Assessing sustainable intensification at landscape scale: four case studies in Europe

Etienne Polge [ab], Marta Debolini [a]

[a] *UMR EMMAH, **INRA**-UPVA, Domaine St Paul, Bât Climat, Site Agroparc, 84914 Avignon Cedex 9*

[b] *UMR Territoires, **IRSTEA**-INRA-Agroparistech-Vetagrosup-UCA, Campus des Cézeaux, 63178 Aubière Cedex 2*

Abstract: *The need to feed a growing population, and to mitigate rural poverty, maintaining or reducing the environmental impact of agricultural production is a challenge for the next decades. Sustainable intensification practices and pathways can be identified at farm or landscape/regional level. The identification of the trigger or fence enhancing these practices is a relevant research question, in order to improve their application. In this paper, we aim to identify a set of relevant indicators characterizing sustainable intensification pathways at landscape scale to determine the main socio-economics triggers depending on different regional context and issues raised. Four contrasted case studies delimited at inter-municipal level (NUTS3 on the European administrative classification), with notable sustainable intensification processes, were chosen around Europe. We applied a methodology to evaluate sustainability and intensification of practices assessing a set of indicators at municipal level (NUTS4 on the European administrative classification). The preliminary results show a huge land system heterogeneity significantly affecting the distribution of sustainability and intensification, confirming that sustainable intensification pathways are strongly dependent on their regional context. Joint sustainable and intensification practices are implemented in some land system types while this seems more difficult in others.*

Keywords: *Land system, Sustainable intensification, territorial dynamics, socio-economic triggers*

Introduction

Sustainable intensification (hereafter SI) can be defined as increasing or maintaining the agricultural production, minimizing negative impacts on the environment and improving the contribution to sustainable development (Pretty, 1997). However, this concept can be declined in different ways depending upon the understanding of the notion, the scale that is mobilized and the specific environmental and socio-economic context of the agricultural systems analysed. Moreover, SI can be measured through practices or impacts by giving different orientations to the analytical framework.

The research assessing and measuring SI practices can rely on agro-ecology (Altieri, 1995; Gliessman, 2014) and also on similar notions, such as ecological intensification (Doré et al., 2011; Tittonell, 2014), climate smart agriculture (Campbell et al., 2014; Lipper et al., 2014) or eco-efficient agriculture (Keating et al., 2010) valorising natural resources and sustainable pathways. Several agronomical solution, such as conception of innovating cropping system (Meynard et al., 2012), precision agriculture helped by technological input (McBratney et al., 2005) and biological control (Bale et al., 2008) are commonly put forwarded as SI pathways. The use of any concept depends generally on the practice of community and also on the level of the societal transformation that is expected.

In the research on SI, understanding of agricultural sustainability often focus on the environmental side, where social and economic sustainability should also be considered as well. The notion of intensification tends to be based onthe value of yield. A more complete connotation would be the added value generated by the unit of land, labour and capital (Cochet, 2015; Dorward, 2013), especially in areas where the yield gaps are limited, as in Europe (Neumann et al., 2010).

Major part of these research have been developed on a farm level scale but sustainable intensification depends on several scales because the impact of agronomic practices go far beyond the limit of the farm (Leenhardt et al., 2010; Weltin et al, 2018). Moreover, assessing

SI at landscape and regional scale not only implies farm agricultural practices but also takes into consideration the other variables linked to land planning and management. These include land sharing / land sparing debate (Fischer et al., 2014) and ecological corridors implementation. Collective action or product valorisation by alternative commercialisation are also ways to significantly increase the value added outputs.

Indicators of SI may based on farmer practices (means-based indicators), farming system characteristics; emissions to the environment or environmental impacts (effect-based indicators) (van der Werf et al., 2009). Effect-based indicators are often preferred to assess the environmental impact for a static analysis assuming that it appears years after implementation of SI practices. However, hybrid indexes methods, mixing state of farming systems and mean-based indicators seem more effective to assess changes during the time considering that some practices are widely admitted as sustainable or lead to intensification.

Finally, SI potentialities strongly depend on the local context both from the biophysical and socio-economics point of view (Benoît et al., 2012). Desirable practices for SI differ from one land system to another and assessment should be adapted.

In this perspective, the VITAL project (Viable InTensification of Agricultural production through sustainable Landscape transition) aims to analyse European agricultural system's dynamics towards SI. Four contrasted case studies with notable SI processes were chosen around Europe: *Comtat Venaissin* of *Vaucluse* (France), *Utiel-requena* in the region of *Valencia* (Spain), *Rhinluch* (North-west Brandenburg, Germany) and *Kromme Rijn* (Utrecht, Netherland).

In this context, the objective of this paper is to identify and assess series of indicators characterizing SI pathways at landscape scale in order to evaluate SI of different land systems. Our purpose is to understand the SI dynamics of land systems and the existing drivers and triggers of SI pathways at landscape scale in order to propose possible future scenarios. Besides farm practices, special attention is given to organisational modalities, institutional arrangements and implemented policies. Stakeholder initiatives in arrangements, such as farmer organisations (cooperative, association), protected area (Natura 2000, biological reserves, national parks) or inter-municipal cooperation as *Pays* and *Parc Naturel Régional* could play an essential role to develop the capacity of local actors to manage the drivers and foster the SI processes. In our work, we plane to analyse the main socio-economic triggers of SI pathways, distinguishing hexogen and endogen drivers, which can be managed by local stakeholders (Polge et al., 2015).

The final objective of this work is to test the use of the SI concept in land and farming system analysis, integrating different types of data in order to understand the current dynamics and the responses. The applied methods could constitute a tool to support decision-making within the territorial governance arrangements and could offer new perspectives on land policies (Debolini et al., 2015).

Case studies

Four case studies were selected on the VITAL project, because of their relevance on presenting some features of sustainable intensification dynamics: *Kromme Rijn* in Utrecht region, *Rhinluch* in North-west *Brandenbourg* region, *Utiel-requena* in *Valencia* region and *Comtat Venaissin* in *Vaucluse* region (figure 1). In order to better understand the SI pathways at landscape scale, we enlarge the analysis to the whole inter-municipal region (NUTS3) including the four case studies.

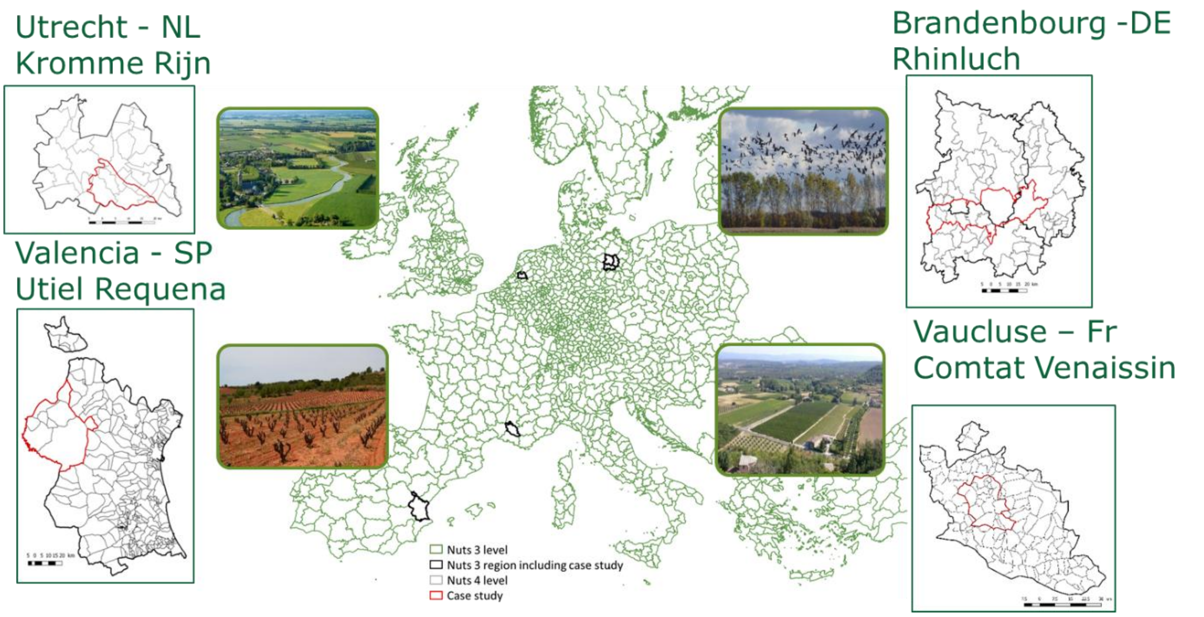

Figure 1: Land system analysis scale

The VITAL project developed a strong knowledge on the context of each of the case study through interviews and workshops with stakeholders. Moreover, analysis of European land use through CORINE land cover data - CLC (Copernicus, 2015b) completes this knowledge thanks to the longitudinal characterisation of the land use profiles of case study. Figure 2 shows the proportion of CLC classes for each of the period available (1990, 2000, 2006, 2012) within the four territories and the four VITAL case studies.

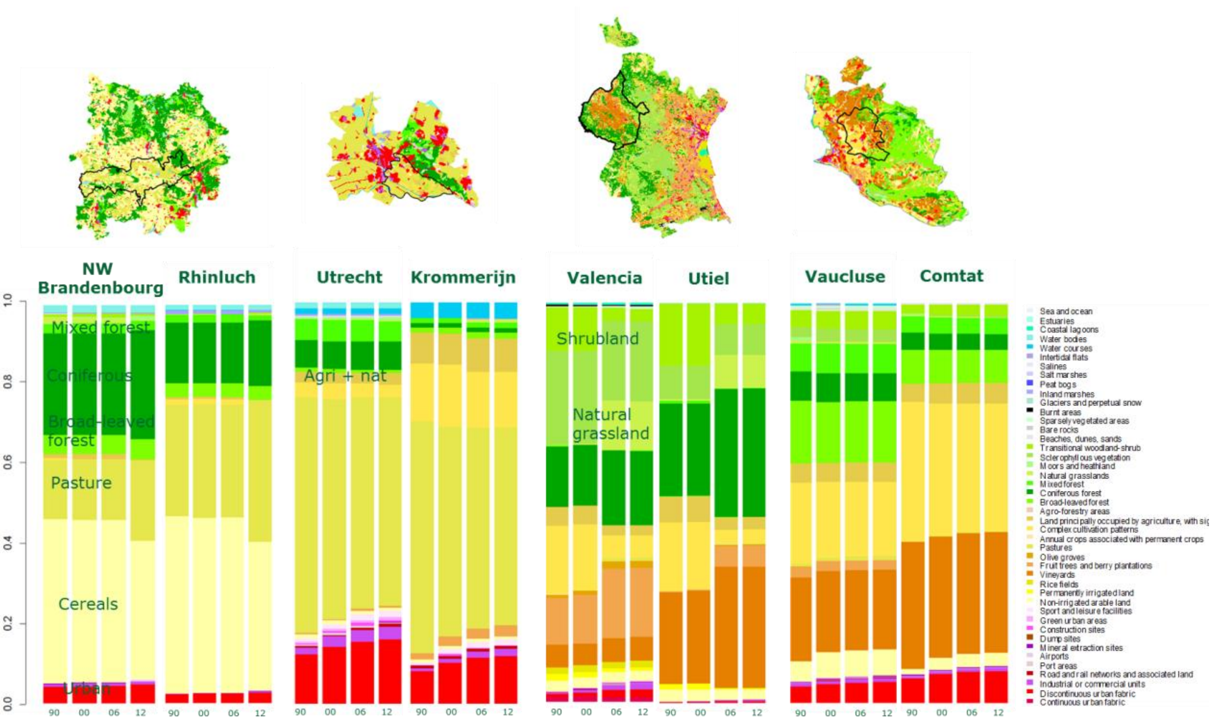

Figure 2: Land use pattern at Nut3 level and at intermunicipal level

North-west Brandenburg is a cereal and livestock oriented region. Arable land are mostly non-irrigated, devoted to cereal production and used as pastures. 40% of the total area is occupied by forests.In contrast, urban areas occupy a small proportion of total land and they include mainly villages like the Berlin peri-urban region. In the analysed period, we observed an increase of pastures and a decrease of non-irrigated agricultural areas. Repartition of land use of *Rhinluch* is slightly different. Forest proportion is lower in favour of the pasture. Livestock production is high in *Rhinluch* and there were some changes from intensive land systems to semi-intensive livestock/crop production ones. Land use profile shows a region dominated by pastures with few urban areas.

Utrecht is a livestock oriented region with increasing artificialized land. It includes the 4th largest city of the Netherlands (Utrecht) and several large municipalities resulting a high residential and recreational pressure. This gives opportunities to develop multifunctionnal agriculture like in *Kromme Rijn* where agriculture consists of dairy farms and fruit orchards (e.g. apples, pears and cherry). In this sub region, proportion of semi-natural land is low. Natural grasslands and arable lands are mainly devoted to livestock production. Moreover, the area includes also some lands composed of small plots of agricultural and artificialized land (complex cultivation pattern).

Valencia is recognized by not only complex cultivation pattern and high fruit production but also a large proportion of semi-natural land. This is due to the presence of two distinct parts: a coastal plain with a strong urbanization on most of the fertile areas, and a more marginal agriculture on the hilly areas. In particular, the coastal region is highly devoted to fruit and vegetable production whereas activities like forestry and vineyards are dominant in the hilly area mainly in *Utiel-requena* region. The arable land of this sub-region is dominated by vineyards while the semi-natural part mainly composed of coniferous forest.

Vaucluse, although consists of specialized agricultural areas dedicated to viticulture but is still diversified. Arable land use is mainly divided between vineyard and complex cultivation pattern whereas semi natural lands are dominated by broadleaves forest. Some places are diverse with vegetable and fruit production, such as *Comtat Venaissin*, which attains a good level of productivity in each of these productions. This sub region has less semi-natural land, more complex cultivation pattern and vineyard land as compared to the other parts of *Vaucluse*.

Materials and method

We applied a 3-step methodology: 1) analyses and classification of land systems 2) assessment of their SI pathways and 3) identification of the main socio-economic triggers. Figure 3 presents the overall methodology.

After characterizing land use, in order to better understand the profile of each landscape, we classified the land systems at municipal level to compare land systems, which have similar SI potentialities. Then we assessed SI by applying the methodological framework of Martinetti and Debolini (2017). Finally we identified the main socio-economic triggers in order to make some recommendation for public action and propose some possible future scenarios. At this stage, we present the results of the first two steps.

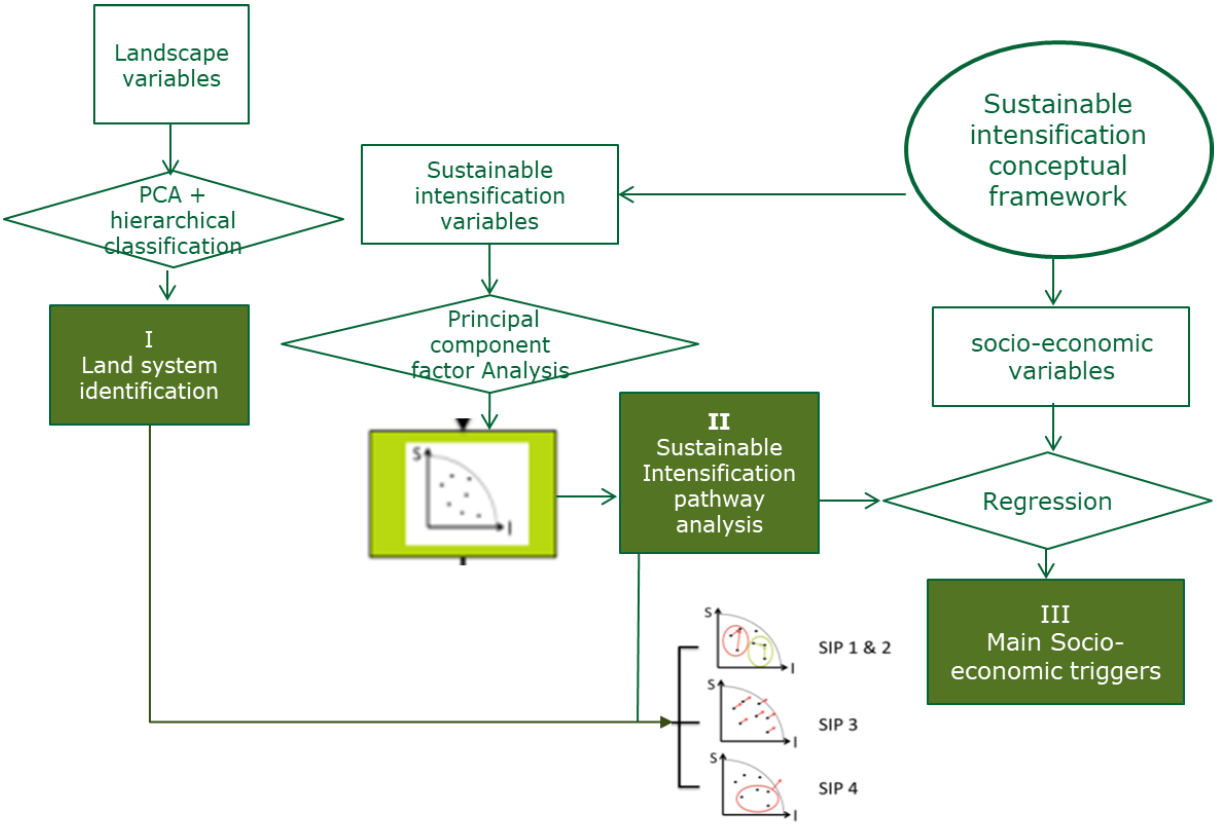

Figure 3: Analytical framework to study sustainable intensification pathways at landscape level

Land system identification

For the first step, in order to identify the land systems, we selected different sets of suitable variables that we tested through principal component analysis combined with a hierarchical classification. We tested two main classifications, in order to understand which one was more adapted for understanding the landscape heterogeneity.

In the first typology, we mobilized the framework proposed by Mücher et al. (2010), where they use four variables as land system characteristics: soil types, altitude, CLC classes and climate. This method is advantageous as it is a simple classification with a homogenous set of data available in Europe. Therefore, we acquired the European soil data (World Reference Base for Soil Resources code) from the European Soil Data Centre at 1 km resolution (Panagos et al., 2012). Then, we used the European digital elevation model (Copernicus, 2015a) considering as variables the mean, maximum, minimum and the variance of the altitude and the CLC (Copernicus, 2015b) data, agglomerating non-agricultural classes and keeping the agricultural classes detailed.

Another way to classify the landscape types was to use indicators of farm specialization and farm surface available in the national agricultural census in addition to CLC class (reduced to 6 main classes) and altitudes variables. These variables can be more adapted to understand the agricultural profile of the area. To qualify the specialization profile, we used the *Otex* indicator, which determine the farm technical orientation. It is based on the relative contribution of each production to the total standard gross margin. A European classification of agricultural holding was based on the *Otex* definition. It is available on the Farm Accountancy Data Network (FADN) on the Nuts 3 level. The basic classification is called TF8 and it splits farm into eight classes. To qualify the farm size we used the mean and the variance of the utilized agricultural surface. As in the previous case, we applied a principal component analysis and a cluster analysis.

Sustainable intensification indicators

For the second step, from review papers (Mahon *et al.*, 2017; Smith *et al.* 2017) on SI indicators, we selected a set of commonly used variables without prioritising them (table 1) adapted to our conceptual framework to evaluate the potentialities and the practices relevant for sustainability and intensification within the municipalities. We implemented a principal component factor analysis (Nardo et al., 2005, Martinetti and Debolini, 2017) to create the two composite indicators. Using this method, we could give a weight to each indicator in a way to avoid an over-representation of correlated variables.

Index	Indicator	Definition and measure (municipal level)	Source
Sustainability	S1_HNV	High natural value farming ratio	EEA
	S2_Natura	Natura 2000 areas ratio	EEA
	S3_Nat_veg	Natural vegetation on farms ratio	RA
	S4_Pasture	Pastures on farms ratio	RA
	S5_Soft_til	Soft tillage on farms ratio	RA
	S6_Wint_cov	Winter coverage on farms ratio	RA
	S7_PNR	Belong to Natural Park (PNR)	PNR
	S8_Short_circ	Short circuit ratio	RA
	S9_Label	Labelling ratio	RA
	S10_Own	Land tenure (owner ratio)	RA
Intensification	I1_Nbr_crop	Number of crop by farm and by surface	RA
	I2_Liv_dens	Livestock density	RA
	I3_Irr	Irrigated surface on farm ratio	RA
	I4_Greenh	Tunnel on farm ratio	RA
	I5_Fert_int	Treated surface with mineral nutrient on farm ratio	RA
	I6_Herb_int	Treated surface with herbicide on farm ratio	RA
	I7_Pest_int	Treated surface with pesticide on farm ratio	RA
	I8_SGB	SGB per hectare on farms	RA
	I9_Work	Quantity of work on farm (hours) by surface	RA

Table 1: indicators of sustainability and intensification

We made a preliminary selection of proxies, which respond to SI dynamics at municipal scale. Some variables were collected at this scale (*Parcs naturel régionaux*), others calculated from European raster files (European environmental Agency – EAA) and rest were collected and agglomerated from the French agricultural census – RA.

In order to assess sustainability from the point of view of the three main pillars, we considered some indicators for environmental (S1 to S6), social and economic sustainability (S7 to S9). High natural value farming described by Paracchini et al. (2008) identifies areas with huge biodiversity on selected CLC classes, mainly agricultural and semi-natural land. Natura 2000 areas identity rare, endangered or vulnerable natural habitats. Intensification was assessed by considering the main factors playing on productivity according to the use of natural resources (I1 and I2), inputs (I3 to I7), work (I8) and standard gross production (SGB) (I9). Use of inputs (natural or chemical) was considered as intensification practices, which potentially lead to decreased sustainability.

As a preliminary step, we analysed data for 2010 but dynamically comparing municipalities of same type. For the next development of the project, we will consider also data for the year 2000. We analysed the situation of intensification on sustainability for each municipality in maps and diagrams and evaluate the tendency of each land system types through linear regression. Finally we identify the Pareto front, which identify the optimal solutions taking into account each of the components (here sustainability and intensification) of a given problem (SI pathways) through the rPref Package (Roocks, 2016).

Results

In this section, we present the results obtained for the *Vaucluse* case study, as a pilot area for testing the proposed methodology. In the next development of the project, the same methods will be applied to all the four case studies around Europe.

Land system typology

As described on the previous section, we tested two classification in order to compare two different typologies of land system: one using soil composition, altitude and land use variables and the other using specialization, altitude and land use variables.

Land system typology using soil composition, altitude and land use

Through the first classification, we identified five land system classes in the *Vaucluse* region (figure 4). The first class is characterized by urban land uses associated with irrigated arable land and fruit production on alluvial soil. The proximity of Rhone River and the possibilities of irrigation systems make possible to have more intensified and irrigated agricultural systems, such as fruit production and horticulture. The second and third classes are dominated by vineyard. The second one has good agronomic soil while the third ones is characterized by stony soil. The fourth class mainly composed of semi natural land associated with natural grasslands, while the fifth class mostly consists of highland pastures.

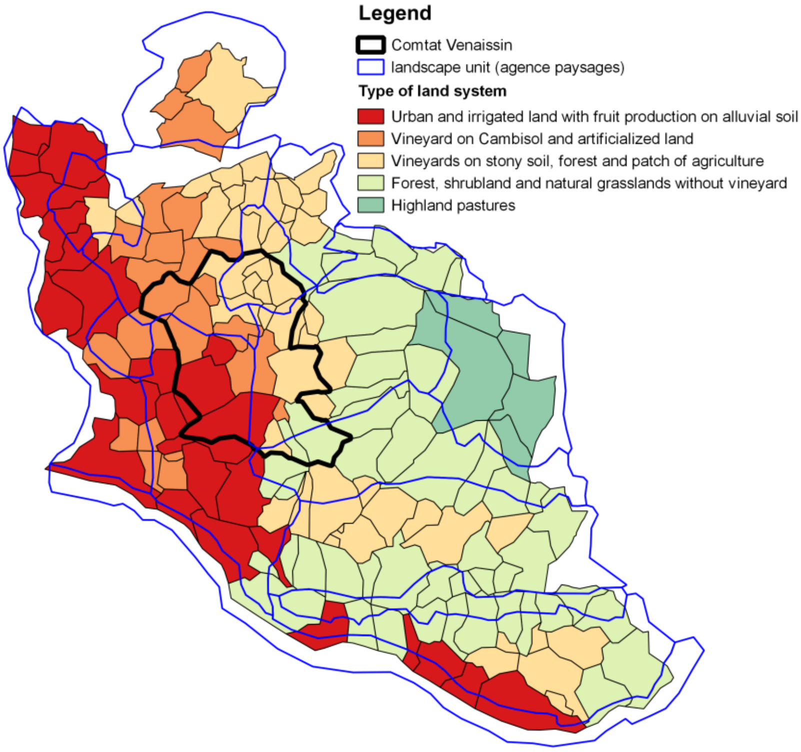

Figure 4: Land system typology of Vaucluse using soil composition, altitude and land use and comparison with the landscape unit identification of the landscape Atlas of Vaucluse.

We compared our results with the *atlas des paysages du Vaucluse* (landscape Atlas of *Vaucluse*) based on field observation (Agence paysages, 2008) and we observed a good correlation between the two classifications.

Land system typology using specialization altitude and land use

The second classification was based on specialization, altitude, utilised agricultural area and land use (figure 5). The results obtained do not substantially differ from the previous typology. Nevertheless, this typology characterizes better agricultural land systems, because it includes specialization variable and farm surface. We identified 4 classes of land system in *Vaucluse* region. The first class is characterized by peri-urban irrigated cultures and urban areas. The second class is oriented on wine production on small farms. The third class has semi-natural lands and fruit production. The fourth class is highlands with livestock production and large farms.

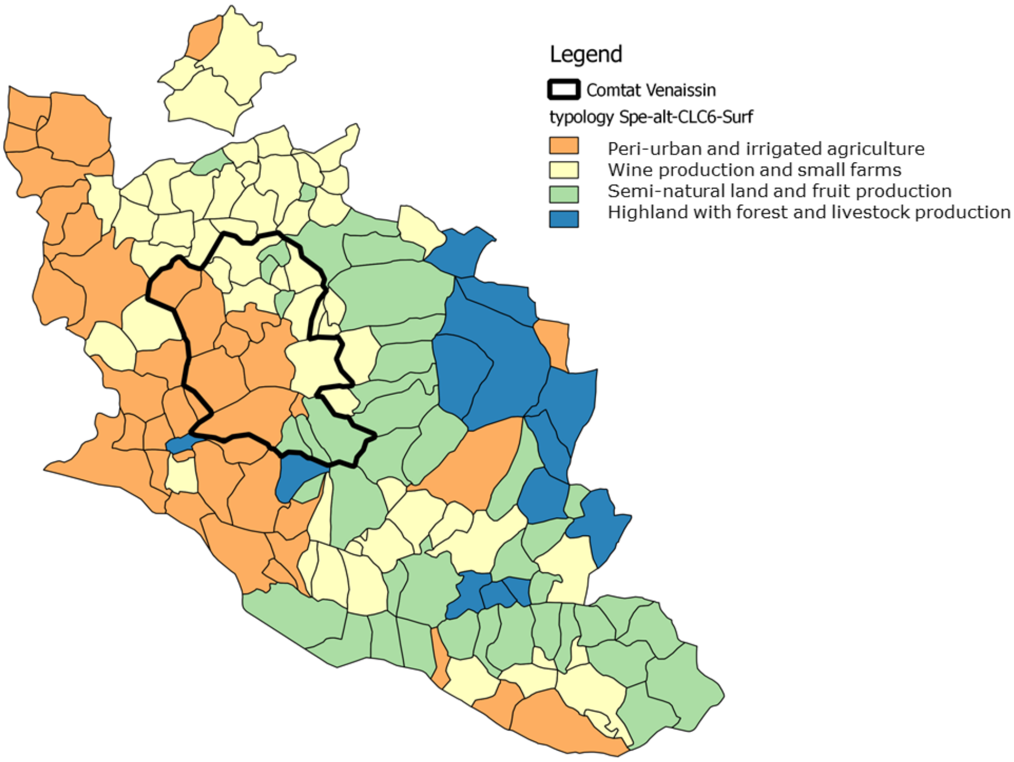

Figure 5: Land system typology of Vaucluse using specialisation, altitude, utilized farm surface and land use

Sustainable intensification analysis

For the assessment of SI for each municipality, we first evaluate a comprehensive index of sustainability and another for intensification. In this section we first show the results of the separate assessment through the mapping of the indexes and then we project the municipal scores in a diagram where intensification is represented on the y-axis and the sustainability on the x-axis. In this way, we could understand which municipality is nearer to the Pareto front and so to the optimality in terms of SI.

Sustainable intensification map

The municipality synthetic indexes give the possibility to spatially visualize the level of intensification (figure 6) and sustainability (figure 7). We can already note that some municipalities have good results in both terms. We can also observe that the sub-area of *Comtat Venaissin* is very heterogeneous in terms of the two factors.

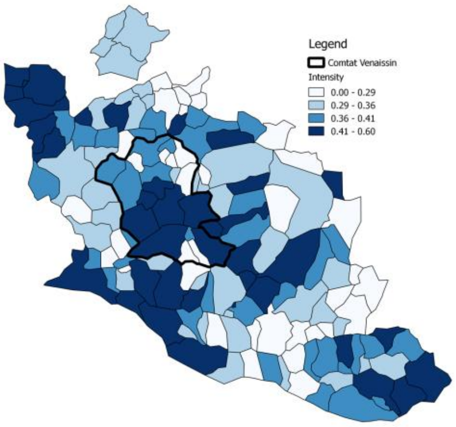

Figure 6: map of intensification

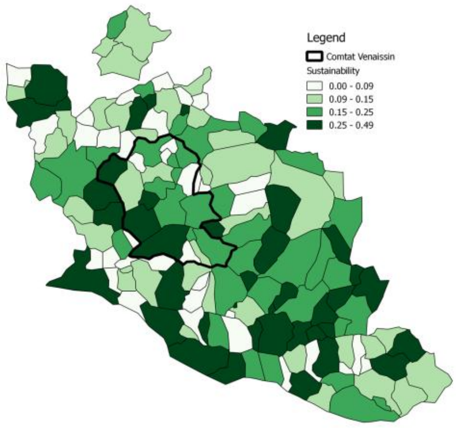

Figure 7 : map of sustainability

Sustainable intensification pathways

Linking the land system typology and the sustainable intensification analysis, we can understand the variety of SI situation according to the land system type (figure 8). Each municipality was computed in a diagram of intensification versus sustainability.

The aim of the analysis was not to compare the different classes of land systems, but to develop understanding within the same class, the factors playing for a Municipality being placed nearer or farther to the Pareto front. Nevertheless, we can observe different pathways.

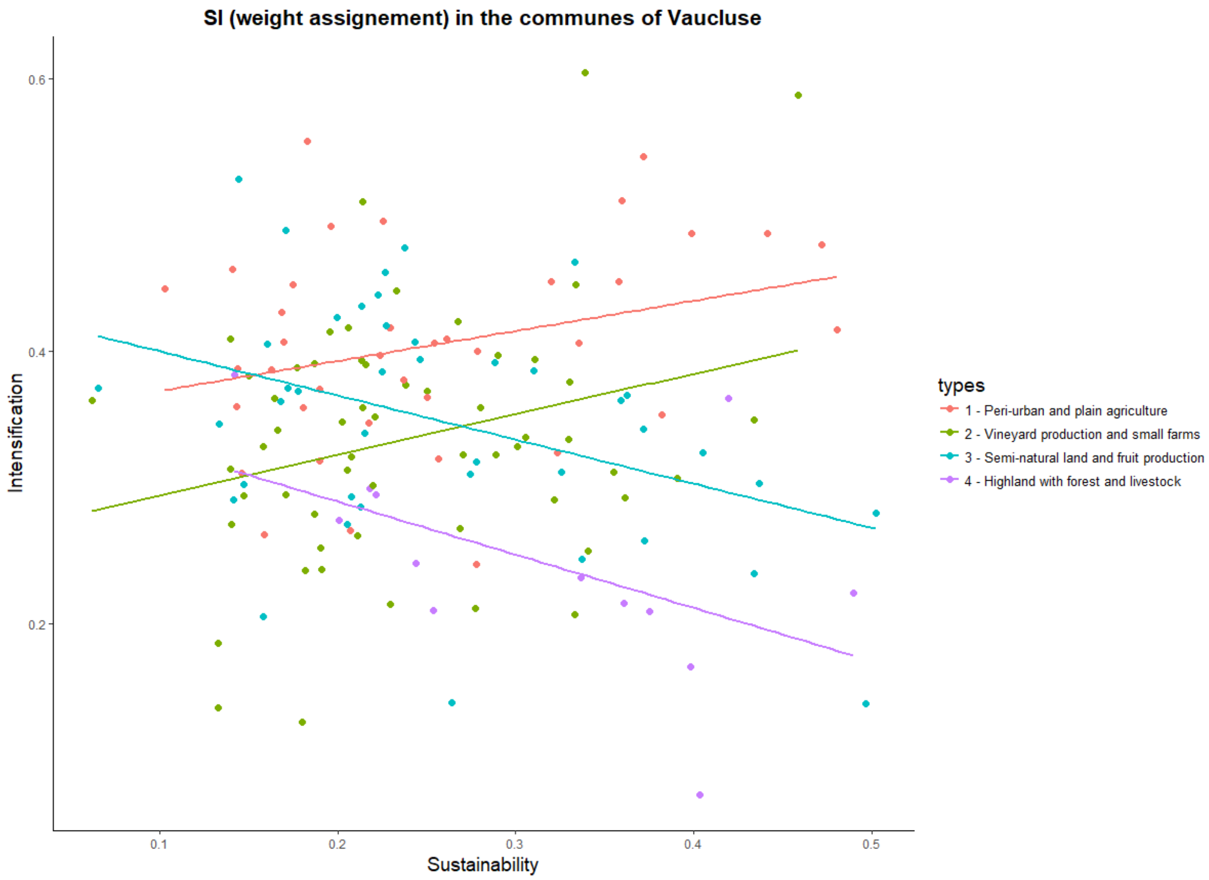

Figure 8: Sustainable intensification pathways

In the *Vaucluse*, for the municipalities characterized by peri-urban and plain agriculture as well as those characterized by Vineyard production (type 1 and 2), we observe that adoption of sustainable practices are positively correlated with the adoption of intensification practices. Some of them attain good level of SI. The municipalities characterized by semi-natural lands and fruit production as well as those characterized by highlands with forest and livestock production (type 3 and 4) are negatively correlated with the adoption of intensification practices.

General overview of the distribution of the SI scores (figure 9) show that land system characteristics and practices tend to intensification more often than sustainability in the whole *Vaucluse* department. We can argue that more effort could be done to develop some sustainable trends on land systems.

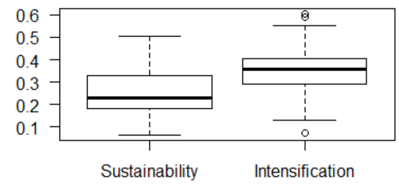

Figure 9: : Distribution of SI scores

To analyse each type of land system separately (figure 10), we can better identify some patterns of SI within the Municipalities. We can identify attainable level of SI through the visualization of the Pareto front, which represents the municipalities with the best SI scores. Moreover, the bisectrix gives the possibility to identify the municipalities which tend to adopt more intensification practices and those which tend to adopt more sustainable practices.

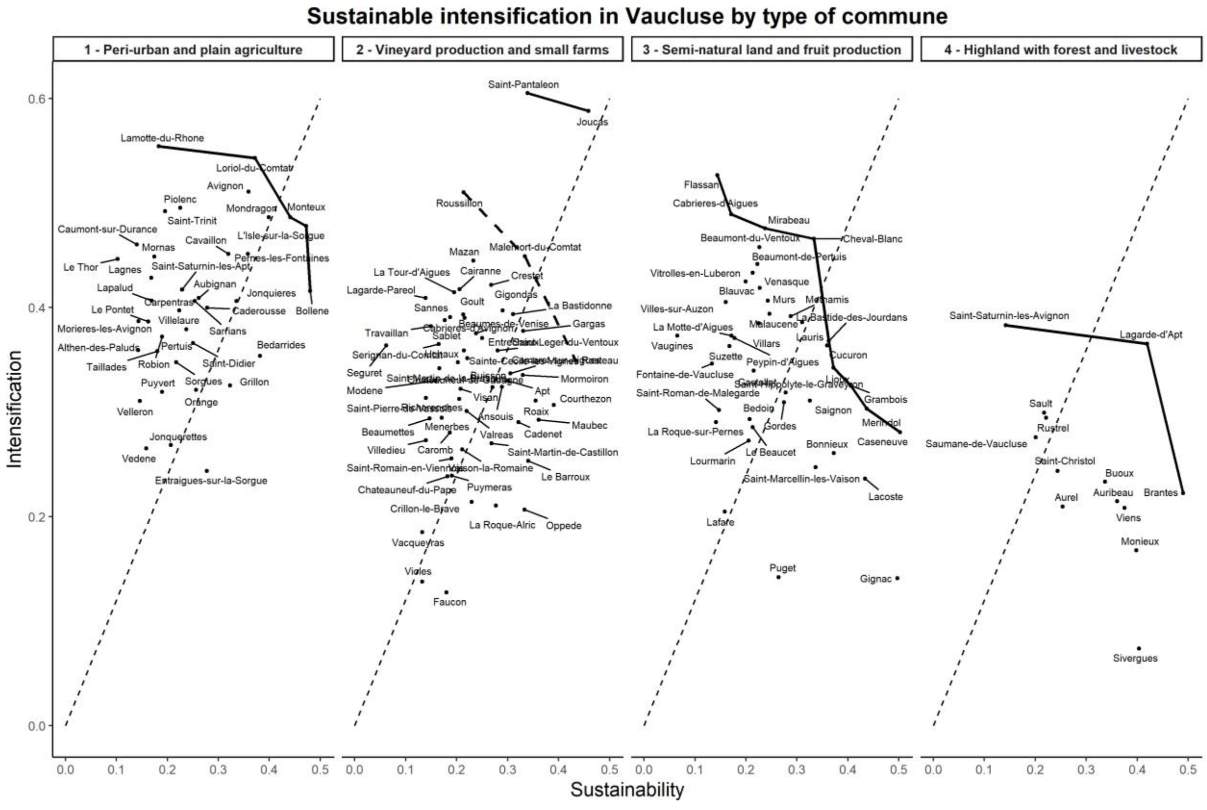

Figure 10: Sustainable intensification pathways by type of municipality

In the first class of land system, the progression of intensification is not linked with a huge augmentation of sustainability. The major part of municipalities is in the intensification dominant side. *Lamotte du Rhone, Loriol du Comtat,* and *Monteux* are on the Pareto Front. In order to better understand which variables play a major role on the performance of the different municipalities, we compared the values of one of the municipality placed on the Pareto front and another placed on a worst position in terms of SI (figure 11). For the first class of land system, we compared *Loriol du Comtat* with *Entraige sur la Sorgue*. On the intensification side, the number of crops within the farms are quite close to the median but work, SGB, irrigated surface and quantity of greenhouses are above the third quantile. Whereas use of fertilizer, herbicide and pesticide are higher for Loriol du Comtat. Nevertheless, this municipality belongs to a PNR and have high ratio of Nature 2000 zones. Winter coverage is high and farms have a lot of natural vegetation within their surfaces. On the contrary, *Entraige sur la sorge* shows high values of SGB, livestock density and irrigated surface ratio, but few crops are grown within the farms.Inputs uses, number of greenhouses and quantity of work are also low. No label, no winter coverage and no soft-tillage along with few natural vegetation within farm and low land security lead to a low sustainability index.

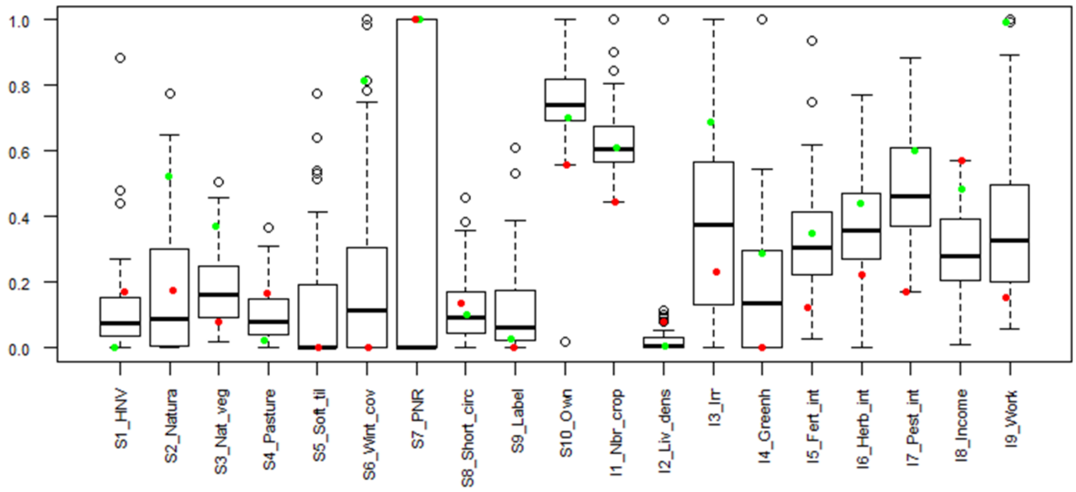

Figure 11: distribution of the SI indicators for the type one municipality and SI results for Loriol du Comtat (green) and Entraige sur la sorge (red)

In the second class of land system, results of the adoption of SI pathway are low but well distributed around the bisectrix. Out of *Saint Pantaleon* and *Joucas,* which have very distinct results comparing to the others municipalities, a second Pareto front includes *Roussillon, Mallemort* and *Rasteau.* Analysing detailed results of *Joucas* (figure 12), we find that, on the intensification side, the variables including use of inputs, greenhouse, irrigated surface and number of crops are high. Nevertheless, this municipality belongs to a PNR and have high ratio of natural vegetation within farms, high natural value farming and Nature 2000 zones. On the other side of the plot, we can identify *Faucon* as a low performant municipality, where even if quantity of work per surface is high, few crops are grown within farms and few investments are devoted to intensify production. The few sustainable practices developed and the low ratio of natural vegetation within farm lead also to a low sustainability index.

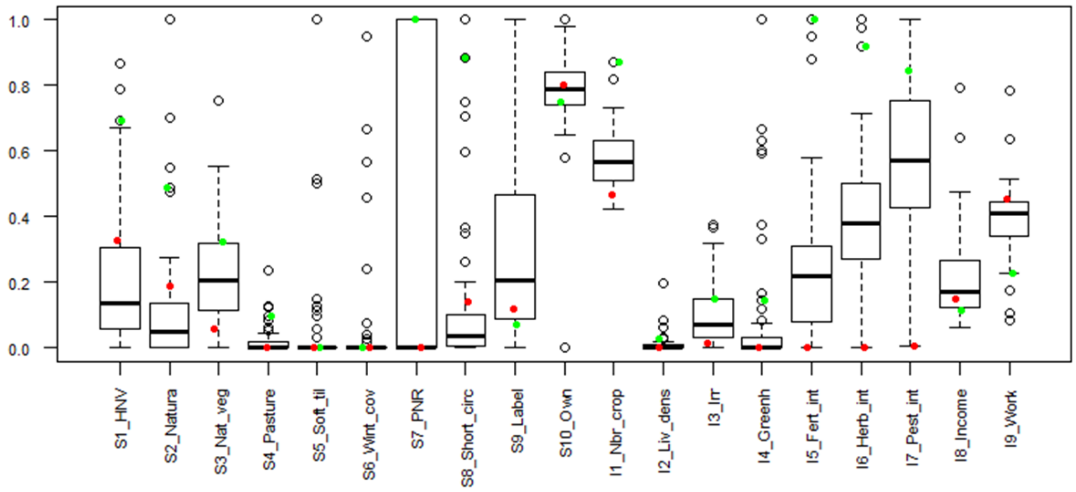

Figure 12: Distribution of the SI indicators for the type 2 municipality and SI results for Joucas (green) and Faucon (red)

In the third class of land system, results of the adoption of SI pathway are very heterogeneous but seem inclined towards intensification side. The Pareto front includes *Flassan, Cabrière d'Aigues, Mirabeau, Cheval-Blanc, La bastides des Jourdans, Cucuron, Saumane de Vaucluse.* After analysing detailed results of *Cheval-blanc* (figure 13) we found that on the intensification side, the variables like use of inputs, greenhouse, irrigated surface and number of crops are high. Nevertheless, it has good performance in terms of sustainability thanks to practices of preservation despite the few sustainable agronomic practices apparently due to the land system type. On the other side, we can identify *Lafare.* In this case, we observed a high value of work per surface but only few crops are grown within farms and limited investments are allocated to intensify production. The few sustainable practices developed lead to a low sustainability index.

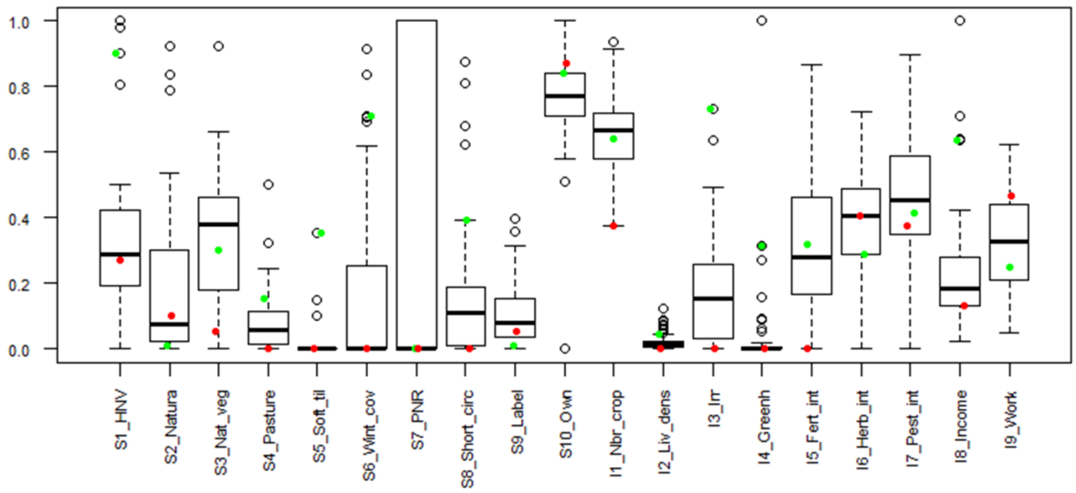

Figure 13: Distribution of the SI indicators for the type 3 municipality and SI results for Cheval-Blanc (green) and Lafare (red)

For the fourth class of land system, results of the adoption of SI pathway are very heterogeneous. In general the municipalities are placed more on the sustainable side of the plot than the intensification side. The Pareto front includes *Saint Saturnin les Avignon, Lagardes d'Apt* and *Brantes.* After analysing detailed results of *Lagarde d'Apt* (figure 14), we found that on the intensification side the three variables indicating the inputs use are on the top of the groups even if SGB and work variable are relatively low. In term of sustainability, the higher performance is mainly due to good ration of HNV and Natura 2000 and winter coverage within farms. On the other side, we can identify *Monieux* where the use of inputs is low. The few sustainable practices developed lead to a low sustainability index even if Natural vegetation and pastures ratios within the farm are high.

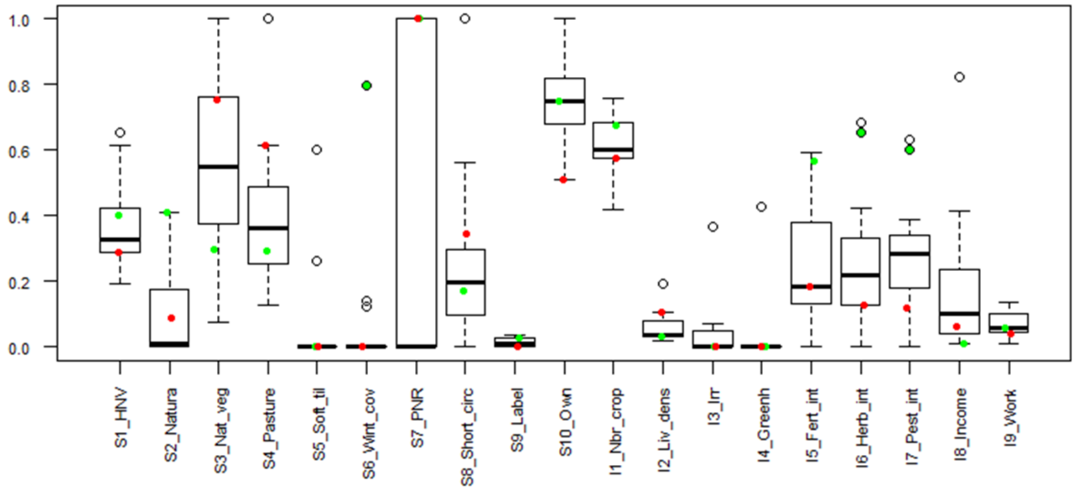

Figure 14 : Distribution of the SI indicators for the type 4 municipality and SI results for Lagarde d'Apt (green) and Monieux (red)

The qualitative observation of specific behaviour of municipalities of the Pareto front, which have the best results, could give good information to understand SI pathways. Distance to the pareto front could bring into knowledge the efforts to provide and to attain good SI results and their triggers through regression methods.

SI index

A contextualized index of SI was built to identify the municipalities, which obtained good results in both intensification and sustainably according to their Land system type. First, from the plots of the figure 10, theoretical SI optimums were defined for each type of land system in the cross point of the pareto front and the bisectrix. Then, the distance of each point (representing municipalities) to this optimum is a way to obtain a proximity matrix, proxy of the SI scores.

For the peri-urban and plain agriculture, Comtat venaissin and northwest of Vaucluse have the best SI results. However for the Vineyard production, Comtat Venaissin has not the better results which are in north of Vaucluse and in the Apt Valley. For the Semi natural land and fruit production, the best results are in the Luberon Mountains and for the Highland, the best are in the south of Ventoux.

Finally, the general overview of the Vaucluse does not allow to identify a specific region with high SI scores. Comtat venaissin appear to be in the mean of the SI scares.

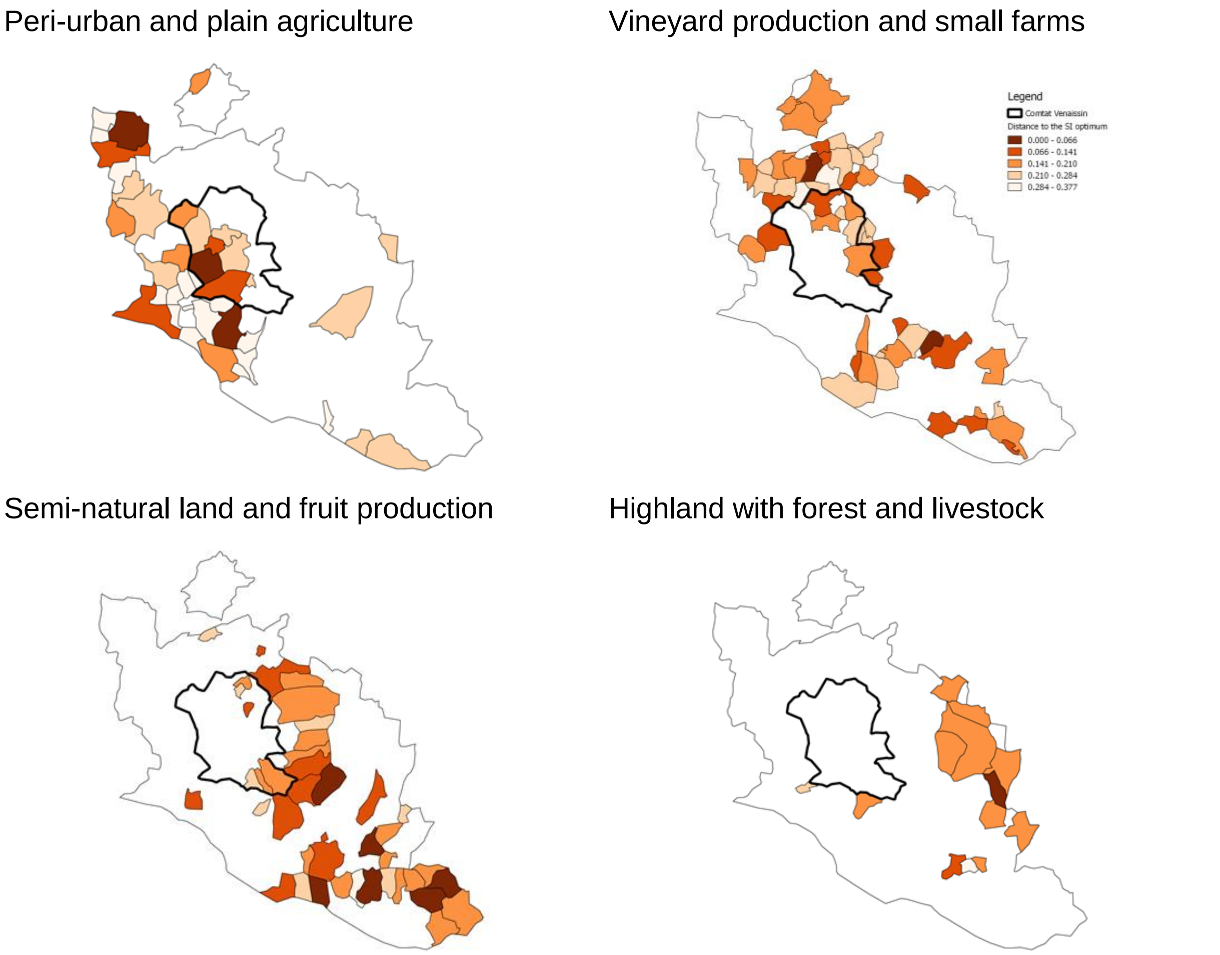

Figure 15 : SI index for each land system type

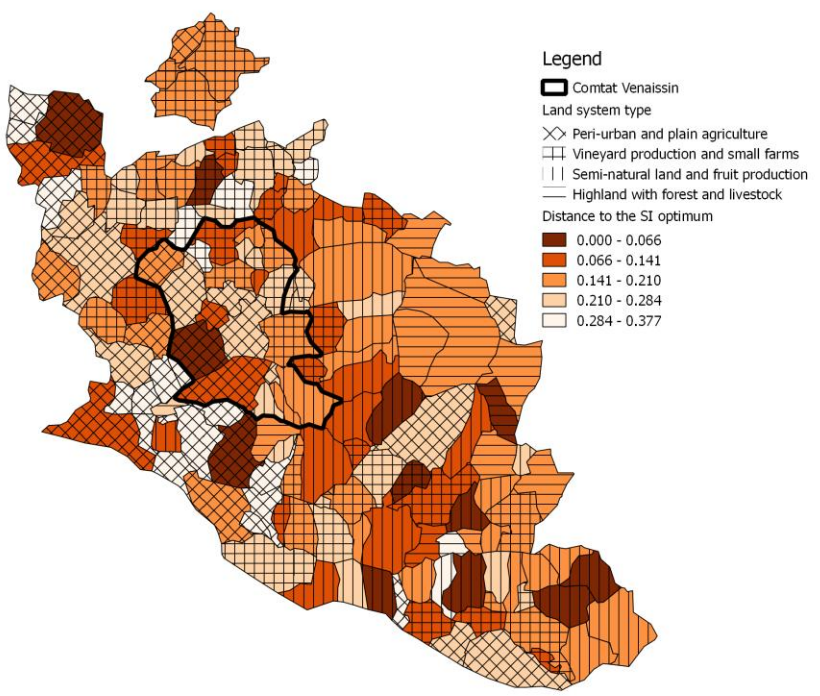

Figure 16: Contextualized SI scores

Discussion

In this paper, we proposed a methodological framework to analyse the SI behaviour of land systems and possibly the temporal trends and the underlying drivers. We built SI indexes, which take into account the three pillars of sustainability (environment, social and economic) as well as the three types of intensification (land, work and resources/capital). We assessed the municipalities of *Vaucluse* that give the possibility to analyse the articulation between intensification and sustainable practices. The first results showed that in some context intensification combine with sustainable practices in the same municipality. We distinguished some municipalities with specific results especially ones that are on the Pareto front (best SI results). We observe on which aspects efforts to attain good SI results could be realized. Finally, we were able to build a map of the sustainable intensification situations taking the land system context into account.

Further development of the study envisages the inclusion of more SI indicators, in order to better characterize land system performance. We plane to integrate data on practices promoting the sustainability as presence of field margins, diversity of land use through the Shannon index, green corridor through the level of fragmentation of natural and semi-natural land. On the intensification side, we plane to add social and economic variables. Furthermore, we plane to analyse more qualitatively the pathways of the municipalities, which have good SI results.

Finally, the perspective of this work is to select socio-economic variables and test them in terms of distance to the Pareto front in a way to identify the main socio-economic triggers to sustainable intensification pathways. Several variables could be selected but as we focus in the project on the role of actors and network in transitions towards sustainable intensification we chose some variables mainly in this field. A challenge of this part of the work can be the assessment of relevant proxies, which could describe the network structural effect. Network centrality indicators or other structural network indicators could be adapted but it might be difficult to have homogenous data in all the four case study. We could choose some indicators of social capital for the transition as Callois and Aubert (2007) proposed for regional development. Collective action in the agricultural domain as the percentage of producers engaged in a cooperative or in an association of mutual material exchange, or the percentage of syndicalist. The number of advisers per producers or the intermunicipal budget dedicated to rural development could be other useful variables but much more bibliography have to be done to choose the appropriate set of variable.

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