Answers to the different comments

Comment: "The paper requires minor editing for grammar and appropriate use of English. Title I suggest replacing 'supporting' with 'support'." (A. Donnelly)

*Replace the title with "*A decision-support methodology for assessing the sustainability of natural risk management strategies in urban areas*"*

Comment: *"*Abstract Consider giving an example of how the proposed framework incorporates sustainability principles in a particular decision.*"* (A. Donnelly)

Replace *"*Therefore, a methodological and operational framework was drafted and tested using a theoretical case study to illustrate its applicability, determine the most sustainable decision and identify its improvement trails.*"*

With *"*Therefore, this paper reports a methodological and operational framework, which aims to incorporate sustainability principles in a particular decision by taking all the dimensions that affect sustainability into account. The suggested framework was then tested using a theoretical example as case study, on one hand, to demonstrate the way it could be used to determine the most sustainable decision, and on the other, to identify its improvement trails.*"*

Comment: "Key words Consider including key words." (A. Donnelly)

Keywords: Natural hazard risks, Risk management, Sustainability assessment, Criteria and indicators, Decision-support tool

Comment: "Introduction P209L7 Rephrase: … to control natural hazards ... there is no way for people to control natural hazards we can only manage the response." (A. Donnelly)

Replace *"*to control those hazards because …*"*

With *"*to manage their response to those hazards in order to reduce their occurrence as well as to lessen their intensity and/or spatial extent because …*"*

Comments:
"The paper needs to reflect also on the term sustainability as this has a quite broad connotation. How would sustainability be 'measured' here?" (Anonymous referee #1, supplement)

"Please discuss this further; what is understood as sustainability of risk management activities" (Anonymous referee #1, supplement)

"P209L13 Sustainability in the context of risk management should be defined at this

point." (A. Donnelly)

To be inserted P209 L14 after "field."

As sustainability is a term that has quite a broad connotation, there is also fuzziness inherent in the concept of sustainability related to risk management so that interpretations differ for researchers. In practice, sustainability in the context of risk management could mean placing greater emphasis on integrating profitable results of risk management with the standards of sustainable development of a given territory through a holistic perspective. It includes initiatives, which allow management activities to contribute to the minimisation of risk losses, alleviation of poverty, enhancement of social equity as well as quality of life of people, growth of community engagement and involvement, maintain and improvement of natural resource base as a whole over long periods of time.

To be inserted P209 L26 after "sectors."

Measuring the degree of sustainability of risk management activities will focus in the assessment of how effective the goals regarding territorial defence against risk, great economic dynamism, social justice, and preservation of natural/cultural resources are or will be achieved.

Comments:
"P209L9-10 Is it possible to give an example of how current practice (focusing on financial and technical concerns) may be improved by a different approach, such as the one being proposed in the current paper? Or perhaps give examples after L18." (A. Donnelly)

"This needs further justification and explanation." (Anonymous referee #1, supplement)

To be inserted P209 L18 after "(Wurbs, 1996; Putri and Rahmanti, 2010)."

Nowadays, the challenges for risk-managers are not only to limit the costs of ensuring territorial defence against risk and to reduce the risk to people and their assets; they also relate to the wider consequences of risk management decisions to the people's well being, the political organisation, and the environment. When considering such neglected aspects, practitioners could make decisions not only based on the effectiveness and economic viability of measures but also on the assessment of environmental, institutional, and social benefits and costs. Where to locate infrastructural projects, how their construction affects land use, ecological system, and public awareness, which institutional functioning and organisational

arrangements for their better social acceptance are some of factors that can significantly influence their expected impacts. The added profits of sustainable management approach are to avoid destruction of socio-ecological fabric of territories in contrary to current approach that seems less incentive to arouse active participation of defence structures beneficiaries.

Comment: "P209L19 Examples of the 'numerous initiatives' would be useful." (A. Donnelly)

Replace *"*as indicated by the numerous initiatives or studies, and has been recognised by several nations and international organisations around the world (Mileti, 1999; Kundzewic, 2002; Galloway, 2004; Scottish Executive, 2005; Werritty, 2006; Agrawala, 2007).*"*

With *"*as indicated by the numerous studies (see for instance Mileti, 1999; Kundzewic, 2002; Galloway, 2004; Scottish Executive, 2005; Werritty, 2006; Agrawala, 2007; Kang et al., 2013) or initiatives (Hyogo Framework for Action, European Flood Directive, different projects such as FLOODsite, LiveWithRisk, CapHaz, etc.). Its significance has been recognised by several nations (Australia, UK, Germany, Japan, Bangladesh, etc.), and international organisations (United Nations, European Union, Asian Disaster Prevention Centre, etc.) around the world."

Comment: "Shortly provide examples of this tools?" (Anonymous referee #1, supplement)

To be inserted P210 L7 after "Kang et al., 2013)."

Benefit-cost analysis, future scenario planning, participatory mapping, etc. are some of them.

Comment: "P210L13-16 The difficulty here is that since each natural hazard is unique indicators must be tailored to each hazard but there may be some cases where common indicators may be used." (A. Donnelly)

To be inserted P210 L17

Even characteristics (physical phenomena, measurement, terms associated with, etc.) differ from one hazard to another; it is helpful to have a commonly adopted tool for fostering sustainability in the risk management process. Such tool must be an inclusive framework, enclosing generic and particular indicators/parameters so that some of technical indicators/parameters should be specific to the treated hazard.

Comment: "Authors discuss 'risk management'. As risk is a widely used term authors need to better justify and explain their definition of risk, and its relation to commonly used concepts defining risk as a function of hazard, vulnerability (and exposure)" (Anonymous referee #1)

Answer: to be inserted P211 L2

Understanding the sustainable management of risk associated with natural hazards requires foremost the explanation of the key concepts: risk, disaster, hazard, vulnerability, and risk management. Due to the importance of terminology, although there is no single definition for those concepts, the following definitions based on the United Nations Office for Disaster Risk Reduction (UNISDR, 2009) terminology on disaster risk reduction should be adopted in this paper. Risk could be defined as the result of the interaction, in space and time, between hazardous events and vulnerability of the exposed elements of a territorial system. In such interaction, risk represents the expectation value of potential consequences associated with the occurrence of a given hazard, where the characteristics of the hazard and the vulnerability level of the endangered system determine the types and levels of losses. A risk that occurs may trigger a disaster. Disaster could be defined as a serious disruption of the functioning of the impacted system due to the amount of damages suffered which exceeds the ability of the system to cope using its own resources.

Hazards, in the context of natural risks, are physical phenomena (single, multiple or concatenated) of natural origin that may potentially cause injury or loss of life, property damage, socio-economic disruption, and environmental deterioration. Vulnerability of exposed systems to natural hazards is an integral factor encompassing physical, economic, social, political and environmental aspects that allows understanding the real extent of risk. It depends both on to the exposure of people, their livelihoods, their support infrastructures and services to hazards, and on the their tendency (sensitiveness, fragility, lack of resilience) to suffer damage when impacted by hazards.

Risk management is a systematic process of preparing a territorial system to cope with the adverse effects of risk through actions for prevention, mitigation, preparedness, response, and recovery. It includes all policies, strategies, and measures that aim to minimise potential losses by either lessening the intensity as well as the spatial extent of hazards or reducing the vulnerability of the elements at risk.

Comment: "Is there a reason for that, why there is a focus on floods" (Anonymous referee #1, supplement)

To be inserted P211 L6 after "… flood-specific"

(this broader emphasis is because flooding is the most common and the costliest natural disaster all around the world), …

Comment: "As discussion on spatial scales especially in vulnerability assessments can be found in Fekete et al. and Kienberger et al." (Anonymous referee #1, supplement)

To be inserted P213 L14 after "they are applied."

As territory is a hierarchical structuring system with different spatial scales (neighbourhood, municipality, county, region, nation) delineated by their administrative boundaries so that risks of natural origin are nested at those various levels, it is crucial to specify on which scale sustainability of the management is to be evaluated (Fekete et al., 2010; Kienberger et al., 2013). According to their specific characteristics, each scale (micro, meso, and macro levels) has to be treated separately: a variable with specific strength at one scale could seem inappropriate at another (for instance damage estimation mainly rely on assets typology at micro level and land-use at meso level). An explicit description of the spatial scale in the conceptualisation of the methodology helps to identify accurate sustainability indicators/parameters, to determine how indicators/parameters on different levels can benefit from each other, and to detect which constraints of data collection have to be faced. In general, the preciseness of analysis increases at small scale and is more generalised towards the more aggregated scale.

It is observed that small-sized hazardous events are more frequent, as consequences it is at the fine spatial scale where theorising a methodology becomes useful for risk-managers.

To be inserted P213 L19

According to Fekete et al. (2010), in comparison to the upper scales the main benefits of this scale are a more detailed information, a better capture of complexity of phenomena, the use of participatory methods for data collection, a higher availability of data related to one item, a lower level of uncertainty. Contrariwise, this scale is limited by loss of information while up-scaling the assessment.

Comments:
"Authors refer to composite indicator construction, therefore it is questioned why the authors do not apply standard procedures such as the assessment of multi-

collinearities etc as for instance outlined in the OECD guide on composite indicator construction." (Anonymous referee #1)
"Case study – it would be useful to explain how the framework can account for 'missing values' as in reality there will inevitably be missing data." (A. Donnelly)

To be inserted P219 L2 after "process"

"… follows almost the steps of the OECD methodology for building composite indices (OECD, 2008) because indicators and criteria are composite indices. Standard procedures such as choosing a representative series of sub-indices (various parameters, indicators), verifying whether normalisation is needed and with which method, dealing with weighting concerns, how to aggregate sub-indices were applied. No assessment of multi-collinearity among the sub-indices has been done to check if there are correlations between them. Nonetheless, users have to selects parameters in a way to combine or eliminate those, which could be collinear.

While operating the methodology, users could make data screening tests (removing outliers, identifying erroneous data values, detecting missing data, etc.). Indeed, the problem of input data (parameters) availability is crucial because in reality there will inevitably be some missing data. It is necessary to supplement missing data, if it is possible. An option is simply to exclude the parameters that are suffering missing data from the set of parameters for all the assessed alternatives. Falling that, users could solve this problem through several missing data imputation procedures. They could build plausible data according to similarities of the study case with other cases (external sources) or based on imputation methods such as mean – median – mode substitution, nearest neighbour interpolation, various regression techniques, etc. (OECD, 2008; Glasson-Cicognani and Berchtold, 2010). Although imputation can help minimize bias, it should always be kept in mind the incompleteness of data because imputed data are not real data.

Given this background, the suggested sustainability assessment methodology …"

Comments:
"However, it would be really useful to have used a worked example(s) throughout the paper because the theory seems good but without examples until the very end makes it a lot to remember." (A. Donnelly)

"I think the paper would be more convincing if it took a more example-based approach. It does not appear to be specific to natural hazards. Even if the authors used a hypothetical natural hazard and worked through the framework it would be more realistic." (A. Donnelly)

"Equations 1 - 7 would be more useful if they had worked examples rather than waiting until section 4." (A. Donnelly)
"A major drawback is the use of a virtual case study, which does not allow any validation of the approach. This may be in line with a 'discussion' paper but needs better justification." (Anonymous referee #1)

"Why virtual data has been chosen and not real test cases; this is somehow awkward." (Anonymous referee #1, supplement)

To be inserted P218 L27 after "management."

For a better understanding of each step of the methodology, the paper presents a pedagogical example to illustrate calculations regarding each equation. This example serves also as case study to demonstrate how the whole methodology may be used as decision-support tool for selecting the most sustainable risk management decision.

To be inserted P220 L17

Assuming that for a given alternative, a parameter value V_{opt} is 21 while reference value V_{ref} is 13, the ImpR of this alternative relatively to the parameter equals to 61,53%.

To be inserted P222 L5

According to the previous example and the adopted scale, ImpS equals to + 3 because impacts induced by the alternative are beneficial (+) and they belong to the interval [0.75 ; 0.5[.

To be inserted P225 L3

Table[1] 4 presents some impact scores values with the resulted IPIs, and CPI of the sample alternative.

Table 4: An example of IPI and CPI values calculated from some ImpS values

Parameters performances	Indicators performances	Criterion performance
$ImpS_{111} = 0$	$IPI_{11} = 0$	$CPI_1 = 0{,}666$
$ImpS_{112} = 0$		
$ImpS_{121} = 0$	$IPI_{12} = 2$	
$ImpS_{122} = 2$		
$ImpS_{123} = 3$		
$ImpS_{124} = 3$		
$ImpS_{131} = 1$	$IPI_{13} = 0$	
$ImpS_{132} = -1$		

[1] Please notice that the order of tables will change

Source: authors

To be inserted P227 L3

If the sample alternative obtained the following values: $CPI_1 = 0.67$, $CPI_2 = 0.6$, $CPI_3 = 0.05$, $CPI_4 = 0.16$, and $CPI_5 = 1.88$, its global sustainability shown by SPI will equal to 0.67.

To be inserted P228 L4

For the sample alternative, SA = 52.7 and SPR = 1.38 as SA (reference situation) = 38.04.

P229 L12 Replace "This case was designed to be as close as possible to a real case study."

With "The core goal of the paper is to present and explain how useful could be the proposed framework. A pedagogic approach is adopted for the case study through a theoretical situation describing sustainable decision-making process to manage a hypothetical natural hazard on a given territory. However, the case was designed to be as close as possible to a real case study."

Comment:

We chose to use this type of case study because at this stage of drafting the methodology, we suppose that it is necessary to test all possible manipulations. This part of the work seems important and would not be feasible in situation of missing data that we will inevitably face when working on a real case. However after the validation of the methodology, the next step of the work will focus on a real case study in order to identify difficulties related to its application and to refine the methodology based on its identified improvement trails.

Comment: "It would be really useful to give examples of some of the indicators and why specifically they were chosen. It would also be useful to know what criteria the experts used to judge the relevance of the indicators. The final list of indicators and suggested parameters are indeed helpful but in my opinion require some discussion in the text." (A. Donnelly)

To be inserted P217 L14 after "knowledge."

Indeed, as the main target of indicators is to reduce the complexity of information needed by decision-makers, they should be "*measurable, scientifically valid and capable of providing information for management decision-making*" (Donnelly et al., 2007). Sustainability parameters have to fulfil the following requirements. They have to be: (1) relevant by showing what is essential to be known, (2) easy to understand by every actor of risk management even if he is not an expert, (3) reliable so that the information they provided will

be trusted, and (4) based on accessible data so that the information will be available when it is needed. However, indicators "*can be developed independently of available datasets*" (Donnelly et al., 2006) and doing that could help drive production of needed data.

The experts when selecting the components of the proposed grid checked all the retained indicators in the light of those requirements. Indicators were retained when they meet the majority of requirements (that to say three), which inevitably include the criterion "relevant" expressing the importance of the indicator in relation to sustainable risk management.

To be inserted P218 L1 after "… et al., 2010)."

In accordance with the sequence of tools through which impacts of a plan or policy can be measured (Donnelly et al., 2006), and in the hierarchical structure of the proposed assessment grid, criteria represent "objectives", indicators represent "general targets" while parameters are the simplest measurable features that can be used to assess and monitor a performance. Commonly indicators are composite indices made of a wealth of complex, and detailed information aggregated in unique understandable information.

To be inserted P218 L9

Regarding the criterion "*environmental sustainability*", the objective is to preserve and maintain ecological heritage. Related general targets are, at one hand, to reduce environmental vulnerability to risk, and at the other, to avoid strategies that would induce significant adverse effects on ecological heritage. Thus, the retained indicators are: "*impact on the environmental vulnerability*" and "*environmental impacts*". To develop the parameters on which the indicator "*impact on the environmental vulnerability*" can be split to, the stakes that, when situated in hazard prone zones, could contribute to the environmental sustainability of a territory were identified. Some possible features to take into account are: areas of protected natural habitats, sites with pollution potential, drinking water sources, wastewater treatment plants, volume of wastes probably resulting from risks that need to be disposed of, etc.

"*Technical and functional effectiveness*" aims to help measure a decision success in achieving damage limitation. To attain this objective, it seems appropriate to consider, as indicators, hazards characteristics (intensity/magnitude, spatial extend, frequency, speed of onset, etc.), structural or physical vulnerability (typology, value and sensitivity of exposed, assets), and the potential of creation or exacerbation of existing or new risks (both hazard and vulnerability measuring variables).

With the "*social sustainability*" objective, through the general target of "*quality of life*", some chosen measurable features are: average travel time/distance to work/amenities (to show transportation trends induced by the decision), number of amenities such as shops, health care centres, recreational public spaces, etc. (because urban amenities facilitate social contact), etc.

The multidisciplinary approach developed through INCERDD project help ensure less bias in the decision-making process by encompassing all dimensions of sustainability with a broad spectrum of influential variables. …

Comment: "Section 3.3.1 How is the 'desired level of sustainability' determined for each parameter? This is very important because putting a value on sustainability is very complex." (A. Donnelly)

To be inserted P219 L9 after "Cauwenbergh et al., 2007)."

This value could be established on empirical, regulatory, or scientific basis in accordance with the related field, and specificities of the territory (Acosta-Alba and van der Werf, 2011).

Comment: "The authors propose a variety of indices, such as the SPI, SPR and SA etc. It is not that much clear how they relate to each other, and what they tell us – and how policy and decision makers may apply them. It may be helpful to provide a less detailed (technical) discussion of the indices, but additionally provide a justification on the purpose of these indices." (Anonymous referee #1)

To be inserted P226 L13 after "effects."

Maximum net gains leads to an overall score for sustainability that incorporates all criteria in order to be able to rank alternatives and select the optimal one.

To be inserted P228 L4

Hereby, two ways of maximum net gains measurement have been proposed to give the opportunity to decision-maker to choose depending on the manner one wishes to present the results. As a composite index (one of the most common approaches to assess overall sustainability), SPI allows for a quick assessment of the absolute sustainability performance of a given policy. Besides, the readability of sustainability profile decreases with the number of considered criteria and alternatives. With the example of Figure[2] 4, it is impossible to precisely determine the biggest area among the four alternatives. To avoid a potential

[2] Please notice that the order of figures will change

misinterpretation, SA and SPR quantify the absolute and relative (comparatively to reference situation) values of the sustainability profile.

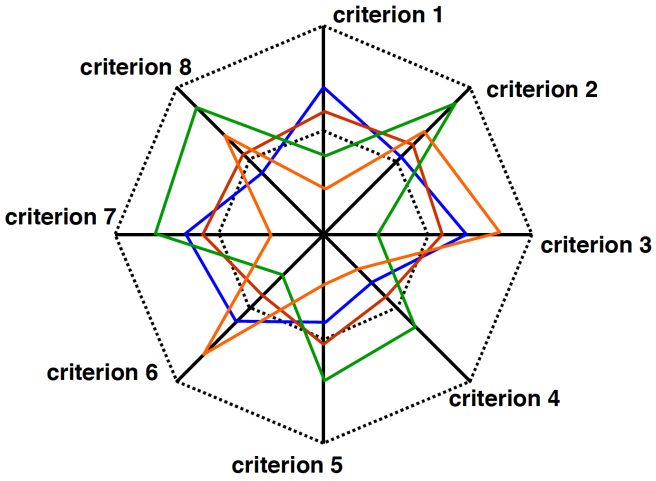

Figure 4: Spider diagram representing four alternatives and eight criteria

To be inserted P228 L7

The major weakness of maximum net gains estimation is the compensatory logic. In the case that the decision-maker does not admit compensability, following rules could be applied according to his specific goals.

Comments:
"Materials and methods P213L20-21 this is an important point. Could the proposed framework be used to retrofit sustainability into previous management decisions?" (A. Donnelly)

"Discussion Would it be possible to retrofit sustainability measures to old decisions?" (A. Donnelly)

To be inserted P236 L12:

Even the framework is proposed to assess the sustainability of future decisions; it could also be a retrofit guide for sustainable update or adaptation of existing decisions. It could help first indicate their strength, weakness, and failures. Then, sustainability merits of predetermined retrofit alternatives could be assessed in view to select the most beneficial ones. Retrofitting sustainability into previous decisions could, at one hand, help correct their lacks by integrating aspects formerly ignored, and at the other, be a strategic way to enhance sustainable risk management as it could help gain time, resources, etc.

Comment: "Results If sustainability requires precise data and this does not exist – what is the point of carrying out a sustainability analysis?" (A. Donnelly)

Comment:

Carrying out the sustainability analysis of decision, in the context of INCERDD project, is primarily a reflective process. It aims to lead to a solid scientific basis for determining strengths and weaknesses of decisions, identifying priorities, stimulating critical debate as well as consultation, gaining consensus, etc.

Comment: "There should be some kind of an overall score for sustainability that incorporates all components in order to be able to select the 'best' alternative. Otherwise, how can a planner select which alternative is the best one i.e. which is better a high score for environmental sustainability or a high score for economic sustainability?" (A. Donnelly)

Comment:

It has been recognised that the complexity of sustainability assessment is such that trade-offs, whereby gains in one dimension are made at the expense of losses in another, are inherent aspect of the process. We identified two types (compensatory and non compensatory logic) of rules, which planners can use.

When a planner decides to adopt a compensatory logic, he should use the maximum net gains rule for estimating an overall composite (absolute or relative) score and then classify alternatives according to their score.

When the planner does not permit compensability among the five considered dimensions, an option is to refer to rules (2 to 4: maximum positive performance, minimum negative performance, respect of critical threshold value or veto) that allow him to select "best" alternative based on performance along each dimension with absence of preference for any dimension to be consistent with sustainability vision.

Further works will also explore Multi-criteria approach to rank alternatives and select the "best" one.

Comment: "Table 4 is missing units for all parameters." (A. Donnelly)

Comment:

The units will be added for each parameter as follows: Total annual costs (€), Average annual avoided damage* (€), GDP per capita (€), Total number of jobs (#), Unemployment rate (%), Total number of enterprises (#), Annual turnover of economic activities (€).

Updating references

To be inserted P237 L12

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To be inserted P237 L15

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To be inserted P238 L3

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To be inserted P238 L23

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To be inserted P239 L17

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To be inserted P239 L22

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To be inserted P240 L7

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To be inserted P241 L5

UNISDR available at: http://www.unisdr.org/we/inform/terminology

Comment: "The text in the diagrams in Table 7 are too small to read." (A. Donnelly)

Replace the previous table with the following: