Reply to RC2: Thank you for your valuable comments and questions to the paper in the review, as well as the detailed comments given within the paper itself. We tried to make the paper as short as possible, but after the review, I realize that the steps in the methodology were a bit scarcely described and justified and that some parts need to be extended to better explain and reason the choices made. In addition, the paper applies and refers to different references with slightly different use of terminology. Terminology used in the paper will therefore be reviewed and uniform use ensured. Replies to your overall comments and questions follow below:

1a) The paper deals with risk related to interaction between natural phenomena and critical infrastructures which is a key issue in risk management process. The authors propose a two level empirical methodology to assess this risk. Despite of its operational interest, the major issue is that the whole methodology is fully empirical with very few references to existing works in such domains. Therefore, despite of some good ideas, it is quite difficult to trust in the method and its results : many subjective choices are done without being clearly explained and described. Using and applying the method would be difficult and it is now clear to see how this process can be generalized.

Semi-quantitative, indicator-based methods will necessarily require use of (expert) judgment and accordingly be associated with subjectivity and uncertainties. Indicators are commonly used in vulnerability and resilience assessment, since it is often difficult to quantify vulnerability and resilience in absolute terms without any external reference with which to validate the calculations. Indicators are typically used to assess relative levels of vulnerability and resilience either to compare between places, or to analyse trends over time. In this paper, an indicator-based approach is combined with an initial quantitative categorization, based on explicit quantitative criteria to limit the uncertainty and effect of subjective judgment on the results. The limitations of the method, sources of uncertainty and needs for calibration will be discussed in the discussing session. Uncertainties are related to properties of indicator-based methods in general (as mentioned above); and to the scope of the method, which are applicable for different infrastructure sectors and uses generic factors for infrastructure vulnerability.

Some explanations to the indicator –based part of the methodology, for your information:

The chosen indices reflect different aspects of vulnerability and resilience of infrastructures. The choice of generic indicators relevant for the probability of infrastructure malfunctioning and for the societal consequences of the malfunctioning infrastructure is in accordance with what is documented in literature as reviewed in the Background-section (Section 3) . The ranking of the indicators are based on their relevance for the probability of a malfunctioning of the infrastructure or for the societal consequences of the malfunctioning. The optimal realization of an indicator (i.e. it's lowest possible contribution to vulnerability) and the least favorable (most unfavorable) realization of an indicator (i.e. its highest possible contribution to the vulnerability) follows implicitly from the reasoning of the choice of that specific indicator. For instance, for the "Redundancy/substitutes" – indicator, the optimal realization is if there exists (or is possible to establish) an alternative that provide the same service as the analysed piece of infrastructure. The most unfavorable realisation is if there are no other way to provide the same service as the analysed piece of infrastructure. The optimal realisation of an indicator is given score 1, while the most unfavorable realization is allocated a score 5. Based on the description of these extremes, one could then leave to the user to decide a score between 1-5 where 1 corresponds to the optimal realisation and 5 to the most unfavorable realisation. However, to limit the use of subjective judgment of the user and to make the method easy to use, 3 levels between the two extremes were also defined, with corresponding descriptions of what the realisation of the indicator within each level implies. The user need to choose between integer values 1-5 according to the description.

A subjective choice left to the user is the choice of weights for each indicator. The weights should e.g. be chosen in accordance with the type of infrastructure, site-specific factors and conditions etc. (The indicators are aggregated through a weighted linear average).

1b) What is the added value in comparison with decision making methods, safety analysis already used to assed criticality of interdependent infrastructures ?

There is no all-encompassing method available to analyse all aspects of critical infrastructures, but different methods serve different purposes and have different advantages (and disadvantages). The advantages with use of the proposed method is that it is generic and has a very broad scope (applicable for assessment of socio-economic risk associated with malfunctioning in different infrastructure sectors), it could be used by local stakeholders as a supporting tool when performing the municipal risk and vulnerability analysis, it is very easy to use, and gives results that are easy to communicate (a risk level). Indicators are useful for reducing complexity, measuring progress, mapping and setting priorities and they could serve as an important tool for decision makers. It serves well the purpose of being a screening tool for scenarios of natural events threatening critical infrastructure in a municipal risk and vulnerability analysis, even if is not feasible for more detailed studies of the risk.

Advantages of the method will be discussed in the discussion section, extended according to suggestions from RC1.

1c) Some example of issues in the text relate are described below: 1. Insufficient definition of concepts used (risk, hazard, phenomena, uncertainty on risk, potential risk, societal vulnerability ? : : :). Some definitions are contradicting with state of the art : this has to be changed or discussed completely. Why are new definitions proposed ? what do they correspond to? How are they justified ?

I agree that issues related to the terminology need to be improved. A separate chapter discussing terminology and scope will be included. (i.e by extending the existing chapter 2.) It should be clearer that the focus of this method is on the indirect losses, focusing on loss of stability for the exposed population. It should also contain the different dimensions of vulnerability referred to in the paper, i.e., physical, social and economical.

I assume, based on comments within the paper, that the "definitions contradicting with the state of the art" – issues are referring to Figure 2 and the decomposing of risk into the probability/frequency of infrastructure malfunctioning caused by natural hazard and the societal consequences following from the malfunctioning infrastructure. The figure shows that risk could be decomposed into probability and consequence as in traditional risk definitions, but a clarification of what the probability and consequences encompass is needed. The methodology presented in this paper is adapted to be in accordance with the guidelines of the Norwegian Directorate for Civil protection, DSB(2014). In these guidelines, the addressed probability is the probability of an adverse event involving material destruction, i.e. not the probability of the natural event. The adverse event could e.g. involve a natural event leading to a damage on the infrastructure (in this paper: destruction leading to malfunctioning of infrastructure). The considered consequences are the societal consequences of the adverse event, here: the malfunctioning infrastructure. Similar subdivisions are found in DSB(2014), Lenz(2009), IRGC(2007), and http://www.nap.edu/read/6425/chapter/4#16: "It is useful to distinguish between the *physical destruction* caused by natural disasters to human beings and property, and the *consequences* of that destruction."

This also corresponds to subdivisions of the strategies for risk reduction into strategies that minimise the probability of infrastructure failure, and those that minimise the negative effects of a failure, (IRGC, 2007). It will be made clearer that the considered risk assessment focuses on the indirect losses and the consequences referred to are in terms of the societal value "Stability".

2. Studied infrastructures are not described

The infrastructure sectors studied/applicable for in the method are Electric power supply; Transportation; Urban water supply and wastewater treatment; ICT systems. However, the focus will be on the three first, as EWE and natural hazards are less relevant direct cause of malfunctioning for ICT systems. These infrastructures were chosen as they provide the essential functions and services of a society. They also share a number of similarities.

Information about this will be included into the paper.

3. Figures are not informative (eg figure 1 , what about existing cause effect consequence diagram)

Figure 1 has the same structure as simple cause and effect diagram – and the cause and effect diagram used by DSB(2014). The main purpose of the figure is to define the scope and terminology. The terminology will be reviewed and if possible simplified and unified. Also figure 2 will be improved according to suggestions form RC 1.

4. Not enough references to existing frameworks related 1) to safety and reliability

analysis (functional analysis, failure modes etc: : :) 2) to classical decision-aiding

methods such as multicriteria decision making methods : proposed aggregation is

a weighted average, why are there no references to classical aggregation methods

(MCDM)?

Paper touches upon several broad topics such as, vulnerability assessment of critical infrastructure, risk assessment, assessment of direct and indirect losses. It might be too detailed for the scope of the method to describe safety and reliability analysis as well as decision theory, but I will look into framework that could be shortly referred to and discussed briefly.

5. Some keys issues about choosing criteria are not described

More details about the ranking criteria will be added. See comment about ranking criteria in point 1a) as well as description in reply to RC1, point 5a):

6. Some tables are not understandable (eg table 5)

I am not sure which part Table 5 is not understandable, but assume that the comment is referring to the ranking criteria? See explanations given to point 1a).

7. The calculation process robustness itself is not tested and described. The adjustment are not understandable. How can vulnerability be used to modify the frequency of a phenomenon ?!!! "The physical vulnerability score is used to adjust the probability category assessed in the initial categorization and the societalvulnerability score is used to adjust the consequence category assessed in the initial categorization"

Calculation process description and reasoning will be included.

Adjustment of the probability of infrastructure malfunctioning:

The adjustment represent the step from the P(natural event), used in the initial categorization to P(infrastructure malfunctioning caused by natural event), which is assessed in the final categorisation. The idea behind this adjustment was to use the physical vulnerability index as a proxy for the conditional probability of infrastructure malfunctioning given/under condition that the natural event has occurred.

P(infrastructure malfunctioning caused by natural event) = P(natural event) * P(infrastructure malfunctioning|natural event)

If the infrastructure has a high physical vulnerability index, then the conditional probability P(infrastructure malfunctioning|natural event) is high, i.e. approximately 1; and thus we get the equation:

P(infrastructure malfunctioning caused by natural event) ≈ P(natural event)

Then the intitial hazard class is kept. (The frequency of the natural event is used for initial categorization of the frequency of the infrastructure malfunctioning)

On the other extreme, if the physical vulnerability index is very low; the conditional probability, P(infrastructure malfunctioning|natural event) is low, e.g. in the order of 0.1, then the relation yields:

P(infrastructure malfunctioning caused by natural event) ≈ 0.1 * P(natural event)

Accordingly, a multiplication of the probability with 0.1 corresponds to a reduction in probability category with 1-2 probability categories, i.e. P(infrastructure malfunctioning caused by natural event) is 1-2 probability categories lower than P(natural event). The step from the P(natural event), used in the initial categorization and P(infrastructure malfunctioning caused by natural event) assessed in the final categorization is the background for adjustment of the probability categories.

Adjustment of the consequence classes:

Similarly, the number of people affected by the malfunctioning infrastructure could be higher or lower than the number of infrastructure users, dependent on how the situation is handled and how important the malfunctioning infrastructure is for the society. The socio-economic vulnerability index is a proxy for the societal capacity to cope with malfunctioning infrastructure. Accordingly, if the socio-economic vulnerability index is low, then the number of affected people will be lower than the number of infrastructure users, e.g. if the infrastructure malfunctioning is managed well and substitutes for the service provided by the malfunctioning infrastructure established. However, if the socio-economic vulnerability index is high, then the number of affected will be higher than the number of infrastructure users, e.g. if there are large cascading effects.