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Living with landslide risk in Europe: Assessment, effects of global change, and risk management strategies

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Methodology for evaluation of the socio-economic impact of landslides (socio-economic vulnerability)

Work Package WP2.2 – Vulnerability to landslides

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SUMMARY

Vulnerability assessment, with respect to natural hazards, is a complex process that must consider multiple dimensions of vulnerability, including both physical and socio-economic factors. Physical vulnerability is a function of the intensity and magnitude of the hazard, the degree of physical protection provided by the natural and built environment, and/or the resistance levels of the exposed elements. However the vulnerability of a society is also related to factors such as demographics, preparedness levels, memory of past events, and institutional and non-institutional abilities for handling natural hazards. Physical models are particularly useful for estimating direct impacts, while socio-economic models more accurately predict indirect and intangible losses, i.e. losses due to long-term effects of the hazard event.

This report deals with the socio-economic vulnerability related to landslides. After a thorough literature review, it presents an indicator-based methodology to assess vulnerability levels. The indicators represent the underlying factors which influence a community's ability to deal with, and recover from the damage associated with landslides. The proposed method includes indicators which represent demographic, economic and social characteristics as well as indicators representing the degree of preparedness and recovery capacity. The purpose of the indicators is to set priorities, serve as background for action, raise awareness, analyze trends and empower risk management.

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CONTENTS

1 INTRODUCTION

1.1 DEFINITIONS AND TERMINOLOGY

The use of terms in this report adheres to the terminology presented in the SafeLand Project Handbook (Deliverable D8.1). Definition of some key terms is presented below:

- Elements at risk – The surrounding environment, population, cultural sites and structures, buildings, engineering works and other infrastructure in the area potentially affected by landslides that are directly at risk. Furthermore, economic activities and public services utilities in the region are also at risk of being adversely affected.

- Risk – A measure of the probability and severity of negative effects to health, property and/or the environment. Risk is often estimated by the product of probability consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form, i.e. as a two-dimensional quantity, where probability and consequence are the two dimensions respectively.

- Vulnerability – The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide. Vulnerability could also refer to the propensity to loss (or the probability of loss), and not the degree of loss.

In this report several terms relevant for socio-economic vulnerability assessment will be used according to the interpretations below, this also includes another definition of vulnerability:

- Vulnerability – characteristic of a system that describes its potential to be harmed.
- Indicator – A variable which is an operational representation of a characteristic or quality of a system able to provide information regarding the susceptibility, coping capacity and resilience of a system to an impact of an, albeit ill-defined, event linked with a hazard (of natural origin) (Birkmann, 2006).

1.2 PERSPECTIVES ON SOCIO-ECONOMIC VULNERABILITY

Vulnerability related to natural hazards is studied by a variety of disciplines, including social, economic or geographical sciences, in engineering as well as in climate change and natural hazard research. Due to the different foci and wide range of methodologies being applied in vulnerability studies, it is virtually impossible to agree on a precise cross-disciplinary definition of the term. According to a review made by Thywissen (2006), more than 15 and 30 definitions are given for risk and vulnerability respectively. The definition in Section 1.1 is well suited for professionals performing quantitative vulnerability assessments. As vulnerability is described as a degree of loss (s. definition in section 1.1.), potential losses need to be categorized and described. A scheme to categorize flood losses was developed by Smith and Ward (1998). They distinguished between direct and indirect and further tangible and intangible flood losses. According to their framework direct tangible losses comprise the physical damages such as destruction of houses and infrastructure, while direct intangible losses include the loss of life or health problems related to a flood disaster. Indirect tangible losses are for example the disruption of traffic and supply chains, which have shown to be a significant contribution to the overall loss, and often last for a long time after an event. Examples for indirect, intangible losses are an increasing vulnerability or a migration from the exposed area. The scheme can be considered suitable also for other hazards, and therefore can be applied to landslide risk and vulnerability assessment as well.

Socio-economic vulnerability is related to parts of these losses. Two principally different interpretations of the socio-economic vulnerability can be made:

1. Socio-economic refers to the *type of elements at risk* to be considered. Intangible losses belong to this interpretation of socio-economic vulnerability. While studies focussing on “technical risk” often try to estimate the number of people killed or the economic value of assets destroyed as a direct consequence (during or immediately after the landslide), a study looking at socio-economic risk may want to include vulnerability of a number of other factors whose value cannot easily be counted or valued in economic terms, at least not in the short term. Such factors or elements at risk may for example be (but are not limited to)
    - Socio-ecological: ecosystem services and functions important for human well-being, livelihood and economic activity (e.g. tourism), etc.
    - Cultural: social structures, historical material, sites of particular cultural value/importance, transforming power of mega disasters in terms of cultural change, etc.
    - Institutional: loss of both human and material resources related to the functioning of public institutions including health, law enforcement, education and maintenance. Such loss typically can lead to moral breakdown, chaos, anarchy as well as breakdown of economic activity and it may take a long time to restore the institutions both formally and informally/with regard to peoples trust in them.
    - Physiological or psychological: emotional impacts inflicted as the result of permanent disabilities or significant personal losses, such as friends or family members.

2. Socio-economic refers to *underlying socio-economic factors in a society causing or producing vulnerability*. In this interpretation of socio-economic vulnerability the focus is on tangible losses. While studies focussing on “technical risk” for example will try to estimate the engineering quality of buildings or infrastructure and its ability to resist direct damage during a landslide event (for example using fragility curves), studies looking at socio-economic vulnerability may try to look deeper into the fabric of society to assess its preparedness and coping/adaptive capacity. A wide range of factors can be considered, and there is no agreed methodology that covers all aspects of socio-economic vulnerability. A review of methodologies can be found in

Birkmann (2006). An example set of factors based on four main indices believed to influence socio-economic vulnerability at country level is presented by Cardona (2005):

- Disaster Deficit Index (DDI; expected financial loss and capacity). The key factors describing economic resilience are insurance and reassurance payments, reserve funds for disasters, aid and donations, new taxes, budgetary reallocations, external credit and internal credit.
- Local Disaster Index (LDI; cumulative impact of smaller scale natural hazard events). A uniform distribution of disasters in the area under consideration gives a high value, whereas a high concentration of disasters in a low number of places gives a low value.
- Prevalent Vulnerability Index (PVI; composed of exposure, socio-economic fragility and lack of social resilience). Each of the three components has eight sub-indices. The indices are for example related to population and urban growth, poverty and inequality, imports/exports, arable land/land degradation, unemployment, debts, human development index, gender inequality, governance and environmental sustainability.
- Risk Management Index (RMI; disaster management/mitigation strategies/systems). This index is composed of four factors estimating capacity related to risk identification, risk reduction, disaster management and financial protection. Sub-indices are related to the quality of, amongst others, loss inventories, monitoring and mapping, public information and training, land use planning, standards, retrofitting, emergency planning and response, community preparedness, reconstruction, decentralised organisation and budget allocation.

1.2.1 Applications of socio-economic vulnerability models

Taking the second perspective above, i.e. socio-economic refers to *underlying socio-economic factors in a society causing or producing vulnerability*, the four “socio-eco entry points” in Figure 2 illustrate four potential applications of a model developed for socio-economic vulnerability assessments to natural hazards. The model shown in Figure 2 can be applied to any natural hazard; however, it can be easily modified to a specific hazard by selecting the appropriate indicators for the vulnerability assessment. The general framework of this model can be defined as follows:

1. Socio-economic models can be used to provide estimates for physical damages. In this case the indicators must be selected to estimate the quality of construction elements used in the region.
2. Socio-economic models can be combined with fragility curves (e.g. for construction elements/building) to estimate the number of casualties expected from a hazardous event. In this situation the indicators must be chosen to provide details on the demographic characteristics of the population as well as the regional levels of preparedness to, and knowledge of, landslides.
3. Socio-economic models can be used to assess direct casualties and economic losses.
4. Socio-economic models can be used to assess indirect casualties and economic losses.

In this report a socio-economic model has been developed that uses a structure similar to that of model 4 above, focused primarily on assessing indirect losses.

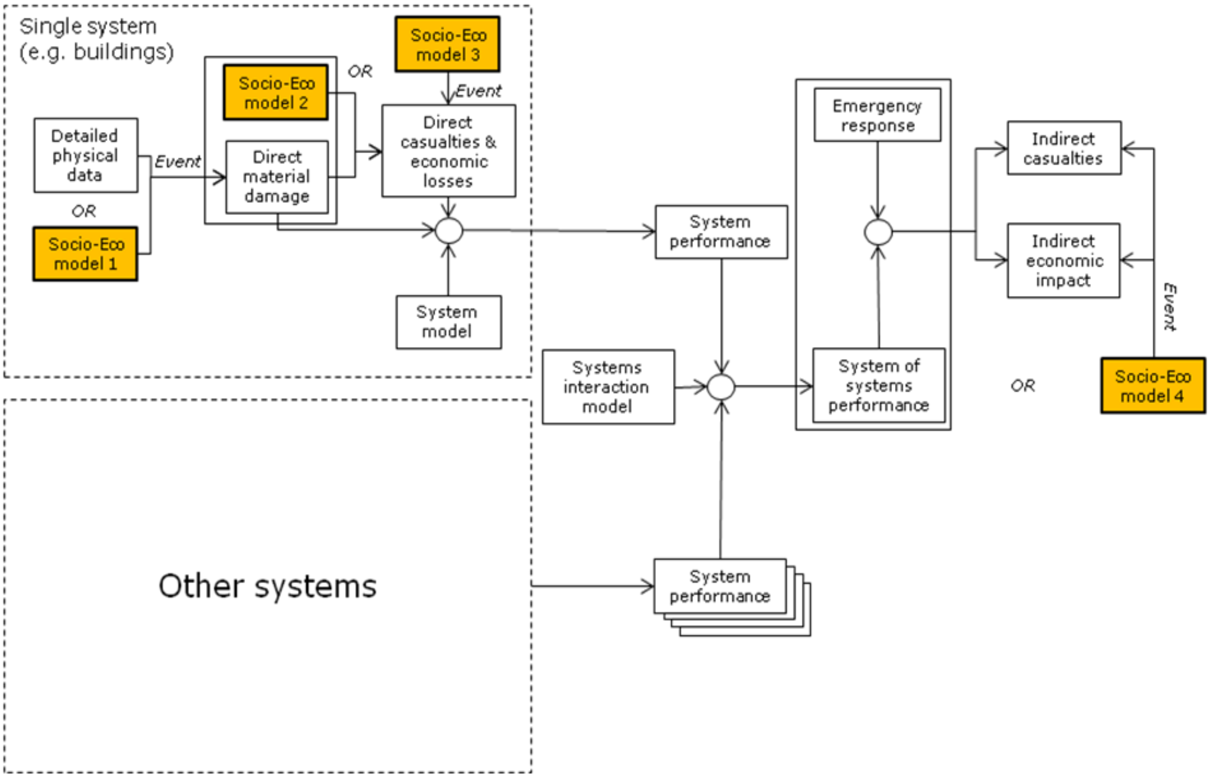

Figure 1 Some principles for how socio-economic models can replace and/or interact with physical vulnerability models. Developed as part of the Syner-G EU project (unpublished).

The structure and content of the model will depend on the spatial scale/organisational level of the analysis. A local study, perhaps at the household level, will require different indicators than a national study both due to differences in data availability and that the indicators must have policy relevance to the decision makers who will use the results of the study. Depending on the loss data availability, as well as whether or not a full risk model is developed; calibration can be performed to obtain absolute vulnerability estimates rather than relative vulnerability numbers.

1.3 DATA AVAILABILITY AND VALIDATION

The link between indicators and vulnerability, as defined at the top of this chapter, can be established through calibration granted that data is available for the hazard level, exposure, losses and socio-economic factors in question.

If appropriate data for validation and calibration are not available, socio-economic factors can be combined using weights determined, for example through an expert judgment process, to produce vulnerability indicators. In this case the result will not be numbers/indicators for absolute vulnerability, but rather best estimate indicators that can be used to judge relative vulnerability between different groups or geographical areas, for example between countries or regions. Such relative factors can be useful in a policy perspective in order to optimise use of limited risk mitigation resources, and can also be used to measure trends or indicate ex-post effects of mitigation policies.

Data availability depends on the geographical region and spatial scale used in the vulnerability study. International actors including UN agencies and World Bank keep databases of relevant socio-economic indicators at national and sometimes sub-national levels, and Desinventar and CRED are examples of databases that hold landslide inventories and loss data. At the sub-national level, statistical bureaus or government institutions responsible for disaster management can provide relevant data, whereas at the community level targeted surveys or data collection efforts may be carried out to produce the necessary data on coping and adaptation capacity. For more information about data sources for indicators it is referred to Section 2.4.

Data scarcity has proven to be a limitation in socio-economic vulnerability studies, and will often determine which type of vulnerability indicators can be included in the model. In order to validate complex models, large resources should be assigned to data mining, quality control and data cleaning efforts. In some cases a complete calibration to obtain absolute risk estimates is not possible due to poor quality of historical data on hazard events and related losses.

1.4 SCOPE OF THIS REPORT

The work presented in this report focuses primarily on socio-economic vulnerability from the second perspective in Section 1.2 (i.e. by considering underlying socio-economic factors influencing vulnerability such as preparedness and coping capacity). At spatial scales ranging from global/national to local, available methodologies linking underlying socio-economic factors influencing landslide vulnerability are reviewed and presented. Except for smaller countries, typically landslide prone island nations, landslides rarely have socio-economic consequences at global or national levels. The most relevant scale for landslides will therefore in most cases be local scale. Thus, this report focuses on methodologies applicable at the local scale or, for methodologies which consider organizational levels rather than geographical scales, the focus will be on methodologies dealing with community vulnerability.

Secondly, there are several time frames for considering vulnerability: immediate impact, emergency response period and recovery period. The physical vulnerability assessments cover the majority of direct losses during and immediately after the impact whereas social vulnerability assessments also focus on the recovery period, which again encompasses indirect and intangible losses. However, intangible losses are especially hard to measure as they are primarily concerned with the psychological effects felt by those affected by the landslide event. Therefore, this report will focus mostly on the indirect losses.

Finally, socio-economic vulnerability is indicative of social and economic fragilities and the partial or total inability of a region to cope with, and recover from, landslides. Often, many indicators of socio-economic vulnerability are independent of the type of hazard, therefore a literature review of existing vulnerability models that study natural hazards in general, or even other types of disasters such as floods, are relevant for landslide models and were used as guidelines for the development of the proposed vulnerability model in this report.

1.5 OTHER PROJECTS

There are several international projects currently dealing with socio-economic vulnerability assessments related to landslides. Two key EC projects are:

1. **Methods for the improvement of vulnerability assessment in Europe** (MOVE, 2010)
   This is a collaborative project composed of various organizations and institutions throughout Europe. It is concerned with vulnerability analyses for a wide range of natural hazards, including landslides, floods, droughts, earthquakes, temperature extremes, wildfires and storms. The project provides a generic vulnerability framework that can be applied to any region, regardless of scale and hazard type. The framework decomposes vulnerability into exposure, susceptibility/fragility and lack of resilience. Six dimensions of vulnerability are described: physical, environmental, social, economic, cultural and institutional. The methodology was tested in seven case study regions throughout Europe analysing different hazards and different dimensions of vulnerability. While this objective of the MOVE project is much broader in scope than that of SafeLand, there is some overlap. For instance, they consider socio-economic indicators in their models, many of which are applicable to landslides, and at least one of their case study investigations is focused on landslides.

2. **Enhancing resilience of communities and territories facing natural and na-tech hazards** (ENSURE, 2010)
   The ENSURE project is similar in scope to that of MOVE as it assesses both physical and socio-economic vulnerability with respect to multiple types of hazards, at multiple scales. However, the ENSURE project goes on further to assess the vulnerability (and risk) of NaTech (technological disasters triggered by natural disasters) hazards in addition to natural hazards and applies their model to regions within, as well as outside of, Europe.

Other EC FP7 projects dealing with the socio-economic vulnerability assessment at different degrees are:

- Syner-G: Systemic Seismic Vulnerability and Risk Analysis for Buildings, Lifeline Networks and Infrastructures Safety Gain
- ConHaz: Cost of Natural Hazards
- Mia-Vita: Mitigate and assess risk from volcanic impact on terrain and human activities)
- MATRIX: New methodologies for multi-hazard and multi-risk assessment

2 GUIDELINES FOR ANALYSIS OF SOCIO-ECONOMIC VULNERABILITY

The most common means of assessing socio-economic vulnerability is with indicator-based models. The indicators serve as inputs into an explicit vulnerability model and the choice of model and corresponding indicators depends on the scale and site-factors, data availability as well as the overall purpose and target audience/users of the vulnerability assessment. In socio-economic vulnerability assessments of landslides, the indicators represent the underlying socio-economic factors in a community which influence their ability to deal with, and recover from, the damage associated with landslides.

2.1 SCALE AND LEVEL

In the following the term *scale* is used to describe the geographical scale or spatial extent being considered, while *level* refers to the organisational unit, i.e. individual level, household level and community level.

The impacts of small and recurring events are often overlooked at the national level causing the problems associated with each event (e.g. damage to the surrounding environment, infrastructure, etc.) to accumulate at the local level - as is common in the case of landslides. There are methodologies available to assess vulnerability and risk at various scales depending on the issue addressed in each case.

National level aggregated variables may facilitate the identification of macro level actions and policies by national level decision makers (Briguglio 2003). However, indicators designed for use at the national scale would provide only a limited amount of the information required by sub-national and local risk managers and decision makers. As a result it is desirable to explore indicator systems that measure relative vulnerability and risk at both the sub-national level (e.g. provinces, states or economic regions) and urban-metropolitan levels including the districts, municipalities or localities that comprise such areas (Cardona 2003; Barbat 2003).

Although the indicators required at each level generally share some common elements, it is also necessary to use some variables specific to the scale of resolution. For example, Figure 3 illustrates a socio-economic model that uses group indicators independent of the considered scale and level. However, the base indicators are chosen and adapted to the particular spatial scale and level of decision making.

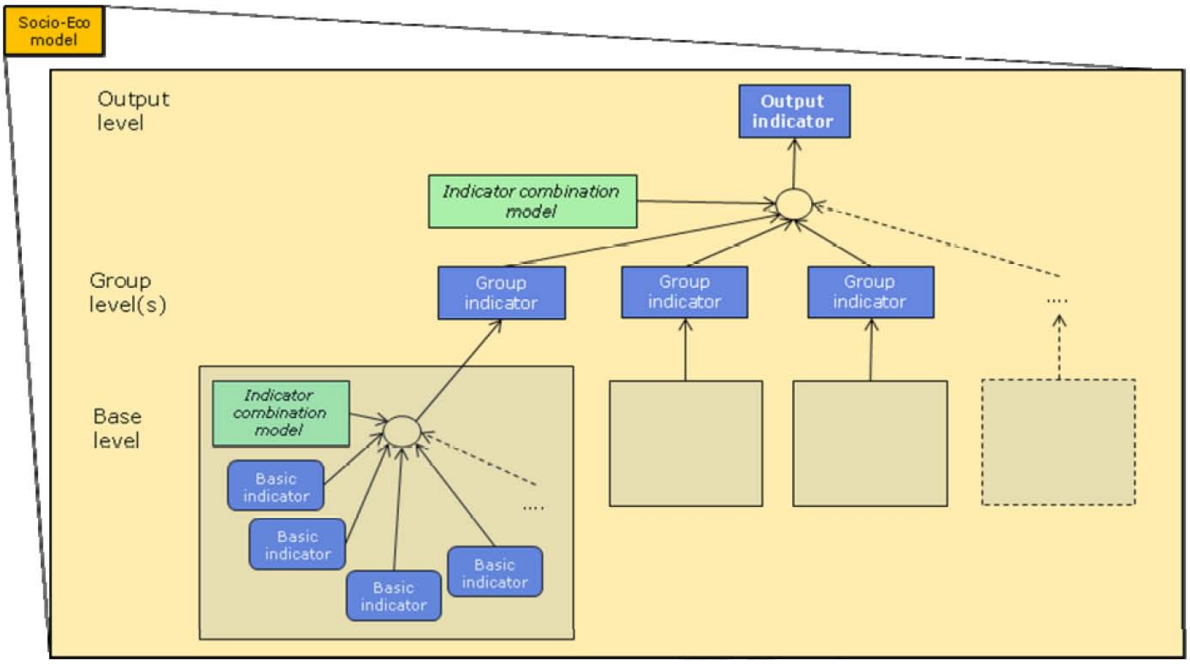

Figure 2 One potential structure for a socio-economic model.

2.2 VULNERABILITY INDICATORS

2.2.1 Purpose of indicators

The purpose of the indicators selected for the socio-economic vulnerability model is to represent the underlying socio-economic factors which influence a community's ability to deal with, and recover from the damage associated with landslides. The most important functions of indicators selected for use in these vulnerability assessments include (Birkmann, 2006):

- Setting priorities
- Background for action
- Awareness raising
- Trend analysis
- Empowerment

2.2.2 Choice of indicators

The selection of *appropriate* indicators is essential as they aid practical understanding through the simplification of reality. In general one can distinguish nine different phases in the development of indicators, (Birkmann, 2006:64):

1. Define or select goals
2. Clarify the scope of the indicator
3. Choose the indicator framework to structure the potential themes and indicators

4. Define selection criteria; i.e. how to ensure "good quality" indicators?
5. Identify potential indicators
6. Choose a final set of indicators (with reference to the criteria defined/developed at stage 3)
7. Analyse indicator results
8. Prepare and present report
9. Assess indicators performance

The whole development process is an "ideal process", which in practice is an iterative procedure of going backwards and forwards (Maclaren, 1996).

With suitable indicator selection, the model developed can provide a clear direction for the development of specific policies. Indicators can be selected with a variety of scales in mind; such as national, regional and local (King and MacGregor, 2000). For example, the following is a list of standard criteria for indicator development as developed by Birkmann (2006:65):

- Measurable
- Relevant, represent an issue that is important to the relevant topic
- Policy-relevant
- Only measure important key-elements instead of trying to indicate all aspects
- Analytically and statistically sound
- Understandable
- Easy to interpret
- Sensitivity; be sensitive and specific to the underlying phenomenon
- Validity/accuracy
- Reproducible
- Based on available data
- Data comparability
- Appropriate scope
- Cost effective

2.2.3 Types of indicators

Indicator-based vulnerability models are usually composed of many indicators, each designed to serve a different purpose. However, not all indicators are equal in significance. Some indicators consider only one aspect of vulnerability while others consider multiple aspects; these are referred to as single- and composite- indicators, respectively.

A single indicator is one that is used to measure one specific feature of vulnerability. For example, *age* is an indicator that measures the level of vulnerability expected based solely on the assumption that children and elderly persons are more likely to be harmed.

In contrast, several main constructs may be important for a specific vulnerability analysis (e.g. social network, preparedness, wealth, etc.) and rather than relying on a single indicator variable for a specific construct, the model can be improved by aggregating several indicator variables together, thereby yielding a composite indicator (Fenton and MacGregor, 1999).

Furthermore, if several indicators are dependent upon one another, it is preferable to combine them into one composite indicator. The benefits of this composite indicator are two-fold; it simplifies the model and ensures that there is no redundancy. For example, if multiple indicators were used to measure the wealth of a region, e.g. GDP per capita and unemployment rate, it would be redundant to use the results of both of these indicators in the model.

2.2.4 Proposed indicator sets

Existing indicator sets and vulnerability models are discussed in detail in section 3. However, *Table 1* from CIMNE (2009) provides a brief overview of the types of indicators commonly used for vulnerability assessments.

Table 1 Indicators used for vulnerability assessment at household and community level, CIMNE (2009).

Reference of case study/methodology		
Reference	**Level**	**Applied indicators**
Cutter et al. (2003)	Community	• Personal wealth • Age • Density of the built environment • Single-sector economic dependence • Housing stock and tenancy • Race • Ethnicity • Occupation • Infrastructure dependence
Tapsell et al. (2005)	Community	• Age • Gender • Employment • Occupation • Educational level • Family/household composition • Nationality/ethnicity • Type of housing • Number of rooms per household • Rural/urban Additionally: • Level of risk awareness and preparedness • Previous flood experience (*can be transferred to landslides or other hazards*) • Access to decision-making • Trust in authorities • Long-term-illness or disability • Length of residence (*refers to the experience and knowledge of the area, potential hazards, and possible experience from former events*)

		• Serviced by (flood) warning system (*can be transferred to landslides or other hazards*)
Steinführer et al. (2009)	Household	The following social groups within communities are more likely to need specific targeting and support: • Those with no previous flood experience (*can be transferred to landslides or other hazards*) • Those who have recently moved to an area • Those with lower social status • Those living alone without disposing of a social network outside their home • Household with long term ill or disabled members • Those living in vulnerable housing (like mobile homes or bungalows) • Older people (in particular the oldest-old not living in homes for the aged
Eakin, H. and Bojórquez-Tapia (2008)	Household	• Human resources (Age, education, adults education, adults in household) • Physical resources (total area, animal units, irrigation, tractor, land rental, farm tenure) • Financial resources (credit, insurance) • Information (technical assistance, farm organization, climate information) • Diversity (income, area in crops, number of crops)
Dwyer et al. (2004)	Household	• Income • Residence type • Tenure • Employment • English skills • Household type • Disability • House insurance • Health insurance • Debt and Savings • Car • Gender Additionally, nine qualitative indicators are mentioned (but not included in the case study): • Sense of community • Emotional capacity • Physiological capacity • Trust in authority figure • Understanding of natural hazard • Perception of risk • Capacity for change • Core beliefs and values • Preparedness and capabilities of local government

Moreover, CIMNE (2009) categorizes all indicators in one of the following groups: physical-, natural-, ecological-, technological-, social-, economic-, territorial-, cultural-, educational-, functional-, political-, institutional-, administrative-, and temporal- issues.

2.3 VULNERABILITY MODELS: AGGREGATION OF INDICATORS

2.3.1 Weighting techniques

The most common weighting methods for social vulnerability indicators include (CIMNE, 2009):

a) **Equal weighting –** all indicators are assigned equal weighting, and are thus assumed to be of equal significance.
b) **Expert judgment weighting –** according to expert opinions (e.g. literature review) weights are assigned to each indicator in relation to their degree of relevance within the model framework.
c) **Analytic hierarchy process** - a technique where a complex problem is broken down to a hierarchy of simpler sub-problems more easily analysed using expert judgment. A numerical procedure is applied to translate the sub-problem expert judgment into an assessment of the initial complex problem
d) **Principal component analysis (PCA) –** a statistical technique transforming a multi-parameter data set into a set of independent parameters ranked by how important each parameter is in representing the variation in the data.
e) **Factor analysis –** a statistical technique applied on a multi-parameter data set, finding a potentially lower number of unobserved/underlying parameters called factors
f) **Multiple regression models –** if data for calibration are available, a regression analysis can be performed to determine how the value of the dependent variable (e.g. vulnerability) changes when any of the independent variables (e.g. indicators) are varied. The weights are selected based on the results of the regression analysis.

2.3.2 Formulation of model

Socio-economic factors can be combined in different ways to build a model. Two principally different ways of doing this are:

a) **Additive combination –** average (weighted) sum of all indicators (e.g. individually ranked on a scale of 1-5). Weighted additive combination is suitable when combining factors where reducing the value of one factor can be compensated by increasing the value of another factor. A simple example is that the nutrition loss by losing some apples can be compensated by having more pears.
b) **Multiplicative combination –** product of all (weighted) indicators (e.g. individually ranked on a scale of 0-1). Multiplicative combination is suitable when the utility of one factor depends on another factor. A simple example can be motorised vehicles and fuel, where maximum utility depends on having the optimum combination of the two factors.

A model can be purely additive or purely multiplicative, or hybrid models can be constructed where factors are partly combined additively and partly combined multiplicatively. For models having several levels, i.e. both base indicators and composite/group indicators, a mix of additive and multiplicative combination can be used at the different levels. The choice of combination should be made considering that the models should represent key elements of reality while still remaining easy to understand and relevant for decision making.
As is the case for determining weights, a series of techniques can be applied to assist the model building including multi-criteria decision approach and defining decision rules with decision trees.

2.4 DATA SOURCES FOR INDICATORS

Common data sources for indicators in socio-economic vulnerability models include:

- Social science methods (e.g. interview, focus group discussions)
- GIS- and remote sensing- based methods (e.g. detection of build-up areas and fragility classifications)
- Departments of statistics (provides socio-economic and census data)

According to King and MacGregor (2000), “The Australian Bureau of Statistics collects and examines a broad range of census data that can provide useful insights to community conditions. These include income, housing type and ownership, employment, crime rates, educational status, ethnicity, English proficiency, family structure to name a few. One of the advantages of using indicators developed from such secondary data sources is that they are readily available and obtainable for a relatively small scale; the Census Collection District (CD). Simply combining the relevant CD’s can then aggregate geographical areas, such as suburbs or whole towns.”Another advantage is that census data is both readily and cheaply available.
King and MacGregor (2000) divide the community model into a matrix of components. The source of individual indicators can be inserted into the matrix (Table 2).

Table 2 Components of community and sources of indicators, King and MacGregor (2000)

	Population Characteristics	Hazard Attitudes	Behaviour & Preparation	Community & Values
Individuals	Census	Quantitative Survey	Quantitative & Post Disaster Surveys	Qualitative research
Family / Household	Census	Quantitative Survey	Quantitative & Post Disaster Surveys	Qualitative research
Community	Census	Quantitative Survey	Quantitative & Post Disaster Surveys	Qualitative research

For Europe, socio-economic indicators from national level down to city and sub-city level have been collected since the mid 1990s in the Urban Audit Database (www.urbanaudit.org).

2.5 STRENGTHS AND WEAKNESSES OF INDICATOR-BASED METHODS

Vulnerability is a multidimensional and thus multivariate concept, where each indicator is likely to have a different degree of influence and thus a distinct purpose (Eakin and Bojórquez-Tapia, 2008). The main weaknesses of indicators or indices is associated with the subjectivity in their estimation, the selection of variables, the measurement technique used, and the aggregation procedures employed (for composite indicators). And if weighting is applied another important subjective component is introduced (Briguglio and Pratt, 1999).

Further problems or challenges involved in the use of indicator based methods for socio-economic vulnerability assessment include:

1. **Lack of data**
   In many cases data availability will determine which type of vulnerability indicators can actually be included in the model. This presents the danger that important indicators may be excluded from, and/or less important indicators included into, the model due to a lack of data.

2. **Indicator dependence**
   It is often difficult to determine whether or not certain indicators are independent of one another. If they are independent they should be represented as two separate indicators. However, if they are not independent they should be combined into one composite indicator to avoid model redundancies. If the indicators are improperly classified they may have either too much or too little effect on the outcome of the model.

3. **Site dependencies**
   Vulnerability indicators need to be verified with respect to the specific local/regional-, socio-economic, demographic and cultural contexts. Site specific parameters may explain a large amount of the variability in vulnerability analyses For instance: in Cutter et al. (2003) the indicators “fraction of African-American” and “fraction of mobile homes” explains an amount of the variation in vulnerability. However, for European conditions, these may not be relevant for vulnerability assessments. The proposed model in this report suggests “Vulnerable groups due to language or cultural barriers” and “Housing type” instead.

4. **Hazard dependencies**
   If a generic model valid for all types of hazards is used, as is often the case, the significance of some indicators may be over- or undervalued depending on the type of hazard being analyzed. For example, the importance of the *quality of medical services* indicator should be different for an earthquake than for a landslide, as there are usually significantly more people injured from an earthquake. However, an indicator such as *age* has similar significance given an earthquake or landslide event.

5. **Scale dependencies**
   The most appropriate scale for a vulnerability analysis is dependent upon the type of hazard under consideration. However, general hazard models usually operate at either a global or national scale. In the case of a landslide, which has impact primarily at the local scale, these methods are often inaccurate.

2.5.1 Landslide-dependent indicators

The majority of the indicators in the socio-economic vulnerability model can be adapted to assess the vulnerability level associated with most types of natural disasters. However, this does not imply that model is generic and can be directly applied for earthquakes, floods, etc. The degree of relevance of each indicator to the model is very hazard-dependent. For instance, landslides generally cause more infrastructure and natural resource losses than casualties, therefore the impact of the 'quality of medical services' indicator should not be weighted as heavily as in, say, an earthquake vulnerability model. Each of the indicators in this model has been weighted to express the expected effects of landslides.

3 LITERATURE REVIEW

An extensive literature review was performed prior to the development of the SafeLand socio-economic landslide vulnerability model.

3.1 SOCIO-ECONOMIC VULNERABILITY ANALYSIS

The following papers describe methodologies and/or developed models relevant to the analysis of socio-economic vulnerability to landslides:

1. Quantitative vulnerability estimation for scenario-based landslide hazards (Li et al., 2010)
2. Measuring the capacity to cope with natural disasters (Lahidji, 2008)
3. Insights into the composition of household vulnerability from multicriteria decision analysis (Eakin and Bojórquez-Tapia, 2008)
4. A disaster risk management performance index (Carreňo et al., 2007)
5. Social indicator set - FLOODsite report (Tapsell et al., 2005)
6. Quantifying Social Vulnerability: A methodology for identifying those at risk to natural hazards (Dwyer et al., 2004)
7. Social vulnerability to environmental hazards (Cutter et. al, 2003)
8. Using social indicators to measure community vulnerability to natural hazards (King and MacGregor, 2000)

In this list, the papers listed as 1, 2, and 5 are especially relevant for landslides. Papers listed in point 3, 4, 6, 7, and 8 are more general, but applicable to several types of natural hazards. Each of these papers is briefly described in the following sections, 3.1.1-3.1.8.

3.1.1 Li et al., 2010

Li et al. (2010) developed a model which assesses landslide vulnerability using a non-dimensional scale of 0 (no loss) to 1 (total loss). Vulnerability is formulated as a function of a dimensionless intensity of the natural hazard and a dimensionless resistance of the exposed elements. They consider the structural resilience in the affected region as well as the resisting and evacuating ability of the local people. Firstly, the total structural resistance factor uses a multiplicative weighting technique that combines the input of four resistance factors; foundation depth (ζ_{sfd}), structure type (ζ_{sty}), maintenance state (ζ_{smm}), and height (ζ_{sht}). The equation is quantified as:

$$R_{str} = \left(\zeta_{sfd} \cdot \zeta_{sty} \cdot \zeta_{smm} \cdot \zeta_{sht}\right)^{\frac{1}{4}}$$

Similarly, the resistance factor for persons is calculated as:

$$R_{str} = \left(\zeta_{phy} \cdot \zeta_{kng}\right)^{\frac{1}{2}}$$

where ζ_{phy} is the physical factor based on age, and ζ_{kng} is the knowledge factor based on the existence of an early warning system and/or some other sort of landslide prevention awareness. Although this model focuses mainly on physical vulnerability, it can be used to show how a socio-economic model can be integrated into a risk framework to produce absolute vulnerability numbers, which represent the degree of loss within a predefined area and timescale, rather than relative numbers. This approach illustrates an alternative to the additive weighting technique used in the proposed SafeLand model (see section 4).

3.1.2 Lahidji, 2008

Lahidji (2008) focuses on a region's coping capacity in case of a natural disaster. While most of his criteria are widely applicable for any type of event, he has also included several hazard-specific indicators that focus on one or more of the following: wildfires, avalanches, tsunamis, volcanoes, droughts, typhoons, landslides, floods and earthquakes. In order to assess the coping capacity Lahidji (2008) used existing data (governance and development indicators) to quantify the legal and regulatory framework, environmental sustainability, infrastructure equipment, macroeconomic activity and social safety net, and developed questionnaires to address the remaining topics:

- Hazard evaluation
- Consequences and vulnerability assessment
- Awareness-raising activities
- Sectoral regulations
- Structural defences
- Continuity planning
- Early warning
- Emergency response
- Insurance and disaster funds
- Reconstruction and rehabilitation planning

The questionnaires categorize each of the above factors into five levels, where level 1 indicates a low level of consideration into the topic in question and level 5 indicates extensive consideration. Several of the factors introduced in this paper have been incorporated into the socio-economic vulnerability model proposed in this paper for SafeLand Deliverable D2.6.

In order to obtain a synthetic indicator to compare coping capacities between regions Lahidji (2008) used the following normalization equation:

$$I = \sum_i \alpha_i \cdot I_i^{all} + \sum_i \sum_j \beta_i \cdot \gamma_j \cdot I_i^{hazard,j}$$

where $\sum \alpha_i = \sum \beta_i = \sum \gamma_i = 1$ and α_i represents the weights of all-hazard indicators I_i^{all}, β_i the weights of hazard-specific indicators $I_i^{hazard\ j}$, and γ_j the relevance of hazard j for the country, calculated in terms of exposure. However, this paper did not discuss methods to calculate the weights or quantify the hazard-relevance.

3.1.3 Eakin and Bojórquez-Tapia, 2008

Eakin and Bojórquez-Tapia (2008) propose a method for assessing the importance of vulnerability indicators at a household level. This technique uses multicriteria decision analysis (MCDA) and fuzzy logic to deal with the inherent subjectivity and uncertainty involved in assigning weights to disparate indicators and categorises vulnerability levels into three classes: low, moderate and high. The proposed methodology is illustrated with a case study of rural livelihood vulnerability in the state of Tamaulipas, México. The vulnerability assessment is illustrated in Figure 4.

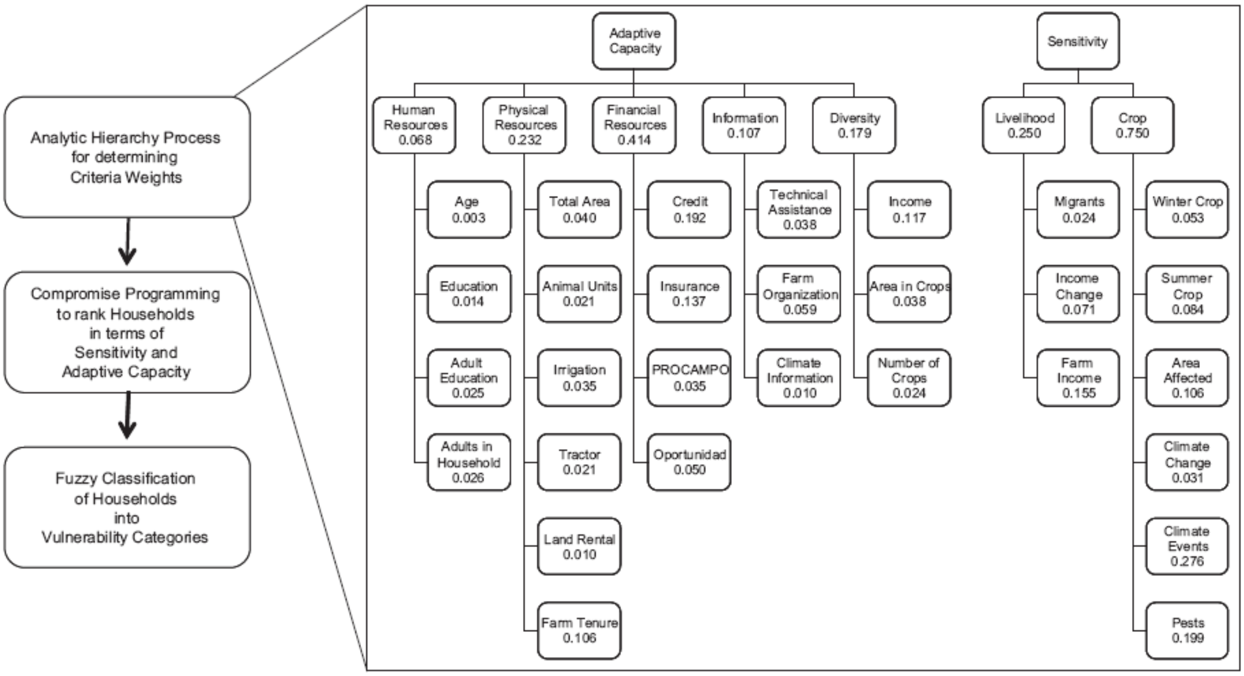

Figure 3 Method for household vulnerability assessment in González, Mexico, Eakin and Bojórquez-Tapia (2008).

3.1.4 Carreňo et al., 2007

Carreňo et al. (2007) developed an international risk management index (RMI) used to measure the capacity of governing bodies at the national, sub-national and urban levels to deal with natural disasters based on their achievements in the following areas: risk identification, risk reduction, disaster management and financial protection. Each of these sub-indices is comprised of six indicators (see Figure 5) which are categorized into one of five performance levels, ranging from low (1) to optimal (5). The weights (1-5) of the individual indicators are selected based on expert opinion and each sub-index is evaluated by incorporating the indicator weights into a fuzzy analysis. Fuzzy set theory was selected because its gradual phase transitions are applicable to qualitative analyses. Finally the RMI value is calculated as the average of the four sub-indices:

$$RMI = \frac{RMI_{RI} + RMI_{RR} + RMI_{DM} + RMI_{FP}}{4}$$

Example analyses were performed in-depth at the urban level for Bogotá, Columbia and the national level for Columbia. Results were also presented for national-level analyses of ten other countries within Latin America and the Caribbean region.

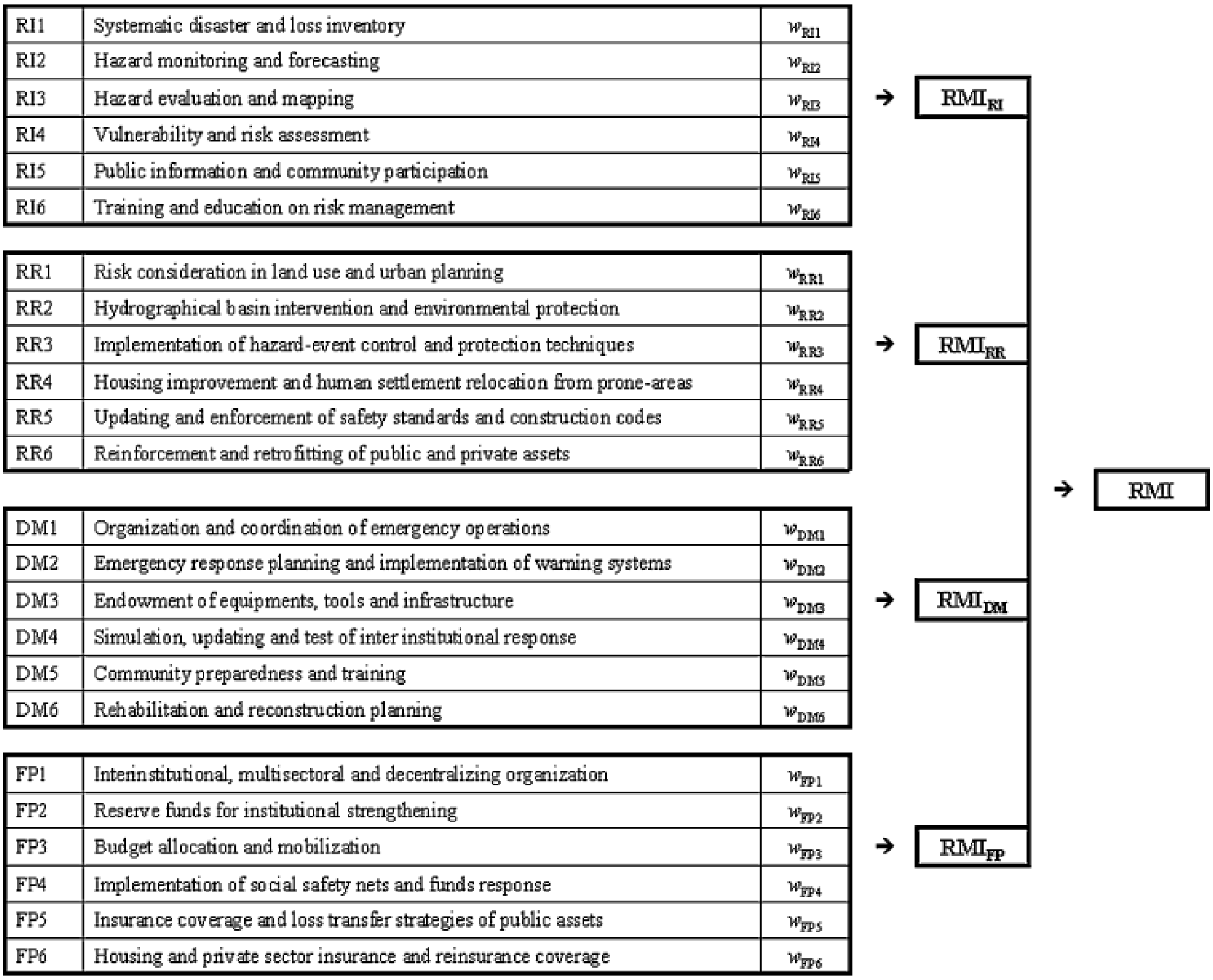

Figure 4 Method Component indicators for RMI, Carreňo et al. (2007).

3.1.5 Tapsell et al., 2005

Tapsell et al. (2005) proposed a set of indicator variables to be used for vulnerability and resiliency analyses of floods within Europe after reviewing both the current hazard vulnerability models and the amount of data available for various European countries. Although the SafeLand project considers landslides, and not floods, there is a lot of overlap between the two types of models because landslides and floods frequently occur together and therefore many of the vulnerability indicators are the same. Tapsell et al. (2005) defined the following set of indicators (a (+) sign is assigned to those that increase vulnerability levels and a (-) sign to those that decrease levels).

- Age – children and very elderly (+)
- Gender – women (+)

- Employment (-)
- Unemployment (+)
- Occupation (+/- depending upon whether skilled or unskilled, also linked to income and financial status)
- Education level (higher education level -, lower education level +)
- Family/household composition (large families +, single parents +, single person households +, home owner -, renter +, etc.)
- Nationality/ethnicity (non-white +, new migrants +)
- Type of housing (single storey accommodation +, mobile housing +)
- Number of rooms (low number indicates overcrowding +)
- Rural/urban (low income rural +, high density urban +)

Furthermore, they suggested qualitative indicators that could also be included to help improve the validity of vulnerability models. However, these additional factors require the completion of questionnaires by members of the community under analysis.

- Levels of risk awareness and preparedness (high awareness -, low +)
- Previous flood experience (no experience +)
- Access to decision-making (increased access -)
- Trust in authorities (no +, yes -)
- Long-term-illness or disability (+)
- Length of residence (linked to prior experience, short residence +)
- Serviced by flood warning system (yes -, no +)
- Type of flood (indicates potential damage levels)
- Flood return period (indicates potential damage levels)

3.1.6 Dwyer et al., 2004

Dwyer et al. (2004) developed a model which assesses vulnerability to natural hazards at the household level by studying the individuals within the households. The indicators used for the case study are provided in Table 3. The relative importance of each indicator was evaluated with a perception questionnaire and categorized based on the weighting scheme shown in Table 3.

Table 2 Relative importance of indicators from Dwyer et al. (2004) and suggested weights.

Indicator	Score	Suggested weight of indicator
1. House insurance	12.4	3
2. Income	11.6	3
3. Tenure type	9.6	3
4. Age Debt	2.1	2
5. Employment	0.06	2
6. Car ownership	0.05	2
7. English skills	0.01	1

8. Household type	< 0.01	1
9. Health insurance	< 0.01	1
10. Residence type	< 0.01	1
11. Disability	< 0.01	1
12. Gender	< 0.01	1

A decision tree is used to define a set of rules which dictate whether or not a household falls in a "high" vulnerability class. The decision rules are organized as a set of logical expression; if one of the expressions is true, the person in study is perceived to have a high vulnerability, otherwise they do not. The decision rules from Dwyer et al. (2004) are shown inTable 4.

Table 3 Decision rules from Dwyer et al. (2004).

Rule	Expression
1	**Injuries** > 3.5
2	$2.5 <$ **Injuries** ≤ 3.5 & **Age** > 60.5
3	$2.5 <$ **Injuries** ≤ 3.5 & $46.5 <$ **Age** ≤ 60.5 & **Residence Damage** > 2.5
4	**Household Type** $\in \{1, 3, 5\}$ & $2.5 <$ **Injuries** ≤ 3.5 & **Age** ≤ 46.5 & **Residence Damage** > 3.5
5	**House Insurance** $= 0$ & **Household Type** $\in \{2, 4\}$ & $2.5 <$ **Injuries** ≤ 3.5 & **Age** ≤ 46.5 & **Residence Damage** > 3.5
6	**Injuries** ≤ 2.5 & **Residence Damage** > 3.5 & **Age** > 66.5
7	**Injuries** ≤ 2.5 & **Residence Damage** > 4.5 & $51.5 <$ **Age** ≤ 66.5 & **Income** ≤ 216.5
8	**Injuries** ≤ 2.5 & **Residence Damage** > 4.5 & $43.5 <$ **Age** ≤ 51.5
9	**Tenure Type** $\in \{1, 4\}$ & **House Insurance** $= 0$ & **Injuries** ≤ 2.5 & **Residence Damage** > 3.5 & **Age** ≤ 43.5
10	**Tenure Type** $\in \{2, 3\}$ & **Injuries** ≤ 2.5 & **Residence Damage** ≤ 3.5 & **Age** > 64.5
11	**Household Type** $\in \{4, 5\}$ & **Tenure Type** $\in \{1, 4\}$ & **Injuries** ≤ 2.5 & **Residence Damage** ≤ 3.5 & **Age** > 73.5

3.1.7 Cutter et al., 2003

Cutter et al. (2003) developed a county-level social vulnerability index (SoVI) for the United States based on 11 independent indicator variables, reduced from 42 using a factor analysis approach. They performed a statistical analysis on the final 11 indicators to determine the amount of variance explained by each and the inter-variable correlations which resulted in the following ranking (see Table 5), from most-to-least important.

Table 4 Dimensions of social vulnerability (Cutter et al., 2003).

Dimensions of Social Vulnerability

Factor	Name	Percent Variation Explained	Dominant Variable	Correlation
1	Personal wealth	12.4	Per capita income	+0.87
2	Age	11.9	Median age	−0.90
3	Density of the built environment	11.2	No. commercial establishments/mi^2	+0.98
4	Single-sector economic dependence	8.6	% employed in extractive industries	+0.80
5	Housing stock and tenancy	7.0	% housing units that are mobile homes	−0.75
6	Race—African American	6.9	% African American	+0.80
7	Ethnicity—Hispanic	4.2	% Hispanic	+0.89
8	Ethnicity—Native American	4.1	% Native American	+0.75
9	Race—Asian	3.9	% Asian	+0.71
10	Occupation	3.2	% employed in service occupations	+0.76
11	Infrastructure dependence	2.9	% employed in transportation, communication, and public utilities	+0.77

Each of the indicators was assigned a ‘factor score’ indicative of its level of importance and the total SoVI score for each county was calculated as the sum of the factors influencing the region (no weights were applied). The SoVI levels were categorized relative to the mean US value – counties with a SoVI score greater than +1 standard deviation were considered the most vulnerable and those with greater than -1 standard deviation the least vulnerable.

3.1.8 King and MacGregor, 2000

King and MacGregor (2000) define a ‘community vulnerability model’ based on 8 constructs of indicators: demography, built structures, economy, environment, values, attitudes, society and behaviour (see Figure 6).

Since much of the required data (demographic, economic, built structures) is readily available in most regions, this paper focuses on the social indicators which are significantly more difficult to measure. King and MacGregor (2000) define a *value* as a single belief and an *attitude* as a set of beliefs, and use the beliefs held by a community to help determine their vulnerabilities to, and resiliencies from, impending natural disasters. For instance, what is the level of mental and physical health, general knowledge, commonsense and caution within the community? They found that the best ways to measure these types of values and attitudes are through quantitative surveys and research into the outcomes of previous natural disasters.

Finally, behaviour and society constructs, also measured with surveys and qualitative research, were deemed useful for understanding interactions and relationships within a community which can be important indicators for the level of preparedness. For example, a tightly knit society is more likely to ensure that warnings are sent out and highly vulnerable groups (the very old, the very young, the disabled, etc.) are taken care of. Likewise a community's behaviour and organization dictates its levels of awareness, preparation, training, recovery ability, planning laws and so on.

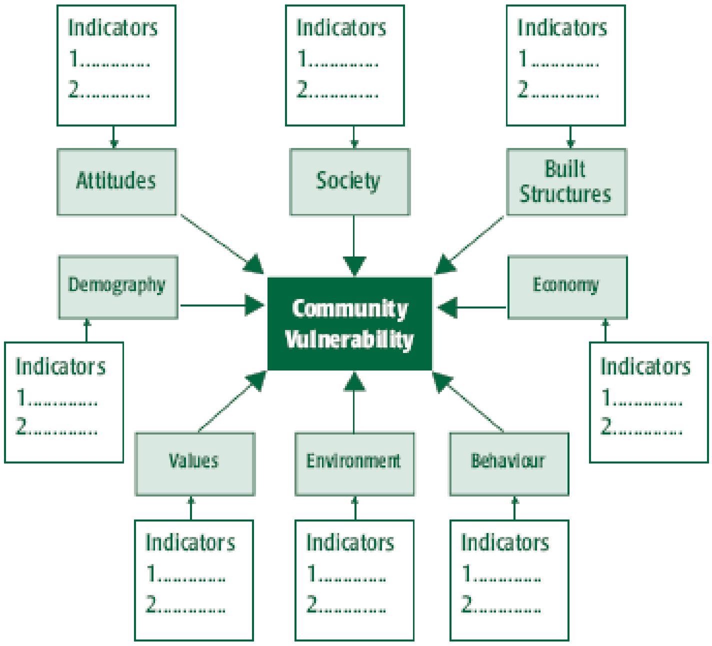

Figure 5 Links between indicators, constructs and models, King and MacGregor (2000).

3.2 COMMENTS ON EXISTING MODELS

Although there are many existing models that address the issue of social or socio-economic vulnerability, there is no single model available that provides a landslide vulnerability index for communities within Europe. The majority of existing models focus on only one aspect of vulnerability (i.e. coping capacity), generalize for all natural hazards, and/or suggest indicators without defining any sort of weighting scheme. Often indicator sets or models describe a wired range of social or socio-economic indicators, which hampers their application in studies, where transferable models are needed to be applied for many different locations. Models with quantitative key-indictors are useful here.
Therefore, the development of a European socio-economic vulnerability model for landslides is important in order to maximize safety levels and optimise resource usage in European regions susceptible to slope instability. The purpose of the indicators used in this model is to raise awareness and to provoke some action to reduce vulnerability.

4 PROPOSED SOCIO-ECONOMIC VULNERABILITY MODEL

In the aftermath of a landslide, a region is forced to repair itself as best it can and the amount of work required is related to its prior level of vulnerability. The consequences of a hazard event are often divided into direct/immediate impacts and indirect/delayed impacts. There are several models available that try to assess the direct impacts by analyzing the number of injuries and fatalities as well as the amount of damage to structures and infrastructure. However, the long term impacts on a society due to injuries, lost lives and a weakened economy are harder to predict. The proposed socio-economic vulnerability model estimates the expected socio-economic impact of a landslide event through the use of indicators, divided into the following categories; (1) demographic, (2) economic, (3) social, as well as those related to (4) the level of preparedness and (5) capacity for recovery (in an updated version the categories are: (1) demographic and social, (2) economic, and (3) preparedness, response and recovery). If a region is deemed to be highly vulnerable it is expected to face significant loss *if* a landslide occurs, however, this does not necessarily indicate a significant risk level.

Based on the Hotspots project (Nadim et al, 2006; UNDRO, 1979) risk can be defined as

$$R = PhExp \cdot Vul$$

where R is the risk, $PhExp$ the physical exposure (a product of hazard and the exposed population) and Vul the vulnerability of the exposed population. Therefore, proximity to unstable slopes and probability of slope failure are considered separately and are not factored into the vulnerability model. This model assesses the coping capacity in the event of a landslide. When multiplied by the region’s physical exposure it can be used to estimate of the level of risk.

The model aims at quantifying socio-economic vulnerability allowing a comparison of communities. Indicators chosen in this model are selected in a way that the required input data can be gathered from statistics, maps or other easily accessible data or comprehensive expert interviews. Some aspects of social vulnerability, which are difficult to quantify are neglected in this model. However, in order to use this model for several case studies in Europe and to derive comparable results some simplifications needed to be made.

4.1 SELECTION OF MODEL INDICATORS

Landslides rarely have socio-economic consequences at the global or national level, thus this model will assess vulnerability on a local scale. Furthermore, this model has been developed for the SafeLand project which focuses on landslide risk within European countries, so factors that do not affect vulnerability levels within Europe will be excluded. For instance, the number of automobiles per household is no longer an effective assessment tool because many European cities are becoming more bike friendly due to an increasingly health conscience and environmentally aware population.

Indicators are not only supposed to measure vulnerability but ideally they should also be able to point at some action to reduce vulnerability. As an example the indicator *risk awareness* can indicate the degree to which people are informed or have experience related to landslide risk and therefore are supposed to be better aware and better prepared for a possible landslide event. At the same time a low measure for this indicator directs to some action o be taken by e.g. local authorities, to improve risk awareness by information campaigns or other measures.

The selection of indicators in the proposed model was made after an in-depth literature review and chosen to cover all aspects of vulnerability, while ensuring that there was no redundancy amongst factors. The selection process is illustrated in Figure 7 below.

Factors that govern...

What is physically vulnerable to damage?

- People
  - Rural/urban population
- Homes
  - Quality/resilience – housing type
- Other infrastructure
  - Quality/resilience – a function of regulation control and personal wealth

Who is most vulnerable?

- Those unable to act quickly once a warning has been issued
  - Age
- Those who do not understand the danger involved/what to do to protect oneself
  - Education level
  - Language/cultural barriers

Community **vulnerability** as a whole

- Are leaders aware of danger levels?
  - Hazard evaluation
- Is the community prepared to respond?
  - Emergency response
- Will the people have time to evacuate?
  - Early warning system

Community **resilience**

- Can damages be fixed promptly?
  - Insurance and disaster funds
- Does the community have the funds required to rebuild after a landslide?
  - Personal wealth
- Are there sufficient facilities to care for the injured?
  - Quality of medical facilities

Figure 6 Indicator selection process.

Once the selection process has been carried out, each indicator is categorized using a semi-quantitative scale with five levels. Level 1 corresponds to a very low vulnerability and level 5 to a very high vulnerability. The method is based on a scoring system where the total score for each indicator is assessed according to the ranking rules described in the method. The final vulnerability value is a weighted average of the vulnerability indicator score values. The reason for using a semi-quantitative model based on a scoring system is:

- Data availability: The ranking of indicators into 5 vulnerability classes requires less data than assessing a quantitative value to each indicator.
- The possibility for combining qualitative and quantitative indicators: Through predefined ranking criteria for indicators, both quantitative and qualitative indicators may be ranked and combined into a semi-quantitative vulnerability parameter.
- Validation of model: an explicit model expressing socio-economic vulnerability quantitatively as the degree of loss (or probability of loss) does not exist.

4.2 VULNERABILITY MODEL

Table 6 shows the proposed socio-economic vulnerability model with suggested indicators, their corresponding weights, suggestions on where to collect the data and criteria for ranking of the indicators. The selection of weight values is described in detail in section 4.2.1

Table 5 Proposed vulnerability model.

Indicators	Weights and means of data collection	Criteria for indicator ranking (1: Low vulnerability, 5: very high vulnerability)
Demographic Indicators		
Age distribution (see note 1)	2 Census	1: Uniform age distribution - less than 20% population is either between 0-5 years of age or over 65.
		2: 20-30% population is either between 0-5 years of age or over 65.
		3: 30-40% population is either between 0-5 years of age or over 65.
		4: 40-50% population is either between 0-5 years of age or over 65.
		5: Over 50% population is either between 0-5 years of age or over 65.
Rural population (see note 2)	2 Census	1: Less than 10% population is dependent on the land for primary source of income.
		2: 10-25% population is dependent on the land for primary source of income.
		3: 25-50% population is dependent on the land for primary source of income.
		4: 50-75% population is dependent on the land for primary source of income.
		5: Over 75% population is dependent on the land for

		primary source of income.
Urban population (see note 2)	1 Census	1: Population density is < 50 people/km^2
		2: Population density is between 50-100 people/km^2
		3: Population density is between 100-250 people/km^2
		4: Population density is between 250-500 people/km^2
		5: Population density is > 500 people/km^2
Economic Indicators		
Personal wealth	*2* Census	*1: GDP per capita > 50 thousand USD*
		1: GDP per capita 30 - 50 thousand USD
		1: GDP per capita 20 - 30 thousand USD
		1: GDP per capita 10 -20 thousand USD
		1: GDP per capita < 10 thousand USD
Housing type (see note 3)	3 Census	1: The majority of constructions are of strong resistance, there are some or none of medium resistance and none of weak resistance.
		2: The majority of constructions are of strong resistance, there are some or none of medium resistance and some of weak resistance.
		3: The majority of constructions are of medium resistance, there are some or none of strong resistance and some or none of weak resistance.
		4: The majority of constructions are of weak resistance, there are some or none of medium resistance and some of strong resistance.
		5: The majority of constructions are of weak resistance, there are some or none of medium resistance and none of strong resistance.
Social Indicators		
Vulnerable groups due to language or cultural barriers	1 Census	1: < 5% of the population is not familiar with majority language and culture
		2: 5-10% of the population is not familiar with majority language and culture
		3: 10-15% of the population is not familiar with majority language and culture
		4: 15-25% of the population is not familiar with majority language and culture
		5: > 25% of the population is not familiar with majority language or culture (indicative of a high percentage of tourists and/or recent immigrants)
Education Level	1	1: > 30% of the eligible population (over 18 years of age) have attended, or are attending, a post-secondary education
		2: 20-30% of the eligible population have attended, or are attending, a post-secondary education
		3: 10-20% of the eligible population have attended, or

	Census	are attending, a post-secondary education
		4: 5-10% of the eligible population have attended, or are attending, a post-secondary education
		5: <5 % of eligible population have attended, or are attending, a post-secondary education
Preparedness indicators		
Landslide hazard evaluation (Lahidji, R., 2008)	3 Local government questionnaire	1: Detailed hazard maps available
		2: Basic hazard maps available
		3: Hazard mapping research ongoing (with some gaps)
		4: Basic assessment of direct impacts to exposed populations completed
		5: Incomplete assessment of direct impacts to exposed populations
Regulation control (Lahidji, R., 2008) (see note 4)	3 Local government questionnaire	1: Stringent guidelines in place to ensure minimal risk to exposed population
		2: Consistent approach to the regulation of construction and land use on the basis of exposure to landslides
		3: Fairly effective regulations for new developments, however, potential problems with older constructions
		4: Some consideration of risk during construction, but inadequate enforcement of regulations
		5: No consideration of risk in planning and construction
Emergency response (Lahidji, R., 2008)	2 Local government questionnaire	1: Permanent coordination between responders in communities; specialized equipment and well-trained rescue services available throughout the country
		2: Clear definition of roles and responsibilities at local level; proportionate allocation of resources
		3: Existence of an organization of emergency response, with coordination authority; adequate supplies of medical transport, communications and other specialized equipment in all important cities
		4: Professional search and rescue services, evacuation possibilities and central operation centers available in the most landslide-prone areas
		5: Fragmented organization and scattered resources; predominance of voluntary responders
Early warning system (Lahidji, R., 2008)	2 Local government questionnaire	1: Advanced early warning systems used in coordination with emergency response procedures
		2: Adequate early warning system coordinated with media announcements capable of reaching the majority of the population prior to the landslide
		3: Basic early warning systems available to the public
		4: Basic early warning system available to risk managers
		5: No early warning system
Recovery indicators		

Insurance and disaster funds (Lahidji, R., 2008)	2 Local government questionnaire	1: Extensive coverage for private and public buildings, existence of government-sponsored landslide funds
		2: Insurance coverage for the majority of private and public buildings, limited government-funding
		3: Widespread landslide insurance in development phase, but not yet accessible to everyone
		4: Incomplete support for victims of past landslide events
		5: Little or no insurance provided
Quality of medical services (see note 5)	1 Government data	1: > 4 hospital beds per 1 000 people
		2: 3-4 hospital beds per 1 000 people
		3: 2-3 hospital beds per 1 000 people
		4: 1-2 hospital beds per 1 000 people
		5: < 1 hospital beds per 1 000 people

Note 1: Age distribution

- The population of young children and senior citizens more vulnerable to harm in the event of a landslide is estimated by the percentage of people between 0-5 years of age or over 65. Since the average life expectancy in Europe is approximately 75 years, a uniform age distribution would indicate that 20% of the population is ‘vulnerable’ – this was used as the basis for the age distribution indicator scale.

Note 2: Rural/urban population

- Rural populations are highly vulnerable due to their lower incomes (on average) and dependence on the surrounding natural resources (e.g., farming, fishing) for sustenance. However, urban regions with very dense populations are more difficult to evacuate during emergencies (Cutter et al., 2003). Although these two categories are not mutually exclusive, they have been separated because the percentage of rural inhabitants appears to be a slightly more influential measure of vulnerability than the percentage of urban inhabitants, therefore rural is weighted as ‘2’ and urban as ‘1’. If the two subsets were amalgamated, together they would be given a weighting value of ‘3’.

Note 3: Housing type

- Strong resistance refers to thick brick or stone wall and reinforced concrete constructions, medium resistance to mixed concrete-timber and thin brick-wall constructions and weak resistance to simple timber and very light constructions (Heinimann, 1999).

Note 4: Regulation control

- This indicator takes into account the quality of infrastructure in the region. If there is a significant amount of control over construction guidelines, the infrastructure is generally well-built and relatively resilient to landslides.

Note 5: Quality of medical services

- This indicator is categorized by the number of hospital beds per 100 000 people. However, since the scale under consideration is usually at the local level, the distance to, and accessibility of, the nearest medical services will also be taken into consideration. The scale used is based on data provided by the European Commission Eurostat (2008).

4.2.1 Selection of indicator weights

Each indicator is assigned a weight which determines its level of influence within the model. The weights for this model are selected, after extensive research and literature review, based on educated judgment.

Firstly, the indicators are ranked by degree of influence:

- *Most influential*: housing type, hazard evaluation, regulation control.
- *Moderately influential*: age, rural population, personal wealth, emergency response, early warning system, insurance and disaster funds.
- *Least influential*: urban population, language/cultural barriers, education level, quality of medical services.

Those indicators deemed to be most influential were estimated to carry about twice as much weight as those considered moderately influential and approximately three times as much as the least influential factors. Therefore, the weighting scheme adopted is based on a 3-2-1 scale where 3 represents the most important indicators and 1 represents the least important indicators.

A graphical representation of the proposed model is provided in Figure 8 and is organized into three levels, output, group and base, in accordance with Figure 3 on page 11. The group level indicators are independent of scale, however, their accuracy is dependent upon the accumulation of base indicators, which are scale-dependent.

The importance of each indicator and category of indicators, relative to the community vulnerability as a whole, can be determined using a decision tree analysis. For example, the total weight of all 13 indicators is 25, and within the *demographic indicator* category the total weight is 5, therefore the demographic indicators describe 20% of the total community vulnerability. Furthermore, the individual indicator *age* within the demographic indicator category accounts for 2 of the 5 weight points and thus describes 40% of the demographic influence on the community vulnerability, or 8% of the community vulnerability directly.

The decision tree analysis provides an easy means of weight re-calibration if more indicators are added to the model, or existing indicators are removed (i.e. due to lack of data).

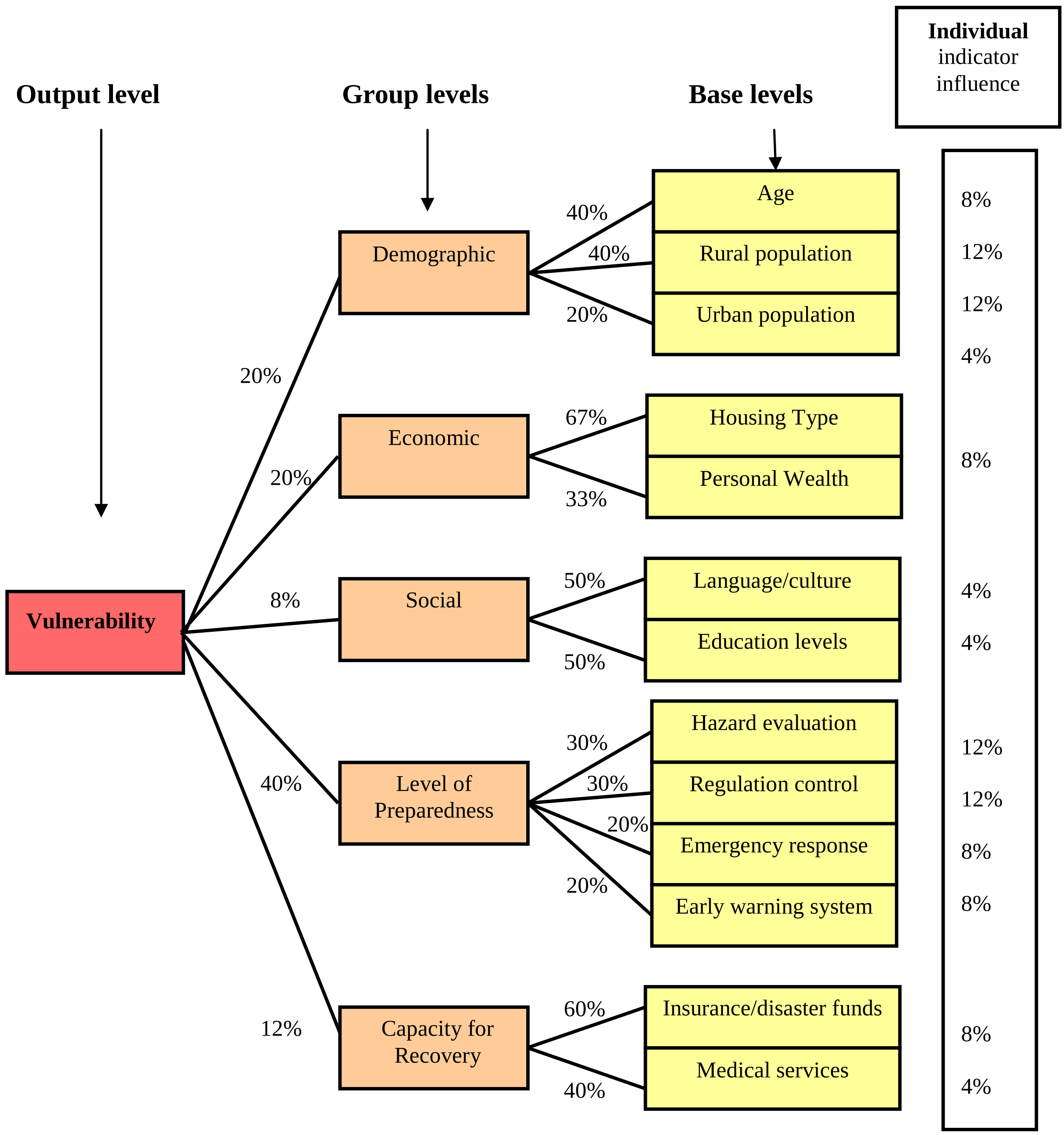

Figure 7 Decision tree analysis used for vulnerability model.

Although this model focuses primarily on the indirect losses that result from landslide events, it also provides some insight into both direct and intangible losses.

Housing types, as well as rural and urban populations, provide direct measures of damage levels. Firstly, ‘low’ resistance buildings are much more likely to suffer significant amounts of damage than those of ‘high’ resistance. Secondly, the extent of damage expected is a result of the type of populations present. For instance, it is more likely that buildings and people will be damaged if a landslide occurs in an urban region, as they are present in higher numbers, but it is more likely that farms and agricultural products, which are often directly tied to incomes, will be damaged if a landslide occurs in a rural region. Such direct losses may further lead to intangible losses tied to personal stress due to temporal evacuation, permanent house loss or destruction of personal possessions having sentimental value. Lack of insurance/disaster funds lead to further increase such stress.

The recovery capacity indicators, medical services and insurance/disaster funds, provide some measure of intangible losses by assessing the quality of care available after a landslide event. Personal stress and psychological issues are more likely to occur if the care provided is of low quality. For example, psychological problems are highly probable if someone becomes permanently injured or loses a loved one because they cannot afford proper medical care, or because it is simply not available.

4.2.2 Application of the model

Guidelines for using the proposed vulnerability model presented in Table 6 are briefly described below.

1) Assign a vulnerability score value for each indicator (1-5) in accordance with the corresponding criteria in the model
2) Multiply the indicator score value with its weight
3) Sum up all weighted vulnerability scores: Σ *weighted vulnerability score*
4) Sum all weights : Σ *weight*
5) The resulting vulnerability score is the sum of the weighted vulnerability score divided by the sum of weights:

$$\text{Total vulnerability score value} = \frac{\sum \text{Weighted vulnerability score}}{\sum \text{Weights}}$$

A simplified example-application of the model is illustrated in Table 7:

Table 6 Simplified vulnerability assessment following the proposed model.

Indicator	**Weight**	**Vulnerability score value**	**Weighted vulnerability score = weight * Vulnerability score value**
Age distribution	3	2	6
Emergency response	2	5	10
…	…	…	…

Weighted average vulnerability score	Σ Weights = 6		Σ Weighted vulnerability score = 16

$$\text{Total vulnerability score value} = \frac{\sum \text{Weighted vulnerability score}}{\sum \text{Weights}} = 16 / 6 = \mathbf{2.7}$$

4.3 VALIDATION

To illustrate the validity of the proposed model, socio-economic vulnerability levels are analyzed for several European communities using the approach described in this paper. Details can be found in SafeLand deliverable D2.7 titled *Case studies of environmental and socio-economic impact of landslides* Part B: Case studies for socio-economic vulnerability.

4.4 EXTENSION OF THE MODEL

Based on reviewer comments and lessons learned during this work the vulnerability model has been extended and updated in a second (final) version. Two new indicators have been introduced and a third indicator has been slightly changed. The new indicators are ‘critical infrastructure’ and ‘risk awareness’.

Critical infrastructure (Papathoma-Köhle et al., 2007, Taubenböck et al., 2008) summarizes critical (care) facilities and lifelines, that are important for the functioning of the society and that have shown to contribute to the impacts of natural hazards, if located in the affected area. Hospitals and schools hit surprisingly by a landslide are considered particularly vulnerable, due to the amount and the susceptibility of people allocated at these places. Besides that, as recently highlighted by the Tohoku earthquake and tsunami, the destruction of life supporting infrastructure and infrastructure necessary for the functioning of the society, such as the road network, telecommunication, or power supply increases vulnerability and hampers emergency management as well as the recovery process.

Risk awareness in the population is supposed to influence peoples’ preparedness and behaviour in case of an emergency (Tapsell et al., 2005, Dwyer et al., 2004, Taubenböck et al., 2008). Education can indicate to what extent people have a basic understanding of processes in nature and society, are able to understand and judge information material, and how they follow media and information flows. However, it is not necessarily related to risk perception and awareness. Risk awareness is particularly related to the exposure (in terms of closeness) to the hazard, their experience with landslides, the time they have been living in the exposed area, and the information they get regarding their specific, local risk situation, possible mitigation measures, and procedures in case of an emergency.
Risk awareness is individual and subjective, and therefore difficult to measure. As the proposed model is a quantitative model, relying on measureable data sources the indicator ‘risk awareness’ here includes mainly two factors: the length of residence (Tapsell et al., 2005), and the information status of the exposed people.

In addition to these new indicators two preparedness indicators have been merged: 'Landslide hazard evaluation' and 'early warning system'. This is mainly to not overestimate the preparedness in the overall vulnerability analysis. Landslides might come as very sudden events (e.g. rockfalls), which would not leave any time for early warning, evacuation or other personal preparedness measures. For this type of landslide hazard a high weight given to preparedness indicators (e.g. presence of an early warning system or hazard maps) would pretend a false safety in this case.

Moreover the indicators 'Rural population' was renamed to 'Diversity of income of rural population' and 'Urban population' to 'Population density'.

The categories have been rearranged so that indicators are grouped in three major groups now: (i) Demographic and social indicators, (ii) Economic indicators, (iii) Preparedness, response and recovery indicators.

The revised model is described in table 8.

Table 7 Proposed vulnerability model- revised version.

Indicators	Weights and means of data collection	Criteria for indicator ranking (1: Low vulnerability, 5: very high vulnerability)
Demographic and social indicators		
Age distribution (see note 1)	2 Census	1: Uniform age distribution - less than 20% population is either between 0-5 years of age or over 65.
		2: 20-30% population is either between 0-5 years of age or over 65.
		3: 30-40% population is either between 0-5 years of age or over 65.
		4: 40-50% population is either between 0-5 years of age or over 65.
		5: Over 50% population is either between 0-5 years of age or over 65.
Diversity of income of rural population (see note 2)	2 Census	1: Less than 10% population is dependent on the land for primary source of income.
		2: 10-25% population is dependent on the land for primary source of income.
		3: 25-50% population is dependent on the land for primary source of income.
		4: 50-75% population is dependent on the land for primary source of income.
		5: Over 75% population is dependent on the land for primary source of income.
	1	1: Population density is < 50 people/km^2
		2: Population density is between 50-100 people/km^2
		3: Population density is between 100-250 people/km^2

Population density (see note 2)	Census	4: Population density is between 250-500 people/km^2
		5: Population density is > 500 people/km^2
Vulnerable groups due to language or cultural barriers	1 Census	1: < 5% of the population is not familiar with majority language and culture
		2: 5-10% of the population is not familiar with majority language and culture
		3: 10-15% of the population is not familiar with majority language and culture
		4: 15-25% of the population is not familiar with majority language and culture
		5: > 25% of the population is not familiar with majority language or culture (indicative of a high percentage of tourists and/or recent immigrants)
Education Level	1 Census	1: > 30% of the eligible population (over 18 years of age) have attended, or are attending, a post-secondary education
		2: 20-30% of the eligible population have attended, or are attending, a post-secondary education
		3: 10-20% of the eligible population have attended, or are attending, a post-secondary education
		4: 5-10% of the eligible population have attended, or are attending, a post-secondary education
		5: <5 % of eligible population have attended, or are attending, a post-secondary education
Economic indicators		
Personal wealth	2 Census	1: GDP per capita > 50 thousand USD
		1: GDP per capita 30 - 50 thousand USD
		1: GDP per capita 20 - 30 thousand USD
		1: GDP per capita 10 -20 thousand USD
		1: GDP per capita < 10 thousand USD
Housing type (see note 3)	3 Census	1: The majority of constructions are of strong resistance, there are some or none of medium resistance and none of weak resistance.
		2: The majority of constructions are of strong resistance, there are some or none of medium resistance and some of weak resistance.
		3: The majority of constructions are of medium resistance, there are some or none of strong resistance and some or none of weak resistance.
		4: The majority of constructions are of weak resistance, there are some or none of medium resistance and some of strong resistance.
		5: The majority of constructions are of weak resistance, there are some or none of medium resistance and none of strong resistance.
		1: Extensive coverage for private and public buildings,

Insurance and disaster funds (Lahidji, R., 2008)	2 Local government questionnaire	existence of government-sponsored landslide funds
		2: Insurance coverage for the majority of private and public buildings, limited government-funding
		3: Widespread landslide insurance in development phase, but not yet accessible to everyone
		4: Incomplete support for victims of past landslide events
		5: Little or no insurance provided
Preparedness, response and recovery indicators		
Risk awareness (see note 4)	2 Local government questionnaire?	1: Stringent information campaigns on local risks in the community, in schools and for households, most of the residents have lived in the area for a long time
		2: Sporadic distribution of information material on local risk and risk management to households, information signs in the hazard zone
		3: Information on possible risks in the area are available on website and on signs in the hazard zone
		4: Information on hazard and risk available for experts, people have to look for information themselves, high fluctuation of population
		5: No information on hazard and risk in the area, high fluctuation of population
Early warning capacity (Lahidji, R., 2008)	3 Local government questionnaire	1: Detailed hazard maps and advanced early warning systems used in coordination with emergency response procedures available
		2: Basic hazard maps available, hazard mapping research ongoing (with some gaps) and basic early warning systems available for researchers
		3: Hazard is a fast moving landslide, hazard maps and early warning system available
		4: Incomplete assessment of direct impacts to exposed populations, no early warning system
		5: Hazard is a fast moving landslide, no hazard maps and early warning system available
Regulation control (Lahidji, R., 2008) (see note 5)	2 Local government questionnaire	1: Stringent guidelines in place to ensure minimal risk to exposed population
		2: Consistent approach to the regulation of construction and land use on the basis of exposure to landslides
		3: Fairly effective regulations for new developments, however, potential problems with older constructions
		4: Some consideration of risk during construction, but inadequate enforcement of regulations
		5: No consideration of risk in planning and construction
		1: Permanent coordination between responders in communities; specialized equipment and well-trained rescue services available throughout the country
		2: Clear definition of roles and responsibilities at local level; proportionate allocation of resources

Emergency response (Lahidji, R., 2008)	2 Local government questionnaire	3: Existence of an organization of emergency response, with coordination authority; adequate supplies of medical transport, communications and other specialized equipment in all important cities
		4: Professional search and rescue services, evacuation possibilities and central operation centers available in the most landslide-prone areas
		5: Fragmented organization and scattered resources; predominance of voluntary responders
Quality of medical services (see note 6)	1 Government data	1: > 4 hospital beds per 1 000 people
		2: 3-4 hospital beds per 1 000 people
		3: 2-3 hospital beds per 1 000 people
		4: 1-2 hospital beds per 1 000 people
		5: < 1 hospital beds per 1 000 people
Critical infrastructure (see note 7)	3 Maps, Census	1: No critical care facilities and lifelines in the hazard zone
		2: Only few critical care facilities and no lifelines in the hazard zone
		3: Several critical facilities and lifelines in the hazard zone
		4: Important care facilities, such as hospitals, and major lifelines in the hazard zone
		5: All major critical care facilities and all lifelines in the hazard zone

Note 1: Age distribution

- The population of young children and senior citizens more vulnerable to harm in the event of a landslide is estimated by the percentage of people between 0-5 years of age or over 65. Since the average life expectancy in Europe is approximately 75 years, a uniform age distribution would indicate that 20% of the population is ‘vulnerable’ – this was used as the basis for the age distribution indicator scale.

Note 2: Diversity of income of rural population/population density

- Rural populations are highly vulnerable due to their lower incomes (on average) and dependence on the surrounding natural resources (e.g., farming, fishing) for sustenance. However, urban regions with very dense populations are more difficult to evacuate during emergencies (Cutter et al., 2003). Although these two categories are not mutually exclusive, they have been separated because the percentage of rural inhabitants appears to be a slightly more influential measure of vulnerability than the percentage of urban inhabitants, therefore rural is weighted as ‘2’ and urban as ‘1’. If the two subsets were amalgamated, together they would be given a weighting value of ‘3’.

Note 3: Housing type

- Strong resistance refers to thick brick or stone wall and reinforced concrete constructions, medium resistance to mixed concrete-timber and thin brick-wall constructions and weak resistance to simple timber and very light constructions

(Heinimann, 1999). The typology of vulnerable houses depends also on the type of landslide

Note 4: Risk awareness:

- Length of residence of the inhabitants in the risk area. Inhabitants who have been living in the area for a long time, are supposed to be better informed about local hazards and risks. More, if landslides occur frequently in the area, inhabitants who have been living there for a long time might have experience from a former event. Those people are supposed to be better prepared, better informed about local organisational structures, and to react adequately in case of an emergency.
- The indicator also includes the information status on hazard, risk and behavior in case of an emergency provided to households, at schools, via the internet, information events or signs in the hazard zone. An informed society is supposed to be better prepared.

Note 5: Regulation control

- This indicator takes into account the quality of infrastructure in the region. If there is a significant amount of control over construction guidelines, the infrastructure is generally well-built and relatively resilient to landslides.

Note 6: Quality of medical services

- This indicator is categorized by the number of hospital beds per 100 000 people. However, since the scale under consideration is usually at the local level, the distance to, and accessibility of, the nearest medical services will also be taken into consideration. The scale used is based on data provided by the European Commission Eurostat (2008).

Note 7: Critical infrastructure

The indicator takes into account:

- Critical care facilities: hospitals, schools, etc.
- Critical facilities: large companies or production facilities, where many people are allocated at the same time
- Lifelines:
  - A railway network or station and/or major roads and bridges in the hazard zone, which might serve as an evacuation route or provide major access to the community
  - Power stations located in the hazard zone. A destruction would lead to an interruption of power supply
  - Major telecommunication stations or cables in the hazard zone. A cable break would lead to an interruption of telecommunication and therefore could hamper early warning and emergency management.
  - Major water pipes or stations in the hazard zone. A destruction of these would lead to an interruption of water supply.

The weighting scheme was adapted accordingly:

- *Most influential*: housing type, early warning capacity, critical infrastructure
- *Moderately influential*: age, diversity of income of rural population, personal wealth, emergency response, insurance and disaster funds, risk awareness, regulation control, emergency response
- *Least influential*: population density, language/cultural barriers, education level, quality of medical services.

According to the new indicators and the changes in weights and new decision tree is depicted in Figure 8.

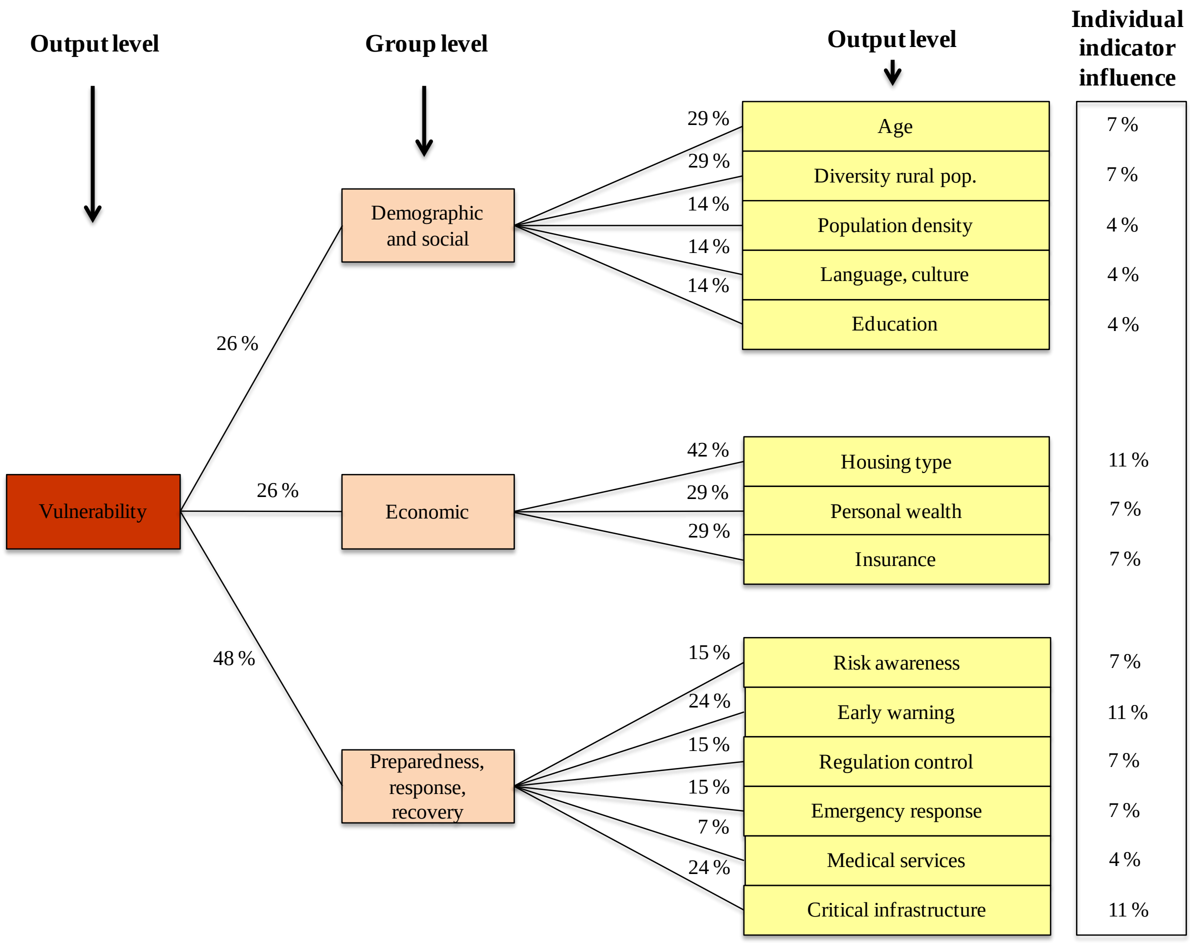

Figure 8 Decision tree analysis used for revised vulnerability model.

The indicators have been chosen so that they are independent from each other. As indicated above dependencies might occur between the indicators language/culture – education – risk awareness. Education can indicate the amount of knowledge and interest people have in the hazard situation in their area and it can indicate that highly educated people have more knowledge and also know better how to be prepared and how to response. However, this not necessarily the case and therefore a direct relation is not automatically given. In contrast people who live close to the hazard source or in a close relationship with their natural environment may have a better risk awareness, regardless their education.

5 SUMMARY AND RECOMMENDATIONS FOR FURTHER WORK

5.1 SUMMARY

The model presented in this paper has been designed to assess the level of socio-economic vulnerability to landslides present in communities throughout Europe. The model is comprised of five group/composite indicators, each of which is made up of one or more base/single indicators. The group indicators are designed to address the demographic, economic and social characteristics of the region under analysis as well as classify its degree of preparedness and capacity for recovery in the event of a landslide. Each indicator is individually ranked from 1 (lowest vulnerability) to 5 (highest vulnerability) and assigned a weight, based on its overall degree of influence. The most influential indicators are most heavily weighted. The final vulnerability estimate is formulated as an average of the individual indicator scores. Furthermore, the proposed model is validated in SafeLand Deliverable D2.7, Part B through case study applications.

5.2 RECOMMENDATIONS FOR FURTHER WORK

The model proposed in this report assesses the level of socio-economic vulnerability and enables comparison of socio-economic vulnerability between communities. The vulnerability is formulated as a semi-quantitative parameter, which rank the vulnerability on a relative scale.

Future work could be to investigate ways to integrate this socio-economic model into a risk framework to produce absolute vulnerability numbers, i.e. numbers that quantify the degree of loss due to both direct and indirect losses within predefined space- and time-frames. This will make it easier to calibrate the models using historic loss data. A quantitative vulnerability analysis could be completed if the socio-economic model proposed in this paper were transferred to and combined with an existing quantitative vulnerability model, such as the one proposed by Li et al. (2010). In addition, the list of indicators needs to be extended to include more physical indicators to account for the direct losses.

In addition, it would be worthwhile to consider how societies respond to risks, why the response varies from one region to another, and how this analysis can be utilized together with the proposed socio-economic vulnerability model to provide a more thorough analysis. For example, Winter and Bromhead’s paper on societal willingness to accept landslide risk (2008) identifies which factors most influence a community’s response to risk. They selected seven test regions, from all over the globe, and assessed the following; willingness to accept risk relative to willingness to pay for mitigation measures and willingness to alter the surrounding environment. They concluded that social and economic factors greatly influence a society’s level of risk aversion, which directly affects the type of response taken towards landslide risk.

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