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Innovations and adaptation to changes

Human capital assessment method to assess sustainability of new low-input viticulture systems

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***Abstract**: Viticulture, like all agricultural systems, must re-invent its production systems to adapt to climate and other changes. New viticulture systems are changing work in the fields. In this paper, we describe (i) a human capital assessment method adapted to new very low-input viticulture systems (NLIVS) and (ii) the implementation of the indicator in 11 NLIVS. The indicator was developed using the INDIGO® method based on the social lifecycle assessment (SLCA) framework. To test the indicator, we applied it to 11 NLIVS selected to cover a range of biophysical, agronomical and innovation conditions. The implemented innovations sought to drastically reduce pesticide spraying. The NLIVS were labelled A to K, with A being integrated viticulture: A to E reflected technical changes, F to I organizational changes and J and K redesign changes. We collected 2015 data to calculate the indicator. The first result is the new 'human capital' indicator, which is further broken down into three sub-indicators. The 'pesticide' risk sub-indicator deals with four variables: chronic toxicity, acute toxicity, the use of personal protective equipment (PPE) and training. The 'safety' risk sub-indicator covers three variables: PPE, adapted and/or safe machines and training. The 'painfulness' risk sub-indicator addresses three variables: noise, low back pain and musculoskeletal disorders, which all carry the same weight. All three sub-indicators are equally weighted. The second result is the implementation of the indicator at vineyard system scale. The pesticide indicator results were unsatisfactory for the painfulness and pesticide risks for the 11 NLIVS, but were satisfactory for the safety risk. This implies that human capital indicator results were not satisfactory, as all ranged from 2.4 to 4.6, except for system B, which scored 9.1, (0–10 scale). Although the human capital indicator is complex, its implementation is simple and quick. The indicator is original and useful for two reasons. First, the use of fuzzy logic expert systems of aggregation makes it possible to avoid an excessive loss of information and makes the results understandable. Second, the indicator makes it possible to assess part of the social sustainability of innovative vineyard systems by taking into account both measurable data and the winegrower's feelings about painfulness factors.*

***Keywords:** sustainable social assessment, viticulture, agroecological system*

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Introduction

Viticulture is one of the most pesticide-intensive agricultural systems, but it yields a very high value-added product (OIV, 2017). Viticulture must reinvent its production systems, practices and strategies to adapt to a multitude of changes while remaining sustainable.

Researchers and winegrowers are striving to innovate to build new viticulture systems (Metral *et al.*, 2012). These innovative viticulture systems are changing the technical and organizational aspects of work in plots and in vineyards (Lamine, 2011). The research question of the present paper is "What are the barriers in plot work to implementing new low-input viticulture systems (NLIVS)?".

In order to identify the specific barriers in the NLIVS fields, one line of work is to evaluate the working conditions in these production systems according to the combination of production practices. Working conditions vary considerably and can be analysed from an agronomic, sociological or other points of view. We evaluated the NLIVS using the social life cycle assessment (SLCA) framework because it makes it possible to formalize the social barriers of the NLIVS (Feschet, 2014). We selected three sub-indicators for the vineyard system: painfulness risk, pesticide risk and human safety risk.

We also based our work on the conceptualization of social impacts in Vanclay (2006), even if agricultural work is not included as an example in the demonstration. The social impacts concept is divided into categories dealing with safety, nutrition, health, autonomy and feelings, which can be very important in getting winegrowers to change their practices.
We then included the social impact in an LCA type of method such as Weidema (2006) does, in line with international consensus on well-being and health for the assessment of innovative vineyard systems. These new innovative vineyard systems must be safe for winegrowers.
To determine the barriers to working conditions in the plots, it is important to assess the sustainability of these new systems to identify what supports and hinders their adoption. Several assessment methods have been developed and applied to agricultural systems (Calleros-Islas, 2019; Pelzer *et al.*, 2012; Sadok *et al.*, 2009), including a social evaluation module, and in particular winegrower health. The social impact of the new innovative agricultural systems must be assessed just as it would in any other system. Changing practices in an agricultural system could change the system's social impacts on the winegrower.
But these methods are applied to existing agricultural systems and do not take into account all innovative systems redesigned to satisfactorily reduce the environmental impacts of agriculture, such as organic farming (Colomb *et al.*, 2013).
Given the lack of a quantitative social sustainability indicator (*i.e.* social and human capital) for innovative systems (Cuegniet, 2015), the present research proposes using the INDIGO® method (Thiollet-Scholtus and Bockstaller, 2015) to design and implement a tool to enable an integrated assessment of social sustainability. These innovative systems will be adopted if all aspects of sustainability – environment, agronomy, economy and social sustainability – have satisfactory assessment values. The objectives of this paper are to present (i) a human capital assessment method adapted to NLIVS and (ii) the implementation of the indicator on 11 NLIVS in northern France.

Method

Indicator development

The indicator is developed according to the construction rules used in the INDIGO® method (Girardin and Bockstaller, 1997). According to the INDIGO®-method, we must first define the objectives and the end-users of the human capital indicator. The human capital indicator is calculated with other INDIGO®-vine indicators and is intended to be used by advisers and agronomists working on vineyard systems. Like the other INDIGO®-method indicators, human capital is calculated for each agricultural year at system scale. Currently, the human capital indicator is calculated only at the system level, relative to the other systems of the farm. The design of this indicator depends on the available knowledge about the relations between winegrowing practices and their social impacts. To keep the human capital indicator operational, we limited the number of variables and selected only input variables that are available to end-users. We designed decision trees based on fuzzy subsets because the data were qualitative. Next, the human capital indicator was expressed on a social performance scale ranging from 0 (worst social impact) to 10 (no negative social impact) to obtain an indicator readable by end-users. A reference value of 7 represents the value of the reference system of the vineyard where the innovative system was introduced. The penultimate step, sensitive analysis, is not presented in this article because it has not yet been performed. The final step, validation, was completed with the peer review of the present article.

Case study

The indicator was calculated for 11 NLIVS for a single year. The design of decision trees with fuzzy subsets consists in linguistic if-then-else rules which are easy for non-specialists to understand. The use of fuzzy subsets avoids the knife-edge limit effect of qualitative classes normally associated with decision trees. The human capital indicator follows the same approach as the INDIGO® method's I-Phy indicator (Thiollet-Scholtus and Bockstaller, 2015). To test the feasibility of the indicator, we used 11 NLIVS that had implemented a large range of innovations, which are described in Table 1. The 11 NLIVS were selected to cover a range of biophysical and agronomical conditions. The innovations sought to drastically reducing the use of inputs, and especially pesticide spraying. The NLIVS were labelled A to K, with A being the least different from conventional viticulture: A to E reflected technical changes, F to I organizational changes and J and K a total system redesign. We ranked the NLIVS according to the intensity of pesticide reduction achieved, as detailed in Thiollet-Scholtus *et al.* (2020). Data collection to calculate the indicator was carried out during vineyard surveys undertaken in 2016, on data from 2015. The innovations were integrated into the systems in 2013. We also assumed that after three years, the innovative system would be stabilized and could be assessed.

		Gradient of new low input vine systems (NLIVS)										
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
Nature of changes		Tek	Tek	Tek	Tek	Tek	Org	Org	Org	Org	Re	Re
Details of changes												
Soil management	Herbicides	xxx	xxx	xxx	xxx	xx	x	_	_	_	_	_
	Ploughing	x	x	x	x	x	xx	xx	x	x	x	x
	Crop soil cover	x	x	x	x	x	xx	xx	xxx	xxx	x	x
Fungicides	Copper	xxx	xxx	xx	xx	xx	x	xx	x	x	x	_
	Sulphur	xx	xxx	xx	xx	xx	xx	xx	x	x	x	_
	Chemical	xxx	xxx	xxx	xxx	xx	x	_	_	_	_	_
Variety	Resistant variety	_	_	_	_	_	_	_	_	_	Yes	Yes

Table 1: Characteristics of new low-input vineyard systems (NLIVS). *For 'herbicides', there is a decrease in their use on the surface of the plot, starting with use everywhere (xxx), then removing use on half of the inter-rows (xx), then on all inter-rows (x), and ending with no use (_). The gradient of notation is reversed for 'ploughing' and for 'crop soil cover'. For 'copper', there is a decrease in the rate of use on the surface of the plot, starting with the reference rate (xxx) according to E-phy database, then by dividing the reference rate by at least 2 (xx), then by dividing the reference dose by at least 5 (x), and finally by completely eliminating the use of copper (_). The gradient is the same for 'Sulphur' and 'Chemical'. Tek: technical, Org: organizational, Re: redesign.*

Data survey for calculation

Information needed for calculation was collected during vineyard surveys undertaken after the winegrowing season. The surveys were conducted in winter 2015 with each winegrower managing each NLIVS. The survey contained closed-ended questions addressing the indicator variables. These on-farm interviews lasted between 30 minutes and one hour and were followed by one hour of data calculation. The interviews were short because interviews were conducted in 2013 and 2014 to obtain most of the technical data, which remained stable throughout the duration of the experiment set (2013–

2018). These data included pesticide spraying conditions, soil cover management, tractor characteristics and farm characteristics (see Thiollet-Scholtus *et al.*, 2020).
According to Merot *et al.* (2020), we considered the productive vineyard area (*i.e.* the area harvested for grape production) as the limit for the studied NLIVS. We first evaluated the NLISV, with a farm scale evaluation that took into consideration other cropping systems, winemaking and commercialization, which could imply another indicator to develop.

Results

Design of human capital indicator

Indicator overview

The new human capital indicator is broken down into three sub-indicators: (i) the chemical risk associated with individual pesticide use and aggregated for all pesticide use over one year ('pesticides'), (ii) the average of painfulness of all the work the winegrower must perform for the NLIVS over one year ('painfulness'), and (iii) aspects of work safety ('safety'). Due to the dissimilarity among the three variables and a lack of quantitative knowledge on the correlations between them, we decided to aggregate them with a fuzzy expert system in form of a decision tree (Figure 1). Information on the three variables is given in Table 2.

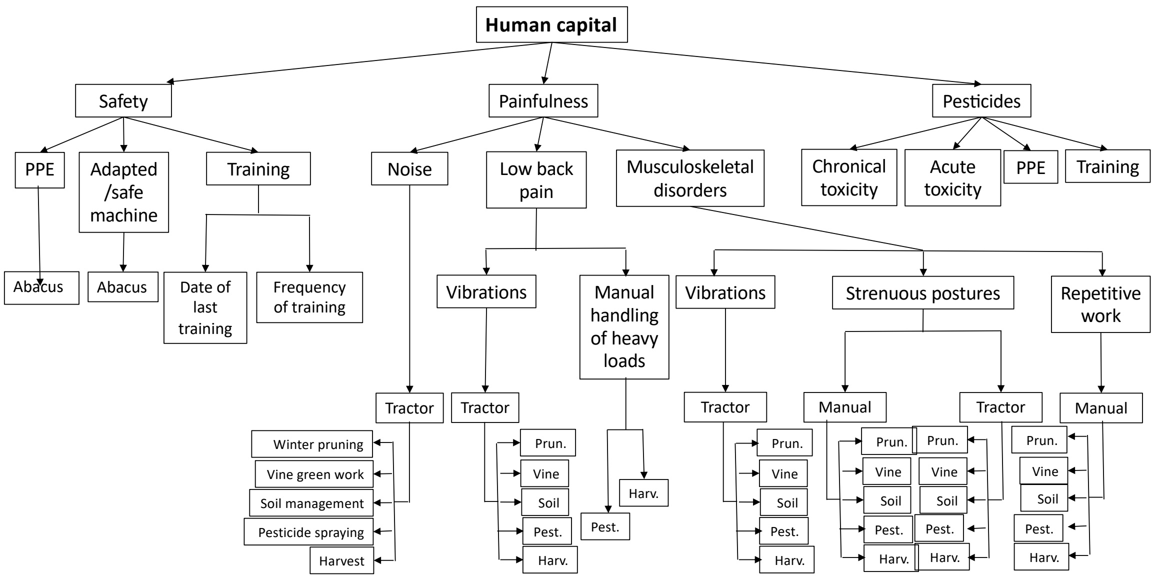

Figure 1. Summary of decision tree of input variables for the human capital indicator;

This time evaluation is annualized on the farm and then broken down to an average time per week and per worker. The time value is then compared to a threshold to obtain a three-class sub-indicator: green (low risk: [0;4[), orange (medium risk: [4;7[) and red (high risk: [7;10]). For the painfulness sub-indicator, the thresholds for green-orange and orange-red are, respectively, 10 and 20 hours per week for repetitive work and 2 and 10 hours per week for strenuous postures and vibrations. The three variables of noise, low back pain and musculoskeletal disorders have the same weight. The three sub-indicators of safety, painfulness and pesticides are weighted equally. The decision rules for aggregation are: (i) the final result is green if all three variables are green, (ii) the final result is orange if one of the three variables is orange and the other two are green and (iii) the final result is red if at least one of the three variables is red or if at least two of the variables are orange.

Sub-indicators	Unit	Limits of fuzzy class	
Pesticides	Dimensionless	0	10
Painfulness	Dimensionless	0	10
Safety	Dimensionless	0	10

Table 2. Characteristics of the human capital sub-indicators: pesticides, painfulness and safety.

Description of the human capital input variables

• Pesticide variables

We listed the potential impacts from the different protection systems identified. Four human components may be impacted: chronic toxicity (acceptable daily intake, or ADI, of the active ingredient), acute toxicity (LD_{50} of the active ingredient), PPE (the use of personal protective equipment in an abacus) and training (aggregation of the date of the last training with frequency of training per year).

•;Painfulness variables

The three painfulness variables are: noise, low back pain and musculoskeletal disorders. Each variable is evaluated for each occupational disease by listing the different types of work as well as the time spent on it per hectare.

• Safety variables

The three safety variables are: PPE (same as for the pesticide variable), adapted and/or safe machines and training (same as for the pesticide variable). The safety sub-indicator is built in the same way as the pesticide sub-indicator.

Reference value

The reference value of 7 corresponds to an acceptable risk for the human components in the corresponding vineyard system without an innovation. If we consider that it takes an average of one person to manage 5 ha of vines, a reference value can be calculated from the five annual treatments and the use of all the individual protections mentioned above. This reference value will correspond to a value of 7 for the indicator (acceptable level).

Indicator validation

The only validation performed for the human capital indicator according to Bockstaller and Girardin (2003) consists in assessing the scientific validity of the design by submitting it to a panel of experts and publishing it in a peer-reviewed conference journal. This was the case for the human capital indicator combined with an economic indicator (Keichinger and Thiollet-Scholtus, 2017).

We did not perform the output validation because we have not yet obtained the necessary set of measurements of human capital impacts. This step aims to assess the perspective quality of the indicator. The final validation – the end-user validation – consists in verifying whether the human capital indicator is implemented by end-users and meets their demands. In addition to the examples shown in Figure 2, we registered the 11 NLIVS and implemented a research dissemination strategy in research projects on innovative viticulture systems. The human capital indicator is used in four ongoing research projects: SALSA, DiverViti and Bee (2018–2023), PPR VITAE (2020–2025). These four projects contain participatory research with the users of the project results, which will be a factor in the success of end-user validation for the human capital indicator.

Implementation of the human capital indicator at system scale

The painfulness risk indicator results were unsatisfactory, meaning that the NLIVS studied did not have a good rating for this indicator. Almost all NLIVS scored zero, which corresponds to a very high risk of painfulness when implementing innovations in the NLIVS. The only exception is for system B which scored 10 (Figure 2). The explanation for the score of system B reduced all of the factors considered for the painfulness risk indicator (noise, low back pain and musculoskeletal disorders) due to more frequent use of mechanization than the other NLIVS.
The pesticide risk indicator results were also unsatisfactory, ranging from 0 to 4.86 on a scale of 0 to 10, compared to the reference value of 7. This means that the NLIVS studied did not have a good rating for this indicator. Systems A and D scored 0 (high pesticide risk to the operator) due to the toxicity of active ingredients used in these systems. The unsatisfactory scores of systems B (4.29), C (4.00), and G (4.86) were due to the rates of pesticide sprayed, while the scores of systems H (3.67) and I (1.33) were due to the frequency of pesticide spraying (Figure 2). These results show that the intensity of pesticide use remains a danger for the operator running the viticulture system, even in very low-input systems. Even if pesticide rates are decreased and pesticides are approved by environmental certifications, there is a risk to the operator.
The safety risk indicator results were satisfactory. All NLIVS scored from 8 to 10. Due to the unsatisfactory scores of most systems for pesticide risk and painfulness risk, the results of the aggregate human capital indicator were not very satisfactory, as all ranged from 2.4 to 4.6, except for system B, which scored 9.1, compared to the reference value of 7 on a scale of 0 to 10. This suggests a risk of a lower acceptability of most NLIVS (Figure 2).

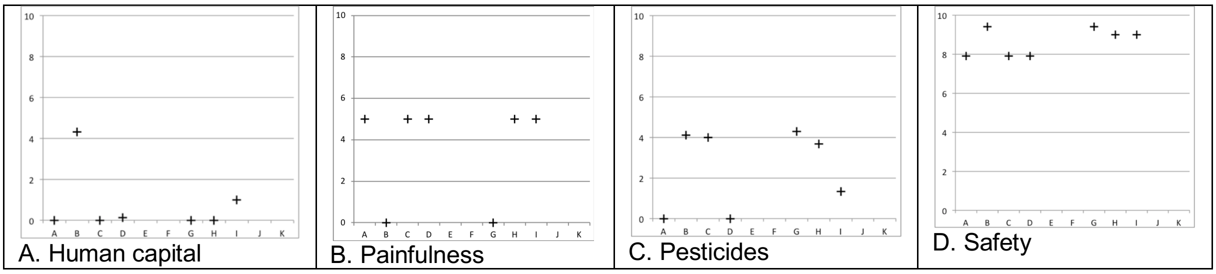

Figure 2. Indicator results (A: Human capital, B: Painfulness, C: Pesticides, D: Safety).

Discussion

The present work aimed to develop a human capital indicator included in a general multi-criteria method to assess the sustainability of new low-input viticulture systems to jointly improve all dimensions of the sustainability of new vineyard systems. We adapted the INDIGO® method, initially developed for conventional arable and viticulture systems, by introducing a social indicator and retaining the other agro-environmental indicators to address issues relevant in work in agriculture systems, and especially in NLIVS. We retained the structure and the scale of the INDIGO® indicators for the human capital indicator.

The type of human capital indicator differs from those of another assessment method used in sociology and more generally in the social sciences (Binder *et al.*, 2010; Feschet, 2014).
Our method used the INDIGO® method expert system combined with fuzzy logic and the conceptual framework used and defined in SLCA (Macombe *et al.*, 2013) applied to very low-input innovative viticulture systems. Our results of high risks of painfulness and the high risk of toxicity of pesticides do not seem favourable to the adoption of innovations by winegrowers. However, this practical method uses a short and simple survey that makes it easy to implement and draws from data already recorded by the winegrower. These features can help identify the social barriers that can limit winegrowers' willingness to adopt these NLIVS systems and complete the list of agronomic, environmental and economic barriers of each NLIVS. Often, agronomic and economic barriers are lifted first, but the majority of viticulture production systems are unsustainable due to social barriers.
Nevertheless, simply identifying these social barriers will not suffice. One point of our original work is to propose an approach at the system scale. The literature makes it clear that other issues exist at the scales of the company, territory and, especially in viticulture, sector and marketers. These aspects must be taken into account to further develop our method in order to envisage a potential territory-wide adoption of NLIVS rather than only partially in winegrowing areas.
Another aspect to be integrated in the social evaluation is the role of professional dialogue networks, which have been shown to be factors in the adoption of more environmental practices by winegrowers (Compagnone, 2004, 2005, 2014).

Conclusion

To answer the research question "what are the barriers in plot work to implementing very low-input viticulture systems?", we detailed the construction of an original human capital indicator and its application to 11 new low-input vineyard systems. These first specific sub-indicators seem to well answer to variations which may suggest a gradient in the ease to adopt the innovations by other winegrowers. We contributed to the social assessment of vineyard practices by proposing an original assessment method drawing from a combination of advantages based on INDIGO® principles and the SLCA framework.
Although the human capital indicator may appear complex in its construction, its implementation in vineyards is simple and quick. The method is original for two reasons: (i) the use of fuzzy logic expert systems of aggregation makes it possible both to avoid an excessive loss of information and to make the results understandable, and (ii) the indicator makes it possible to assess the social sustainability of innovative vineyard systems by taking into account measurable data (working time, pesticide spraying, cost, etc.) as well as the winegrower's feelings about painfulness at work. Indeed, the winegrower's feelings are an extremely important factor in their willingness to appropriate and apply the innovative system on the farm.

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