A quantitative approach to assess farming systems vulnerability: an application to mixed crop-livestock systems

Inès Sneessens, Stéphane Ingrand, Hanitra Randrianasolo, Loïc Sauvée

▶ To cite this version:

Inès Sneessens, Stéphane Ingrand, Hanitra Randrianasolo, Loïc Sauvée. A quantitative approach to assess farming systems vulnerability: an application to mixed crop-livestock systems. 11. Journées de Recherches en Sciences Sociales (JRSS), Dec 2017, Lyon, France. hal-02734677

HAL Id: hal-02734677
https://hal.inrae.fr/hal-02734677v1

Submitted on 2 Jun 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

11èmes Journées de Recherches en Sciences Sociales

Lyon, France – 14 et 15 décembre 2017

A quantitative approach to assess farming systems vulnerability: an application to mixed crop-livestock systems

Inès SNEESSENS[a, b, *], Stéphane INGRAND[c], Hanitra RANDRIANASOLO[a, d], Loïc SAUVEE[a]

[a] INTERACT research unit, UniLaSalle, 60000 Beauvais, France

[b] Economic unit, ICEDD asbl, 5000 Namur, Belgium

[c] Université Clermont-Auvergne, AgroParisTech, Inra, Irstea, VetAgro Sup, Territoires, F63000 Clermont-Ferrand, France

[d] Cei-Idest research unit, Paris Sud University, France

*Corresponding author: ines.sneessens@outlook.com

Abstract

The vulnerability of a given system corresponds to its susceptibility to be harmed, reflecting its inability to cope with adverse effects. This inability is the consequence of three key parameters that are interconnected, the sensitivity, the exposure and the adaptive capacity of the system in front of adverse effect. At the farming systems scale, some authors tried to understand links between sensitivity, exposure, while others focused on a conceptual analysis of adaptive capacity without proposing a quantification of the level of vulnerability. Other authors propose a measurement of vulnerability based on the evaluation of farming systems characteristics, as if the factors explaining vulnerability where yet known. In this paper, we first propose quantitative indicators for the three key parameters of vulnerability. Then, we apply our framework to mixed crop-livestock systems and we show that various levels of vulnerability should be explained by both some characteristics of the systems and strategies of farmers. Low vulnerable systems are more diversified, with one additional production unit and significantly higher sales of transformed products on average (+1.5 points of percentage in comparison with moderate vulnerable systems). A lower dependency to markets through better feed management (lower stocking rate) and a higher efficiency in energy and water consumption are also key determinants of low vulnerability. This management permits having bigger farms (+43 to 20 hectares) and higher flock sizes (+13 livestock units on average). The ability to cope with adverse effect is not significantly different between stable, non-stable, flexible and rigid farming systems. Our findings are a first step toward a better understanding of farming systems vulnerability: their validation on another sample would help contributing to the conception of innovative farming systems in research and to better advices for vulnerable farmers in operational projects.

Keywords: vulnerability, operational framework, sensitivity, exposure, adaptive capacity, mixed crop-livestock systems.

1 Introduction

According to its Latin roots, vulnerability refers to a state of fragility, a disposition to be hurt (Urruty et al. 2016). This concept was primarily used in the 1970s in social science to describe the fragility of some communities facing environmental and socio-economic risks. In 2001, the adoption of this concept by the Intergovernmental Panel on Climate Change (IPCC) largely increased its use in scientific research, and permitted reaching a consensus on its definition. Vulnerability is then defined as the degree to which a system is susceptible to and unable to cope with adverse effects, i.e. to experience harm due to a perturbation or stress (IPCC 2001; Luers et al. 2003; Turner et al. 2003). In all formulations, the key parameters of vulnerability are the stress to which a system is exposed, its sensitivity and its adaptive capacity (Adger 2006).

Studies aiming at better understanding vulnerability of farming systems also increased those last years, given the increasingly changeable environment, characterized by the increasing occurrence of unpredictable perturbations (Urruty et al. 2016). However, as the commonly accepted definition of vulnerability is still broad, contrasted ways of measuring vulnerability emerged due to different epistemological positions of research, different objectives of research and the complexity of interrelations between the occurrence of adverse effects and their impacts on a farming system (Adger 2006; Luers et al. 2003). As, a consequence, through our literature review, we distinguished many ways of studying and quantifying vulnerability of agricultural systems. The most used methodology consists in quantifying a composite index of vulnerability, based on the evaluation and aggregation of various indicators previously identified as determinants of vulnerability (Aleksandrova et al. 2015; Nazari et al. 2015; Oliveira et al. 2015; Sharma et al. 2013). Even if the chosen indicators focus on mechanisms that facilitate or constrain a system's ability to cope, adapt or recover from various disturbing force, this methodology presents various limits that were yet identified by Wirhen et al. (2015). First, the applicability is limited by considerable subjectivity in the selection of variables. Indeed, indicators chosen are supposed to increase or decrease the vulnerability of a farming system. It is sometimes a paradox to study vulnerability and try to understand vulnerability with an analysis that is entirely based on indicators that were assumed to be explaining factors of vulnerability. In the same way, the hierarchization and aggregation of the criteria to define the composite indicators is also a source of subjectivity. Furthermore, this approach doesn't allow taking into account the probabilistic side of vulnerability.

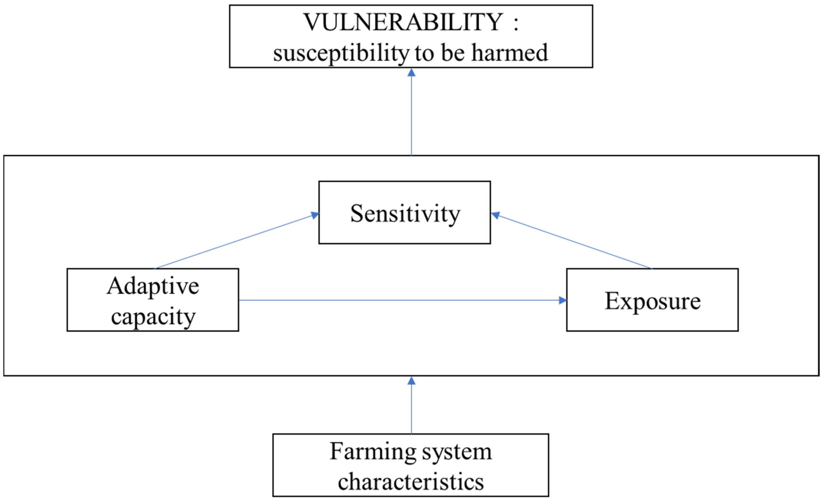
Another important stream of the literature on vulnerability assessment focuses on the analysis of the stressor and its corresponding impacts on a component of the farming system. This stream of literature ranges from authors analyzing the sensitivity of agricultural outputs to environmental systems conditions (Farhangfar et al. 2015; Mosnier et al. 2009) to more complex analysis that take more explicitly into account each component of vulnerability. For instance, Luers et al. (2003) proposed assessing vulnerability by integrating four essential concepts for quantifying vulnerability: the state of the system relative to a threshold of damage, sensitivity, exposure and adaptive capacity. The main limit of their work is its low applicability given that a lot of data are necessary to define frequencies of occurrence, function of response to perturbation, etc. Furthermore, adaptive capacity is either omitted or only succinctly considered in vulnerability assessment. A lot of interesting studies, however, exist on this topic but without linking it to vulnerability assessment. Sauvant and Martin (2010) proposed for instance an interesting description of the components of adaptive capacity in the context of perturbations, by defining various indicators characterizing the impact of a perturbation on farming systems but also by highlighting various modalities of recuperation after a disruption. While their notion of resistance may be compared to the notion of sensibility used in the vulnerability literature, they introduced the concept of "resilience" in the description of adaptive capacity, determining the capacity of recuperation or regeneration of the system. Resilience of farming systems is then compared as the rate of come back to the situation before the perturbation. Various modalities of return are then defined to characterize the resilience, opposing cases where no change in structure and finalities of production are observed (rigidity) and cases where changes – transitory or permanent – are observed (flexibility, plasticity and elasticity) (Sauvant and Martin 2010)

In this study, we propose a generic framework for vulnerability assessment and characterization by considering its three key parameters. Indeed, we agree that it cannot be said that a farming system is vulnerable strictly on basis of its sensitivity and exposure to external stressors: adaptive capacity plays a key role (Fellmann 2012; Gallopin 2006). The first step of our framework consists in assessing four indicators – representing all vulnerability components – that are used to define levels of vulnerability of farming systems. In a second step, factors explaining the vulnerability level of farming systems are characterized. Our framework is considered generic as it is not focused on one specific external stressor, but on all hazards that occurred during a given period of time. Furthermore, our evaluation is focused on economic vulnerability, considering the farming system as a whole. As a consequence, less technical and specific data is necessary for vulnerability assessment whereas past information on the trajectories and economic results of farming systems are primordial information. Our framework not only permits identifying which systems are most at risk but also permits understanding why. In this sense, our study is a step forward in better understanding farming systems that are able to cope with unexpected events, a critical information for decision makers. Our framework is then applied on a panel of 208 farming systems from three regions of France (Picardy, Auvergne, Poitou-Charentes) for which structural and economic data are available for 14 successive years.

2 Framework of evaluation

In this study, we argue that defining and assessing vulnerability considering its three key parameters (exposure, sensitivity, adaptive capacity) is a first obligatory step toward vulnerability understanding. The level of **exposure** corresponds to the frequency, the intensity and duration of perturbations affecting the studied systems (Urruty et al. 2016). The level of **sensitivity** corresponds to the degree to which the studied system is affected by exposure to perturbations. The **adaptive capacity** corresponds to the ability of agriculture systems to transform their nature or structure to cope with an ever-changing environment (Milestad et al. 2012), i.e. to move toward a less vulnerable condition. These three key parameters are interlinked and the omission of one of those parameters won't permit considering the whole complexity of the vulnerability concept. For instance, exposure and adaptive capacity influence sensitivity, while the degree of exposure may itself be influenced by the adaptive capacity of the system (Figure 1). In a second step, we proposed to identify the key elements of a farming system explaining the vulnerability, and thus the level of sensitivity, exposure and adaptive capacity of the faming system. These two steps are described in the following subsections.

Figure 1 : Links between concepts of vulnerability, its three key parameters and farming systems characteristics



2.1 Step 1: Vulnerability assessment

Vulnerability assessment of farming systems may focus on a myriad of elements composing or surrounding the system, from social vulnerability to landscape vulnerability. In this study, we focus on the economic vulnerability of farming systems, i.e. their susceptibility to live bad economic situations. In our analysis, we deal with the notion of risk inherent to the concept of vulnerability by focusing on the analysis of past experiences, and arguing that these past experiences are valuable information on probabilities to be harmed again. In this way, analyzing the long term “behavior” of the economic return per labor unit (ErLu) is considered as a valuable way to assess vulnerability. We argue that four pieces of information are necessary to describe this “behavior”:

- The temporal variability of the ErLu during the period of analysis, reflecting the degree of exposure, the sensibility and the adaptive capacity of the system to cope with adverse effects.
- The ErLu’s degree of variation around a given threshold, reflecting if the system has been harmed by the above-mentioned variation highlighted. This indicator permits considering that two systems showing the same variation from their ErLu’s mean during the period of analysis may be more or less vulnerable according to the level of this mean (more or less close to the threshold).
- The number of time the ErLu decreases more than a given threshold, reflecting cases of disruption. This indicator is important as disruptions situations point out the beginning of recovering and/or reorganizational processes that give some information about the adaptive capacity of farming systems (UMI Resiliences, Dubois and Ouattara 2014).
- The number of years that are necessary to recover the same ErLu than before the disruptions, as an indicator of resilience reflecting the adaptive capacity component of vulnerability (Sauvant and Martin 2010).

2.2 Step 2: Linking vulnerability levels and farming systems characteristics

In this second step, the objective is to understand the conditions of production that permit farming systems reaching a low economic vulnerability. We argue that two kinds of characterization of farming systems are necessary to understand the complexity of the vulnerability concept. First, a description of the general production systems is necessary to understand the production types, the structural and the organizational factors affecting vulnerability. Second, an analysis of farming system trajectories and dynamics is necessary to better understand the capacity of farming systems to cope, adapt and recover from adverse effects.

While the first step of characterization is commonly used to describe farming system, the dynamic characterization of farming system in vulnerability assessment is less common. The combination of both characterization methods is nevertheless primordial to be able to distinguish adapted and non-adapted systems to external stressors, but also to identify efficient strategies of recovery based either on rigidity or flexibility. More concretely, the analysis of farming systems trajectories and dynamics will consist in evaluating the evolution of strategic parameters of the farming system and the degree of variation of tactical adjustment parameters along the period of analysis. The strategy is defined by the structural, organizational and production decisions that are made between production campaigns. For instance, the decision of increasing the agricultural area or of producing both crop and livestock correspond to strategies whereas the level of feed concentrates used is a tactical decision in function of inter-annual parameters, as the feed prices and crop yields. Tactical decisions correspond thus to adjustments feasible inside a campaign of production.

2.2.1 Evolution of the strategy in a given farming system

The analysis of the evolution of strategies will permit defining if they was adapted since the beginning of the period (no evolution) or if some adaptations have been done. Linking these results with the vulnerability level of the farming systems will allow discussing whereas these adaptations where sufficient or not.

Thus, regarding low vulnerable farming systems, this analysis will permit distinguishing two categories of farming systems, “adapted” ones and “with adaptive capacity” ones. Adapted farming systems are characterized by stable strategies along the period of analysis whereas farming systems that have demonstrated evolutions in farmers strategy will be considered as having a good adaptive capacity. Regarding farming systems with higher vulnerability levels, two situations may be opposed. First, farming systems which have demonstrated an adaptive capacity but that is insufficient to decrease their vulnerability. Second, farming systems where no decisional change occurred along the period, despite their vulnerability to external events.

2.2.2 Degree of variation of tactical decision factors

The analysis of the degree of variation of tactical decision factors will allow defining two kinds of profiles, permitting further defining the adaptive capacity of farming systems in front of external events: the “rigid” and “flexible” farming systems (adapted from Sauvant and Martin, 2010). Farming systems that are “rigid” are systems where there are no modifications in any characteristic of the system of production along the period of analysis, whereas “flexible” systems are systems where some agricultural practices are modified inside a production campaign to enhance their adaptive capacity.

3 Application to three regions of France

3.1 Data description

The framework for vulnerability assessment was applied on a constant sample of farming systems from three regions of France (Picardie, Auvergne, Poitou-Charentes), containing structural, economic and organizational data for 208 farms during a period of 14 years (2001-2014) (Agreste). These data come from the Farm Accountancy Data Network (FADN), a European instrument designed for evaluating the income of agricultural holdings and the impacts of the Common Agricultural Policy.

One half of the sample (104 farms out of 208) is composed of mixed crop-livestock systems, equally distributed between the three regions (Table 1). The other half is composed of farming systems producing only crops (67%), only livestock (6%), only fruits and legumes (2%) or changing of orientation during the period of analysis (25%). The whole sample is used to assess and define vulnerability levels, whereas the characterization of vulnerability levels by the analysis farming management practices is done only on the mixed crop-livestock systems. The focus on mixed crop-livestock systems will permit highlighting farming management practices that are specific to these interconnected production systems.

Table 1: Data description

Farming system categories	Auvergne (n=55)	Picardie (n=96)	Poitou-Charentes (n=57)	Total (n=208)
Mixed crop-livestock systems	38	36	30	104
Cropping systems	9	44	17	70
Livestock systems	4	1	1	6
Evolutive farming systems : Mixed crop-livestock systems/ Cropping systems/ Livestock systems	4	14	8	26
Other (fruit, legumes)	0	1	1	2

Data source: FADN data, Agreste.

3.2 Vulnerability assessment

The assessment and definition of vulnerability levels of farming systems is done in a two steps procedure. First, the four indicators that define vulnerability are assessed, in relation with sensibility, exposure and adaptive capacity. Then, vulnerability levels are defined.

3.2.1 Indicators used to assess vulnerability

Indicators used to assess vulnerability of farming systems are the following:

- The Relative standard deviation (RSD) of the annual consolidated current result before tax per worker (CR.LU) for a period of 14 years. It corresponds to the absolute value of the standard deviation divided by the mean. We consider it as an indicator of sensitivity.

$$RSD^{CR.LU}\ (\%) = \left|\ \frac{SD^{CR.LU}}{\mu^{CR.LU}}\ \right| * 100$$

- The mean relative distance (RD) of the annual consolidated current result before tax per worker (CR.LU) to the French minimum wage (SMIC). We consider it as an indicator of the system's exposure to environmental perturbations.

$$RD^{CR.LU}\ (\%) = \text{mean}\ \left(\frac{CR.LU - SMIC}{SMIC}\right) * 100$$

- The number of economic disruption (ED), defined as the number of times the annual consolidated current result before tax per worker (CR.LU) diminished more than 25% from one year to another. We consider it as an indicator of the system's exposure to environmental perturbations.

- The number of years for economic recuperation after disruption, called resilience (RESIL), corresponding to the number of years necessary to recover the annual consolidated current result before tax per worker (CR.LU) that was observed before the disruption. We consider it as an indicator of the adaptive capacity of the system.

3.2.2 Definition of vulnerability profiles

The combination of results obtained for the four indicators of vulnerability through an Ascending Hierarchical Classification (AHC) permits identifying clusters of farming systems that have equivalent results for each indicator of vulnerability. The statistical analysis of these clusters permits then to define the vulnerability levels of each cluster identified.

3.3 Characterization of farming systems

After having assessed and defined vulnerability levels on the basis of results obtained for the whole sample on each vulnerability indicator, we propose to identify the explaining factors of vulnerability levels for one specific category of farming systems: the mixed crop-livestock systems. This focus on one category of farming system will permit testing and identifying explaining factors that are specific to mixed crop-livestock systems. As stated previously, we argue that two types of factors may influence the vulnerability levels of farming systems: factors describing the general characteristics of farming systems and factors reflecting the farming system trajectory and dynamics.

3.3.1 General characteristics

A lot of strategies yet have been identified to be valuable to cope with climate and economic hazards. The main strategies identified are the dispersion of risks by diversifying the production systems (Bonaudo et al. 2014; Lemaire et al. 2014), the diminution of market dependency through self-sufficiency and efficiency improvement (Bernués et al. 2011; Thomas 2008) and the enhancement of resistance to climate hazards through the choice of more adapted varieties/species (Tambo and Abdoulaye 2012). Another important strategy consists in a better management of financial factors, in order to generate a sufficient profit to enable savings, the repayment of loans and/or the relaunching of production activity in case of hazards (Simelton et al. 2009; Ullah et al., 2015).

We used FADN data to define farmers strategies based on the analysis of indicators describing the general characteristics of each farming system (total agricultural area, the number of labour unit, etc.) and of indicators describing diversification and self-consumption strategies (number of production units, proportion of self-consumption, etc.). The impact of the financial situation of farmers will be assessed through five indicators: the working capital requirements, the cash surplus, the debt ratio, the net cash and the public subsidies.

3.3.2 Farming system trajectories and dynamics

3.3.2.1 Evolution of the strategy

Farming system trajectories will be assessed through the analysis of the evolution of the general strategy of farmers. In that objective, the evolution of four indicators will be assessed: the total agricultural area, the number of labour units, the percentage of crops in terms of agricultural area and the number of production unit on the farm. This evolution is calculated in percentage, as a deviation between the start and the end of the period of analysis.

3.3.2.2 Tactical adjustments

The farming system dynamics will be studied through the identification and analysis of tactical adjustments mobilized by farmers along the period of analysis. We propose to focus on the analysis of tactical adjustments that are supposed to decrease farming system vulnerability. The analysis of scientific literature permits highlighting various potential adjustments factors as the modification of the percentage of crops self-consumed on farm, of the quantity of feed concentrates purchased per livestock unit, of the quantity of water used for irrigation, etc. (Jones et al., 2006; Mosnier et al. 2009). In this study, we estimated the relative standard deviation of high adjustment factors to define profiles tactical adjustments: the quantity of fertilizers and seeds purchased by hectare to reflect potential need to relaunch a campaign of production after a climatic hazard. Both indicators, together with the quantity of energy consumed by hectare and the percentage of transformed products sold, may also reflect an effort to cope with market price volatility. In the same way, the feeding strategy may be adjusted to climatic and economic hazards by varying the percentage of self-consumption, the stocking rate (by selling or buying animals) and the quantity of feed concentrates purchased. Finally, irrigation may also be an important adjustment lever to cope with drought periods.

4 Results

4.1 Identification of three vulnerability levels

Three clusters have been identified, based on the four vulnerability indicators (Table 1). The first cluster concerns 37.5% of the sample, or 78 farms. These farming systems are characterized by a very low variability of their current result per worker and a significantly higher performance than the minimum wage (SMIC). These farms have also faced significantly less disruption situations than those of the two other identified clusters, with an average of three breaks. As a conclusion, this first cluster concerns farms that appeared to be the less vulnerable to hazards along the period of analysis. This is the “Low vulnerability” cluster.

More than the half of the farms analyzed (57.7%) are composing the second cluster. Those farming systems are characterized by an intermediate current result variability per worker (89% on average), and by a current result per worker value moderately higher than the minimum wage (+64% on average). The average number of disruption situations increase by two in comparison with the previous cluster, reaching an average of five disruptions along the period of analysis. This cluster regroups thus farming systems that have shown a "Moderate vulnerability" along the period of analysis.

The third cluster identified concerns farming systems with a "High vulnerability". Indeed, it regroups ten farming systems that have shown a very high variability of the current result per worker along the period of analysis (684% on average) and with a performance that is much lower than the minimum wage on average (-87%). The number of disruption situations is identical to the one observed for farms with a moderate vulnerability.

Table 2: Description of three vulnerability profiles (208 farms)

	Low vulnerability (n=78)	Moderate vulnerability (n=120)	High vulnerability (n=10)
$RSD^{CR.LU}$ (%)	53%^{a}	89%^{b}	684%^{c}
$RD^{CR.LU}$ (%)	259%^{a}	64%^{b}	-87%^{c}
EC (n years)	2.8^{a}	5.0^{b}	5.5^{b}
RESIL (n years)	1.7	2.1	2.0

a,b,c,d : values having a different letter as exponent on a given row have a significantly different average (p-value <0.05, Tukey Test, n=208).

The farms breakdown in the different vulnerability profiles isn't influenced by their geographical location (Table 2, p-value > 0.05). In Picardie, 39.6% of farms have a low vulnerability and 56.3% are moderately vulnerable. In Auvergne and Poitou-Charentes, the "Low vulnerability" cluster concerns 30.1% and 40.6% of the farms respectively.

Table 3: Repartition of farming systems (n=208), among vulnerability profiles and geographical localizations

	Low vulnerability (n=78)	Moderate vulnerability (n=120)	High vulnerability (n=10)
Picardie	38	54	4
Auvergne	17	35	3
Poitou-Charentes	23	31	3

Fisher Exact Test (p-value > 0.05)

The category of farming systems has an impact on the vulnerability level (Table 4, p-value < 0.05). For instance, 65.4% of mixed crop-livestock systems have a moderate vulnerability while this percentage decreases to 47.1% for cropping systems. Furthermore, six out the ten farming systems with a high vulnerability are mixed crop-livestock systems. In the next sections, we focus on the analysis of mixed crop-livestock systems in order to identify the factors explaining why some of these farms have a lower vulnerability level.

Table 4: Repartition of farming systems (n=208), among vulnerability profiles and production strategies

Farming system categories	Low vulnerability (n=78)	Moderate vulnerability (n=120)	High vulnerability (n=10)
Mixed crop-livestock systems	30	68	6
Cropping systems	36	33	1
Livestock systems	3	1	2
Evolutive farming systems: Mixed crop-livestock systems/ Cropping systems/ Livestock systems	8	17	1
Other (fruit, legumes)	1	1	0

Fisher Exact Test (p-value < 0.05)

4.2 Characterization of vulnerable and non-vulnerable mixed crop-livestock systems

4.2.1 Impacts of production systems decisions

Mixed crop-livestock systems with low vulnerability are characterized by (i) a higher agricultural area (168.8 ha on average); (ii) a higher number of labor units (2.4 on average) and (iii) a higher diversification level (7.6 production units on average) compared to the two other profiles (Table 5). Their energy consumption per hectare is significantly lower than that of the moderately vulnerable farming systems.

Regarding livestock production, less vulnerable farms differ from moderately vulnerable ones by their larger flock size together with a lower stocking rate (respectively 2.4 versus 5.2 livestock unit/ha on average). This lower stocking rate leads to a lower dependency on feed concentrates purchases. It should also be noted that animal diversification is higher in the less vulnerable systems than in other ones.

Table 5: Characteristics of mixed crop-livestock systems according to their level of vulnerability, using a farm.year metric (104 farms during 14 years = 1456 observations)

	Low vulnerability (n= 420)	Moderate vulnerability (n= 952)	High vulnerability (n= 84)
General characteristics			
Agricultural area (ha)	168.8 ^{a}	148.6 ^{b}	125.5 ^{c}
Labour unit (LU)	2.4 ^{a}	2.2 ^{b}	1.9 ^{c}
Production units	7.6 ^{a}	7.3 ^{b}	6.4 ^{c}
€ energy/ha	63.2 ^{a}	71.8 ^{b}	69.8
Livestock production			
Livestock units (UGB)	142.2 ^{a}	129.1 ^{b}	129.2
Stocking rate (UGB/ha)	2.4 ^{a}	5.2 ^{b}	3.0
Feed concentrates/UGB (€/UGB)	198.7 ^{a}	243.8 ^{b}	245.1
Livestock production units	1.4 ^{a}	1.2 ^{b}	1.3
Crop production			
Crop percentage (%)	52.2 ^{a}	56.9 ^{b}	46.2 ^{a}
Wheat yield (qx/ha)	57.4 ^{a}	55.6 ^{a}	41.7 ^{b}
Part vente veg transformés (%)	2.5 % ^{a}	1.0% ^{b}	0.1% ^{b}
Crop production units	4.1 ^{a}	4.1 ^{a}	3.2 ^{b}
Seeds/ha (€/ha)	52.6	53.7	55.1
Irrigation water/ha (€/ha)	0.4 ^{a}	1.3 ^{b}	0.0
Crop-Livestock interactions			
Selfconsumption (%)	1.6% ^{a}	2.4% ^{b}	2.0%
Fertilizers/ha (€/ha)	111.0	118.3	120.7
Financial situation			
Working capital requirements (€)	6 700	3 400	-200
Cash surplus (€/ha)	457 ^{a}	390 ^{b}	303 ^{c}
Debt ratio (%)	36.0 ^{a}	46.9 ^{b}	51.6 ^{b}
Net cash (€)	1 020	-70	-600
Public subsidies (€)	387	396	369

a,b,c,d : values having a different letter as exponent on a given row have a significantly different average (p-value <0.05, Tukey Test, n=1456).

Regarding crop production, the least vulnerable farming systems differ from moderately vulnerable ones by (i) a lower proportion of crop in the total agricultural area, (ii) a lower dependence on irrigation and (iii) a higher sales level of transformed vegetable products. Compared to “highly vulnerable systems”, wheat yields and the number of crops within rotations are also significantly higher.

Finally, farming systems characterized by a low vulnerability have a lower percentage of self-consumption compared to moderately vulnerable ones. They also have a significantly higher cash surplus, much more public subsidies and a lower debt ratio compared to the two other types of vulnerability profiles (Table 5).

4.2.2 Impacts of mixed crop-livestock systems trajectories and dynamics

4.2.2.1 Evolution of mixed-crop livestock systems strategies

The analysis of the evolution of farmer's strategies in mixed crop-livestock systems allowed to specify three types of evolution of those strategies (**Erreur ! Source du renvoi introuvable.**):

- Type 1 - " No evolution": This first type is characterized by a low evolution of both agricultural area and number of labor units, and a rather stable crop percentage. The number of production units tends to fall.
- Type 2 - "Moderate evolution": This type of evolution is characterized by a moderate growth of agricultural area and a stable evolution of labor units. The percentage of crop in agricultural area and the number of production units tend to increase (through the introduction of a new crop in rotations).
- Type 3 - "High evolution": This third and last type is characterized by a very high increase of agricultural area accompanied by an increase of labor units and of the pcrop percentage in the total agricultural area. The number of production units remains stable.

Table 6: Characterization of three profiles of evolution of mixed crop-livestock systems (104 farms)

	No evolution (n=52)	« Moderate » evolution (n=27)	« High » evolution (n=25)
Agricultural area (ha)	5.2 ^{a}	14.6 ^{a}	77.2 ^{b}
Labour units	-0.3 ^{a}	-0.2 ^{a}	1.0 ^{b}
Crop percentage (%)	-1.7% ^{a}	4.3% ^{b}	7.8% ^{b}
Nb of production units	-0.9 ^{a}	1.6 ^{b}	0.6 ^{c}

a,b,c,d: values having a different letter as exponent on a given row have a significantly different average (p-value <0.05, Tukey Test, n=104)

Having identified the three types of evolution of farmer's strategies in mixed crop livestock systems makes it possible to discuss the need for farmers to constantly evolve in order to achieve a low vulnerability profile. Thus, crossing those types of evolution strategies with their level of vulnerability shows that 57% of low vulnerable farming systems were already "adapted". Indeed, they were able to cope with occurred hazards during the analysis period without modifying the strategy (Table 7). Regarding the least vulnerable farming systems, 24% had significant but insufficient adaptive capacity in the short run to be considered as part of the low vulnerability profile during the analysis period.

Table 7: Links between adaptive strategies and level of vulnerability in 104 mixed crop-livestock farms

Evolution type	Low vulnerability		Other levels of vulnerability	
	« Adapted »	« With sufficient adaptive capacity »	« With insufficient adaptive capacity »	« No adaptive capacity »
Stable	17	/	/	35
Moderate	/	6	21	/
High	/	7	18	/

4.2.2.2 Farming system dynamics: a distinction between « rigid » and « flexible » farming systems

The analysis of the variation of adjustable variables during a production campaign didn't permit highlighting the effect of one or the other adjustment variable on the farmers' vulnerability level. Even though no link was made between the adjustments made during a production campaign and the vulnerability level, this section is a contribution in describing the types of adjustments conducted within mixed crop livestock systems, whatever their level of vulnerability.

An Ascending Hierarchical Classification on the adjustment components of agricultural systems results in identifying five adjustment profiles (Table 8). Four of these profiles are characterized as "flexible" systems given their ability to adjust at least one component of their production system in order to cope with an ever-changing context. "Flexible" systems identified adjusted either on their percentage of self-consumption, their stocking rate, their water consumption for irrigation, their fertilizer and seed consumptions, and their feed concentrates consumption per livestock unit. The latter profile is composed by "rigid" farms because they never make adjustments, whatever the context.

In 67.2% of cases, « rigid » farming systems have a moderate to high vulnerability level (Table 9). Of these, 60% have implemented strategic adjustment but insufficient to impact and reduce their level of vulnerability on the long run. “Flexible” farming systems also concerns – in most of cases – agricultural systems whose vulnerability is moderate to high (61.7%). “Adapted” systems apply to both “rigid” and “flexible” farming systems.

Table 8: Identification and characterization of tactical adjustment profiles in 104 mixed crop-livestock farms

	With adjustments – Flexible farming systems				No adjustments – rigid farming systems
	Self consumption	Stocking rate & Irrigation	Fertilizers & Seeds consumption	Feed concentrates consumption	
Nb farms	15	12	12	8	57
Self-consumption	281% ^{a}	31% ^{b}	88% ^{b}	72% ^{b}	47% ^{b}
Stocking rate	17% ^{a}	49% ^{b}	16% ^{a}	26% ^{a}	16% ^{a}
Quantity of transformed vegetal products sold	206%	183%	97%	142%	122%
Energy consumption/ha	55%	54%	49%	53%	54%
Fertilizers consumption /ha	51% ^{a}	53% ^{a}	64% ^{c}	49% ^{a,b}	43% ^{b}
Seeds consumption /ha	20% ^{a}	25% ^{a,b}	53% ^{d}	36% ^{c}	28% ^{b,c}
Irrigation water consumption /ha	0% ^{a}	143% ^{b}	32% ^{a}	28% ^{a}	3% ^{a}
Feed concentrates consumption /UGB	55% ^{a}	50% ^{a}	58% ^{a}	306% ^{b}	49% ^{a}

a,b,c,d : values having a different letter as exponent on a given row have a significantly different average (p-value <0.05, Tukey Test, n=104)

Table 9: Links between strategical adjustment, tactical adjustment and vulnerability profiles in 104 mixed crop-livestock farms

Tactical adjustments types	Low vulnerability		Other levels of vulnerability	
	« Adapted »	« With sufficient adaptive capacity »	« Adapted »	« With sufficient adaptive capacity »
Rigid	7	5	27	18
Flexible	10	8	12	17

5 Discussion

The framework of evaluation we propose permits both defining and assessing vulnerability levels of farming systems by considering its three key components and characterizing this levels by information on static and dynamic strategies and tactics that were set up in farming systems along the period of analysis. This dual approach is quite innovative as previous works on vulnerability assessment were either focused on one component of vulnerability for a specific adverse effect or were assessing vulnerabilities from subjective explaining factors related to the farming systems (Luers et al. 2003; Oliviera et al. 2015). Regarding the studies focusing on specific components of vulnerability, some authors focused on the analysis of the exposure of agricultural systems to climatic perturbations or diverse socio-economic changes (Luers et al. 2003; Simelton et al. 2009; Silva and Lucio 2014; Martin et al. 2017). Exposure is then estimated by calculating the expected value of the ratio of sensitivity to the state relative to a threshold based on frequency distribution of the stressors of concern. Sensitivity was largely studied on specific factors of production as crop yields, considering various explaining factors (Farhangfar et al. 2015). For instance, Luers et al. (2003) proposed estimating sensitivity as the absolute value of the derivative of well-being with respect to the stressor. The main inconvenient of this kind of analysis is the necessity to collect a lot of data that are not always available. Furthermore, they generally focus on only one or two component of vulnerability.

Not many studies analyzed the links between adaptive capacity and vulnerability. To our knowledge, only Luers et al. (2003) proposed to consider the capacity of adaptation in vulnerability assessment, by evaluating a minimum vulnerability index as if the highest yield achieved in past years was achieved every year. This evaluation corresponds thus much more to a measurement of potential for decreasing vulnerability through a better management than a way to identify clear guidelines on efficient adaptations made in the past. Many other studies focused nevertheless on adaptive capacity, without necessarily linking their evaluation to the concept of vulnerability. For instance, there is a wide literature on adaptive capacity in livestock production, taking into account behavioral and physiological responses of livestock or other biological, technical and organizational components of farming systems (Astigarraga and Ingrand 2011; Blanc et al. 2010). These studies are nevertheless indirectly linked to the concept of vulnerability given that their main objective is to better understand how to decrease the sensitivity, how to change of position relatively to the threshold of damage and how to decrease a system exposure to critical stressors.

Our paper is thus a first attempt to better understand economic vulnerability of farming systems by assessing and exploring its explaining factors based on the analysis of its three components at the same time. The validity of our framework may be consolidated by the results we obtained regarding the identification of the main characteristics of low vulnerable systems. Indeed, the higher diversification of farming systems – either in terms of number of agricultural productions and in terms of number transformed products – was already identified to be a key factor to enhance the ability of farming systems to cope with adverse effects. In addition to reaffirming this fact, our framework permits quantifying the related significant thresholds defining vulnerability levels of mixed crop-livestock systems for three regions of France. In the same way, our analysis demonstrates that the less vulnerable systems are farming systems that are less dependent to markets. Indeed, their charges by hectare is lower regarding energy, water and feed concentrates consumptions, demonstrating more efficient practices. For instance, the lower consumption feed concentrates per animal may be directly linked to the lower stocking rate. This higher efficiency may also be seen by the higher financial performances of low vulnerable farming systems in terms of cash surplus and debt ratio.

One limit to our study if that we did not take into account farms which disappeared between 2001 and 2014, as we kept only the farms which available data all along the period. This could suggest that we missed some particular cases of high vulnerability and some interesting causes of systems disruption. However, we can argue that those cases may exist in our sample, disrupting after 2014 (but we do not have the possibility to identify those farms). Another limit is that we focused also on agricultural activities and we know that other activities can partially or totally compensate weaknesses of farming systems (Ingrand et al. 2007).We tried in the current study to assess the conditions for a 100%-agricultural system to be less vulnerable, considering the annual economic income and its variability.

Our framework of evaluation also permitted studying the links between adaptive capacity and vulnerability levels of farming systems by exploring farming systems trajectories and dynamics. Our results demonstrate that strategic evolutions and tactical adjustment profiles are not determinants of farming system vulnerability. Indeed, low vulnerable systems may be both adapted farming systems (no evolution) and farming systems that have introduced adaptations in their strategy of production. In the same way, farming systems may both be “rigid” or “flexible” during a production campaign. As a consequence, our results confirm that a myriad of responses may be addressed to adverse effects in low vulnerable systems. Further investigation is however needed to characterize the most valuable options for each situation, some complementary critical information for farmers, farm advisors and decision markets.

6 Conclusion

The framework we propose is a generic framework permitting assessing economic vulnerability of farming systems by analysing their past economic results and trajectories of evolution. The application of this framework on a group of 208 farming systems from three regions of France (Picardy, Auvergne, Poitou-Charentes) along a period of 14 years permits identifying three levels of vulnerability for those systems. The “low vulnerable” systems are characterized by a low variation of economic result per labour unit (53% on average), a mean performance on average 259% higher than the minimum salary level in France (SMIC) and a low number of economic disruption along the period in comparison with other farming systems (3 on average). The “moderate vulnerable” systems have a mean performance that is much closer to the minimum salary and show a higher economic sensitivity along the period with a relative standard deviation (RSD) of 89% on average. Finally, the “high vulnerable” systems are characterized by a performance much lower than the minimum salary (-87% on average) and a very high variation of their economic results per labour unit (average RSD of 684%).

The in-depth analysis of mixed crop-livestock systems, representing the half of our sample, permits highlighting that diversification was a key factor permitting reaching a low vulnerability level. Indeed, low vulnerable systems have on average one additional production unit than other systems and have a higher percentage of their economic product coming from the sales of transformed vegetal products (2.5% on average instead of 1.0% or 0.1% in moderate and high vulnerable systems). A lower dependency to markets through better feed management and a higher efficiency in energy and water consumption are also key determinants of low vulnerability. Indeed, low vulnerable farming systems are characterized by a higher flock size

(+13 livestock units on average) but with a stocking rate of 2.4 livestock units per hectare, i.e. the half of that of moderate vulnerable systems. Feed concentrates charges per livestock unit are thus much lower (-18% on average). The ability to cope with adverse effect is either seen in stable farming systems that in farming systems that have introduced structural and organizational evolutions. In the same way, farming systems mobilizing tactical adjustments during their campaign of production aren't showing lower vulnerability levels than rigid farming systems (no adjustments).

The perspectives of this work are to validate our results on other farming systems by defining their vulnerability levels through the analysis of their strategy. Our findings could then be mobilized at two levels. First, they should contribute to research to enhance the conception of innovative farming systems less vulnerable to hazards. Second, our findings should be used in a more operational way in order to establish farming systems monitoring and to design scenarios of evolution to decrease their level of vulnerability.

Acknowledgments

This study is part of the research project of the Chair "Risk in Agriculture", co-financed by Groupama and UniLaSalle. We thank all the members of the scientific committee of the Chair for the fruitful discussions, and especially Sylvie Lupton and Michel Dubois for their implication.

References

Adger, W.N. (2006). Vulnerability. *Global environmental change*, 16(3), 268-281.

Agreste, FADN data. http://agreste.agriculture.gouv.fr

Aleksandrova, M., Gain, A.K. & Giupponi, C. (2016). Assessing agricultural systems vulnerability to climate change to inform adaptation planning: an application in Khorezm, Uzbekistan. *Mitigation and Adaptation Strategies for Global Change*, 21(8), 1263-1287.

Astigarraga, L. & Ingrand, S. (2011). Production flexibility in extensive beef farming systems. *Ecologyand Society* 16(1): 7. http://www.ecologyandsociety.org/vol16/iss1/art7/

Bernués, A., Ruiz, R., Olaizola, A., Villalba, D. & Casasús, I. (2011). Sustainability of pasture-based livestock farming systems in the European Mediterranean context: Synergies and trade-offs. *Livestock Science*, 139(1), 44-57.

Blanc, F., Dumont, B., Brunschwig, G., Bocquier, F. & Agabriel, J. (2010). Robustesse, flexibilité, plasticité : des processus adaptatifs révélés dans les systèmes d'élevage extensifs de ruminants. *Productions Animales*, 23, 65-80.

Bonaudo, T., Bendahan, A.B., Sabatier, R., Ryschawy, J., Bellon, S., Leger, F., Magda, D. & Tichit, M. (2014). Agroecological principles for the redesign of integrated crop–livestock systems. *European Journal of Agronomy*, 57, 43-51.

Dubois, J.-L. & Ouattara, M. (2014). Vous avez dit "résilience" ? Eléments conceptuels et politiques publiques. In : Châtaigner J.M. (ed.) *Fragilités et résilience : les nouvelles frontières de la mondialisation*. Paris : Karthala.

Farhangfar, S., Bannayan, M., Reza Khazaei, H. & Mousavi Baygi, M. (2015). Vulnerability assessment of wheat and maize production affected by drought and climatechange. *International Journal of Disaster Risk Reduction*,13, 37–51.

Fellmann, T. (2012). The assessment of climate change-related vulnerability in the agricultural sector: reviewing conceptual frameworks. In: *Proceedings of a Joint FAO/OECD Workshop on building resilience for adaptation to climate change in the agriculture sector*, Rome, Italy, 23–24 April, 2012, 37–61.

Gallopin, G.C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change*, 16, 293–303.

Jones, R., Cacho, O. & Sinden, J. (2006). The importance of seasonal variability and tactical responses to risk on estimating the economic benefits of integrated weed management. A*gricultural Economics*, 35(3), 245-256.

Ingrand, S., Bardey, H. & Brossier, J. (2007). Flexibility of suckler cattle farms in the face of uncertainty within the beef industry. A proposed definition. Journal of Agricultural Education and Extension, 13 (1) : 39-48.

IPCC (Intergovernmental Panel on Climate Change) (2001). Impacts, adaptation, and vulnerability climate change 2001, Third Assessment Report of the IPCC, University Press, Cambridge, UK.

Lemaire, G., Franzluebbers, A., de Faccio Carvalho, P.C. & Dedieu, B. (2014). Integrated crop–livestock systems: Strategies to achieve synergy between agricultural production and environmental quality. *Agriculture, Ecosystems & Environment*, 190, 4-8.

Luers, A.L., Lobell, D.B., Sklar, L.S., Addams, C.L. & Matson, P.A. (2003). A method for quantifying vulnerability, applied to the agricultural system of the Yaqui Valley, Mexico. *Global Environmental Change*, 13(4), 255-267.

Martin G, Magne M.A, & Cristobal M.S. (2017). An integrated method to analyze farm vulnerability to climatic and economic variability according to farm configurations and farmers' adaptations. Front. Plant Sci. 8:1483. doi: 10.3389/fpls.2017.01483.

Milestad, R., Dedieu, B., Darnhofer, I. & Bellon, S. (2012). Farms and farmers facing change: The adaptive approach. In *Farming Systems Research into the 21st century: The new dynamic* (pp. 365-385). Springer Netherlands.

Mosnier, C., Agabriel, J., Lherm, M. & Reynaud, A. (2009). A dynamic bio-economic model to simulate optimal adjustments of suckler cow farm management to production and market shocks in France. *Agricultural Systems*, 102(1), 77-88.

Nazari, S., Pezeshki Rad, G., Sedighi, H. & Azadi H. (2015). Vulnerability of wheat farmers: Toward a conceptual framework. *Ecological indicators,* 52, 517-522.

Oliveira, M.N., Triomphe, B., Rigolot, C., Cialdella, N. & Ingrand, S. (2015). Evaluation de la vulnérabilité des systèmes bovins lait familiaux au Brésil : proposition d'une méthode quantitative, *Fourrages*, 222, 135-142.

Sauvant, D. & Martin, O. (2010). Robustesse, rusticité, flexibilité, plasticité… les nouveaux critères de qualité des animaux et des systèmes d'élevage : définitions systémique et biologique des différents concepts. *Inra Productions Animales*, 23, 5-10.

Sharma, J., Chaturvedi, R. K., Bala, G. & Ravindranath, N. H. (2015). Assessing "inherent vulnerability" of forests: a methodological approach and a case study from Western Ghats, India. *Mitigation and Adaptation Strategies for Global Change*, 20(4), 573-590.

Silva, B.K.N. & Lucio, P.S. (2014). Indicator of Agriculture Vulnerability to Climatic Extremes. A Conceptual Model with Case Study for the Northeast Brazil. *Atmospheric and Climate Sciences*, 4(02), p.334.

Simelton, E., Fraser, E.D., Termansen, M., Forster, P.M. & Dougill, A.J. (2009). Typologies of crop-drought vulnerability: an empirical analysis of the socio-economic factors that influence the sensitivity and resilience to drought of three major food crops in China (1961–2001). *Environmental Science & Policy*, 12(4), 438-452.

Tambo, J.A., & Abdoulaye, T. (2012). Climate change and agricultural technology adoption: the case of drought tolerant maize in rural Nigeria. *Mitigation and Adaptation Strategies for Global Change*, 17(3), 277-292.

Thomas, R.J. (2008). Opportunities to reduce the vulnerability of dryland farmers in Central and West Asia and North Africa to climate change. *Agriculture, Ecosystems & Environment*, 126(1), 36-45.

Turner, B.L., Kasperson, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A., Martello, M.L. & Polsky, C. (2003). A framework for vulnerability analysis in sustainability science. *Proceedings of the national academy of sciences*, 100(14), 8074-8079

Ullah, R., Jourdain, D., Shivakoti, G.P. & Dhakal, S. (2015). Managing catastrophic risks in agriculture: simultaneous adoption of diversification and precautionary savings. *International Journal of Disaster Risk Reduction*, 12, 268-277.

Urruty, N., Tailliez-Lefebvre, D. & Huyghe, C. (2016). Stability, robustness, vulnerability and resilience of agricultural systems. A review. *Agronomy for sustainable development*, 36(1), p.15

Wiréhn, L., Danielsson, Å. & Neset, T.S.S. (2015). Assessment of composite index methods for agricultural vulnerability to climate change. *Journal of environmental management*, 156, 70-80.