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"Meteorological risks as drivers of environmental innovation in agro-ecosystem management"

«Merinova»

A. Gobin, H. Van de Vyver, F. Vanwindekens, Y. Curnel, V. Planchon, A. Verspecht, J. de Frutos Cachorro, J. Buysse

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Thematic Risks

FINAL REPORT

METEOROLOGICAL RISKS AS DRIVERS OF ENVIRONMENTAL INNOVATION IN AGRO-ECOSYSTEM MANAGEMENT

"MERINOVA"

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ABSTRACT

Agricultural production risk is to a great extent determined by weather conditions. A chain of risk approach allowed for investigating the hypothesis that meteorological risks act as drivers for agricultural innovation. Generalized Extreme Value (GEV) theory and spatial interpolation of GEV-derived parameters were used to model 20-year return level maps of frost, heat stress, drought, waterlogging and field access. The degree of temporal overlap between these adverse weather events and sensitive periods in the agricultural system was determined using a bio-physically based modelling framework. The combination of multiple adverse weather conditions explained low arable yields, defined as the lower quintile of the yield distribution. A transdisciplinary approach combined expert interviews, farmers' focus groups, fuzzy inference and geographical information system was augmented to assess agro-ecosystem vulnerability. Resulting maps of cropland vulnerability to heavy rain and grassland vulnerability to drought identified vulnerable and resilient zones. Farmers' risk management was analysed using questionnaires, farmers' focus groups and economic modelling methods. Adaptation options favoured field management and crop rotation, while irrigation was not always justified. Belgian farmers relied on farmer to farmer networks for innovation and preferred on-farm strategies to cope with extreme weather events.

Keywords: Extreme Weather Events, Arable Agriculture, Climate Impacts, Vulnerability, Risk Management, Adaptation

1. INTRODUCTION

Devastating weather-related events recorded in recent years have captured the interest of the general public (Vicente-Serrano et al 2014). In August 2003, Europe recorded an unprecedented heat and subsequent drougth that led to a reduction in primary productivity (Ciais et al 2005). In recent years, most European countries have been affected by drought (EC 2010; Gudmundsson and Seneviratne 2016; Tallaksen et al 2015). Extreme weather events are meteorological phenomena that are at the extremes of the historical distribution (IPCC 2001). The probability of occurrence of extreme weather events (Van de Vyver, 2012) such as droughts, heat stress, rain storms and floods allows for predicting their agricultural impact (Gobin, 2012). Based on climate modelling, Christensen and Christensen (2003) showed that an increase of excessive rainfall is very likely in many European countries and that excess rainfall followed by severe flooding may become more frequent. Extreme weather events such as droughts, heat stress, rain storms and floods are projected to increase both in frequency and magnitude with climate change (Field, 2012; WMO, 2011; Solomon et al. 2007), and so are their impacts on agricultural production (Gobin, 2010).

Risk management in agriculture has been implemented probably as long as agriculture exists. It is expected that farmers will more frequently be exposed to extreme weather events in the future (Gobin, 2012), as there are trends to increased occurrence for these extreme weather events (Rust et al., 2009; IPCC, 2012). The more often an event occurs, the more actions are taken to minimize the damage or losses that occur, so that over time the events do not cause the same degree of damage (Wreford and Adger, 2010). Therefore it is likely that farmers have introduced certain strategies to cope with or prevent these events. As a one-size-fits-all strategy may prove limiting for local adaptation to climate extremes, a balanced portfolio of approaches is needed (Seneviratne, Nicholls et al., 2012). In a next we investigate to what extent Belgian farmers already use a balanced portfolio of strategies.

National governments are key actors in managing the impacts of extreme weather events (Mechler et al., 2010). Over the last few years, there has been a paradigm shift in national and international responses to this problem towards more proactive efforts and upgrading the role of pre disaster risk management (Mechler, Hochrainer et al., 2010), however preventive approaches continue to receive less attention than disaster relief and recovery (Davies et al., 2008). Priest (1996) questions if a policy based approach is efficient to manage risks and estimates strategies provided through the private market will give actors higher incentives to prevent risks. Some authors believe that ad-hoc disaster funds, will slow down the development of market based insurance products (Bielza et al., 2008; Aakre et al., 2010) or will lead to a lower uptake of private insurance. Referring to insurances, this is called the “charity hazard” (Browne and Hoyt, 2000; Raschky et al., 2013) or the “Samaritan’s dilemma” (Buchanan, 1975), but this concept can easily be extended to other on-farm strategies. In Belgium, policy introduced risk management strategies are mainly focusing on relief through a disaster relief fund and an agricultural calamity fund. To a lesser extent there are some subsidized investments or educational activities tackling risk. Today no multi-peril insurance schemes exist with private companies in Belgium (de Frahan, 2008), although the EU is increasingly exerting pressure to establish private insurances in all Member States.

Since more than half of the Belgian territory is managed by the agricultural sector, extreme events have significant impacts on agro-ecosystems and pose severe limitations to sustainable agricultural land management. The perspective of rising risk-exposure is exacerbated further by more limits to aid received for agricultural damage (amendments to EC Regulation 1857/2006) and an overall reduction of direct income support to farmers. Current knowledge gaps relate to the occurrence of extreme events and the response of agro-ecosystems need to be addressed in conjunction with their vulnerability, resilience and adaptive possibilities.

2. STATE OF THE ART AND OBJECTIVES

Agricultural production is to a great extent determined by weather conditions. In response to high risk and damage (Punge and Kunz, 2016), single risk insurance for hail is the most developed private insurance product available in all European countries (Mauelshagen, 2011), but there is gathering interest to include other meteorological triggers such as drought and frost, and offer a more comprehensive weather-based insurance cover. Extreme value theory provides the statistical framework to make inferences about the probability of very rare or extreme events (Coles, 2001; Dey and Yan, 2016). The assumption is that the probability of an extreme event can be determined from an event's climatological distribution. Classical extreme value models therefore assume that the underlying variables are stationary. A sample of extremes can be fit to the Generalized Extreme Value distribution to obtain the parameters that best explain the probability distribution of the extremes. From the fitted distributions, the frequency of extreme quantiles can be estimated with a certain return level (Beirlant et al., 2004).

The degree of temporal overlap between extreme or severe weather events and the sensitive periods of the agro-ecosystem in terms of farming calendar, crop development and seasonality may lead to different responses of the agro-ecosystem. Such events may lead to critical physical and/or physiological thresholds being exceeded during sensitive stages of the growing season. For example, the timing of frost events can have a serious impact on the final yield of fruit trees, but many arable crops are also susceptible to frost during the growing period (Gu et al., 2007; Kolář et al., 2014). Most arable crops are sensitive to drought, particularly around the flowering period (Jaggard et al., 2007; Wheeler et al., 2000). The impact of an extreme weather event on crop performance depends on the nature of the event; the crop type; and, the occurrence in relation to the agricultural calendar.

Vulnerability of agroecosystems to extreme weather events not only depends on ecological variables, but also on social and human variables like farmers' practices (Turner et al 2003). These variables are less easily taken into account in quantitative studies and models (Vanwindekens et al 2013). Farmers, advisers, agricultural scientists can be considered as experts of agroecosystems. They have the knowledge on how the influencing socio-ecological variables are affecting agroecosystems vulnerability and their mutual interaction (Uricchio et al 2004). Mapping vulnerability of agroecosystems to climate change has been done at district scale with case studies in India (o'Brien et al 2004), in South Africa (Gbetibouo and Ringler 2009) and in Nordic Region (Carter et al 2009).

Agriculture is a sector so often confronted with risk, that it has in the past often adapted to deal with shocks in response to weather, policy, market or social conditions (Wreford and Adger, 2010). Yet the topic of risk management in agriculture is more and more emphasized by policymakers (e.g. the introduction of risk management in the CAP) or other international organizations (OECD (Anton et al., 2012), Worldbank (2005)). Farmers' perception of risk and how they can prevent or mitigate these risks, determine whether adaptation responses are initiated or not (Grothmann and Patt, 2005). How people perceive a specific risk is a key issue for risk management since this perception will or will not lead to actions (Seneviratne et al., 2012). In many cases, it is not the existence of the risk that plays an important role in the decision making to adopt certain measures, but the perception of that risk by the farmer (Slovic and Weber, 2002). This subjective assessment is related to the degree of risk aversion of a farmer.

There is a relatively recent but large literature about adaptation strategies to climate change. Studies have considered different adaptation measures to deal with the challenges; these includes irrigation (Finger et al., 2011), land-use (Kaiser et al., 1993), technology adoption (Foudi and Erdlenbruch, 2012), financial support (Berrang-Ford et al., 2011) among others. Different methods are employed in the literature to study this topic, e.g. econometric models (Seo and Mendelsohn, 2008; Mu et al., 2013) and integrated models (see Kaiser et al. 1993) at different levels of decision-making (global, regional and farm levels). Kalaugher et al. (2013) call for the use of integrated models with interdisciplinary approaches. They argue that much of the recent literature deals with the assessment of climate impacts in an inadequate way because of the "profound failure of knowledge" in the different disciplines. Moreover, most of the European empirical studies about climate adaptation strategies are made in Southern Europe where changes in weather conditions due to climate change would be more pronounced. Studies in Atlantic and continental regions are limited but impacts are also expected such as the increase in extreme events and shifts in land-use (Iglesias and Garrote, 2015). In this report, we analyze baseline and adaptation land-use strategies by using an integrated agro-economic model at the farm level that takes into account risk in the decision making. Furthermore we build an agro-economic model to assess the impact of extreme weather scenarios on the crop choice of farmers.

The project research hypothesis is that meteorological risks act as drivers of environmental innovation in agro-ecosystem management. This hypothesis was tested using a chain of risk approach. The major objectives were to: (1) assess the probability of extreme meteorological events by means of probability density functions; (2) analyse the impact of extreme events on agro-ecosystems using process-based bio-physical modelling methods; (3) identify the most vulnerable agro-ecosystems using fuzzy multi-criteria and spatial analysis; (4) uncover innovative risk management and adaptation options using actor-network theory and economic modelling; and, (5) communicate to research, policy and practitioner communities. In particular the willingness of farmers, insurance companies and policy makers in Belgium to expand broad weather insurances needs to be investigated in Belgium.

3. METHODOLOGY

3.1. Overall project methodology

The MERINOVA project deals with risks associated with extreme weather phenomena and with risks of biological origin. The project comprises of five major parts that reflect the chain of risks (Figure 1):

I. Hazard: Assessing the likely frequency and magnitude of extreme meteorological events by means of probability density functions;
II. Impact: Analysing the potential bio-physical and socio-economic impact of extreme weather events on agro-ecosystems in Belgium using process-based modelling techniques commensurate with the regional scale;
III. Vulnerability: Identifying the most vulnerable agro-ecosystems using fuzzy multi-criteria and spatial analysis;
IV. Risk Management: Uncovering innovative risk management and adaptation options using actor-network theory and fuzzy cognitive mapping techniques; and,
V. Communication: Communicating to research, policy and practitioner communities using web-based techniques.

The different tasks of the MERINOVA project require expertise in several scientific disciplines: meteorology, statistics, spatial database management, agronomy, bio-physical impact modelling, socio-economic modelling, actor-network theory, fuzzy cognitive mapping techniques. These expertises are shared by the four scientific partners who each lead one work package.

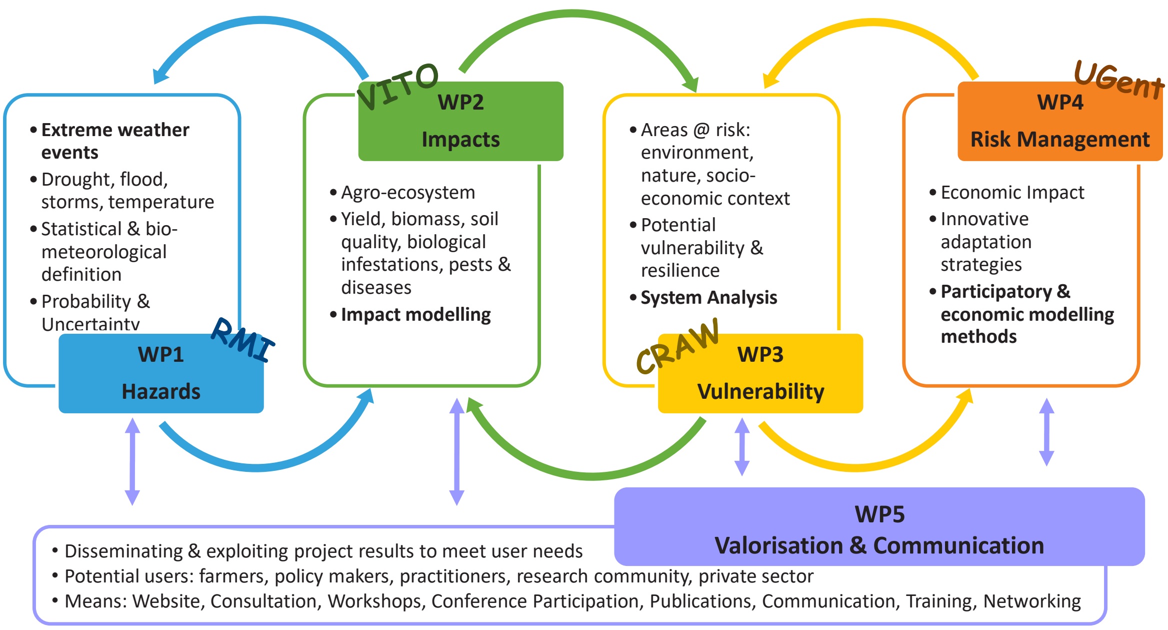

Figure 1 Chain of risk approach adopted by the MERINOVA project

3.2. Characterising the hazards

We defined risks associated with severe weather events which have an important impact on agro-ecosystems such as high precipitation (waterlogging, floods), high/low temperatures (heat waves, frosts), and droughts. Precipitation amounts were considered for several rainfall durations from 10 min up to 30 days. Regarding extreme temperature, we have considered hot summer extremes and cold winter extremes. Particular attention was paid to the study of droughts. Roughly speaking, there are three main ways to define droughts: meteorological-, hydrological- and agricultural droughts. We are mainly interested in the latter two definitions. Initially, we have adopted the frequently used definitions in the Netherlands, Beersma and Buishand (2004, 2007). Concerning a hydrological drought, the precipitation deficit in any period is the difference between precipitation (P) and potential evaporation (PET) in that period. Around early April the daily average potential evaporation becomes larger than the daily average precipitation. The deficit is therefore accumulated from April 1 onward. After 30 September the average cumulative precipitation deficit tends to decrease because global radiation and thus potential evaporation are reduced. The annual maximum precipitation deficit is the largest precipitation deficit that occurs during the summer half-year (1 April – 30 September). Likewise, we can define agricultural droughts by using potential evapotranspiration of crops. In the analysis we have adopted the FAO definition (=0.5*PET-P).

The research was based on the climatological series provided by the RMI. In particular, we have used (i) the climatological network for daily precipitation and temperature observations, and (ii) the synoptic/hydro-meteorological networks for sub-daily observations. In addition, the following long-term series at Uccle were also considered: (i) 10-min precipitation (1898--2007), (Demarée, 2003), and (ii) daily PET of free open water surfaces and grass (1901--2005), (Bleiman, 1976). Daily PET-series were calculated for open water surface, grass, coniferous and deciduous forest, for the period 1967–2005 for 12 additional stations across the country (Gellens-Meulenberghs and Gellens, 1992).

For a reliable extreme value analysis, time series must be homogeneous: i.e. no changes in site-conditions such as replacements or change of instruments, changes in the environment or new buildings. We used the homogeneity tests and the classification of Wijngaard et al. (2003) in terms of useful, doubtful and suspect to retain stations and their time series.

The main goal was to apply extreme value theory (EVT) to climatological series, with a view to agricultural applications. Extreme value theory characterises the behaviour of extreme observations, Coles (2001), Beirlant et al. (2004), de Haan and Ferreira (2006), Embrechts et al. (1997). A reliable prediction of the likelihood of rare but plausible events, allows EVT to be applicable in many domains of environmental research, e.g. climate, hydrology, soil analysis. The generalised extreme value (GEV) distribution is used to model annual rainfall maxima, annual number of consecutive rainy/dry days, annual precipitation deficit, and annual minimum and maximum temperature.

The T-year return level is defined as a value which, on average, is exceeded once in T years. They can be easily calculated by means of the GEV-distribution. For adequate risk management, continuous return level maps are often needed. This requires the computation of spatial estimates of return levels. The past decade, there is a growing interest in modelling spatial extremes, Cooley et al. (2012), Davison et al. (2012), Ribatet (2011). In fact, the use of spatial data appears so often in atmospheric sciences that the construction of models for them is currently seen as a well-established area of investigation. The methodology we used was based on (R. L. Smith, Regional estimation from spatially dependent data, University of Chapel Hill, unpublished manuscript, 1990), and the comparative study in Zheng et al. (2015) confirms that it is superior to all other spatial statistical methods.

3.3. Quantifying the impacts on agriculture

The extreme weather events considered are temperature (heat waves, frosts), water (drought, waterlogging, flooding) and storms (wind, hail). The agro-ecosystems included arable farming, fruit farming, horticulture, and dairy farming. The indicator crops include winter cereals, sugar beet, potatoes, maize, oilseed, grass, vegetables and fruit for which yields were obtained between 1947 and 2008. The impacts of extreme events were investigated on the following agro-ecosystem services: yield, biomass production, soil quality (moisture, organic matter, erosion) and occurrence of pests and diseases. Agrometeorological modelling methods were developed and tested on the synoptic station of Ukkel for 1947-2012 to elaborate the impact on these services and further implemented on the other synoptic stations since they provide for a long time series of a wide range of meteorological variables.

The degree of temporal overlap between extreme or severe weather conditions and the sensitive periods of the agro-ecosystem may lead to different responses that can be expressed as critical physical and/or physiological thresholds being exceeded during the sensitive stages of the growing season. For example, the timing of frost events can have a dramatic impact on the final yield, e.g. of fruit trees. Most arable crops are susceptible to drought and heat around the flowering period; other sensitive periods include crop establishment and harvest. Different sensitive crop stages were therefore expressed in thermal time and indicators were derived using the REGCROP modelling framework (Gobin, 2012). The indicators as related to sensitivity were derived for different crops using different methods with an increasing degree of complexity (examples, see Table 1). Probability distributions were fitted to derive 20-year return values since the Belgian disaster fund and insurances define extreme weather events as events equalling or exceeding the 20-year return value.

Table 1: Methods used to derive indicators related to agro-ecosystem sensitivity

Method	**Indicators related to agro-ecosystem sensitivity**
Single agro-meteorological variables	date of last frost, threshold temperature
Complex agro-meteorological variables	evapotranspiration, vapour pressure deficit
Modelled agro-meteorological indices	agricultural/hydrological drought, field access, waterlogging, heat stress
Crop model	Yield, biomass
Environmental model	Soil organic matter, soil moisture, erosion, pests and diseases

The impact of extreme or severe weather events on soil quality is well documented in the case of soil erosion (Cerdan et al., 2010; Gobin et al., 2004). The impact on soil moisture in terms of waterlogging or drought is not so well documented. We defined an indicator that reflects field access and that is based on the soil water balance. We fitted return periods through the distribution to derive the 20-year return values.

Yields integrate weather variability during the growing season and their relation with single extreme events is not straightforward. In addition yields are often aggregated over larger regions. We detrended longer time series of yields to determine extreme yields (Peltonen-Sainio et al., 2010; Gobin, 2010). Probability distribution functions were fitted to detrended yields and biomass to derive low and high yields represented by the lower and upper quintile of the distribution. The relation between crop water use and yield was further explored using concepts of water productivity and the water footprint.

The effect of extreme climate events on pest and disease populations depends entirely on the species and the timing of the event. Most pest and disease models use a combination of temperature, relative humidity, first frost, precipitation frequency, amount of rainfall, dew or leaf moisture and radiation (Magarey et al., 2007; Billing, 2000). We concentrated our efforts on finding proxies for potato blight in terms of number of consecutive rainy days during the cropping season.

3.4. Assessing vulnerability

The MAVABEK approach highlighted key ecological, economic and social factors and their respective influence on agroecosystems vulnerability to extreme weather events. Expert knowledge was simulated using a coupling of a Fuzzy Inference System (FIS) and a Geographical Information System (GIS). The MAVABEK approach consisted of four major steps: (1) qualitative data collection; (2) cognitive mapping; (3) vulnerability assessment; and, (4) coupling with a GIS. The MAVABEK approach was applied on two case studies in Belgium: (1) vulnerability to heavy rain; and, (2) vulnerability to drought.

In a **first step** expert knowledge was collected by surveying stakeholders of the studied agricultural system(s): farmers, advisers, and researchers. The sample of stakeholders constituted key persons having a systemic conception of the studied system(s) and being able to clearly express the conception they have of this system. The interview process was guided by topics linked to the agricultural systems and its vulnerability. Each interview was divided in three broad open-ended questions: (i) What kind of vulnerability characterizes the studied system (ecological, economic, social)? (ii) What are the key factors influencing the vulnerability of studied system?; and, (iii) How do these key factors affect the vulnerability of this system? Interviews were recorded and fully transcribed in computer text files. These text files were used to produce a first qualitative model of the systems.

The **second step** aimed at building a qualitative model of experts' knowledge on agroecosystems vulnerabilty, and connecting relevant information in a cognitive map. A cognitive map is a network of nodes and directed edges, i.e. a directed graph used for showing causal relationships based on actors' descriptions (Axelrod and Arbor 1976). Cognitive mapping is a tool commonly used for qualitative modelling complex socio-ecological systems (Fairweather 2010; Özesmi and Özesmi 2004; Vanwindekens et al 2013, 2014). Main advantages of this technique are its relative simplicity, its flexibility and its capacity to encompass the complexity of modelled systems. Cognitive mapping is proposed for showing causal relationships based on actor's descriptions of agroecosystems' vulnerability. The practical method for building cognitive maps is fairly open: coding transcription files using a Computer Assisted Qualitative Data Analysis approach (e.g. Vanwindekens et al 2013); mapping directly with actors during the interview; and, mapping based on the transcription of the interviews. For each analysed couple of agroecosystems/extreme weather event, a cognitive map was composed by variables that had a perceived influence on agroecosystems' vulnerability regarding to the extreme weather event. The variables were linked to each other by relationships that (i) were causal; (ii) were oriented and (ii) could be weighted regarding their importance. The cognitive map was used as principal source of information for building the model to evaluate the agroecosystem vulnerability to extreme weather events.

The **third step** represented the model of the agroecosystems' vulnerability. The modelling approach is based on a Fuzzy Inference System (FIS) using the R-package "sets" (Meyer and Hornik 2009). The experts' knowledge encompassed in the cognitive map was used for editing a series of rules that qualitatively described the influence of key factors on the system's vulnerability. Each rule had the following form:

IF (*var*1 **is**…) **ANDIF** (*var*2 **is**…) **THEN** (*vulnerability* **is**…) (1)

where

- *var1*, *var2*, are the key factors
- *vulnerability* is the element to be evaluate
- …are the levels of the variables, e.g. in a five-point scale: *very low*, *low*, *medium*, *high*, *very high*
- boolean operations between elements of the rule can be **AND** or **OR**

The Fuzzy Inference System required some further technical parameters:

- the universe was defined from 0 to 1 by a step of 0.01 (figure **Error! Reference source not found.**)
- the memberships function of the five-point fuzzy classes were fuzzy cone with a radius (base) of 0.2 universe unit (Figure 2)
- the fuzzy inference method used was the common Mamdani's direct method
- the conclusions of each rule were aggregated using the maximum operators
- the aggregated conclusion of the FIS was defuzzified using the centroid method

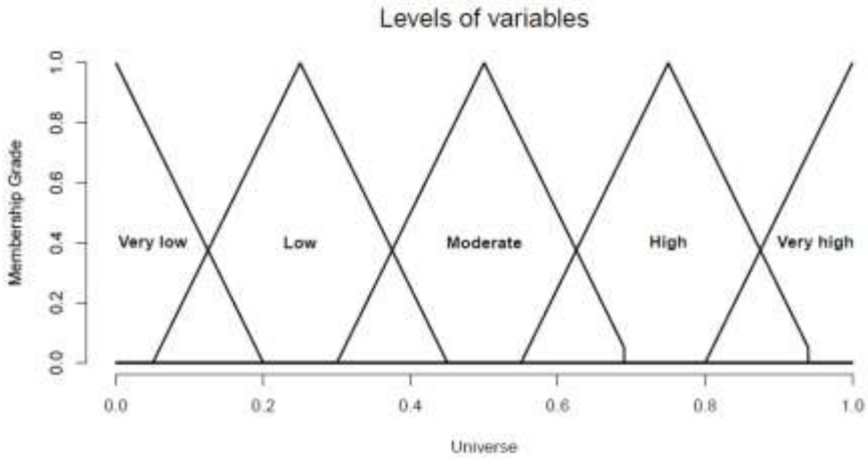

Figure 2 Fuzzy cones defined the memberships of a quantitative value (universe) to a five-point class of each variable

Practically, the inputs of the FIS were quantitative values for each of the key variables. These values were linearly scaled to match with the universe of the FIS between 0 and 1 by 0.01 (Equation 2).

$$X_{isc} = \frac{X_i}{max(X)} \qquad (2)$$

A vector of scaled values was evaluated as input to the FIS. The FIS return a quantitative value of the universe between 0 and 1 which equalled an assessment of the agroecosystem vulnerability.

The **fourth step** involved the incorporation of available spatial data across the assessed areas. Agroecosystems are complex entities and their intrinsic properties are varying in space. This variability induces the variability of their vulnerability. In order to incorporate this variability and to assess vulnerability of agroecosystems at various spatial scales (local, regional, national), the FIS module was coupled with a Geographical Information System (GIS) using R (R Core Team 2015a) and a cohort of packages for data and spatial analyses : gdata (Warnes et al 2015), grid (R Core Team 2015b), tidyr (Wickham 2014), plyr (Wickham 2011), sp (Pebesma and Bivand 2005), raster (Hijmans 2015), lattice (Sarkar 2008), and rgdal (Bivand et al 2015). The data were processed in the following steps:

- the projection of all spatial data was uniformised ;
- rasters were used as is and shapefiles were rasterised ;
- the resolution of the desired grid was defined and the resolution of inputs (rasters) were adapted accordingly ;
- cells with at least one NA (not available) data were removed from the grid (e.g. cities, roads).

For each cell of the grid, related variables were extracted and used as input of the FIS. The output of the FIS enabled the evaluation of agroecosystem vulnerability for each cell. The results of the FIS were used to reproduce a vulnerability raster. This vulnerability raster formed a principal output of the MAVABEK approach: a map of the vulnerability of the agroecosystem.

3.5. Risk management

A broad range of methodologies was used for the work package on risk management. A literature review was conducted to analyse possible strategies and get insight in the motivation of farmers to take up certain strategies.

We organised an **on-line survey** with Belgian farmers to get insight in the risk behaviour, the perception on EWE and their current and preferred strategies. In total 766 farmers started the survey, 510 surveys were used for further analysis. The response in the northern part of the country was remarkable higher than in the south of Belgium. Agriculture is different in the two regions. In the southern part more extensive agriculture occurs with bigger arable or mixed farms, northern agriculture is more intensified and have in general smaller mean surfaces.

To be able to go more in detail on the farmers' preferences and the process of innovation four **focus groups** were organised, two in Flanders, two in Wallonia. Strategy preferences and reasons for approval or disapproval were assessed by means of the focus group discussions. These focus groups covered three main topics: (1) innovative adaptation strategies for withstanding EWE's, the process of implementing a strategy and preferred strategies in coping with EWE's, (2) criteria the strategies have to fulfil before a farmer would be willing to adopt these strategies, (3) the farmers' perception of climate change and its influence on strategy adoption.

Several **interviews** were done with the banking and insurance sector in Flanders to know the opinion on the impact of EWE on the farmers' situation, on the regionalisation of the ad-hoc calamity fund and on the potential for broad weather insurances in Belgium.

The MERINOVA project also included a simulation on the impact of extreme weather scenarios on the crop choice of farmers. Agronomic data were delivered based on data from WP2. The simulated average yields for different crops, over different years for 4 scenarios: current normal yields and projected yields under climate change, with and without weather related stress. Data on crop rotation and crop surfaces were found in the ADSEI database. The economic data and prices and costs for producing the different crops were collected within the ADSEI and FADN databases.

The objective function used in this agro-economic model is to maximise profit and is defined as:

$$\max_{X(K)} E(U) = E(Profit)_K - OperCosts_K - TermRiskAversion \ (1)$$

where X_K : land allocated to crop K.

In a second step the operating cost and risk aversion term is calibrated for the scenario "Now" with respect of the observed data of 2013. In a third step these calibrated parameters are used in the climate change scenario to assess the impact on crop areas. Results calculate the relative share of the different crops area in a scenario "Now" and under "climate change".

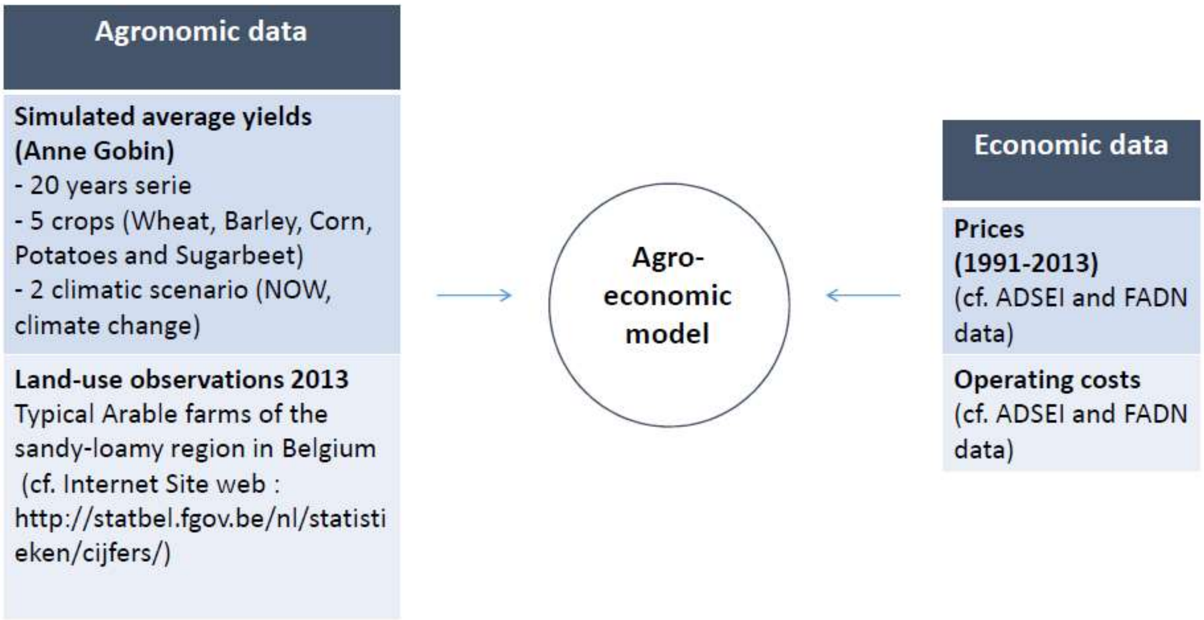

Figure 3 Conceptual framework of the agro-economic model

4. SCIENTIFIC RESULTS AND RECOMMENDATIONS

4.1. Characterising the hazards

The study was preceded by a thorough quality and homogeneity analysis. Concerning precipitation: we have selected 68 useful stations of the climatological network with 60 year of daily data (1951--2010), and 18 stations of the hydro-meteorological network with 38 year of 10-min data (1967--2004). Concerning temperature, we have found that only 9 long -time series were classified as useful. In order to obtain enough data, it was necessary to relax the homogeneity requirements. In total, 74 stations were selected with 32 year of data (1983 --2014).

The GEV distribution has been fitted to annual maximum precipitation depth, summer maximum temperature/winter minimum temperature and maximum precipitation deficit. We have concluded with an excellent fit of the GEV-distribution for most of the series. The spatially extended GEV-distribution has been developed as the main product of WP1 (Van de Vyver, 2012, 2013; Zamani et al., 2015). Examples of 20-year return level maps are given in Figure 4. Particular attention was paid to the *uncertainty analysis* of the spatial extremes methods; Figure 5 shows the upper- and lower-confidence bounds of the spatial estimation. In conclusion, the degree of uncertainty is relatively high, but this is a generally known limitation of extreme value analysis.

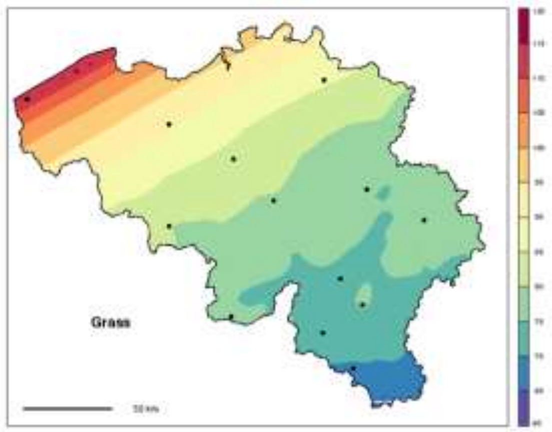

Figure 4 20-year return level maps of maximum cumulated precipitation deficit (mm). Vegetation type: short grass. Dots represents the stations were the PET-series were obtained.

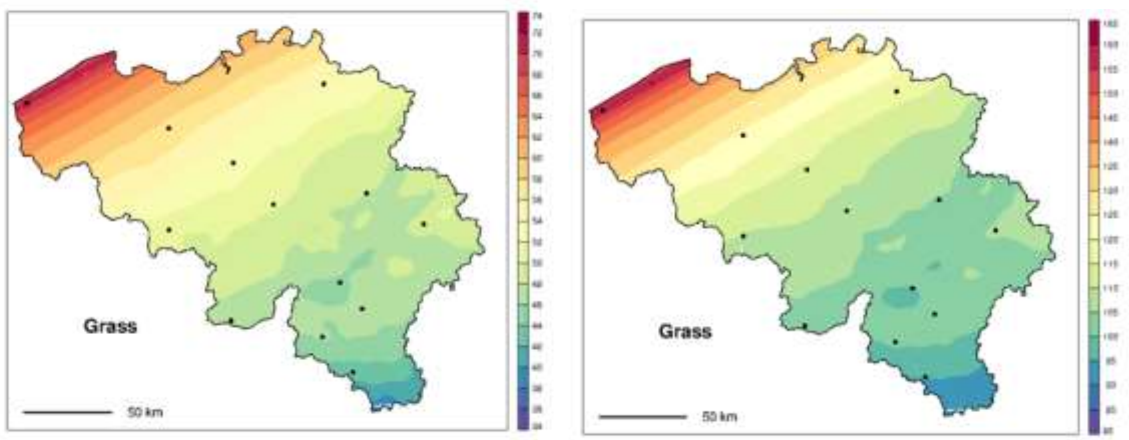

Figure 5 Upper- and lower- confidence bounds (mm) of the spatial return level estimation of Figure 1.

The same methodologies have been applied to extreme precipitation, temperature, dry and wet periods. Examples are provided in Figure 6. Concerning 24-h precipitation, further refinements were made in Van de Vyver (2015). Practitioners often use daily measurements (usually 08:00–08:00 local time) since high-frequency measurements are scarce. Annual maxima of daily series are smaller or equal to sliding 24-h precipitation maxima such that the resulting return levels may be systematically underestimated. We have developed a new estimator which converts the GEV distribution of daily to sliding 24-h maxima.

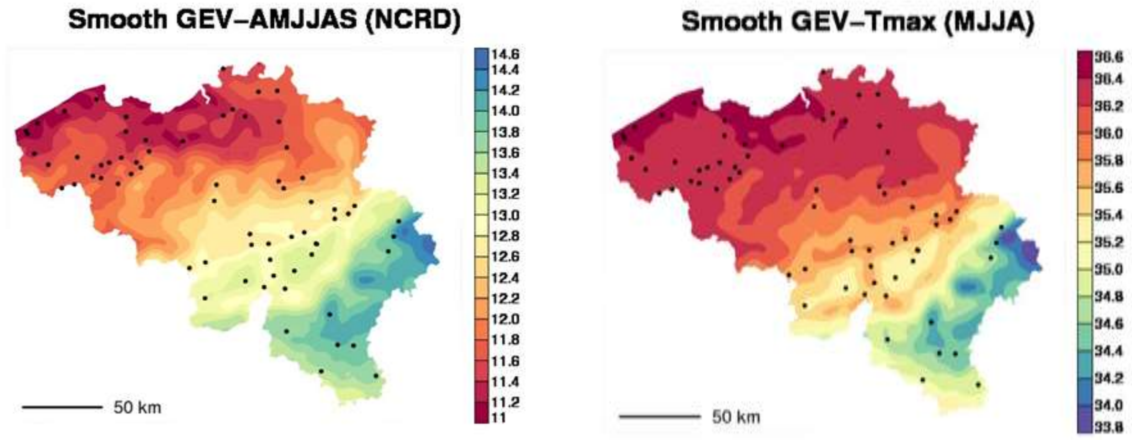

Figure 6 20-year return level map of number of consecutive rainy days (left) and annual maximum temperature (right)

4.2. Quantifying the impacts on agriculture

Crucial to the quantification of impacts is the phenological crop cycle which is primarily based on growing degree days and day length. Growth stages such as flowering occur significantly earlier during the growing season in the 1988-2008 period (Figure 7; Gobin, 2012) with implications for the coincidence between a meteorological hazard and the sensitive stages and harvesting across the years. A phenological model was used to determine sensitive crop growth stages and maturity.

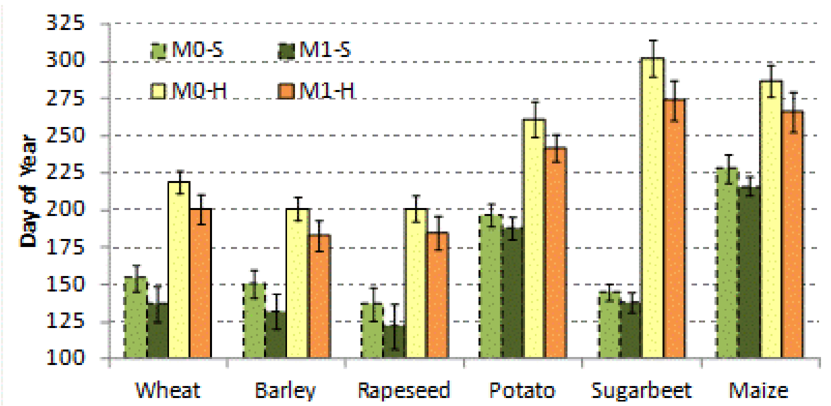

Figure 7 Shift in harvest (H) and sensitive crop stages (S) before (M0) and after (M1) 1988 (modified after Gobin, 2012). Sensitive stages are defined as germination of sugar beet, flowering of wheat, barley, maize and rapeseed; tuber initiation of potato.

Return periods were derived for adverse weather conditions such as frost, drought, heat and waterlogging, and for general weather conditions such as radiation, temperature, precipitation and the water balance using fitted statistical distributions for the period 1947-2012. Crop-weather interactions were captured using a physically based crop modelling approach (Gobin, 2010, 2012). Probability distributions enabled quantification of 20-year return values for weather events occurring during different stages of the growing season. Weather related stress varied significantly between years, crops and growth stages (Figure 8). The combination of multiple adverse weather conditions explained low arable yields, defined as the 20% lower tail of the yield distribution (Gobin, in press 2017).

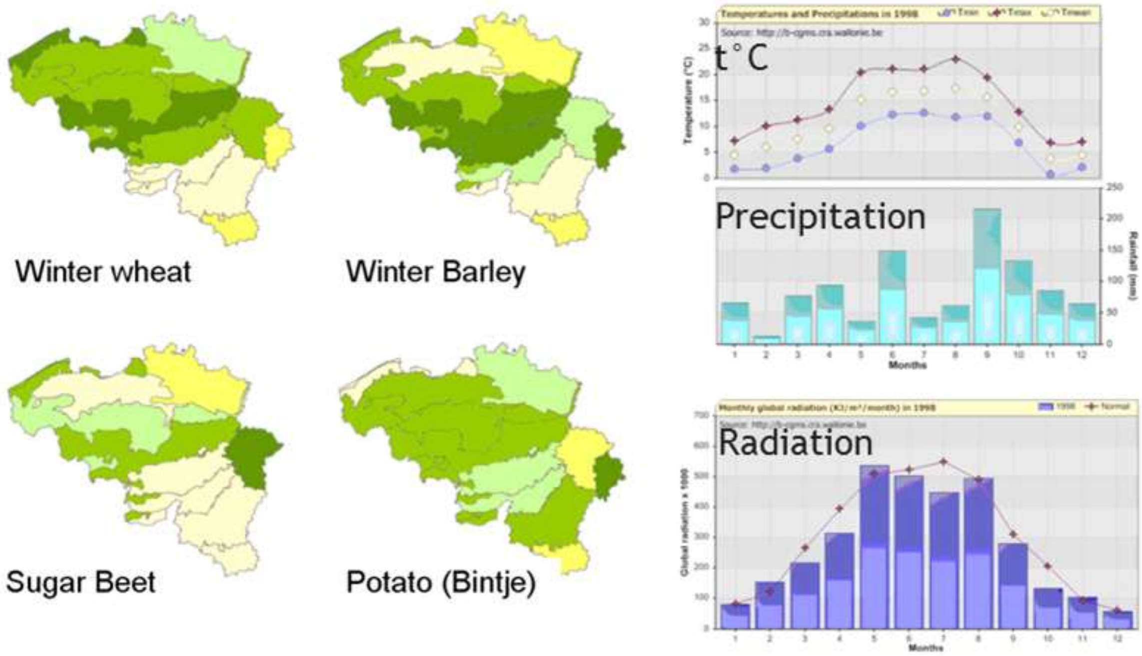

Figure 8 Yield variability between regions relates to the growing season.

The relation between crop water use and yields was further explored using concepts of water productivity and the water footprint (Gobin, 2015; Gobin et al., 2017). Crop growth and yield are affected by water use during the season. The water footprint was calculated as the water use per harvested crop for the six major agricultural crops in Belgium using meteorological and yield data series for the 1988-2012 period. The results demonstrate the importance of soil moisture as an important soil quality indicator. The water footprint of seed and grain crops is larger than for tuber and root crops, and depends on the proportion of marketable produce to biomass produced per surface area (Figure 9; Gobin, 2015).

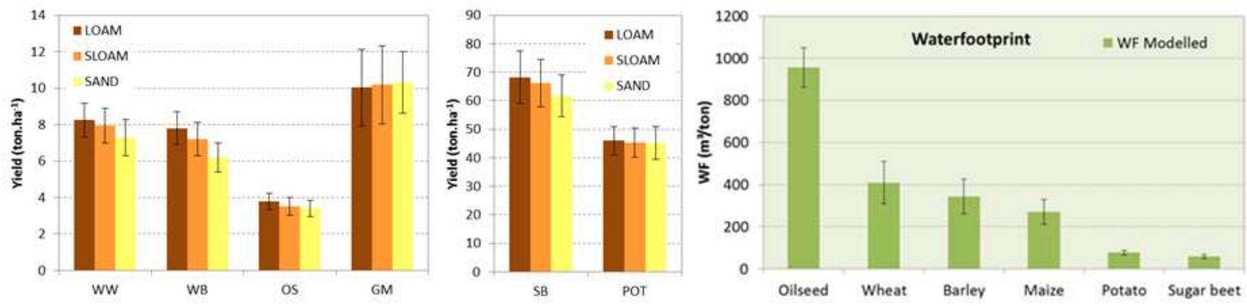

Figure 9 Yields of major arable crops for loam, sandy loam and sandy soils, and their water footprint in Belgium (Gobin, 2015).

The modelling framework (Gobin, 2010, 2012) was used to project climate impact and stress limitations on biomass and yield for winter wheat, winter barley, late potato, sugar beet and grain maize. Stress alleviation or adaptation measures included irrigation and soil conservation measures that result from crop diversity and returning organic matter residues to the soil. Under a climate scenario without adaptation measures the summer crops were projected to have lower yields (Figure 10). Adaptation measures will enable to alleviate drought and heat stress but will not reach current non-stress limited yields. Winter cereals will produce higher yields due to a combined effect of CO_2 fertilisation, warmer temperatures and efficient crop water use. The introduction of adaptation measures will enable higher non-stress limited yields as compared to current yields. These results were subsequently used for economic modelling (de Frutos Cachorro, 2017 submitted).

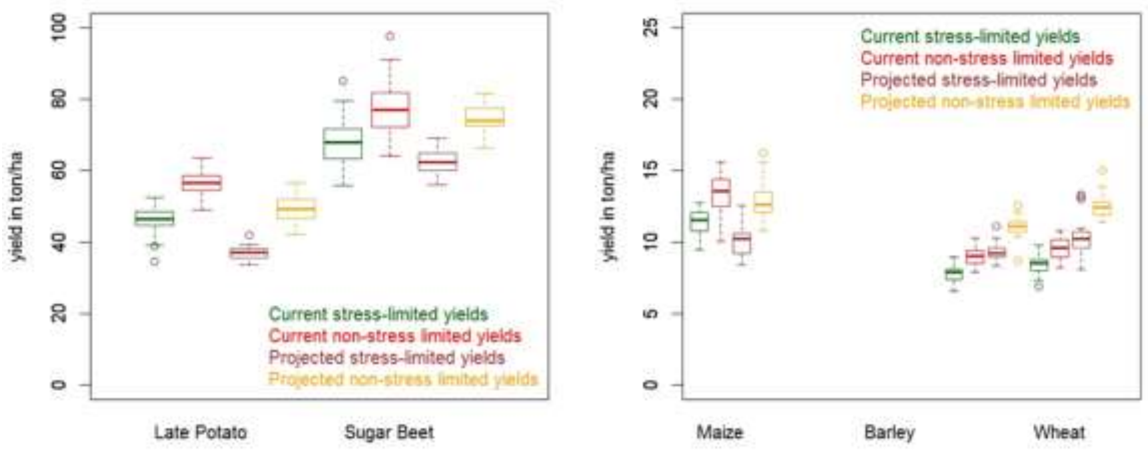

Figure 10 Yields of major arable crops in Belgium, simulated for current and projected climate under stress-limited and non-stress limited conditions.

The effect of extreme climate events on pest and disease populations depends entirely on the species and the timing of the event. Most pest and disease models use a combination of temperature, relative humidity, first frost, precipitation frequency, amount of rainfall, dew or leaf moisture and radiation (Magarey et al., 2007; Billing, 2000). We concentrated our efforts on finding proxies for potato blight in terms of number of consecutive rainy days during the cropping season

(Figure 11). The most sensitive periods for potato are planting and harvesting with associated risks for water logging as expressed by number of days with saturated soil profiles and the number of consecutive rainy days. Drought expressed as water deficit during the growing season or wetness expressed as number of consecutive rainy days during the growing season pose severe risks to potato cultivation.

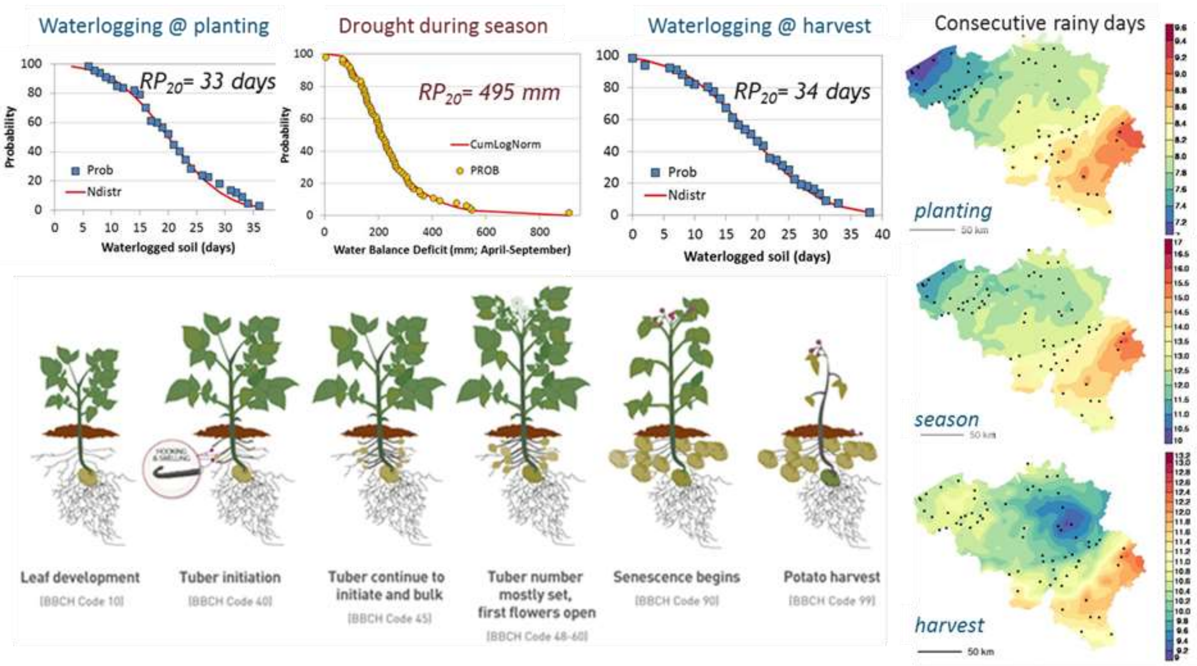

Figure 11 Weather related risks for potato cultivation in Belgium.

4.3. Assessing vulnerability

The developed approach has been applied to two case-studies for assessing Belgian agroecosystems' vulnerability: erosion due to heavy rain and drought in grassland-based livestock farming systems. The practical details of these applications and the results are presented in the two following sections.

Vulnerability to heavy rain

Two soil scientists were interviewed for describing the vulnerability of agroecosystems due to heavy rain. These two in-depth interviews were augmented with shared knowledge from farmers' focus groups. The interviews were at the basis of the global cognitive map (Figure 12). The influencing factors covered two main categories: farming practices (human factors) and environmental variables (ecological factors). The ecological factors were the slope and various soil characteristics (organic matter, texture). The main influencing farming practices were the presence of row crops, the rotation and the mean acreage of fields.

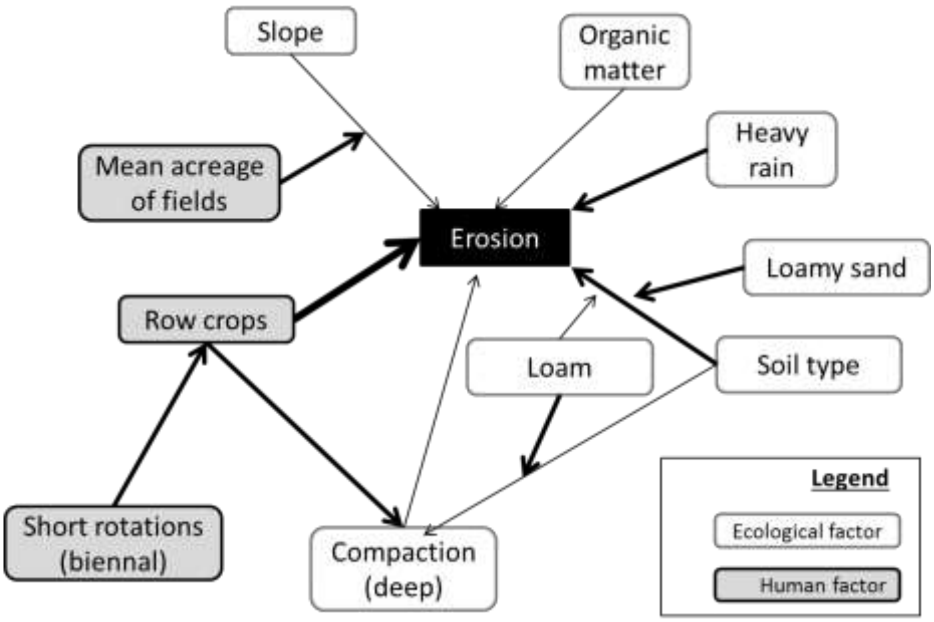

Figure 12: Cognitive map of the vulnerability of Belgian agroecosystem to heavy rain (erosion)

Based on expert's cognitive map, three variables have been chosen as inputs of the MAVABEK approach:

- the part of row crops (maize, potato, sugar beet) in the Utilized Agricultural Area (UAA) (%), data at municipality level from IACS parcel information ;
- the slope (%) from National Geographic Institute of Belgium ;
- the erodibility of soil ([-]) (Panagos et al 2014, data available from European Soil Data Centre).

The values of these variables were mapped in appendix. The variables were scaled subsequently according to Eq. 1. Their mutual influence and their impact on vulnerability of agroecosystems have been set up using the rules in Table 2.

Table 2 Set of fuzzy rules for the heavy rain case study. *factor k* is the erodibility of soil, *rowcrops* is the part of row crops (mainly maize, potatoes, suger beets) in the utilized agricultural area (UAA).

IF	factor k	**is** very low	**OR IF**	rowcrops	**is** very low	**THEN**	vulnerability	**is** very low
IF	factor k	**is** low	**OR IF**	rowcrops	**is** low	**THEN**	vulnerability	**is** low
IF	factor k	**is** low	**AND IF**	rowcrops	**is** low	**THEN**	vulnerability	**is** very low
IF	factor k	**is** moderate	**OR IF**	rowcrops	**is** moderate	**THEN**	vulnerability	**is** moderate
IF	factor k	**is** high	**OR IF**	rowcrops	**is** high	**THEN**	vulnerability	**is** high
IF	factor k	**is** high	**AND IF**	rowcrops	**is** high	**THEN**	vulnerability	**is** very high
IF	factor k	**is** very high	**OR IF**	rowcrops	**is** very high	**THEN**	vulnerability	**is** very high
IF	slope	**is** very low				**THEN**	vulnerability	**is** very low

Based on these variables and fuzzy rules, the FIS-based approach was used for evaluating the vulnerability of Belgian agroecosystems to heavy rain. As all data were geolocated, the MAVABEK approach enabled the assessment of the vulnerability for each cell of a raster. In addition, various resolutions were tested: 10000m, 5000m, 2000m, 1000m and 500m to evaluate the optimal resolution in relation to information present in the resulting map and in relation to computation time.

The output of the MAVABEK approach was a map of the relative vulnerability of Belgian agroecosystems to heavy rain (500m resolution map, Figure 13).

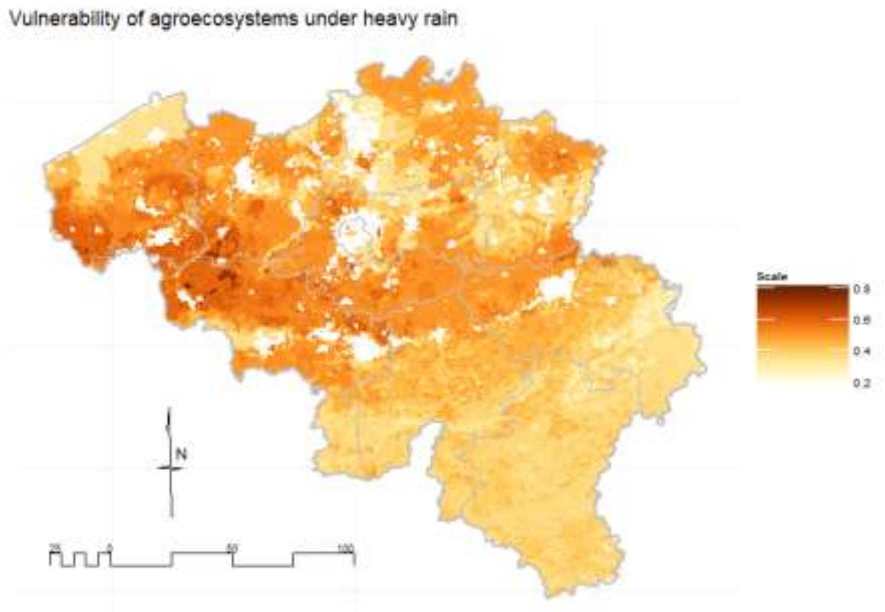

Figure 13 Vulnerability of Belgian agroecosystems to heavy rain (resolution=500m)

Vulnerability to drought

Three grassland scientists were interviewed for describing the vulnerability of grassland-based agroecosystems to drought. These three in-depth interviews were augmented with shared knowledge from farmers' focus groups. The interviews were at the basis of the global cognitive map (Figure 14). Various influencing factors were taken into account for describing this part of vulnerability. The main contributing factors were linked (i) to local ecological conditions (soil type, topography, location in the landscape) and (ii) to farming practices and farm specificities: stocking rate, grass species, forage reserve, …

According to experts'interviews, and constrained by data availability, three variables were chosen as inputs for the second case-study :

- the total available water capacity (*i.e.* field capacity minus wilting point), from the b-CGMS model (Buffet et al 1999) ;
- the stocking rate (number of bovines per hectare of forage area) at municipality level, from Statistics Belgium (available online at http://www.atlas-belgique.be) ;

- the share of permanent and temporary grassland in the total agricultural area, from Statistics Belgium (available online at http://www.atlas-belgique.be).

The variables were scaled according to Equation 2. Their mutual influence and their impact on vulnerability of agroecosystems were set up using the rules in Table 3.

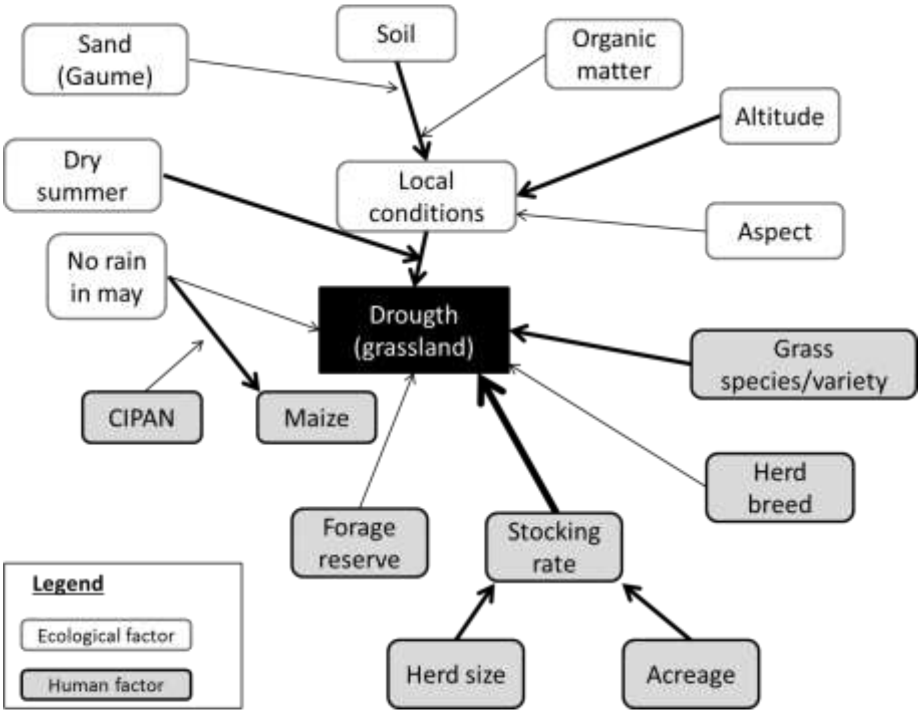

Figure 14 Cognitive map of the vulnerability of Belgian grassland-based farming systems to drought. CIPAN is a French-abbreviation for "catch crop".

Table 3 Set of fuzzy rules for the drought case study. *tawc* is the total available water content, *livestock* is the stocking rate of livestock,*grassland* is the part of grassland in the UAA.

IF	tawc	**is** very high	**OR IF**	livestock	**is** very low	**THEN**	vulnerability	**is**	very low
IF	tawc	**is** high				**THEN**	vulnerability	**is**	low
IF	tawc	**is** high	**AND IF**	livestock	**is** low	**THEN**	vulnerability	**is**	very low
IF	tawc	**is** moderate	**OR IF**	livestock	**is** low	**THEN**	vulnerability	**is**	moderate
IF	tawc	**is** low	**OR IF**	livestock	**is** (high OR moderate)	**THEN**	vulnerability	**is**	high
IF	tawc	**is** low	**AND IF**	livestock	**is** high	**THEN**	vulnerability	**is**	very high
IF	tawc	**is** very low	**OR IF**	livestock	**is** very high	**THEN**	vulnerability	**is**	very high
IF	grassland	**is** very low				**THEN**	vulnerability	**is**	very low

The output of the application of the MAVABEK approach to this case study is a map of relative vulnerability of Belgian grassland agroecosystems to drought (500m resolution map, Figure 15).

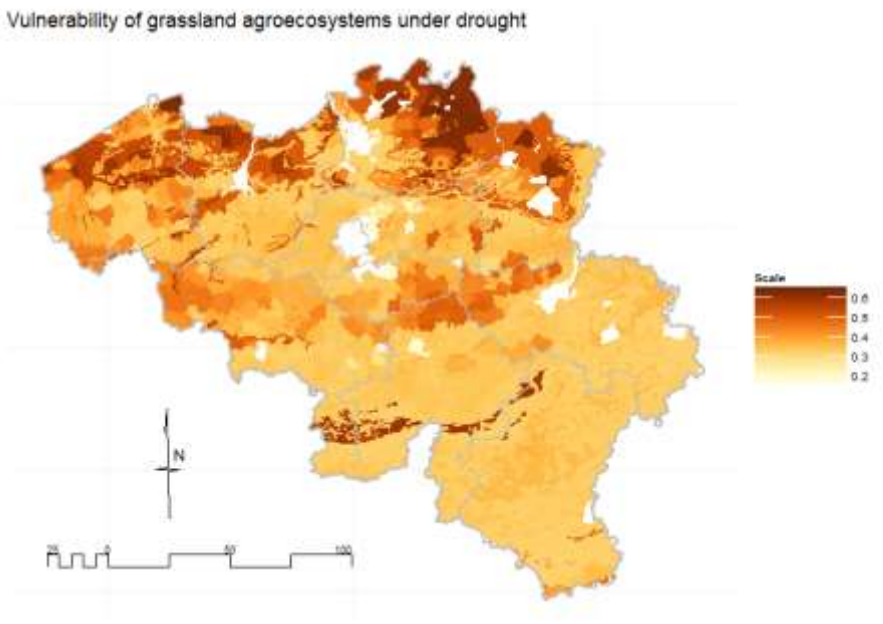

Figure 15 Vulnerability of Belgian grassland agroecosystems to drought

The MAVABEK approach for assessing agroecosystems vulnerability offers an original combination of strength in terms of (i) anchorage of the modelling process in experts' knowledge ; (ii) flexibility of the type of influencing variables that could constitute inputs to the model ; and (iii) information on the model's outputs that are visual and accessible for a wide public (specialist and non-specialist).

Complex systems have to be studied as a whole for effective understanding (Bossel 2001). Experts, including main actors, are best qualified for understanding but also expressing and explaining the complexity of the vulnerability of the agroecosystem to extreme weather events. It has been shown for various complex systems linked to a diversity of socio-ecological systems: sustainabilty at community scale (Rajaram and Das, 2010) or practices in grassland based farming systems (Vanwindekens et al 2013).

As shown in previous studies Nelson et al (2010), the vulnerability is better assessed using holistic approaches, taken into account variables from diverse fields and directly linked to rural communities's prosperity, e.g. incomes. This kind of holistic variables can be included as inputs of the modelling approach. In this paper, the two applications of the MAVABEK approach were focused on the ecological part of vulnerability. Further applications would include more holistic variables in order to assess the resilience of agroecosystems, including socio-economic indicators.

Another originality of the MAVABEK approach is the indirect establishment of rules, which are not directly expressed by experts. On the one hand, it is easier for experts to describe their systems in an open-ended way than to establish a long list of fuzzy rules. On the other hand, this indirect way implies the generation of fuzzy rules by the researcher itself, which can lead to some misunderstanding. An improvement of the MAVABEK approach could be the use of a step involving the coding of experts' interviews when producing cognitive maps like in Vanwindekens et al (2013). This improvement would objectivate fuzzy rules by linking them to experts' quotes describing each relevant rule.

As shortcomings of the present study, our two applications of the MAVABEK use only a limited number of variables and a short list of rules collected during a limited number of interviews. Further applications would involve a betted explanation of the different aspects of vulnerability to a wider panel of experts. This will allow considering more social-ecological variables and, therefore, assessing adaptive capacity and resilience of studied agroecosystem to climate change (Folke et al 2010).

We consider the strength of the MAVABEK approach twofold: (i) its implementation in R; and, (ii) its combination with a Geographical Information System. These properties allow sequential assessment of a large amount of points and subsequent mapping of the results of geolocalized data. This kind of output has the advantage to contain a large amount of information, but also to remain simple and informative for main actors e.g. farmers, researchers, administrations. The flexibility of the MAVABEK approach allows increasing the number of rules. Compared to previous works (Carter et al 2009; Gbetibouo and Ringler 2009; o'Brien et al 2004), our approach is dealing with data of various nature: continuous raster, statistics at district or regional scale and even categorical data.

If mapping vulnerability shows a clear added-value in terms of clarity and communication, maps can be seen as the panacea by actors and lead to rapid decisions (Preston et al 2011). We consider that maps are able to reveal vulnerable parts of the landscape, but have to be critically reviewed by actors and taken into account with other tools (*e.g.* cognitive maps, interviews and other modelling approaches).

4.4. Risk management

The on-line survey showed that 80% of the Belgian farmers perceive price or market risks as a large or very large risk in their farm management (see Figure 1). This is only slightly more (76%) than the importance they attach to the risk caused by weather conditions. In that sense, this survey comes up with similar conclusions as Deuninck et al. (2007). Price and market risks are perceived to be (very) relevant to all sectors. They found that weather related risks are mostly relevant for fruit (hail, frost, drought) and vegetable production in open air (rain, drought), arable farming (drought, rain, storm) and beef or milk production (heat). However, another Belgian study by Harmignie et al. (2004) dismisses the risk of extreme weather events, stating that the impact will mostly be felt in southern Europe and not in Belgium. Our findings clearly contradict this.

Risk averse farmers in the survey perceive the risk for extreme weather events as more important than less risk averse farmers. This is the case for all surveyed extreme events. This is also mentioned in literature (Bond and Wonder, 1980). Furthermore it seems that farmers who already faced a certain extreme weather event, perceive the impact of these events as more serious than farmers who did not suffered form an extreme event on their farm.

Farmers do perceive extreme weather events a risk for their farm management; however it is striking that between 20% up to 30% of the farmers who were recently confronted with an extreme weather event are not implementing any risk management strategy. In Belgium farmers undertake more strategies to reduce the impact of extreme rainfall than for other events (52% compared to 40% has more than one strategy).

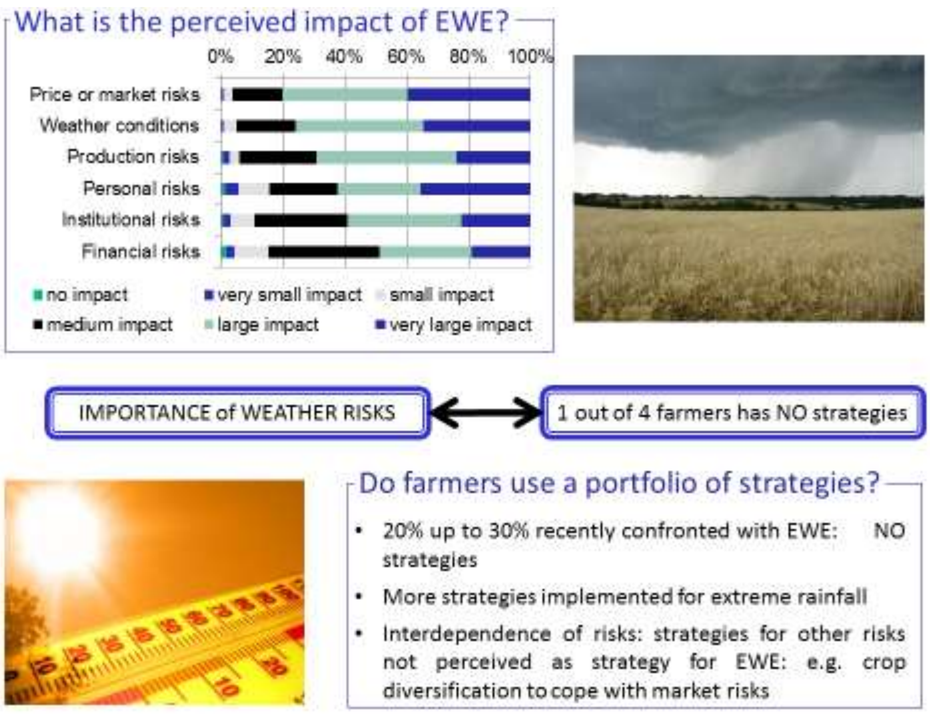

Figure 16 Result overview on impact of EWE and used strategies

There is a gap between the actual undertaken measures and the preferred future strategies (Figure 16). The preferred on-farm measures are in line with the actual implemented strategies (irrigation, drainage and other technological improvements). But all other preferred strategies of the top 5 are policy based strategies. This indicates that farmers see an important role for policy intervention regarding extreme weather events. Having a look at the least promising measures, farmers do not see much effect to mitigate extreme weather events in the use of other inputs of crop diversification as on farm measures. Neither market contracts, nor future options are marked as good strategies towards EWE.

Policy based strategies are perceived important, but is there a correlation with the number of strategies a farmer has? Does a farmer who believes policy measures are important, will undertake less on farm measures? For extreme rainfall, storm or hail and heat there is no significant difference in the number of on-farm strategies a farmer implements related to how effective he thinks disaster fund, tax deduction is. Surprisingly, for extreme drought farmers who perceive policy based instruments as more efficient, have also more on farm strategies. Overall we did not find proof of charity hazard: it seems that on the one hand policy based mitigation or recovery actions like tax deduction or disaster funds do not obstruct farmers to take their own responsibilities. On the other hand, due to the considerable percentage of farmers not undertaken any strategy towards EWE, it is recommendable to create awareness of on-farm strategies through extension and education.

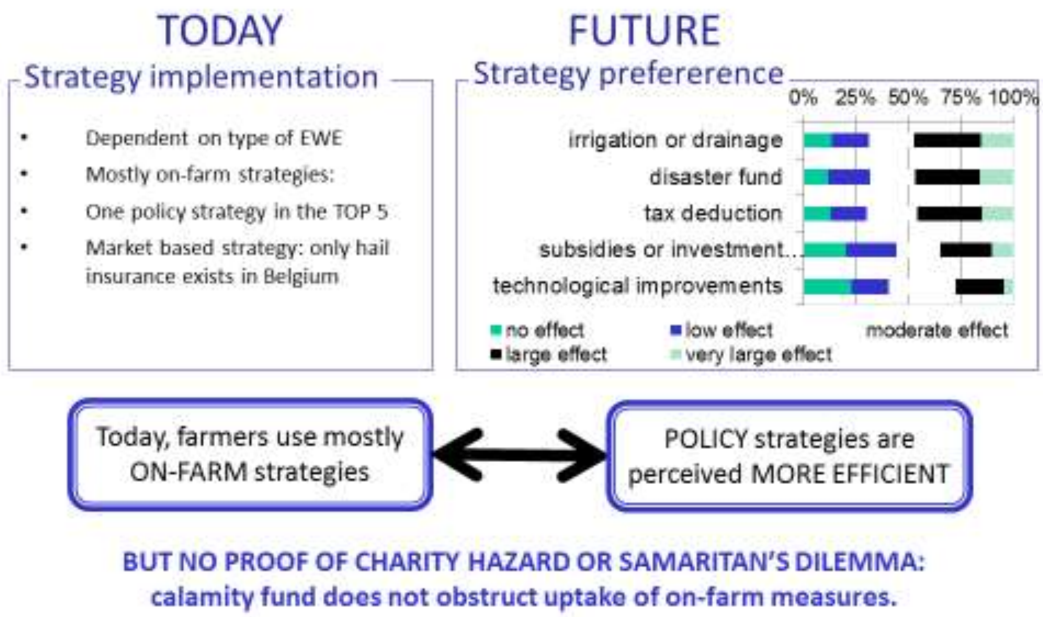

Figure 17 Result overview on currently used and preferred strategies

The focus groups with farmers learned however that most farmers do not see climate change as a big issue. Compared to other risks (e.g. financial crisis, Russian ban) they see this as not less important and uncertain of the impact. It was mentioned that this climate change is not per se negative for Belgium, other regions will have more adverse effects with a beneficial consequence to them. Farmers will adapt gradually to climate change and will do that automatically (as they always have). When not so much worried about climate change in general, they do are worried about the evolution of EWE. Depending on the more frequent occurrence of these extremes, farmers will look more actively and adopt strategies faster.

In the econometric simulation, we started from the agronomic projection of climate change. When combining economic data with these agronomic data, we obtain series of 20-years simulated average yields for 5 crops (Wheat, Barley, Potato, Sugar beet and Grain Maize) and 4 scenarios: current normal yields and projected yields under climate change, with and without weather related stress. The agronomic data show under climate change higher winter cereal yields and lower summer crops yields respect to the current normal scenario. The results are found in Table XXX. Simulations results show that in the climate change scenario with weather related stress the share of land of wheat increases by 24 hectares (ha), while the surface allocated to barley, sugar beet, potatoes and grain maize decreases by around 10, 6, 5 and respectively 3 ha compared tot. More specifically, winter barley gradually phases out and grain maize covers a small acreage in projected simulations under climate change. These results are in the same line as agronomic simulations for projected yields except in the case of winter barley where yields are expected to increase while the share of land is declining. This is related to the fact that the calibrated value of the non-linear parameters associated with winter barley are zero and the "risk cost" is greater than that the winter wheat. Thus, among winter crops, it is preferable to keep the crop with the lowest risk, i.e. winter wheat.

Table 4 Surfaces allocated to the different crops and expected utility for the different scenarios

Land use change (in ha)	Now	Climate change	Now with adaptation	Climate change with adaptation
winter wheat	52,10	76,17	57,05	78,34
winter barley	9,74	0,00	0,44	0,00
late potatoes	15,15	8,96	17,60	8,39
sugar beet	18,62	13,94	21,88	13,27
grain maize	4,39	0,93	3,04	0,00

Furthermore, climate change adaptation leads to an increase of individual utility of around 6 000 euros, which corresponds to a significant increase of 9 points with respect to the current normal years. However, results change if we assume that crops grow without weather related stress in the current normal and climate change scenarios (i.e. because of irrigation). Tendencies concerning land-use adaptation are maintained, but the expected utility now decreases by around 9 069 euros (which corresponds to the 14 %). Indeed, an assumption of an increase in irrigation needs is considered under climate change, leading to higher irrigation costs and an important loss on the farmer's individual utility.

Table 5 Surfaces allocated to the different crops and expected utility for the different scenarios

Scenario	Income (EUR)
NOW	63064
NOW with irrigation	64839
Climate Change	68983
Climate Change with irrigation	55770

Interviews related to the broad weather insurance learned that there is a clear contradiction between the point of view from the policy makers and the insurance and farming sector. Where the government is in favor and is trying to motivate farmers and insurers, the latter group is clearly not interested. The perception of these extreme weather events is business as usual. They are convinced to tackle the problem when needed and do not see a broad weather insurance as the ultimate solution. Different reasons as the income support and the fear for full transparency in management and financial issues is keeping them reluctant. They prefer a wide range all risks crop or income insurance. From the point of view of the insurers, is the technicality of the product the main bottleneck together with the small region and low number of potential interested farmers. The systemic risk of the EWE together with higher chance for moral hazard, they believe this to be infeasible. They think more support from the government is needed to launch these products.

Recommendations about how Belgian farmers could be better supported in dealing with the risk of EWEs on their farm include: i) farmers should be provided with more information on today’s and future risks of EWE’s on their farm; ii) to enhance collaboration between industry and the agricultural sector in order to stimulate innovations and increase the farmers’ resilience to the risk of EWE’s; iii) policy makers should undertake more action to increase the farmers’ resilience to the risk of EWE’s; and iv) should be more collaboration between societal organisations and the agricultural sector in order to stimulate innovations and increase the farmers’ resilience to the risk of EWE’s. Additionally, they frequently rely on fellow farmers who have experience with a new strategy for information on implementation and application of this strategy. The results provide support for the evolvement of farmer to farmer networks. These could act as a communication channel between the farm sector and research institutions, help improving climate change awareness amongst farmers and stimulate information exchange about innovative adaptation strategies. The major obstacle hindering strategy adoption was identified as legislation because they experienced contradictions in the objective of strategies being good f.ex for soil structure and thus heavy rainfall but not allowed within the water framework.

Future research topics to address the awareness of EWE’s and agriculture included further research about innovations to enhance resilience of farmers to the risks of EWE’s; the research and development of adequate models that could enable the precise prediction of the risk that EWE’s pose; the analysis of feasible and adequate policy measures to support farmers in dealing with the risk of EWE’s.

5. DISSEMINATION AND VALORISATION

A separate work package was devoted to dissemination and exploitation of project results to identify potential next users. The communication means were a project website (https://merinova.vito.be/Pages/home.aspx); participation in workshops, conferences and meetings; publications in scientific peer reviewed journals and in the press; and participation in large networks and targeted visits to organisations and companies. A session on "risk assessment in agriculture and agroecosystems" was yearly organised at the EGU (European Geophysical Union) General Assembly in Vienna (session NH1.11 "Hazard Risk Management in Agriculture and Agroecosystems"; SSS10.8 "Effects of changes in land use on soil properties and processes"). This conference attracts more than 10,000 scientists from around the world. The Merinova project was promoted using posters and keynote talks. Large networks established included: COST action ES1106 Euro-AGRIWAT, AgMIP, MACSUR (JPI FACCE), COST/ESF, OECD, European/American meteorological society, and the European agricultural economy society. Use was made of social media to promote project results to include ResearchGate, Mendeley, Academia and LinkedIn.

CRA-W has been part of a television programme on RTBF (national TV) concerning the impacts and vulnerability of Belgian agriculture to extreme weather events. Several other national presentation were reported in the press, notably http://www.vilt.be/bemesting-en-gewasbescherming-zal-preciezer-moeten, http://www.vilt.be/Klimaat_Word_jij_ook_klimaatmanager, http://www.vilt.be/Goed_geboerd_Ook_het_klimaat_is_u_dankbaar.

Different users and stakeholders were reached through targeted meetings with several organisations. Potential users and stakeholders included farmers, policy makers, consultants, researchers and the private sector. Organisations and companies include famers' unions (Boerenbond, FIWAP, market sector groups…); Government (Ministry of Agriculture, Ministry of Environment); Insurances (the Belgian Disaster Fund, KBC, European Insurance & Re-insurance Federations); Crop breeding companies (Semzabel, Syngenta); Producers of agri-chemicals and seeds (Syngenta, Bayer, Monsanto); and, Food processing industries (Belgapom, Farmfrites, Lutosa, Agristo, Sudsucker, Retail sector of fresh food and vegetables). Several departments of the Ministry of Agriculture and the Ministry of Environment were visited upon invitation from follow-up committee members to explain different aspects related to the project. The following topics were discussed in separate thematic meetings: (1) insurances and crop damage; (2) use of parcel databases for scientific research; (3) impact of extreme weather events on agricultural yields and soil quality; and, (4) impact on soil water balances. At these occasions the information on the MERINOVA website proved useful.

Different members of the follow-up committee were contacted to provide their input. This has led to an increased interaction with the government on issues of climate impacts on agriculture for the environment agency, impacts of extreme weather events for the regional disaster fund and for the Ministry of Agriculture. Several departments of the ministry of agriculture and the ministry of environment were visited to present the results of the project. Professional organizations such as FIWAP, PCA and Boerenbond were contacted and data were obtained from them.

RMI (Hans Van de Vyver, keynote) and VITO (Anne Gobin) were invited to present their findings on a workshop on "Climate impacts on agriculture" organised by the Flemish Ministry of Agriculture at the 2013 Agriflanders exhibition (Expo Gent). VITO was invited to a task force session on agricultural insurances held on 24/09/2013 at the Flemish Parliament with presentations from Robert Keating from Financière Agricole du Québec (FADQ). Other support activities are detailed in a working document on users and their expectations (DL5.1) and in section 7 on the follow-up committee of this report.

A specific result of the study on spatial precipitation extremes is provided in Van de Vyver (2013) where the methodology has been implemented for practical purposes. In particular, an R-code has been written and is actually used in the Department Meteorological and Climatological Services of RMI. For example, decisions made by the Government Disaster Fund have been based on the information provided by RMI. Other users include planners, structural engineers, policy makers and many others.

6. PUBLICATIONS

International Peer Reviewed Journals (SCI Publications)

1. Van de Vyver, H. 2012. Spatial regression models for extreme precipitation in Belgium. *Water Resources Research* **48** W09549.
2. Gobin, A., 2012. Impact of heat and drought stress on arable crop production in Belgium. Natural Hazards and Earth System Sciences 12, 1911-1922.
3. Gobin, A., Tarquis, A.M., Dalezios, N., 2013. Weather-related hazards and risks in agriculture. Natural Hazards and Earth System Sciences 13: 2599–2603.
4. Gobin, A., 2015. The water footprint of Belgian arable crops. Italian Journal of Agricultural Meteorology, 2015 (3): 91-97.
5. Nadeu, E., Gobin, A., Fiener, P., Van Wesemael, B., Van Oost, K., 2015. Modelling the impact of agricultural management on soil carbon stocks at the regional scale: the role of lateral fluxes. Global Change Biology: 3181–3192. Doi: 10.1111/gcb.12889
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2. Gobin, A. , 2014. Hoe je teelt beschermen tegen extreem weer? Management en Techniek Nr 5, 7 maart 2014.
3. Curnel, Y., 2014. Les risques météorologiques sont-ils des moteurs d'innovation environnementale dans la gestion de nos agro-écosystèmes ? Plein Champ N°6, 6 février 2014.
4. Y. Curnel: Certaines activités liées au projet MERINOVA seront présentées lors de l'enregistrement de l'émission de la RTBF "la clé des champs" (http://www.rtbf.be/tv/emission/detail_la-clef-des-champs?emissionId=29). Cet enregistrement est prévu le 15/05/2014 et la diffusion le 24/05/2014.

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1. Van de Vyver, H.: Spatial regression models for extreme precipitation. Facets of Uncertainty, Kos Island, Greece, 17—19 October 2013.
2. Van de Vyver, H. Spatial regression models for extreme precipitation in Belgium, 2nd Conference on Modelling Hydrology, Climate and Land Surface Processes, 10th-12th of September 2012 – Losby Gods, Norway.
3. Van De Vyver, H.: Algemene toelichting rond gewijzigde klimaatpatronen en extreme weersomstandigheden. Studiedag "Goed geboerd? Ook het klimaat is u dankbaar!" Agriflanders, Gent, 11 januari 2013.
4. Gobin, A., 2013. Keynote on "Meteorological risks and impacts on crop production systems" natural hazards session on climate impacts on agriculture at EGU 2013 General Assembly.
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2. Gobin, A., Impacten van klimaat op landbouw. Studiedag Goed geboerd? Ook het klimaat is u dankbaar!, 11th January 2013, Agriflanders, Gent.
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ANNEXES

The annexes are available on our website

http://www.belspo.be/belspo/SSD/science/pr_risk_en.stm