into a significantly larger number of 92 documents (Query 2). Analysis of keywords reveals that impact significance is most commonly associated with the topics of Environmental Impact Assessment (47/92 documents, Query 3) and Decision Making (10/92 documents, Query 4). Spatial Analysis or GIS are among the keywords in only 5 out of 92 documents (Query 5).

Impact significance assessment may serve two purposes (Zulueta et al. 2017): (1) identification of significant impacts to trigger authoritative actions after conducting an impact assessment of a certain project, and (2) impact significance assessment for the purpose of comparison between multiple alternatives as a support to the decision making process. The latter purpose is considered in context of this paper.

It differs notably how impact significance is assessed by different jurisdictions, as there is clearly an absence of a legal definition for the concept (Jones and Morrison-Saunders 2016). Wood (2008) describes impact significance as a dynamic, contextual, and political concept, characterised by uncertainty. The need for greater transparency, clarity and understanding of the significance determination process is recognized in the literature for decades. However, there is little apparent progress evident as the latest publications on the topic, such as Retief et al. (2016), Ehrlich and Ross (2015), Jones and Morrison-Saunders (2016), still mention the same issues related to significance assessment—i.e. lack of guidelines, vague terminology, high lexical and process uncertainty and low consistency and coherence.

The act of decision making is closely associated with social and political conflicts and deeply held values that reflect cultural, historical and social norms rendered acceptable by the community (Jones and Morrison-Saunders 2016). When the primary goal of significance assessment is sustainability, the focus shifts from minimising damage to maximising long-term gains (Gibson et al. 2005). The timespan

Table 1 A list of literature queries

No.	Query	Platform	Date
1	TITLE-ABS-KEY (“Impact Significance Assessment” OR “Impact Significance Determination”)	Scopus	15 Sep 2017
2	TITLE-ABS-KEY (“Impact Significance”)	Scopus	15 Sep 2017
3	TITLE-ABS-KEY (“Impact Significance”) AND (LIMIT-TO (EXACTKEYWORD, “Environmental Impact Assessment”) OR LIMIT-TO (EXACTKEYWORD, “Environmental Impact”) OR LIMIT-TO (EXACTKEYWORD, “Environmental Impact Assessments”) OR LIMIT-TO (EXACTKEYWORD, “EIA”) OR LIMIT-TO (EXACTKEYWORD, “Environmental Impact Assessment (EIA)”) OR LIMIT-TO (EXACTKEYWORD, “Environmental Assessment”) OR LIMIT-TO (EXACTKEYWORD, “Environmental Impact Significance Assessment”)	Scopus	22 Nov 2017
4	TITLE-ABS-KEY (“Impact Significance”) AND (LIMIT-TO (EXACTKEYWORD, “Decision Making”)	Scopus	22 Nov 2017
5	TITLE-ABS-KEY (“Impact Significance”) AND (LIMIT-TO (EXACTKEYWORD, “GIS”) OR LIMIT-TO (EXACTKEYWORD, “Geographic Information Systems”) OR LIMIT-TO (EXACTKEYWORD, “Spatial Analysis”)	Scopus	22 Nov 2017
6	“GIS AND” multi criteria “AND” decision support “AND (collaborative OR participatory OR cooperative) AND sustainability AND urban YEAR > 2015”	Google Scholar	1 March 2017

considered is longer, to include future generations, and more attention is given to assessing cumulative impacts (Lawrence 2007c). Both negative and positive impacts are addressed in contrast with assessments targeted solely at project approval. An impact of a proposed action is considered negatively significant if it inhibits sustainability. It is considered positively significant if it makes a durable contribution to achieving sustainable visions and strategies as compared to the baseline scenario (Barrow 2000).

To investigate what supplements impact magnitude to determine impact significance, a number of scientific publications have been reviewed. Besides publications returned by Query 1, additional studies have been chosen based on the summary made by Cloquell-Ballester et al. (2007), namely Table 1: Criteria to determine the significance of environmental impacts according to different authors (pg. 64); and some related citations in recent publications (Table 2).

One statement researchers and reviewers seem to agree on is that impact magnitude and impact significance are essentially different concepts that must not be confused (Thompson 1990; Lawrence 2007a; Wood 2008; Ehrlich and Ross

Table 2 A list of literature used for the review on impact significance assessment

List of references	
Duinker and Beanlands (1986)	Wood (2008)
Thompson (1990)	Ijäs et al. (2010)
Canter and Canty (1993)	Gangolells et al. (2011)
Antunes et al. (2001)	Briggs and Hudson (2013)
Bojórquez-Tapia et al. (2002)	Zulueta et al. (2013)
Cloquell-Ballester et al. (2007)	Ehrlich and Ross (2015)
Lawrence (2007a)	Jones and Morrison-Saunders (2016)
Lawrence (2007c)	Zulueta et al. (2017)
Lawrence (2007b)	

2015). Furthermore, there is general agreement that subjectivity cannot be avoided in the process, although it can be well informed by science and maximally transparent (Briggs and Hudson 2013). Thus, all reviewed publications seem to agree that there are two sides of impact significance—the rather objective side related with the impact's assessment, and the rather subjective one related to the values of importance given to that impact. Table 3 gives an overview of how different authors define significance and its two major components.

In its essence, impact significance determination is a multicriteria problem (Cloquell-Ballester et al. 2007). What the different authors (as well as official regulations) do not seem to agree on is which factors exactly characterise impacts, and which ones characterise importance. Generally, there is a lot of inconsistency in how the arguments are classified by authors. E.g. Bojórquez-Tapia et al. (2002), Cloquell-Ballester et al. (2007) regard synergic and cumulative effects as properties of the impact intensity, while Antunes et al. (2001), Lawrence (2007b), Wood (2008) regard cumulative effects as properties of the impact receiving context. Institutional arrangements are often viewed as constraints or background of the significance determination procedures (Briggs and Hudson 2013; Ehrlich and Ross 2015) rather than context properties (Lawrence 2007a; Wood 2008). Ijäs et al. (2010) classify impact permanence and reversibility on the same side as context susceptibility and Ehrlich and Ross (2015) regards everything as impact properties, while decision makers are responsible for setting a subjective threshold value to determine how all of these properties qualify for significance.

Moreover, there does not seem to be consensus between the authors on who is responsible for providing value judgements to determine the significance. While some authors attribute this responsibility to the experts and scientists (Antunes et al. 2001; Cloquell-Ballester et al. 2007; Zulueta et al. 2017), others suggest to ask public opinion (Antunes et al. 2001; Gibson et al. 2005; Gangolells et al. 2011; Briggs and Hudson 2013) or to leave it in the hands of decision-makers as advocates of society (Duinker and Beanlands 1986; Ehrlich and Ross 2015).

Table 3 Variables of impact significance according to different authors

Publication	Objective (impact) measure	Subjective (judgement) measure
Duinker and Beanlands (1986)	Magnitude and spatiotemporal distribution of change, reliability of prediction	Importance of environmental attribute to project decision makers
Canter and Canty (1993)	Impact intensity	Impact Context
Antunes et al. (2001), Wood (2008)	Impact magnitude	Context sensitivity
Bojórquez-Tapia et al. (2002)	Interaction intensity	Environmental vulnerability
Lawrence (2007a)	Impact characteristics	Characteristics of the receiving environment
Cloquell-Ballester et al. (2007)	Project activities	Environmental factors
Ijäs et al. (2010)	Scale of importance, magnitude of change	Permanence, reversibility, cumulativity, context susceptibility
Gangolells et al. (2011)	Impact severity	Concerns of interested parties
Zulueta et al. (2013, 2017)	Impact characteristics	Expert judgement
Briggs and Hudson (2013)	Impact on a receptor	Value of the receptor
Ehrlich and Ross (2015)	Impact adversity	Threshold of acceptability
Jones and Morrison-Saunders (2016)	Impact characterisation	Impact importance

This article's focus is on adding a spatial dimension to the objective procedure of impact assessment and to the subjective procedure of judgement. To offer a clear definition of the two, the arguments collected during the literature review were sorted into two groups (Table 4), one for the arguments given on the basis of impact characteristics and the other for the arguments given on the basis of the impact receiving context, based on the following definitions:

Impact Characteristics refer to all characteristics that would be computed using the same formula, if the same intervention was moved to a different context. E.g. if odour from a new facility affects 1000 m radius around the facility, then moving the facility to a new location would not change the radius.

Context Characteristics refer to all characteristics that would be computed with the same formula if an intervention with different impact would be placed in the same context. E.g. if habitat is negatively affected by odour, then placing a facility with smaller odour radius would not change habitat's sensitivity.

Based on the literature review, it has been concluded that Impact Significance can be defined as a function between Impact Characteristics and Context Importance (Eq. 1), where impact characteristics are provided by an objective assessment procedure and context importance is provided by a subjective judgement.

Table 4 Arguments for significance determination, based on impact characteristics and context characteristics

Arguments based on impact characteristics	Examples	References
Magnitude or intensity	Noise levels, odour intensity, amount of pollutants, amount of required resources, amount of employment	All
Extent of potentially affected factors	Amount of affected population, volume of polluted water, "the greatest good for the greatest number"	Duinker and Beanlands (1986), Canter and Canty (1993), Antunes et al. (2001), Lawrence (2007a), Ijäs et al. (2010), Briggs and Hudson (2013), Zulueta et al. (2017)
Economic considerations	Costs for certain institutions, revenue potential	Wood (2008)
Spatial patterns	Spreading distance, density, affected area, fragmentation, inclusion	Duinker and Beanlands (1986), Bojórquez-Tapia et al. (1998), Antunes et al. (2001), Lawrence (2007a), Wood (2008)
Temporal patterns	Duration, frequency, periodicity, swiftness	Duinker and Beanlands (1986), Canter and Canty (1993), Bojórquez-Tapia et al. (1998), Antunes et al. (2001), Lawrence (2007a), Wood (2008), Ijäs et al. (2010), Briggs and Hudson (2013), Zulueta et al. (2017)
Reversibility	Depletion of fossil fuels, erosion of tropical forests, human toxicity	Canter and Canty (1993), Antunes et al. (2001), Ijäs et al. (2010), Briggs and Hudson (2013), Zulueta et al. (2017)
Reliability	Certainity, probability, predictability	Duinker and Beanlands (1986); Canter and Canty (1993)
Social and ethical importance	Child labour, public controversy, public priority, "the greatest good for the least advantaged"	Duinker and Beanlands (1986), Canter and Canty (1993), Bojórquez-Tapia et al. (1998), Lawrence (2007a), Wood (2008)
Ecological sensitivity	Species extinction potential, resilience, recovery capacity	Canter and Canty (1993), Bojórquez-Tapia et al. (1998), Wood (2008)

(continued)

Table 4 (continued)

Arguments based on impact characteristics	Examples	References
Cultural sensitivity	Proximity to scientific, cultural or historic resources, aesthetic effect in scenic landscapes	Canter and Canty (1993)
Competition for resources	Groundwater depletion, agricultural land use	Duinker and Beanlands (1986)
Socioeconomic sensitivity	Accessibility, employment, agricultural production	Antunes et al. (2001), Canter and Canty (1993)
Institutional arrangements	Legal noise thresholds, target recycling rates, political targets	Duinker and Beanlands (1986), Canter and Canty (1993), Lawrence (2007a), Wood (2008)
Cumulative effects	Current pollution rates, synergy, spatiotemporal crowding of effects, induction potential, precedent setting, feedback resistance, biomagnification	Canter and Canty (1993), Bojórquez-Tapia et al. (2002), Lawrence (2007a), Wood (2008), Ijäs et al. (2010), Zulueta et al. (2017)

$$IS = f(I, C) \quad (1)$$

where:

IS Impact Significance,
I Impact Characteristics,
C Context Importance.

3 Spatial Variability

It has been noticed almost three decades ago "that methodologies which proceed through full aggregation of impacts to a 'final score', should not be used as an assessment technique, the results of which are intended for use by the decision-maker. Such an approach would remove the decision from those appointed or elected for that purpose and place it in the hands of the study-team" (Thompson 1990).

Based on the reviewed literature, it seems that although 'final score' is avoided for the clarification of diverse impacts, the significance of impacts is still spatially invariable. The spatial extent and spatial patterns are used only as one of the impact defining characteristics. E.g. the Spatial Impact Assessment Methodology (SIAM) proposed by Antunes et al. (2001) is mainly aimed at performing an aggregation of impacts in the spatial dimension. However, the spatial differences between alternatives are not communicated back to the decision makers.

There are multiple reasons why impact significance should not be a spatially uniform measure. First, by stripping the spatial dimension local impacts either get completely absorbed by the impacts at the larger scale or are wrongly given the same weight (Antunes et al. 2001). Second, impacts of different nature can accumulate in space and time and that way synergistically affect not only environmental but also social or economic sustainability. Third, impact assessment practices "will increasingly have to deal with significance judgements in relation to new proposals where existing thresholds, even without the proposal, have already been exceeded for various valued components" (Retief et al. 2016).

Furthermore, the concerns of the affected communities may differ from place to place (Gangolells et al. 2011). Therefore, using values of one community may not fit the judgements of the neighbouring one. In case of large scale changes that involve national or regional policies, each of the multiple affected communities would take the changes differently. E.g. a small development proposal in an ecologically sensitive environment may have a more significant impact than a far larger development located in a more robust setting. Similarly, a community dominated by high unemployment may be more supportive of controversial development proposals than comparable areas with full employment (Wood 2008).

Finally, two conditions must be controlled to accept a judgement as well-founded: consistency and consensus (Cloquell-Ballester et al. 2007). While consistency refers to the standard deviation of individual judgements, a study by Janssen et al. (2015) has demonstrated that associating individual stakeholder values with particular locations helped to arrive to a consensus which could not be reached otherwise.

Having spatial variability in impact significance assessment requires a spatially explicit model. Goodchild (2001) suggests four tests to determine if a model is (or should be) spatially explicit:

The Invariance Test considers a model spatially explicit if its outcomes (rankings or orderings of decision alternatives) are not invariant under relocation of the feasible alternatives. This implies that a change in the spatial pattern of feasible alternatives result in the changes of their rankings.

The Representation Test requires decision alternatives to be geographically defined. Such alternatives consist of, at least, two elements: action (what to do?) and location (where to do it?).

The Formulation Test declares a model spatially explicit if it contains spatial concepts such as location, distance, contiguity, connectivity, adjacency, or direction.

The Outcome Test checks if the spatial form of outputs is different than the spatial form of its inputs. E.g. the input values of spatial decision problems may be assigned to various spatial objects, while the output maps would represent the overall values associated with each location using raster data format.

4 Analysis of Impact Significance Assessment Methods

Although rarely considered as a subject on its own, impact significance assessment is an intrinsic part of Impact Assessment methods and Decision Support Systems. Based on the review in Sect. 2, impact significance assessment is a procedure that can rank or classify impacts taking into account both impact characteristics and the importance of the context where they occur. To determine current state-of-the-art of spatial variability in impact significance assessment, four methods have been selected as the most relevant in context of transitioning towards CE: Environmental Impact Assessment (EIA), Life Cycle Assessment (LCA), impact assessment in Geodesign and Spatial Decision Support Systems (SDSS). These methods were evaluated using spatial variability tests (Goodchild 2001). The analysis results (Tables 5, 6, 8 and 9) have shown that the spatial variability of impact significance corresponds to one of the two equations (Eqs. 2 and 3).

$$IS_{(x,y)} = f(I_{(x,y)}, C) \tag{2}$$

where:

$IS_{(x,y)}$ Impact Significance at location (x, y),
$I_{(x,y)}$ Impact Characteristics at location (x, y),
C Context Importance.

Table 5 Spatial variability of impact significance assessment in EIA

Spatial variability test	Impact Characteristics	Context Importance
Invariance	±	–
	Subject to change based on the project relocation	No requirement for spatially differentiated environmental sensitivity or public judgement values
Representation	–	–
	Decision alternatives may not be associated with project relocation	No requirement for spatially differentiated environmental sensitivity or public judgement values
Formulation	+	–
	Project and its impacts must be associated with particular geographical location	No requirement for geographic definition of environmental sensitivity or public opinion
Outcome	±	–
	Spatial extent must be provided, but there is no defined format	No required format for the description of environmental sensitivity

$$IS_{(x,y)} = f(I, C_{(x,y)}) \tag{3}$$

where:

$IS_{(x,y)}$ Impact Significance at location (x, y),
I Impact Characteristics,
$C_{(x,y)}$ Context Importance at location (x, y).

4.1 Environmental Impact Assessment

Environmental Impact Assessment (EIA) is a procedure used to provide an analysis of the potential significant environmental effects associated with major development proposals and to communicate this information to decision-makers and the broader public (Wood 2008). As a vast amount of different methodologies exist for impact identification and assessment, it is characterized by diversity in its practice, and by associated ambivalence (Pope et al. 2013). The latest review on EIA state-of-the-art by Zelenakova and Zvijakova (2017) describes EIA as a seven step procedure: scoping, impact identification, description of environment, impact prediction, impact assessment, decision making and communication of results. Although, impact significance assessment is not explicitly mentioned as a separate step, it should intrinsically be part of decision making.

The analysis of spatial variability has been made on the basis of Directive 2011/92/EU as amended by Directive 2014/52/EU (known as the "EIA Directive"). The main principle of the EIA Directive is to ensure that plans, programmes and projects likely to have significant effects on the environment are assessed and their implications made public prior to their approval or authorisation (European Commission 2014). The Directive indicates the rules for reporting the carried EIA, however it does not appoint a single method of assessment. Nevertheless, the Directive provides a list of impact characteristics that need to be considered, among which is spatial extent. A description of the location of the project, with particular regard to the environmental sensitivity of geographical areas likely to be affected is also required.

According to the EIA Directive "Member States may set thresholds or criteria to determine when projects need not undergo [...] environmental impact assessment" European Commission (2014). Also the public interested in environmental decision-making needs to be informed and allowed to express comments and opinions. However, the Directive does not require project developers to collect either the importance judgement of the public or institutional judgements, which would later be juxtaposed with the predicted impacts.

Based on the analysis results in Table 5, it appears that according to the EIA Directive, Impact Significance in a particular location is determined by the Impact Characteristics in that location and spatially non-differentiated values of Context Importance as in Eq. 2.

4.2 Life Cycle Assessment

LCA is especially relevant in the context of transitioning towards the CE as it can tell whether the achieved circularity of a certain resource would actually enhance the overall sustainability or not (Haupt and Zschokke 2017). LCA is “primarily a steady-state-tool” that does not consider temporal or spatial information and mostly has no relation with the context. In fact, often this information becomes lost due to aggregation (Udo de Haes 2006). The comparison between impacts is instead done by employing a functional unit (e.g. treatment of household waste produced in the city of Amsterdam during one year) and aggregating all the emissions into indicators that can be compared directly, or at midpoint or endpoint levels. While LCA is able to provide a complete picture of all impacts associated with a product or process, the communication of results usually requires an expert audience (Elia et al. 2017).

Although LCA was developed as a spatially independent approach, spatial LCA attempts associated with every stage can be found in the literature (Nitschelm et al. 2016). The significance of impacts in LCA is typically determined by the impact indicators and characterisation factors. Both impact inventory and characterisation factors may be spatially differentiated. The spatial variability of impact significance assessment is analysed based on the selection of recent publications (Table 7).

Based on the analysis results in Table 6, it seems that impact significance in a particular location is typically determined according to the Eq. 1, although Eqs. 2 and 3 are also possible in case of spatial LCA.

Table 6 Spatial variability of impact significance assessment in LCA according to the selection of literature as in Table 7

Spatial variability test	Impact characteristics	Context importance
Invariance	±	±
	May be subject to change on relocation of alternatives in both spatial and non-spatial LCA	Typically not spatially differentiated, although precedents exist
Representation	±	±
	The decision alternatives may have both a choice of actions and locations, although typically on a coarse granularity	Typically not spatially differentiated, although precedents exist
Formulation	–	–
	Spatial concepts are not included in impact assessment	Spatial concepts are not included in characterisation
Outcome	±	–
	Impacts may be geolocated based on processesses as objects in different spatial form (e.g. grid cell assignment)	Spatially differentiated characterisation factors typically do not change spatial form

Table 7 A list of literature used for the review on Life Cycle Assessment

List of references	
Haupt and Zschokke (2017)	Nitschelm et al. (2016)
Hiloidhari et al. (2017)	Kim et al. (2015)
Maier et al. (2017)	Smetana et al. (2015)
Escamilla and Habert (2016)	Hellweg and Mila i Canals (2014)

4.3 Geodesign

Geodesign has been chosen as a leading methodology for the decision support environment in the REPAiR project (REPAiR 2016) as it is a design and planning method that tightly couples the creation of design proposals with impact simulations informed by geographical context. Impact Assessment is the 4th step of the geodesign methodology (Steinitz 2012) and refers to the question "What differences might the changes cause"? The impacts are then assessed by experts and stakeholders using simple assessment matrices, that assign values from "very bad" to "very good" to each scenario of change for each of the valued factors. Impact significance is determined based on a consensus between the workshop participants considering their judgement and expertise.

Analysis results in Table 8 reveal that impact significance in geodesign is generally not spatially differentiated because context importance is not spatially explicit. Moreover, although impact characteristics are of spatial nature and determined by

Table 8 Spatial variability of impact significance assessment in geodesign methodology

Spatial variability test	Impact characteristics	Context importance
Invariance	+	–
	All alternatives are of a spatial nature, thus the ranking of impacts directly depends on them	The stakeholder values are not spatially defined
Representation	+	–
	The decision alternatives consist of actions and geographical locations	Stakeholder values are associated with actions but not particular locations
Formulation	–	–
	Impacts are not characterised by spatial concepts	Stakeholder values are not characterised by spatial concepts
Outcome	±	–
	Output is not presented in spatial format, but as a matrix	Output is not presented in spatial format, but as a matrix

Table 9 Spatial variability of impact significance assessment in SDSS according to the selected literature as in Table 10

Spatial variability test	Impact characteristics	Context importance
Invariance	−	+
	Uniform throughout the study area	Expressed per spatial unit in means of sensitivity, vulnerability or potential
Representation	−	+
	Location varies among alternatives, but actions and thus their impacts remain spatially constant	Decision alternatives are associated with context characteristics that define its importance
Formulation	−	±
	Not spatially defined	Mostly limited to location, but may also include distance, adjacency, direction, etc.
Outcome	−	+
	Not spatially defined and therefore not output in spatial format	May be based on different spatial form than decision alternatives

Table 10 A list of literature used for the review on Spatial Decision Support Systems

List of references	
Meerow and Newell (2017)	Corral et al. (2016)
Bonzanigo et al. (2016)	Janssen et al. (2015)
Jeong and Garcia-Moruno (2016)	Dapueto et al. (2015)
Rovai et al. (2016)	Bojesen et al. (2015)
Ottomano Palmisano et al. (2016)	van Niekerk et al. (2015)
Grêt-Regamey et al. (2016)	Erfani et al. (2015)

the spatial alternatives, impact significance is assessed uniformly for the whole study area. This would lead to Eq. 2 as the most suitable to describe impact significance determination in geodesign. However, workshop participants may implicitly assume spatial variability and accordingly adjust their ratings of the alternatives without expressing them formally.

4.4 Spatial Decision Support Systems

An SDSS can be defined as an interactive, computer-based system designed to support a user or group of users in achieving higher effectiveness in decision making while solving a semi-structured problem that has spatial consequences (Malczewski

1999). Decision Support Systems are meant to rather support than replace human judgements and improve effectiveness rather than efficiency of a process (Uran and Janssen 2003). This means that a user is expected to utilise the system as an advisory unit that is simply more capable to digest large amounts of data and perform quick computations.

There is an increasing amount of SDSS related scientific articles being published every year on solving an increasing variety of spatial decision problems that follow rather distinct methodologies (Ferretti and Montibeller 2016). In order to investigate the current practices and how they approach impact significance assessment, a small set of 12 relevant publications has been chosen based on Query 6 (Table 10).

Evidently, none of the studies have performed an actual impact assessment. Instead impact significance has been decided purely based on the context importance. E.g. presence of ecosystem services increases access to green spaces. Therefore ecosystem services should be located in a cell where the access to green spaces is the lowest (Meerow and Newell 2017). In some studies impacts refer not to the impacts a project would cause to the environment but to the impacts environment would have on project's success. E.g. more transport infrastructure is better for urban development. Therefore urban development should be located where transport infrastructure is the best (Grêt-Regamey et al. 2016). Equation 3 is the most suitable to describe how impact significance in a particular location is determined in SDSS.

5 Recommendations for Spatially Differentiated Impact Significance

According to Eqs. 2 and 3, for Impact Significance to be spatially differentiated it is sufficient that either Impact Characteristics or Context Importance is spatially differentiated. However, if only one variable in the equation is spatially differentiated and the other is spatially constant, the value of impact significance does not account equally for both impact characteristics and context importance. Instead, it aligns with the variability of the spatially differentiated one. Spatial variations of both impact characteristics and context importance should be taken into account in order to conduct a spatially differentiated impact significance assessment, as per Eq. 4.

$$IS_{(x,y)} = f(I_{(x,y)}, C_{(x,y)}) \tag{4}$$

where:

$IS_{(x,y)}$ Impact Significance at location (x, y),
$I_{(x,y)}$ Impact Characteristics at location (x, y),
$C_{(x,y)}$ Context Importance at location (x, y).

Several recommendations are provided for achieving spatially differentiated impact significance that reuse elements from existing methodologies, following the four tests defined by Goodchild (2001).

The Invariance Test on Impact Characteristics. Impact characteristics should be subject to change if the location of an object or action is changed. E.g. if a decision needs to be made upon which neighborhood to place a compost park, and one of the considered impacts is "increased accessibility to green spaces", then the number of people able to access the new park needs to be calculated for each of the neighborhoods.

The Invariance Test on Context Importance. The values of context importance should as well be varying between different locations. E.g. following the same example of locating a compost park, context importance may be dependant on the neighbourhood demographics with higher preference for young families and lower for students, which will be varying from neighborhood to neighborhood.

The Representation Test on Impact Characteristics. If decision alternatives involve both choice of actions and their locations, the characteristics of impacts need to change accordingly. E.g. if a choice needs to be made between locating a compost park in an existing green space or in a newly created one, then impact assessment should describe the impact of the new and adapted park dependent on the location characteristics, as some of them might be more favourable for adaptation while the others for a new green space.

The Representation Test on Context Importance. When decision alternatives involve both choice of actions and their locations, the importance needs to be given not only on basis of the preferred action but also considering the different location possibilities. E.g. acceptability and usage of a compost park may depend on the social composition of a particular neighborhood, while a need for greater green space accessibility may depend solely on neighborhood demographics.

The Formulation Test on Impact Characteristics. Those impact characteristics that change depending on the context characteristics, should be formulated with spatial concepts. While impact characteristics such as reversibility or duration may be dependent only on the chosen action and not vary in different contexts, impact magnitude may be well associated with the context characteristics. E.g. possible odour from the composting facilities may affect different areas by different intensities depending on the wind patterns.

The Formulation Test on Context Importance. Distance, adjacency, connectivity or direction may also serve for defining context importance. The importance does not always to have to be bounded to specific cells but expressed as adjacency to certain facilities or sensitive habitats, a function of distance from risk inducing object, accessibility over a network or gradually decreasing while moving north or south due to climate or cultural variations.

The Outcome Test on Impact Characteristics. In order to evaluate the impact on each valued component, it is necessary to identify the receptors and to describe the impact pathways affecting those receptors (Antunes et al. 2001). The receptors will eventually have a spatial dimension (e.g. population density, species distribution, location of resources). However, the spatial form of an impact may be different than that of the receptor.

The Outcome Test on Context Importance. Similar to impact characteristics, context importance can be expressed in a different spatial form than the significance assessment. Context importance may be based on e.g. topography, network centrality or administrative boundaries, while impact significance may be assessed per individual neighborhoods.

The four tests help to determine whether the assessment is or could be spatially differentiated and on what grounds. Passing one of the four tests is sufficient to qualify for the spatially differentiated impact significance assessment, however a balance between spatial differentiation in impact characteristics and context importance needs to be retained, i.e. if Impact Characteristics are spatially explicit, then Context Characteristics must also be spatially explicit.

The need for spatial differentiation in impact significance should also be critically evaluated based on its added value. As Nitschelm et al. (2016) have noted "the debate about whether spatialized LCA reduces uncertainties in LCA studies remains open. The amount of local data needed for spatialized LCA studies can indeed increase uncertainties in the LCI phase." The same observation stands true not only for LCA but impact assessment and decision support methods in general. However, evidence from SDSS demonstrates that judgement of context characteristics is spatially varying, while Impact Assessment studies prove the same about impact characteristics. This suggests that accounting for both components of the significance assessment should lead to a more informative and just result.

6 Conclusions and Future Work

The literature review on impact significance assessment has revealed that although the process is commonly performed during impact assessment and decision making, there is no single method that could be followed. Significance assessment is required by legal documents such as the EIA Directive, but there is a lack of legal definition or standardised method. What different authors agree on is that impact significance assessment is a double-sided procedure that involves objective assessment of impacts and subjective judgement of their importance. However, there is no consensus on what exactly characterises impacts, and who needs to provide judgement of importance and how. The review provides an overview of how different authors describe the two components of impact significance and what arguments are used to support the judgement.

As a result, this research suggests to regard impact significance assessment as a function between impact characteristics and the importance of the context that the impact occurs in. While impact characteristics can be estimated using objective measures, context importance requires judgement of importance that may be provided by stakeholders, decision makers, public opinion or institutionally.

It has been observed that up to now publications on impact significance regard spatial aspects only as possible impact characteristics and not a separate dimension of assessment. However, when decision making involves local impacts whose significance highly depends on context characteristics, the assessment requires spatial differentiation. Following this assumption, three main challenges need to be overcome: (1) probable impacts need to be characterised according to their geographical context; (2) the geographical context needs to be evaluated for its relative importance; and (3) finally, the values need to be combined to represent impact significance that may have spatial variability dependent on both components.

Environmental Impact Assessment, Life Cycle Assessment, Geodesign and Spatial Decision Support Systems, all employ impact significance assessment prior to comparison of decision alternatives. Although the alternatives often have spatial form and cause impacts that can be represented spatially, the four spatial tests by Goodchild (2001) have revealed that spatial differentiation is mostly based on either impact characteristics or context importance but not both of them simultaneously. As a result of this study, recommendations have been provided to overcome this gap in future impact significance determinations.

The recommendations drawn from the analysis will be further tested and refined in practice during the development of a Geodesign Decision Support Environment. They could, when supplemented by further related analyses, contribute to more systematic and spatially explicit significance determination approaches. In order to do so future work still includes providing clear unambiguous definitions of the used terms (e.g. context vs. impact) and demonstrations how the devised theory can be implemented in decision support. The created frameworks and tools aim to be sustainable and exceed the specifics of a single case study (Circular Economy). Finally, the same or very similar principles could be applied for temporal dimension to provide temporally differentiated significance assessment.

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