

Alma Mater Studiorum Università di Bologna  
Archivio istituzionale della ricerca

A decision support system for territorial resilience assessment and planning: An application to the Douro Valley (Portugal)

This is the final peer-reviewed author's accepted manuscript (postprint) of the following publication:

*Published Version:*

Assumma V., Bottero M., De Angelis E., Lourenco J. M., Monaco R., Soares A. J. (2021). A decision support system for territorial resilience assessment and planning: An application to the Douro Valley (Portugal). *SCIENCE OF THE TOTAL ENVIRONMENT*, 756, 1-10 [10.1016/j.scitotenv.2020.143806].

*Availability:*

This version is available at: <https://hdl.handle.net/11585/912950> since: 2024-05-11

*Published:*

DOI: <http://doi.org/10.1016/j.scitotenv.2020.143806>

*Terms of use:*

Some rights reserved. The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. For all terms of use and more information see the publisher's website.

This item was downloaded from IRIS Università di Bologna (<https://cris.unibo.it/>).  
When citing, please refer to the published version.

(Article begins on next page)

## Accepted Manuscript

Journal of Science of the Total Environment:

### **A decision support system for territorial resilience assessment and planning: An application to the Douro Valley (Portugal)**

Vanessa Assumma, Marta Bottero, Elena De Angelis, Júlia M. Lourenço, Roberto Monaco, Ana Jacinta Soares

To appear in: Science of the Total Environment

Received 31 July 2020

Received in revised form 12 October 2020

Accepted 25 October 2020

Available online 26 November 2020

Doi: <https://doi.org/10.1016/j.scitotenv.2020.143806>

Please cite this article as:

Assumma, V., Bottero, M., De Angelis, E., Lourenço J.M., Monaco, R., Soares, A.J: (2021). A decision support system for territorial resilience assessment and planning: An application to the Douro Valley (Portugal). *Journal of Science of the Total Environment*, vol 756, 143806, pp. 1-10. DOI: 10.1016/j.scitotenv.2020.143806

This PDF is an unedited version of a manuscript that has been peer reviewed and accepted for publication. The manuscript has not yet copyedited or typeset, to allow readers its most rapid access. The present form may be subjected to possible changes that will be made before its final publication.

1 **A Decision Support System for Territorial Resilience Assessment and Planning: an Application to the**  
2 **Douro Valley (Portugal)**

3  
4 Vanessa Assumma<sup>a</sup>, Marta Bottero<sup>a1</sup>, Elena De Angelis<sup>a</sup>, Júlia M. Lourenço<sup>b</sup>,

5 Roberto Monaco<sup>c</sup>, Ana Jacinta Soares<sup>d</sup>

6  
7 <sup>a</sup>Interuniversity Department of Regional and Urban Studies and Planning, Polytechnic of Turin, Italy

8 <sup>b</sup>Centre for Territory, Environment and Construction, University of Minho, Braga, Portugal

9 <sup>c</sup>Polytechnic of Turin, Italy

10 <sup>d</sup>Centre of Mathematics, University of Minho, Braga, Portugal

11  
12 **Abstract**

13 This paper aims to assess the territorial resilience of a socio-ecological system through an innovative integrated  
14 evaluation framework to aid the decision-making process in the planning of transformation scenarios. This framework  
15 employs a set of resilience indicators through a Multicriteria Decision Analysis (MCDA) coupled with a Lotka-Volterra  
16 mathematical model of cooperative type. The set of indicators aims to calculate a composite index of Territorial  
17 Resilience (TRI), whereas the mathematical model is an extension of an existing model, aimed to predict possible long-  
18 time scenarios. The proposed operational framework for rural and vineyard landscapes aims to bridge the existing gap  
19 between territorial resilience theory and practice, with an innovative Decision Support System able to assist decision  
20 makers and territory planners in the planning and management of resilient territorial systems. This integrated evaluation  
21 framework is applied to a famous wine region in Portugal, the Douro Valley, where Port-wine grows. Such framework,  
22 especially in a context of adaptive governance, proves to be a suitable support in the field of landscape and urban  
23 planning to evaluate the dynamics of socio-ecological systems and to envision long-term policies and actions.

24  
25 **Keywords:** Territorial resilience; Multicriteria Decision Analysis; Mathematical modelling; Spatial mapping.

---

<sup>1</sup> *Corresponding author:* Marta Bottero, Politecnico di Torino, Interuniversity Department of Regional and Urban Studies and Planning, Viale Mattioli 39, 10125 Turin (Italy), e-mail: [marta.bottero@polito.it](mailto:marta.bottero@polito.it),

## 26 1. Introduction

27 The planet's health continues deteriorating due to the combined impacts of anthropogenic activities and the  
28 ongoing situation of climate-change, thus causing a loss of ecosystem services (Carreiro and Zipperer, 2011;  
29 MEA, 2005; TEEB, 2010). The International Panel on Climate Change reported alarming data that could  
30 cause irreversible changes if a worldwide strategy is not adopted (IPCC, 2019).

31 Research on resilience (Berkes and Folke, 1998; Holling, 1996, 1973) has been going on for more than fifty  
32 years, and the new millennium has assisted to a great interest from academics, organizations, governments  
33 and freelancers. The Latin word *resilire* translates literally resilience as the ability "to leap back" and it is  
34 used as a polysemic concept (Gunderson, 2010). Resilience is employed in various disciplines along time,  
35 such as by engineering, ecology, psychology, economy, urban planning, disaster risk management, climate  
36 planning, among other.

37 In Engineering, resilience means the "stability at a presumed steady-state, and stresses resistance to a  
38 disturbance and the speed of return to the equilibrium point" (Berkes and Folke, 1998). It reveals suitable for  
39 actions, e.g. testing materials stability or evaluating the risk of cultural heritage (Appiotti et al., 2018;  
40 Ceravolo et al., 2016). Psychology conceives resilience to study the individual and since the 80s was  
41 intended as the community's capacity to respond after disasters and dramatic events (Adger, 2000; Prati and  
42 Pietrantoni, 2009; Tobin and Whiteford, 2002).

43 Studies on ecological resilience began during the 60's with attempts to model the ecosystems and investigate  
44 the alternative ecological states (Allen and Holling, 2010; Gunderson, 2000). Holling defined ecological  
45 resilience the "measure of the persistence of systems and of their ability to absorb change and disturbance  
46 and still maintain the same relationships between populations or state variables", so differentiating it from  
47 the engineering resilience (Holling, 1996, 1973). Resilience is not necessarily characterized by hierarchical  
48 interactions. The system can skip directly to a reorganization phase, without intermediate phases, and even  
49 can interact across scales (Gunderson and Holling, 2002). This definition lends itself to the unpredictable  
50 nature of resilience (Holling, 1996; Pendall et al., 2010). Holling's studies became the main reference to  
51 conceptualize a formal analytical framework (Cote and Nightingale, 2012; Walker et al., 2007), which  
52 incorporated also studies in ecological economics (Anderies et al., 2004; Ludwig et al., 1997; Norgaard,  
53 1994; Perrings, 2006). Subsequently, a co-evolutionary approach was defined through that the coupled socio-

54 ecological systems (SES) were introduced: ecosystems, urban and territorial systems, landscapes (Berkes and  
55 Folke, 1998) which “grow, adapt, transform and collapse, at different scales” (Lambin, 2005), thus  
56 identifying complex adaptive systems (Folke et al., 2010; Gunderson, 2010). The mentioned studies  
57 generated an important step towards a transdisciplinary approach to practice the resilience thinking (Kallis  
58 and Norgaard, 2010): the conceptualization of urban resilience according to a holistic approach and  
59 considering the dynamic behavior of systems (Meerow et al., 2016), the combination of resilience,  
60 sustainability and transformability to trigger important planning challenges (Elmqvist et al., 2019), among  
61 other.

62 International organizations incorporated resilience within their frameworks. The Global Agenda has  
63 introduced 17 Sustainability Goals which are today the main reference for all member countries (United  
64 Nations, 2015). The Urban Agenda Habitat III (Agenda, 2016) supports the SDGs achievements through  
65 guidelines. The Hyogo framework and the Sendai Framework (UNISDR, 2015, 2005) intend resilience as a  
66 process within the disaster risk management. Despite the development of various frameworks, mismatches  
67 have been detected between government actions and environmental outcomes (Pillay and Buschke, 2020).  
68 The growing attention and the overuse of resilience generated confusion in the academic, political and  
69 professional fields (Cutter, 2016), leading to have divergent concepts (Huck and Monstadt, 2019). The  
70 common trend is to take position definitions with respect to a single dimension, the scale and investigated  
71 object or to combine definitions by merging common features and minimizing differences (Chambers et al.,  
72 2019).

73 In recent years, territorial resilience was defined as “an emerging concept capable of aiding the decision-  
74 making process of identifying vulnerabilities and improving the socio ecological and technological systems  
75 (SETSs)” (Brunetta et al., 2019). Even if the idea of territorial resilience is ever more important for the  
76 assessment and planning, its application to the real world is almost absent.

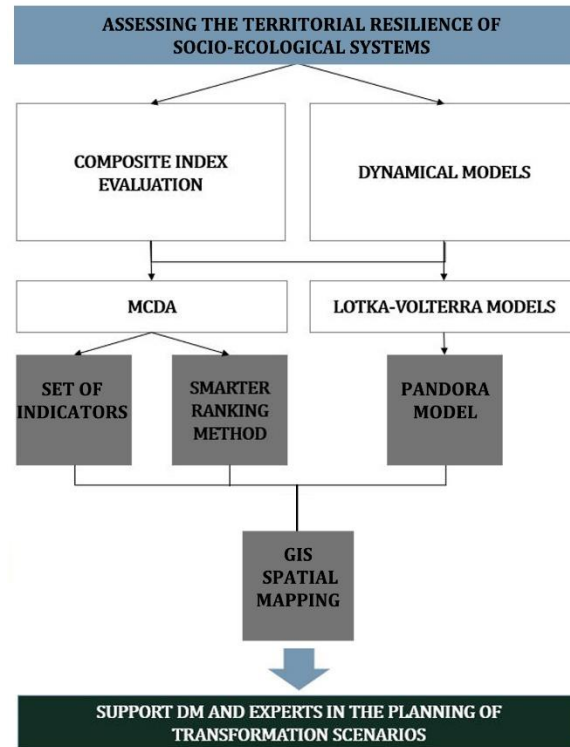
77 This paper (re)defines territorial resilience as “the ability of a territorial system to absorb the impacts  
78 generated by endogenous and exogenous drivers, itself toward a new dynamic equilibrium”, where territorial  
79 system intends regions, sub-regions or provinces. This definition takes into account that robust evaluations  
80 are required to aid the decision makers in planning resilient policy decisions (Dumitru et al., 2020).

81 Few studies focus effectively on the resilience practice to deliver best-practices (Bennett et al., 2016), to  
82 prepare communities to risk events, to define long-term strategies, to increase governance and adaptive  
83 management (Ayre and Nettle, 2017; Mitchell, 2013; Pelling, 2003; Schultz et al., 2015).  
84 The paper aims to bridge the gap between territorial resilience theory and practice with an original Decision  
85 Support System, to support the planning and management of territorial systems.  
86 The proposed framework combines indicators developed through a multicriteria approach with a dynamical  
87 model of Lotka-Volterra cooperative type (Assumma et al., 2019b; Gobattoni et al., 2011; Monaco and  
88 Soares, 2017), finalized by spatial mapping through GIS methods (Malczewski, 2006). It is applied to the  
89 wine region of the Douro Valley in Portugal, a UNESCO site inscribed in the World Heritage List (2001).  
90 The application to a real territory with its specific characteristics and local/regional agents demonstrates that  
91 ecologically-based technical knowledge on territorial resilience can integrate different sets of components,  
92 values, criteria and focus in implementation, not necessarily top-down. This novel framework fosters  
93 participatory adaptive management based on dissemination of conceptual knowledge and discussion of base-  
94 line scenarios. In so doing, it addresses criticisms about resilience involving a top-down approach that does  
95 not address decision contexts or about it lacking focus on implementation, especially of transformative  
96 adaptation (Colloff et al., 2017).

## 99 **2. Materials and methods**

100 This study combines Multicriteria Decision Analysis (MCDA), dynamical modelling to support Decision  
101 Makers in the planning and management of resilient territorial systems.  
102 The MCDA is employed for the calculation of a composite index of territorial resilience, organizing a set of  
103 indicators according to the value tree approach (Keeney and Raiffa, 1979). The SMARTER method (Barron  
104 and Barrett, 1996; Edwards and Barron, 1994) has been used as weighting phase of the MCDA to deliver a  
105 set of weights for investigating the importance of the indicators and calculating a synthetic index of  
106 Territorial Resilience (TRI). As far as the ecological evaluation is considered, several references exist on  
107 dynamical models of cooperative type applied to various contexts, known as PANDORA models (Bonacini

108 et al., 2017; Gobattoni et al., 2011; Monaco and Soares, 2017). A revisited version of the dynamical model  
109 by Monaco and Soares (2017) is here developed. Figure 1 illustrates the proposed evaluation framework.  
110



111  
112  
113 **Figure 1.** Structure of the evaluation framework.

114

## 115 2.1. Composite index evaluation

116 Since resilience is a multidimensional concept, the research proposes a composite index evaluation that  
117 considers different variables and indicators. The construction of composite indexes has been extensively  
118 investigated in the scientific literature and different methods have been suggested (Barron and Barrett, 1996;  
119 Edwards and Barron, 1994; Keeney and Raiffa, 1979). Multicriteria Decision Analysis (MCDA) is a wide  
120 family of techniques that includes multiple features of a decision problem, both qualitative and quantitative  
121 and it takes into account the interests of the actors and stakeholders. Differently from the nonparametric  
122 estimation techniques (e.g. discounting cash-flow, Cost Benefit Analysis), MCDA is retained as suitable to

123 deal with complex problems which require multidimensional solutions (Bottero and Mondini, 2009); Kitsiou  
124 et al., 2002).

125 In particular, a three-step procedure has been followed for the calculation of the TRI:

126 (i) Indicators selection and data collection;

127 (ii) Weighting and aggregation;

128 (iii) Spatial analysis and visualization.

129

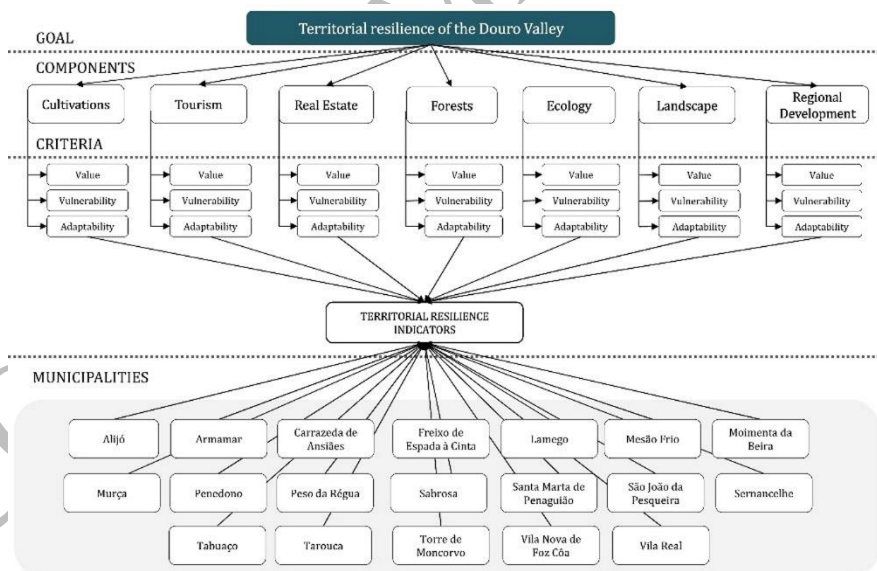
### 130 **2.1.1 Indicators selection and data collection**

131 This set of indicators has been hierarchically organized (Figure 2), where:

- 132 • Goal is the territorial resilience assessment of the Douro Valley which performs the Territorial  
133 Resilience Index (TRI).
- 134 • Components are seven features retained relevant for the territorial resilience of the case study:  
135 Cultivations component refers to the relations between the rural landscape, economic aspects and  
136 climate change features (Gottero and Cassatella, 2017; Schaller et al., 2018). Tourism considers the  
137 tourism offer and the impacts generated on a rural landscape by tourism flows (Terkenli, 2014). Real  
138 Estate considers cultural landscapes as positive externalities able to generate benefits on real estate  
139 prices (Panduro and Veie, 2013; Tyrväinen, 1997; Waltert and Schläpfer, 2010). Forests are a  
140 fundamental resource because deliver benefits to local communities and needs the management to  
141 prevent risk events (Jacinto et al., 2015; MEA, 2005; Santos et al., 2018; Steenberg et al., 2012;  
142 TEEB, 2010; Todman et al., 2016; Valente et al., 2013; Zêzere et al., 2014). Ecology refers to the  
143 ecological features of a SES, e.g. the biological energy, green areas of high quality, or the presence  
144 of urban areas that may obstacle the connectivity of the system. Some of them have been used as  
145 parameters of the dynamical model as it will be explained in Section 2.3. (Babí Almenar et al., 2018;  
146 Bonacini et al., 2017; Dalerum, 2014; Gobattoni et al., 2011). Landscape considers the presence of  
147 protected areas and cultural heritage and also those features that may enhance or compromise  
148 landscape (Cassatella and Peano, 2011; De Vries et al., 2013, 2007). Regional Development  
149 considers socio-economic features, as well as programs and initiatives to increase territorial  
150 resilience (Dente, 2014; Scrivens and Smith, 2013).

151 The indicators are organized into components and they are reported in Tables A.1-A.7  
 152 (Supplementary Material).

- 153 • Criteria are the system aspects acting on the resilience capability. In particular, Value is represented  
 154 by the elements that generate benefits to the system under investigation; Vulnerability refers to those  
 155 factors that solicit perturbations within the system and thus influencing negatively its state;  
 156 Adaptability represents the ability of the system to respond to one or more perturbations, evolving  
 157 towards a new equilibrium.
- 158 • Indicators measure the performances of the municipalities in terms of territorial resilience and are  
 159 classified into general and site-specific. The firsts are applicable to whatever wine region, whereas  
 160 the latter measure the specific characteristics of the Douro Valley. This set of indicators can be  
 161 considered innovative for assessing territorial resilience of wine regions.
- 162 • The alternatives are the municipalities of the NUTS III, Douro, which have been organized into 19  
 163 landscape units. More information are reported in section 2.2.



165  
 166 **Figure 2.** Structure of the set of indicators.

167 Various data sources were considered (Tables A.1-A.7): statistical data sources (e.g. Instituto Nacional de  
 168 Estatística - INE, PORDATA, ICNF, among other), the knowledge of selected experts of the Douro Valley,

169 geographical databases (e.g. IPMA - Portal do Clima, iGEO - Informação Geográfica, INSPIRE Geoportal,  
170 or OpenStreetMap) and other data (e.g. urban plans, programs, or SEA and EIA procedures).

171

## 172 2.1.2 Weights assessment and aggregation

173 An important part of the evaluation procedure is related to the weighting phase. In fact, weights measure the  
174 importance of the indicators, criteria and components in the decision problem under examination. Among the  
175 different protocols for weights elicitation, the present study makes use of the SMARTER method. This  
176 method allows to rank groups of elements from the most important to the less important (Barron and Barrett,  
177 1996; Edwards and Barron, 1994) and to calculate normalized weights. It was chosen due to different  
178 motivations: firstly, the SMARTER procedure facilitates an evaluation of numerous elements into the  
179 process, and in this sense the ranking reduces the number of comparisons; secondly, it allows the experts to  
180 give qualitative judgments and not numerical values, thus increasing the confidence of the experts in the  
181 evaluation.

182 Another crucial aspect for the calculation of the composite index is related to the normalization procedure  
183 which allows to compare non-commensurable items. Among the several normalization procedures, this study  
184 is based on the min-max transformation that allows to rescale the original values in a 0-1 range (OECD,  
185 2008). The problem under analysis involves both aspects that positively affects the decision (whose  
186 corresponding indicators have thus to be maximized) and aspects that negatively affects the decision (whose  
187 corresponding indicators have thus to be minimized). Consequently, intermediate values between the  
188 minimum and the maximum have been converted through the following formulas (OECD, 2008), depending  
189 on the need to maximize or minimize the indicator, respectively:

$$190 \quad I_i = \frac{x - x_{min}}{x_{max} - x_{min}}, \quad I_i = \frac{x_{max} - x}{x_{max} - x_{min}}$$

191 (1)

192 in which  $I_i$  is the normalized value for each indicator and  $x$  indicates the raw value of the indicator.

193 After having defined the weights and completed the normalization procedure, the indicators are then

194 aggregated through the hierarchy using an additive function:

195

$$TRI_j = \sum_i w_i I_{ij}$$

196

(2)

197 where  $TRI_j$  is the composite Territorial Resilience Index for the municipality  $j$ ,  $w_i$  is the weight of the  
198 indicator  $i$  and  $I_{ij}$  is the normalized value of the indicator  $i$  for the municipality  $j$ .

199

### 200 **2.1.3 Spatial analysis and visualization**

201 Spatial analyses can be considered suitable techniques to provide opportunities for resilience thinking and  
202 planning (Borie et al., 2019). The final results of the TRI can be then visualized through specific spatial maps  
203 developed in GIS environment. The overall objective of this part of the evaluation is to identify those  
204 Municipalities with common resilience features, thus defining specific areas of intervention.

205

### 206 **2.2. The mathematical model for ecological assessment**

207 In the field of Landscape Ecology (Turner and Gardner, 2015), mathematical models provide dynamical  
208 evolutions of possible scenarios of complex environmental systems. Models of cooperative type, already  
209 quoted in this paper, are frequently employed in integrating strategic evaluations as support in the assessing  
210 process for aiding the decision makers to identify suitable policy decisions. Many applications of such  
211 models are described in the literature (Bonacini et al., 2017; Gobattoni et al., 2011; Monaco and Soares,  
212 2017; Murray, 2002), presenting promising results in the study of the ecological-economic evaluation of  
213 rural and vineyard landscapes (Assumma et al., 2019b, 2019a). The proposed dynamical model maintains the  
214 structure of the one presented (Pelorosso et al., 2012). The novelty is the application to the case study under  
215 investigation to obtain evolutionary scenarios of ecological type, thanks to the identification of the meaning  
216 and numerical value of the parameters from real data. Moreover, this dynamical model, with respect to the  
217 one studied in Monaco and Soares (2017), links the ecological scenarios with the results obtained through an  
218 innovative MCDA approach. Thanks to the combination with the SMARTER method it has been possible to  
219 modify the role of the parameters, taking into account the particularities of the Douro Valley, a region that is

220 characterized by a significant level of naturalness and contains specific cultivations as the vineyards, so that  
 221 the ecological component is one of the most important to be considered in this analysis.  
 222 The main aim of the model is to describe the ecological state of an environmental system. An environment is  
 223 intended as an isolated system divided in  $n$  landscape units (LU) which are specified by their borders,  
 224 constituted by natural or anthropological barriers, e.g. roads, motorways, railways, buildings, industrial  
 225 infrastructures, rivers, or hill ridges. Each  $i$ -th LU,  $i = 1, \dots, n$ , is formed by  $m_i$ -biotopes which are patches  
 226 characterized by a uniform land cover. In our model, the ecological state of the  $i$ -th LU is described by two  
 227 normalized variables varying in  $[0; 1]$ , namely  $V_i$  and  $b_i$ , for  $i = 1, \dots, n$ . Variable  $V_i$  represents the  
 228 percentage of all green areas with high ecological quality in the  $i$ -th LU. More in details,  $V_i$  is obtained by  
 229 dividing the sum of all green areas with Biological and Territorial Capacity (BTC), greater than  
 230  $2.4 \text{ Mcal}/\text{m}^2 \text{ per year}$  (Gobattoni et al., 2011) by the total area of the LU itself. Moreover, variable  $b_i$  is  
 231 the percentage of biological energy produced by the LU's biotopes and it is defined as follows

$$b_i(t) = \frac{1}{B_{max} S_i} \sum_{j=1}^{m_i} B_{ji} S_{ji}$$

(3)

234 where  $B_{ji}$  is the BTC value of the biotope  $j$  belonging to the  $i$ -th LU of area  $S_i$  and  $s_{ji}$  is the area of the  
 235 biotope  $j$ . Moreover,  $B_{max} = 6.5 \text{ Mcal}/\text{m}^2 \text{ per year}$  is the maximum value of BTC for the vegetation at  
 236 the European latitudes and corresponds to oak woods. Variables  $V_i(t)$  and  $b_i(t)$  change in time and their  
 237 evolution is given by the following system of ordinary differential equations (ODEs),

$$\begin{cases} b'_i(t) = a_i b_i(t)[1 - b_i(t)] - [1 - V_i(t)]b_i(t) \\ V'_i(t) = \varphi_i d_i V_i(t)[1 - V_i(t)] - U_i V_i(t) \end{cases}, \quad i = 1, \dots, n$$

(4)

240 coupled with the initial data at  $t = 0$ ,

$$V_i(0) = V_{i0}, \quad b_i(0) = V_{i0}, \quad i = 1, \dots, n$$

(5)

243 System (4) includes the parameters  $a_i, d_i, U_i$  and  $\varphi_i$  which can be considered as ecological indicators. It has  
 244 to be noticed that the same parameters are also included in the MCDA procedure in the form of indicators  
 245 belonging to the component Ecology. Indeed, the main novelty of the proposed model is that the ecological  
 246 parameters are included both in the dynamical model as input data to predict future possible scenarios, both  
 247 in the MCDA to evaluate the current ecological performance of the Douro Valley. In detail:

248

249 *Indicator  $a_i$  of solar exposure of biotopes*

250

251 The indicator  $a_i$  measures the solar exposure of the  $i$ -th LU by considering the following formula

$$252 \quad a_i = \frac{w_1 S_i^{SE} + w_2 S_i^W + w_3 S_i^{NE}}{S_i} \leq 1$$

253 (6)

254 where  $S_i^{SE}, S_i^W, S_i^{NE}$  indicate the area of the LU exposed at South-East, West and North-East, respectively,  
 255 and the weights  $w_1, w_2, w_3$  are respectively given by 0.50, 0.25 and 0.25.

256

257 *Indicator  $d_i$  of solar exposure, humidity and ecotone length*

258

259 The indicator  $d_i$  is the average value of the indicators of solar exposure  $a_i$ , relative humidity  $k_i^{hu}$  and  
 260 ecotone length  $k_i^{ec}$ , that is

$$261 \quad d_i = \frac{1}{3}(a_i + k_i^{hu} + k_i^{ec})$$

262 (7)

263 where the parameters  $k_i^{hu}$  and  $k_i^{ec}$  are given by

$$264 \quad k_i^{hu} = \frac{1}{S_i}(w_1 S_i^h + w_2 S_i^s), \quad k_i^{ec} = 1 - P_i \left( \sum_{j=1}^{m_i} P_{ij} \right)^{-1}$$

265 (8)

266 where  $S_i^h$  and  $S_i^s$  are respectively the humid and the semi-humid areas of the LU,  $w_1 = 0.75$  and  $w_2 = 0.25$ .

267 Moreover,  $P_i$  is the perimeter of the  $i$ -th LU and  $P_{ij}$  the perimeter of the  $j$ -th biotope.

268

269 *Indicator  $U_i$  of building density*

270

271 The indicator  $U_i$  is defined by the ratio of the total building area of the  $i$ -th LU and  $S_i$ .

272

273 *Indicator  $\varphi_i$  of connectivity*

274

275 The indicator  $\varphi_i$  refers to the global connectivity among the LUs that exchange bioenergy with their  
276 neighbors, according to the formula, see Monaco and Soares (2017),

$$\varphi_i = \sum_{k \in I_i} \frac{H_{ki}}{L_{ki}} \quad (9)$$

279 where  $I_i$  is the number of the LUs bordering the  $i$ -th LU and

$$H_{ki} = \sum_{r=1}^s L_{ki}^r p_r, \quad L_{ki} = \sum_{r=1}^s L_{ki}^r \quad (10)$$

282

283 with  $L_{ki}^r$  being the length of the portion  $r, r = 1, \dots, s$  of the border between the LU  $i$  and  $k$ , with a  
284 permeability index  $p_r \in [0, 1]$ .

285 An important step for the qualitative analysis of our model consists in determining its equilibrium solutions  
286 and analyzing their stability behavior. The equilibrium solutions represent some possible ecological  
287 scenarios for the LUs and their stability analysis establish if they represent an attainable future scenario for  
288 each LU.

289

### 290 2.2.1 Equilibrium solutions

291  
292 The equilibrium solutions of system (4) (Murray, 2002) are obtained by solving

$$\begin{cases} a_i b_i(t)[1 - b_i(t)] - [1 - V_i(t)]b_i(t) = 0 \\ \varphi_i d_i V_i(t)[1 - V_i(t)] - U_i V_i(t) = 0 \end{cases}, \quad i = 1, \dots, n$$

295 We obtain:

$$\left( V_i^{(1)}(t), b_i^{(1)}(t) \right) = (0, 0),$$

(11)

298 which represents a scenario of strong fragmentation characterized by a strong loss of bio-energy and green  
299 area of high ecological quality;

$$\left( V_i^{(2)}(t), b_i^{(2)}(t) \right) = \left( 1 - \frac{U_i}{\varphi_i d_i}, 0 \right),$$

(12)

303 which corresponds to a scenario with a poor value of bio-energy and some sparse green islands and it occurs  
304 if  $U_i < \varphi_i d_i$ . Finally, the third equilibrium is given by

$$\left( V_i^{(3)}(t), b_i^{(3)}(t) \right) = \left( 1 - \frac{U_i}{\varphi_i d_i}, 1 - \frac{U_i}{\varphi_i a_i d_i} \right),$$

(13)

308 which represents a scenario with appreciable ecological quality, characterized by significant or even large  
309 values of both green areas and bio-energy. This equilibrium point occurs if  $U_i < \varphi_i a_i d_i < \varphi_i d_i$ .

### 311 2.2.2 Stability conditions

312 In order to complete the analysis of the model, it is necessary to determine the stability conditions for the  
313 equilibrium solutions. Such an analysis consists in determining the sign of the eigenvalues of the Jacobian

314 matrix of system (4), (Murray, 2002). Thus, for the equilibrium solutions of system (4) we obtain three  
315 couples of eigenvalues, given by

316

317 First equilibrium

$$318 \quad \lambda_{1i}^{(1)} = a_i - 1, \quad \lambda_{2i}^{(1)} = \varphi_i d_i - U_i$$

319 (14)

320 Second equilibrium

$$321 \quad \lambda_{1i}^{(2)} = U_i - \varphi_i d_i, \quad \lambda_{2i}^{(2)} = a_i - \frac{U_i}{\varphi_i d_i}$$

322 (15)

323 Third equilibrium

$$324 \quad \lambda_{1i}^{(3)} = U_i - \varphi_i d_i, \quad \lambda_{2i}^{(3)} = \frac{U_i}{\varphi_i d_i} - a_i$$

325 (16)

326

327 The stability conditions ask that both eigenvalues are negative, so that we get

- 328 • the first equilibrium is asymptotically stable if  $\varphi_i d_i < U_i$ , otherwise it is unstable;
- 329 • the second equilibrium is respectively asymptotically stable or unstable if  $\varphi_i a_i d_i < U_i < \varphi_i d_i$ ;
- 330 • the third equilibrium, if it exists, that is if  $U_i < \varphi_i a_i d_i$ , it is asymptotically stable.

331

332

### 333 3. Results

#### 334 3.1. Case study: the Douro Valley

335 The Douro Valley is a wine region in the North-Eastern side of Portugal and it extends for about 40.000 ha.

336 The Douro Valley is partially included in the UNESCO site "Alto Douro Wine Region" as "an evolving and

337 living cultural landscape" (World Heritage Committee, 2001): the boundaries of its core zone are the result

338 of landscape studies and assessments, whereas the boundaries of its buffer zone overlay most of the  
339 Demarcated Douro wine region (DDR).

340 A non-uniform urban morphology can be recognized between the internal area and the coast as testimony of  
341 a common trend in Portugal since the 18th century (Lourenço et al., 2009). The Douro region was involved  
342 in several territorial development plans and programs, EU investments to raise the local economy for  
343 triggering a socioeconomic improvement, job creation and life quality (Lourenço et al., 2009). This research  
344 work has selected the 19 Municipalities of the NUTS III, Douro. From an ecological point of view, each  
345 Municipality has been intended as a Landscape Unit:

346

347 LU1 - Alijó	LU8 - Murça	LU15 - Tabuaço
348 LU2 - Armamar	LU9 - Penedono	LU16 - Tarouca
349 LU3 - Carrazeda de Ansiães	LU10 - Peso da Régua	LU17 - Torre de Moncorvo
350 LU4 - Freixo de Espada à Cinta	LU11 - Sabrosa	LU18 - Vila Nova de Foz Côa
351 LU5 - Lamego	LU12 - Santa Marta de Penaguião	LU19 - Vila Real
352 LU6 - Mesão Frio	LU13 - São João da Pesqueira	
353 LU7 - Moimenta da Beira	LU14 - Sernancelhe	

354

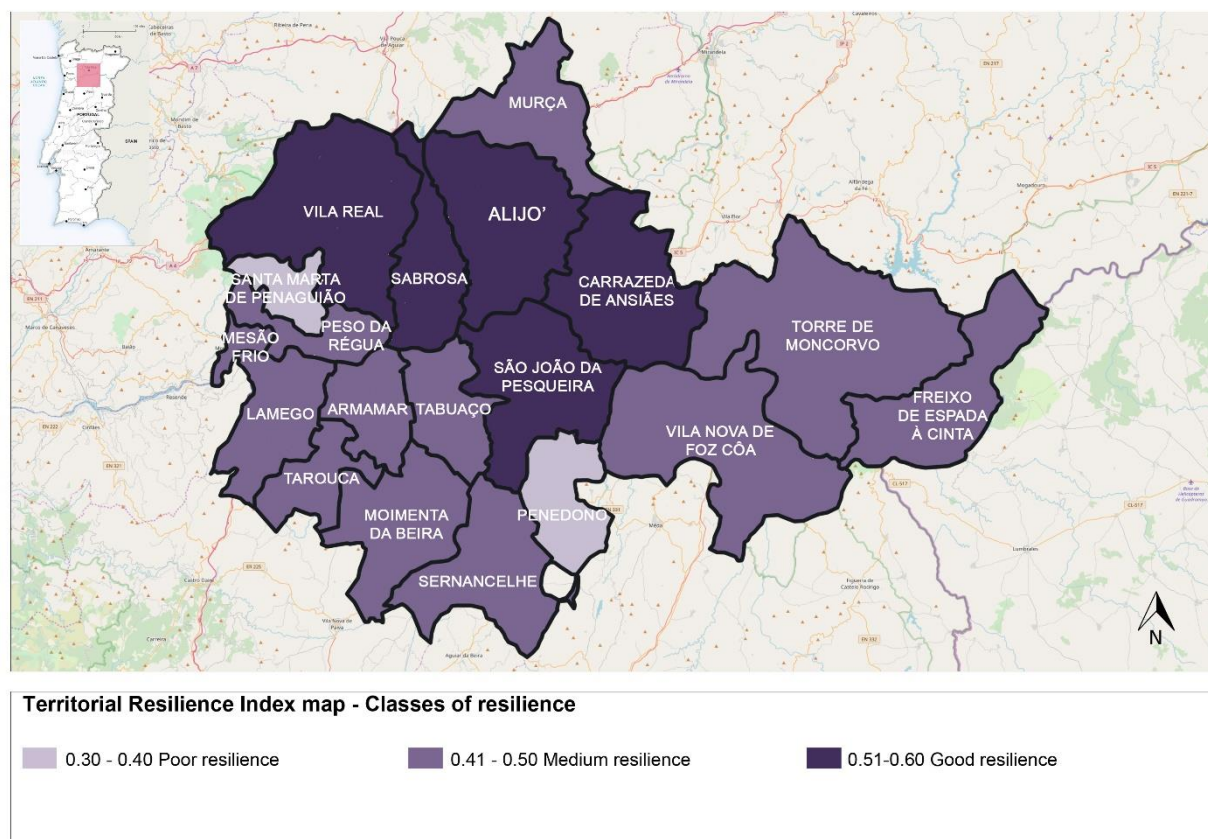
### 355 **3.2 Results of the Territorial Resilience Index**

356 A crucial part of the evaluation was related to the organization of different panels and focus group with local  
357 experts and stakeholders for collecting their preferences about the weights to be used in the calculation  
358 model.

359 A pre-test was performed in April 2019 involving a panel of experts, one expert for each component. The  
360 objective was the investigation of the importance of the set of indicators to deliver an initial set of weights of  
361 territorial resilience.

362 The complete survey (September - November 2019) was addressed to a larger group of actors and  
363 stakeholders involved in the Douro Valley activities. Work meetings were organized to ask to the experts to  
364 rank the indicators and to define potential actions of territorial resilience for the Douro Valley. The survey  
365 was also proposed online to the members of the Association of Port Wine Companies (AEVP).

366 The average set of weights obtained through this survey was applied to calculate the TRI for each  
367 municipality (Figure A.1, Supplementary Material). The results were represented in thematic maps (Figure  
368 A.2) and then aggregated into a final map (Figure 3).



369

370 **Figure 3.** Spatial visualization of the TRI indices using resilience classes.

371

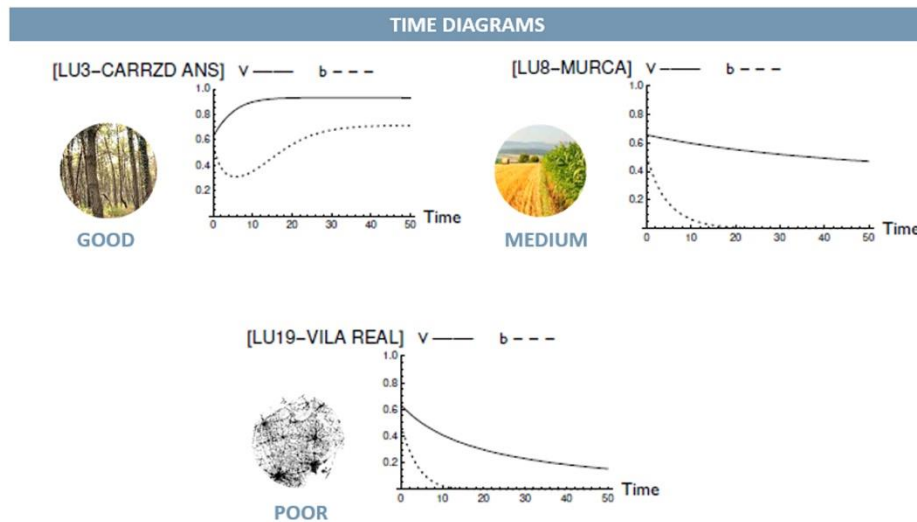
372 Most of the municipalities record a medium resilience. São João da Pesqueira and Vila Real are the most  
373 resilient (0.59 and 0.58) thanks to the high performance recorded in each component. Some municipalities  
374 recorded a medium-low resilience, e.g. Penedono (0.41) due to low performances on cultivations and  
375 landscape. Santa Marta de Penaguião confirms its low performances with the lowest resilience (0.38).

376

### 377 3.1.2 Results of the dynamical model

378 Most of the LUs reach the third scenario with appreciable ecological quality (Table A.8, Supplementary  
379 Material). Nevertheless, there are several LUs (LU4, LU5, LU8, LU9, LU16 and LU17) that reach scenarios  
380 presenting poor bio-energy and isolated green areas. Finally, there are two LUs (LU6 and LU19) that reach

381 the scenario of strong fragmentation. In order to show some examples of the evolution behavior of the state  
 382 variables, Figure 4 shows the time behavior of  $V_i(t)$ ,  $b_i(t)$ , for three LUs: LU3 (Carrazeda de Ansiães,  
 383 Good), LU8 (Murça, Medium) and LU19 (Vila Real, Poor). The results of the other LUs are shown in  
 384 Supplementary Material (Figures A.3 and A.4).



385  
 386 **Figure 4.** Some ecological scenarios as output of the model.

387

#### 388 4. Discussion and conclusions

389 The compared analysis of the models' results allows to interpret the connection between the territorial  
 390 resilience status and the possible ecological evolution scenarios. As described in the previous sections, the  
 391 TRI has been calculated by aggregating specific indicators across different territorial dimensions, i.e.  
 392 cultivations, tourism, real estate, forests, ecology, landscape and regional development. As far as the  
 393 ecological dimension is considered, the indicators are those employed also in the dynamical model which  
 394 enabled to predict future evolution scenarios. The integration of the two evaluations allowed to have a  
 395 complete picture of the territory under investigation that is the one provided by the TRI values, as well as a  
 396 prediction of future possible evolution scenarios, which are those delivered by the dynamical model. Table 1  
 397 shows the results of the two models. It is interesting to observe that while 5 LUs are portrayed with Good  
 398 Resilience by the TRI index, the category of Good Ecological Scenario reaches the double of the LUs.

399 Therefore, there is a match at the highest level, between the highest TRI classified with Good Resilience and  
 400 the dynamical modelling of the Ecological Scenario. But this is not necessarily the case at lower  
 401 classifications of TRI.

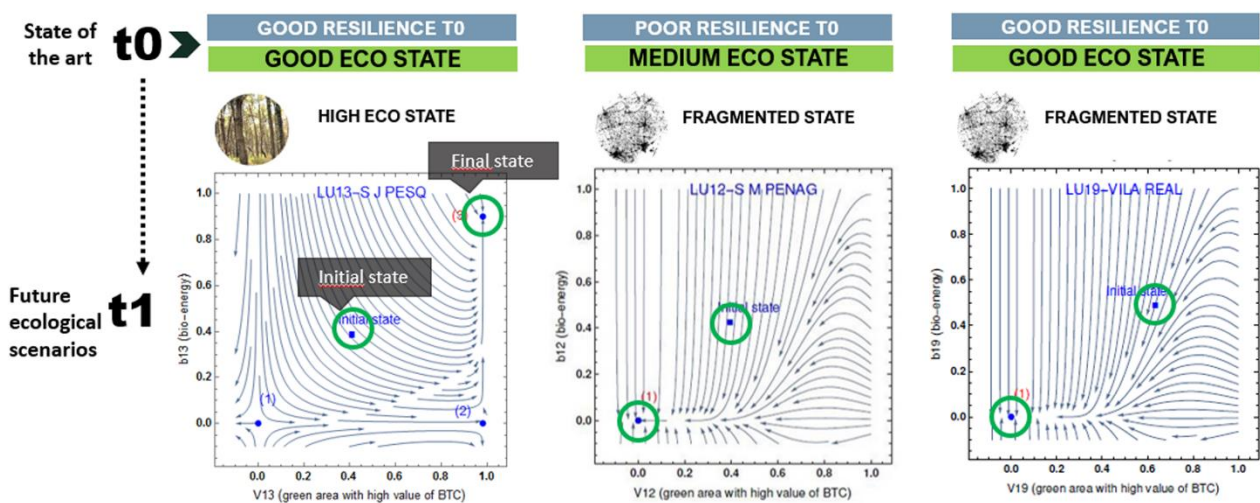
402

Municipalities	Cultivation	Tourism	Real Estate	Forests	Ecology	Landscape	Regional Develop.	TRI	Classes of resilience	Ecological Scenario
LU1-Alijó	0.58	0.44	0.68	0.53	0.58	0.44	0.52	0.52	Good	E3-Good
LU2-Armamar	0.33	0.50	0.44	0.37	0.47	0.49	0.54	0.45	Medium	E3-Good
LU3-Carrazada de Ansiães	0.38	0.63	0.41	0.59	0.63	0.48	0.54	0.52	Good	E3-Good
LU4-Freixo de Espada à Cinta	0.26	0.48	0.44	0.39	0.42	0.45	0.55	0.42	Medium	E2-Medium
LU5-Lamego	0.52	0.68	0.45	0.48	0.29	0.42	0.55	0.47	Medium	E2-Medium
LU6-Mesão Frio	0.12	0.44	0.51	0.43	0.49	0.48	0.56	0.42	Medium	E1-Poor
LU7-Moimenta da Beira	0.28	0.45	0.64	0.58	0.57	0.46	0.60	0.48	Medium	E3-Good
LU8-Murça	0.20	0.47	0.62	0.40	0.48	0.56	0.58	0.46	Medium	E2-Medium
LU9-Penedono	0.14	0.54	0.39	0.49	0.63	0.35	0.45	0.41	Poor	E2-Medium
LU10-Peso da Régua	0.31	0.47	0.68	0.36	0.48	0.47	0.57	0.46	Medium	E3-Good
LU11-Sabrosa	0.29	0.51	0.40	0.60	0.62	0.60	0.58	0.53	Good	E3-Good
LU12-Santa Marta de Penaguião	0.25	0.54	0.57	0.47	0.37	0.31	0.45	0.38	Poor	E1 - Poor
LU13-São João da Pesqueira	0.61	0.51	0.49	0.64	0.62	0.58	0.59	0.59	Good	E3 - Good
LU14-Sernancelhe	0.18	0.58	0.44	0.55	0.61	0.39	0.59	0.46	Medium	E3 - Good
LU15-Tabuaço	0.28	0.39	0.51	0.50	0.53	0.50	0.53	0.46	Medium	E3 - Good
LU16-Tarouca	0.14	0.52	0.45	0.51	0.49	0.50	0.53	0.44	Medium	E2 - Medium
LU17-Torre de Moncorvo	0.41	0.60	0.28	0.76	0.39	0.51	0.55	0.50	Medium	E2 - Medium
LU18-Vila Nova de Foz Côa	0.49	0.41	0.61	0.60	0.40	0.43	0.60	0.48	Medium	E3 - Good
LU19-Vila Real	0.46	0.84	0.59	0.74	0.40	0.57	0.68	0.58	Good	E1 - Poor

403 **Table 1.** MCDA and dynamical model results.

404 Some representative LUs revealed interesting results (see Figure 5): from the left side, São João da Pesqueira  
 405 is characterized by a good territorial resilience and a good ecological performance at the initial time  $t_0$  and

406 asymptotically evolves towards a scenario with appreciable ecological quality at time  $t_1$ . The second case is  
 407 Santa Marta de Penaguião, which shows a poor territorial resilience and a poor ecological performance at  
 408 initial  $t_0$  and it maintains the same conditions when asymptotically evolves to the limiting scenario at  $t_1$ . The  
 409 third case is Vila Real, which records a good territorial resilience and a poor ecological quality at the state of  
 410 the art, and its potential ecological scenario tends to asymptotically degenerate toward a strong fragmentation  
 411 at  $t_1$ .



412  
 413 **Figure 5.** Dynamic interpretation of the territorial resilience in some LUs.

414  
 415 The presented framework has bridged the gap between territorial resilience theory and practice with an  
 416 innovative and original Decision Support System to assist Decision Makers in the planning and management  
 417 of resilient territorial systems. This paper focused on the territorial resilience assessment of a SES  
 418 represented by a famous wine region. The use of specific decision support systems is extremely important  
 419 when public administrations need to incorporate the resilience thinking within plans and programs.  
 420 This framework has combined a set of indicators developed through a multicriteria approach and a Lotka-  
 421 Volterra model of cooperative type, obtaining a dynamic territory interpretation.  
 422 The TRI index was useful to represent the actual conditions of the wine region that is vast and  
 423 heterogeneous. The mathematical model has predicted possible ecological scenarios by maintaining the  
 424 actual conditions of the region. The strong participation of local actors and stakeholders in the discussions of

425 the organized meetings confirms that the GIS visualization allows for more democratic participation of  
426 involved stakeholders as they relate in visual and user-friendly ways to their local territories.  
427 In this study, the asymptotic behavior of the ecological variables underlined the need to include the other  
428 components investigated with the MCDA model. An average TRI index will be calculated as new parameter  
429 of the dynamical model. Although these remarks retain very promising future steps for this research, the  
430 proposed framework needs further application into other vineyard territories to confirm its reliability.  
431 A further step into adaptive governance can be fostered if, for example, Geodesign methods (Steinitz, 2014)  
432 and integrated GIS tools (Yousefi et al. 2020) are introduced for aiding the local actors and stakeholders to  
433 design shared policies and actions in the planning of resilient futures.

434

435

#### 436 **Acknowledgements**

437 Part of this research work has been developed within the Ph.D. thesis by V. Assumma “Assessing the  
438 Resilience of Socio-Ecological Systems to Shape Scenarios of Territorial Transformation”. The authors are  
439 indebted to many CCDR-N staff members such as the ex-Vice President Eng. R. Magalhães, Dr. V. Devesa,  
440 Arch. F. Girão, the Head of Division Eng. H. Teles and several collaborators of Missão Douro/CCDR-N.  
441 Many thanks are also due to Dr. S. Machado (AEVP), Prof. D. Souto Rodrigues (C-TAC, UMINHO), Prof.  
442 R. Bento, Prof. I. Bentes, Prof. D. Lopez and Prof J. Rebelo (UTAD) and experts from Douro organizations  
443 and wine companies Dr. P. Russell-Pinto (IVDP) and Dr. O. Martinez (Lavradores de Feitoria).

444

#### 445 **Funding**

446 The research by A.J.S. has been partially supported by the Portuguese Funds FCT Projects  
447 UIDB/00013/2020 and UIDP/00013/2020.

448

#### 449 **Disclosure statement**

450 The authors declare no conflict of interest.

451 **References**

- 452 Adger, W.N., 2000. Social and ecological resilience: Are they related? *Prog. Hum. Geogr.*  
453 <https://doi.org/10.1191/030913200701540465>
- 454 Agenda, N.U., 2016. Habitat III New Urban Agenda: Quito Declaration on Sustainable Cities and Human  
455 Settlements for All. Habitat III Conf.
- 456 Allen, C.R., Holling, C.S., 2010. Novelty, adaptive capacity, and resilience. *Ecol. Soc.* 15.  
457 <https://doi.org/10.5751/ES-03720-150324>
- 458 Anderies, J.M., Janssen, M.A., Ostrom, E., 2004. A Framework to Analyze the Robustness of Social-  
459 ecological Systems from an Institutional Perspective. *Ecol. Soc.* 9, 1–17. [https://doi.org/10.5751/es-](https://doi.org/10.5751/es-00610-090118)  
460 [00610-090118](https://doi.org/10.5751/es-00610-090118)
- 461 Appiotti, F., Assumma, V., Bottero, M., Campostrini, P., Datola, G., Rinaldi, E., 2018. Un modello di  
462 valutazione del rischio per il Patrimonio Culturale. *RIV Rass. Ital. di Valutazione* 121–148.  
463 <https://doi.org/10.3280/riv2018-071007>
- 464 Assumma, V., Bottero, M., Monaco, R., Mondini, G., 2019a. Assessing the landscape value: An integrated  
465 approach to measure the attractiveness and pressures of the vineyard landscape of piedmont (Italy), in:  
466 *Smart Innovation, Systems and Technologies*. pp. 251–259. [https://doi.org/10.1007/978-3-319-92102-](https://doi.org/10.1007/978-3-319-92102-0_27)  
467 [0\\_27](https://doi.org/10.1007/978-3-319-92102-0_27)
- 468 Assumma, V., Bottero, M., Monaco, R., Soares, A.J., 2019b. An integrated evaluation methodology to  
469 measure ecological and economic landscape states for territorial transformation scenarios: an  
470 application in Piedmont (Italy). *Ecol. Indic.* 105, 156–165.  
471 <https://doi.org/https://doi.org/10.1016/j.ecolind.2019.04.071>
- 472 Ayre, M.L., Nettle, R.A., 2017. Enacting resilience for adaptive water governance: A case study of irrigation  
473 modernization in an Australian catchment. *Ecol. Soc.* 22. <https://doi.org/10.5751/ES-09256-220301>
- 474 Babí Almenar, J., Rugani, B., Geneletti, D., Brewer, T., 2018. Integration of ecosystem services into a

475 conceptual spatial planning framework based on a landscape ecology perspective. *Landsc. Ecol.* 33,  
476 2047–2059. <https://doi.org/10.1007/s10980-018-0727-8>

477 Barron, F.H., Barrett, B.E., 1996. The efficacy of SMARTER - Simple Multi-Attribute Rating Technique  
478 Extended to Ranking. *Acta Psychol. (Amst.)* 93, 23–36. [https://doi.org/10.1016/0001-6918\(96\)00010-8](https://doi.org/10.1016/0001-6918(96)00010-8)

479 Bennett, E.M., Solan, M., Biggs, R., McPhearson, T., Norström, A. V., Olsson, P., Pereira, L., Peterson,  
480 G.D., Raudsepp-Hearne, C., Biermann, F., Carpenter, S.R., Ellis, E.C., Hichert, T., Galaz, V., Lahsen,  
481 M., Milkoreit, M., Martin López, B., Nicholas, K.A., Preiser, R., Vince, G., Vervoort, J.M., Xu, J.,  
482 2016. Bright spots: seeds of a good Anthropocene. *Front. Ecol. Environ.* 14, 441–448.  
483 <https://doi.org/10.1002/fee.1309>

484 Berkes, F., Folke, C., 1998. Linking social and ecological systems for resilience and sustainability, Linking  
485 Social and Ecological Systems. Cambridge University Press.

486 Bonacini, E., Groppi, M., Monaco, R., Soares, A.J., Soresina, C., 2017. A network landscape model: stability  
487 analysis and numerical tests. *Commun. Nonlinear Sci. Numer. Simul.* 48, 569–584.  
488 <https://doi.org/10.1016/j.cnsns.2017.01.013>

489 Borie, M., Ziervogel, G., Taylor, F.E., Millington, J.D.A., Sitas, R., Pelling, M., 2019. Mapping (for)  
490 resilience across city scales: An opportunity to open-up conversations for more inclusive resilience  
491 policy? *Environ. Sci. Policy* 99. <https://doi.org/10.1016/j.envsci.2019.05.014>

492 Bottero, M., Mondini, G., 2009. Valutazione e sostenibilità. Piani, programmi, progetti, Ambiente  
493 valutazioni e sostenibilità. CELID.

494 Brunetta, G., Ceravolo, R., Barbieri, C.A., Borghini, A., de Carlo, F., Mela, A., Beltramo, S., Longhi, A., De  
495 Lucia, G., Ferraris, S., Pezzoli, A., Quagliolo, C., Salata, S., Voghera, A., 2019. Territorial Resilience:  
496 Toward a Proactive Meaning for Spatial Planning. *Sustain.* . <https://doi.org/10.3390/su11082286>

497 Carreiro, M.M., Zipperer, W.C., 2011. Co-adapting societal and ecological interactions following large  
498 disturbances in urban park woodlands. *Austral Ecol.* 36, 904–915.

499 9993.2010.02237.x

500 Cassatella, C., Peano, A., 2011. Landscape indicators: Assessing and monitoring landscape quality,  
501 Landscape Indicators: Assessing and Monitoring Landscape Quality. Springer Netherlands.  
502 <https://doi.org/10.1007/978-94-007-0366-7>

503 Ceravolo, R., Pistone, G., Fragonara, L.Z., Massetto, S., Abbiati, G., 2016. Vibration-based monitoring and  
504 diagnosis of cultural heritage: A methodological discussion in three examples. *Int. J. Archit. Herit.* 10,  
505 375–395. <https://doi.org/10.1080/15583058.2013.850554>

506 Chambers, J.C., Allen, C.R., Cushman, S.A., 2019. Operationalizing Ecological Resilience Concepts for  
507 Managing Species and Ecosystems at Risk. *Front. Ecol. Evol.* 7.  
508 <https://doi.org/10.3389/fevo.2019.00241>

509 Colloff, M.J., Martín-López, B., Lavorel, S., Locatelli, B., Gorddard, R., Longaretti, P.-Y., Walters, G., van  
510 Kerkhoff, L., Wyborn, C., Coreau, A., Wise, R.M., Dunlop, M., Degeorges, P., Grantham, H., Overton,  
511 I.C., Williams, R.D., Doherty, M.D., Capon, T., Sanderson, T., Murphy, H.T., 2017. An integrative  
512 research framework for enabling transformative adaptation. *Environ. Sci. Policy* 68, 87–96.  
513 <https://doi.org/https://doi.org/10.1016/j.envsci.2016.11.007>

514 Cote, M., Nightingale, A.J., 2012. Resilience thinking meets social theory: Situating social change in socio-  
515 ecological systems (SES) research. *Prog. Hum. Geogr.* 36, 475–489.  
516 <https://doi.org/10.1177/0309132511425708>

517 Cutter, S.L., 2016. The landscape of disaster resilience indicators in the USA. *Nat. Hazards* 80, 741–758.  
518 <https://doi.org/https://doi.org/10.1007/s11069-015-1993-2>

519 Dalerum, F., 2014. Identifying the role of conservation biology for solving the environmental crisis. *Ambio*  
520 43, 839–846. <https://doi.org/10.1007/s13280-014-0546-3>

521 De Vries, S., Buijs, A.E., Langers, F., Farjon, H., Van Hinsberg, A., Sijtsma, F.J., 2013. Measuring the  
522 attractiveness of Dutch landscapes: Identifying national hotspots of highly valued places using Google

523 Maps. Appl. Geogr. 45, 220–229. <https://doi.org/10.1016/j.apgeog.2013.09.017>

524 De Vries, S., Lankhorst, J.R.K., Buijs, A.E., 2007. Mapping the attractiveness of the Dutch countryside: A  
525 GIS-based landscape appreciation model. *For. Snow Landsc. Res.* 81, 43–58.

526 Dente, B., 2014. Understanding Policy Decisions, in: SpringerBriefs in Applied Sciences and Technology,  
527 SpringerBriefs in Applied Sciences and Technology. Springer International Publishing, Cham, pp. 1–  
528 27. [https://doi.org/10.1007/978-3-319-02520-9\\_1](https://doi.org/10.1007/978-3-319-02520-9_1)

529 Dumitru, A., Frantzeskaki, N., Collier, M., 2020. Identifying principles for the design of robust impact  
530 evaluation frameworks for nature-based solutions in cities. *Environ. Sci. Policy* 112, 107–116.  
531 <https://doi.org/https://doi.org/10.1016/j.envsci.2020.05.024>

532 Edwards, W., Barron, F.H., 1994. Smarts and smarter: Improved simple methods for multiattribute utility  
533 measurement. *Organ. Behav. Hum. Decis. Process.* 60, 306–325.  
534 <https://doi.org/10.1006/obhd.1994.1087>

535 Elmqvist, T., Andersson, E., Frantzeskaki, N., McPhearson, T., Gaffney, O., Takeuchi, K., Folke, C., 2019.  
536 Sustainability and resilience for transformation in the urban century. *Nat. Sustain.* 2.  
537 <https://doi.org/10.1038/s41893-019-0250-1>

538 Folke, C., Carpenter, S.R., Walker, B., Scheffer, M., Chapin, T., Rockström, J., 2010. Resilience thinking:  
539 Integrating resilience, adaptability and transformability. *Ecol. Soc.* 15, 1–9. [https://doi.org/10.5751/ES-](https://doi.org/10.5751/ES-03610-150420)  
540 [03610-150420](https://doi.org/10.5751/ES-03610-150420)

541 Gobattoni, F., Pelorosso, R., Lauro, G., Leone, A., Monaco, R., 2011. A procedure for mathematical analysis  
542 of landscape evolution and equilibrium scenarios assessment. *Landsc. Urban Plan.* 103, 289–302.  
543 <https://doi.org/10.1016/j.landurbplan.2011.08.011>

544 Gottero, E., Cassatella, C., 2017. Landscape indicators for rural development policies. Application of a core  
545 set in the case study of Piedmont Region. *Environ. Impact Assess. Rev.* 65, 75–85.  
546 <https://doi.org/10.1016/j.eiar.2017.04.002>

- 547 Gunderson, L., 2010. Ecological and human community resilience in response to natural disasters. *Ecol. Soc.*  
548 15, 1–11. <https://doi.org/10.5751/ES-03381-150218>
- 549 Gunderson, L.H., 2000. Ecological resilience - In theory and application. *Annu. Rev. Ecol. Syst.* 31, 425–  
550 439. <https://doi.org/10.1146/annurev.ecolsys.31.1.425>
- 551 Gunderson, L.H., Holling, C.S., 2002. *Panarchy: understanding transformations in systems of humans and*  
552 *nature*, Island, Washington.
- 553 Holling, C.S., 1996. Engineering resilience versus ecological resilience, in: *Engineering within Ecological*  
554 *Constraints*. The National Academy of Sciences, pp. 31–44.
- 555 Holling, C.S., 1973. Resilience and Stability. *Annu. Rev. Ecol. Syst.* 4, 1–23.
- 556 Huck, A., Monstadt, J., 2019. Urban and infrastructure resilience: Diverging concepts and the need for cross-  
557 boundary learning. *Environ. Sci. Policy* 100, 211–220.  
558 <https://doi.org/https://doi.org/10.1016/j.envsci.2019.05.008>
- 559 IPCC, 2019. : Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C  
560 above pre-industrial levels and related global greenhouse gas emission pathways, in the context of  
561 strengthening the global response to the threat of climate change, Ipcc - Sr15.
- 562 Jacinto, R., Grosso, N., Reis, E., Dias, L., Santos, F.D., Garrett, P., 2015. Continental Portuguese Territory  
563 Flood Susceptibility Index - Contribution to a vulnerability index. *Nat. Hazards Earth Syst. Sci.* 15,  
564 1907–1919. <https://doi.org/10.5194/nhess-15-1907-2015>
- 565 Kallis, G., Norgaard, R.B., 2010. Coevolutionary ecological economics. *Ecol. Econ.* 69, 690–699.  
566 <https://doi.org/10.1016/j.ecolecon.2009.09.017>
- 567 Keeney, R.L., Raiffa, H., 1979. *Decisions with Multiple Objectives: Preferences and Value Trade-Offs*.  
568 *IEEE Trans. Syst. Man Cybern.* 9, 403–403. <https://doi.org/10.1109/TSMC.1979.4310245>
- 569 Lambin, E.F., 2005. Conditions for sustainability of human-environment systems: Information, motivation,

570 and capacity. *Glob. Environ. Chang.* 15, 177–180. <https://doi.org/10.1016/j.gloenvcha.2005.06.002>

571 Lourenço, J.M., Danko, C.C., Pereira, N., Ramos, L., Bento, R., Bentes, I., 2009. Increasing CO2 emission in  
572 the Douro Valley: The role of land uses and fires, in: *ISOCARP Review* 05. pp. 126–145.

573 Ludwig, D., Walker, B., Holling, C.S., 1997. Sustainability, stability, and resilience. *Ecol. Soc.* 1.  
574 <https://doi.org/10.5751/es-00012-010107>

575 Malczewski, J., 2006. GIS-based multicriteria decision analysis: A survey of the literature. *Int. J. Geogr. Inf.*  
576 *Sci.* 20, 703–726. <https://doi.org/10.1080/13658810600661508>

577 MEA, 2005. *Ecosystems and Human Well-Being. Synthesis*, World Health.

578 Meerow, S., Newell, J.P., Stults, M., 2016. Defining urban resilience: A review. *Landsc. Urban Plan.* 147,  
579 38–49. <https://doi.org/10.1016/j.landurbplan.2015.11.011>

580 Mitchell, A., 2013. *From Good Idea to Good Practice*, OECD Working Paper 13/2013.

581 Monaco, R., Soares, A.J., 2017. A new mathematical model for environmental monitoring and assessment.  
582 *Springer Proc. Math. Stat.* 209, 263–283. [https://doi.org/10.1007/978-3-319-66839-0\\_13](https://doi.org/10.1007/978-3-319-66839-0_13)

583 Murray, J.D., 2002. *Mathematical Biology: I. An Introduction*, Third Edition, Interdisciplinary Applied  
584 Mathematics. Springer-Verlag, New York. <https://doi.org/10.1086/421587>

585 Norgaard, R.B., 1994. Development betrayed: the end of progress and a coevolutionary revisioning of the  
586 future, *Development betrayed: the end of progress and a coevolutionary revisioning of the future*.  
587 Routledge. [https://doi.org/10.1016/0921-8009\(95\)90157-4](https://doi.org/10.1016/0921-8009(95)90157-4)

588 OECD, 2008. *Handbook on Constructing Composite Indicators: Methodology and User Guide*, Handbook on  
589 *Constructing Composite Indicators: Methodology and User Guide*.  
590 <https://doi.org/10.1787/9789264043466-en>

591 Panduro, T.E., Veie, K.L., 2013. Classification and valuation of urban green spaces-A hedonic house price  
592 valuation. *Landsc. Urban Plan.* <https://doi.org/10.1016/j.landurbplan.2013.08.009>

- 593 Pelling, M., 2003. Natural disasters and development in a globalizing world, *Natural Disasters and*  
594 *Development in a Globalizing World*. Routledge. <https://doi.org/10.4324/9780203402375>
- 595 Pelorosso, R., Gobattoni, F., Monaco, R., Leone, A., 2012. A new approach for the assessment of landscape  
596 evolution scenarios: from whole to local scale, in: *Planning Support Tools: Policy Analysis,*  
597 *Implementation and Evaluation*. FrancoAngeli, pp. 1023–1033.
- 598 Pendall, R., Foster, K.A., Cowell, M., 2010. Resilience and regions: Building understanding of the metaphor.  
599 *Cambridge J. Reg. Econ. Soc.* <https://doi.org/10.1093/cjres/rsp028>
- 600 Perrings, C., 2006. Resilience and sustainable development. *Environ. Dev. Econ.* 11, 417–427.  
601 <https://doi.org/10.1017/S1355770X06003020>
- 602 Pillay, Y.P., Buschke, F.T., 2020. Misaligned environmental governance indicators and the mismatch  
603 between government actions and positive environmental outcomes. *Environ. Sci. Policy* 112, 374–380.  
604 <https://doi.org/https://doi.org/10.1016/j.envsci.2020.07.010>
- 605 Prati, G., Pietrantoni, L., 2009. Resilienza di comunità: definizioni, concezioni ed applicazioni. *Psychofenia*  
606 12, 1–26. <https://doi.org/10.1285/i17201632vXIIIn20p9>
- 607 Santos, M., Fragoso, M., Santos, J.A., 2018. Damaging flood severity assessment in Northern Portugal over  
608 more than 150 years (1865–2016). *Nat. Hazards* 91, pages983–1002. [https://doi.org/10.1007/s11069-](https://doi.org/10.1007/s11069-017-3166-y)  
609 [017-3166-y](https://doi.org/10.1007/s11069-017-3166-y)
- 610 Schaller, L., Targetti, S., Villanueva, A.J., Zasada, I., Kantelhardt, J., Arriaza, M., Bal, T., Fedrigotti, V.B.,  
611 Giray, F.H., Häfner, K., Majewski, E., Malak-Rawlikowska, A., Nikolov, D., Paoli, J.C., Piorr, A.,  
612 Rodríguez-Entrena, M., Ungaro, F., Verburg, P.H., van Zanten, B., Viaggi, D., 2018. Agricultural  
613 landscapes, ecosystem services and regional competitiveness—Assessing drivers and mechanisms in  
614 nine European case study areas. *Land use policy* 76, 735–745.  
615 <https://doi.org/10.1016/j.landusepol.2018.03.001>
- 616 Schultz, L., Folke, C., Österblom, H., Olsson, P., 2015. Adaptive governance, ecosystem management, and

617 natural capital. *Proc. Natl. Acad. Sci. U. S. A.* 112, 7369–7374.  
618 <https://doi.org/10.1073/pnas.1406493112>

619 Scrivens, K., Smith, C., 2013. Four Interpretations of Social Capital: An Agenda for Measurement. *OECD*  
620 *Stat. Work. Pap.* <https://doi.org/http://dx.doi.org/10.1787/5jzbcx010wmt-en>

621 Steenberg, J.W.N., Duinker, P.N., Van Damme, L., Zielke, K., 2012. Criteria and Indicators of Sustainable  
622 Forest Management in a Changing Climate: An Evaluation of Canada’s National Framework. *J.*  
623 *Sustain. Dev.* 6, 32–64. <https://doi.org/10.5539/jsd.v6n1p32>

624 Steinitz, C.A., 2014. *A Framework for geodesign*, ESRI press. <https://doi.org/10.1007/s13398-014-0173-7.2>

625 TEEB, 2010. *Teeb - The Economics of Ecosystem and Biodiversity for local and regional policy makers*,  
626 Report.

627 Terkenli, T.S., 2014. *Landscapes of Tourism*, in: Alan A. Lew C. Michael Hall Allan M. Williams (Ed.), *The*  
628 *Wiley Blackwell Companion to Tourism*. John Wiley & Sons, Ltd, Oxford, UK, pp. 282–293.  
629 <https://doi.org/10.1002/9781118474648.ch22>

630 Tobin, G.A., Whiteford, L.M., 2002. Community resilience and volcano hazard: The eruptions of  
631 Tungurahua and evacuation of the Faldas in Ecuador. *Disasters* 26, 28–48.  
632 <https://doi.org/10.1111/1467-7717.00189>

633 Todman, L.C., Fraser, F.C., Corstanje, R., Deeks, L.K., Harris, J.A., Pawlett, M., Ritz, K., Whitmore, A.P.,  
634 2016. Defining and quantifying the resilience of responses to disturbance: A conceptual and modelling  
635 approach from soil science. *Sci. Rep.* 6, 1–11. <https://doi.org/10.1038/srep28426>

636 Turner, M.G., Gardner, R.H., 2015. *Landscape Ecology in Theory and Practice*, *Landscape Ecology in*  
637 *Theory and Practice*. <https://doi.org/10.1007/978-1-4939-2794-4>

638 Tyrväinen, L., 1997. The amenity value of the urban forest: an application of the hedonic pricing method.  
639 *Landsc. Urban Plan.* 37, 211–222. [https://doi.org/10.1016/S0169-2046\(97\)80005-9](https://doi.org/10.1016/S0169-2046(97)80005-9)

640 UNISDR, 2015. The Sendai Framework for Disaster Risk Reduction: the challenge for science. R. Soc.  
641 Meet. Note. <https://doi.org/A/CONF.224/CRP.1>

642 UNISDR, 2005. Hyogo Framework for Action 2005-2015, in: United Nations International Strategy for  
643 Disaster Reduc. <https://doi.org/10.1017/CBO9781107415324.004>

644 United Nations, 2015. Transforming Our World: the 2030 Agenda for Sustainable Development United  
645 Nations United Nations Transforming Our World: the 2030 Agenda for Sustainable Development.  
646 A/RES/70/1. United Nations.

647 Valente, S., Coelho, C., Ribeiro, C., Soares, J., 2013. Forest Intervention Areas (ZIF): A New Approach for  
648 Non-Industrial Private Forest Management in Portugal. *Silva Lusit.* 21, 137–161.

649 Walker, B., Gunderson, L., Quinlan, A., Kinzig, A., Cundill, G., Beier, C., Crona, B., Bodin, Ö., 2007.  
650 Assessing resilience in Social-Ecological Systems - A workbook for scientists, Transformation.  
651 Resilience Alliance. <https://doi.org/10.1007/s11284-006-0074-0>

652 Waltert, F., Schläpfer, F., 2010. Landscape amenities and local development: A review of migration,  
653 regional economic and hedonic pricing studies. *Ecol. Econ.* 70, 141–152.  
654 <https://doi.org/10.1016/j.ecolecon.2010.09.031>

655 World Heritage Committee, 2001. Nomination of Alto Douro Wine Region for the World Heritage List.  
656 Helsinki.

657 Zêzere, J.L., Pereira, S., Tavares, A.O., Bateira, C., Trigo, R.M., Quaresma, I., Santos, P.P., Santos, M.,  
658 Verde, J., 2014. DISASTER: A GIS database on hydro-geomorphologic disasters in Portugal. *Nat.*  
659 *Hazards* 72, 503–532. <https://doi.org/10.1007/s11069-013-1018-y>


660

CULTIVATIONS 						
Code	Indicators	Description	um	Preference	Type	Source
Value	Agriculture farms	The indicator considers the number of enterprises by head office municipality and according to CAE-Rev.3 classification (2016)	No.	max	General	CCDR-N
	Agriculture labour force	It measures the number of workers qualified in agriculture, hunt and forests	No.		General	CCDR-N
	Utilized Agriculture Surface	It represents the incidence of Utilized Agricultural Surface	ha.		General	CCDR-N
	Permanent cultivations	It summarizes the Mediterranean cultivations, such as almonds and olive trees. This indicator may represent the elements that characterize, together vineyards, the agriculture tradition and landscape composition.	No.		General	CCDR-N
	Vineyard surface	It measures the hectares of vineyards surface in the territory.	ha		General	CCDR-N
	PDO/PGI Wine production declared	It records the annual wine production with PDO/PGI certification	hl/year		Site-specific	CCDR-N
Vulnerability	Precipitation variation	It measures the annual precipitation variation between 1988-2012	mm/year	min	General	CCDR-N
	Temperature variation	It measures the annual temperature variation by considering the time period 1988-2012	C°/year		General	CCDR-N
	Wind speed	It measures the wind speed by modelling the historical series 1971-2000 as number of days average 10m > 5,5 m/s	No. days		Site-specific	IPMA - Portal do Clima
	Soil slope higher than 30%	It considers the soil with slope >30% where the grape harvest is more difficult, and it causes an economic loss	ha		Site-specific	COPERNICUS DEM
Adaptability	LEADER programme investments	It considers the economic resources provided by LEADER (2006-2013) to support farmers and rural development	€	max	Site-specific	LEADER 2006-2013
	Participation of Municipalities in projects of rural development	It considers the Municipalities participation in projects of rural development within the PDR-UTAD 2014-2020	No.		Site-specific	PDR-UTAD 2014-2020
	Young farmers	It considers the young farmers (21-36 yo) as generational renovation and at the same time the generation who preserves local knowledge.	No.		General	CCDR-N

**Table A.1.** Set of resilience indicators: Cultivations component.

661

662

TOURISM 						
Criteria	Indicators	Description	un	Preference	Type	Source
Value	Tourism operators	The indicator measures the incidence of tourism operators in the territory	No.	max	General	RNT
	Tourism presences	It refers to the tourists that sleep at least one night in tourism establishments	No.		General	INE
	Accommodation capacity	It refers to the number of rooms provided by the tourism establishments	No.		General	INE
	Cultural events and recreative activities	It considers the number of events (e.g. seminars, workshops, exhibitions) that promote the territory	No.		General	Municipalities cultural agendas
	Average cost of tourism destinations	It is the weighted average between the prices on travel, transportation, food - drink and sport activities in the tourism heavy season and the base period. If the value is near to 1, it shows a criticality, whereas if the value is near to 0 it shows a lack of vulnerability	0; 1		General	Airbnb - Tripadvisor- GuidaMichelin
Vulnerability	Tourism pressure	It provides the incidence of tourists (in a year) with respect to the residents that live in the territory	%	min	General	INE
	Days of cold waves	It refers to the days of cold waves that may influence tourism flows, especially in out-season	days		General	IPMA - Portal do Clima
	Days of heavy rains $\geq 10$ mm/h	It refers to the days of heavy rains $\geq 10$ mm that may influence tourism flows.	days		Site-specific	IPMA - Portal do Clima
	Days of heat waves	It refers to the days of heat that may influence the tourism flows and in the long- term also the type of tourism in the territory.	days		General	IPMA - Portal do Clima
Adaptability	Programmes and Projects of tourism development	It considers programmes and projects finalized to the tourism development.	No.	max	General	UTAD, PIOT-ADV, Municipalities websites
	Initiatives of tourism innovation	It considers the initiatives of tourism promotion through the support of innovation technologies (e.g. <i>Loja interativas</i> , DOUROTOUR)	No.		Site-specific	Porto e Norte (TEM)

**Table A.2.** Set of resilience indicators: Tourism component.


REAL ESTATE 						
Criteria	Indicators	Description	um	Preference	Type	Source
Value	Average real estate value	The indicator measures the average real estate value of buildings	€/m <sup>2</sup>	max	General	INE
Vulnerability	Age of buildings	The indicator considers the amount of buildings realized before 1919 and between 1919 and 1945	Age	min	General	PORDATA 2017
Adaptability	Restructured buildings	The indicator measures the number of restructured buildings as indirect measure of urban life quality	No	max	General	PORDATA 2017

Table A.3. Set of resilience indicators: Real Estate component.



FORESTS 						
Criteria	Indicators	Description	um	Preference	Type	Source
Value	Forest surface	The indicator measures the total forests surface	ha	max	General	COS 2015
	Forest road network	It refers to the presence of road for the safeguard of forests against fire events	kml		General	OSM data
	Fire-fighters workers	It considers the fire workers with respect to the Norte fire workers as forestry management.	No.		General	CCDR-N
Vulnerability	Forest surface burnt by fires	It measures hectares of forests that have been destroyed by fires in the last year.	ha	min	General	CCDR-N
	Land take	It is given by the land take in terms of urban areas and infrastructures with respect to the total surface of the Municipality	%		General	CLC 2000, COS 2015
	Extreme precipitations > 50 mm/h	It refers to the occurrence of extreme precipitation higher than 50 mm/h. The forests cannot contain a large amount of water in the short time, thus causing floods and landslides events	%		General	IPMA - Portal do Clima
Adaptability	Municipal Forest Fire Protection Plans (PDMFCI)	It considers the presence of local plans for the prevention of fire risk in the forests	%	max	Site-specific	ICNF
	Areas of Forests Intervention (ZIF)	The ZIF is a tool that has been integrated in Portuguese legal framework for forest management and protection against fires (DFCI) after the wildfires in 2003. The ZIF law was amended in 2009.	ha		Site-specific	CCDR-N
	Investments for forest management (PDR, PRODER)	It considers the amounts of investments in national and international programs for managing and preserving forestry heritage.	€		Site-specific	ICNF

Table A.4. Set of resilience indicators: Forests component.

ECOLOGY 						
Criteria	Indicators	Description	um	Preference	Type	Source
Value	Biological and territorial energy capacity	The indicator measures the flux of bio-energy produced by a Municipality (or Landscape Unit)	%	max	General	COS 2015
	Green areas of high ecological quality	It considers the green areas that produces bio-energy higher than 6,5 Mcal/m <sup>2</sup> * year	%		General	COS 2015
Vulnerability	Density of urban areas	It is obtained by dividing the total built-up areas with the total surface of Municipality	%	min	General	COS 2015
	Dispersion of urban areas	It is calculated by dividing the overall perimeter of the Municipality by the sum of all perimeters of the urban fabric	%		General	COS 2015
	Density of impermeable barriers	It is obtained by considering the total surface of the environmental system and the surface of impermeable barriers. The indicator should be minor or equal to 1.	%		General	COS 2015
Adaptability	Global connectivity	It measures the connectivity between municipal boundaries that are able to exchange fluxes of bioenergy with neighbouring landscape units.	%	max	General	COS 2015
	Solar exposure of biotopes	It measures the solar exposure of biotopes, by considering the weighted aggregation of biotopes surfaces exposed at South-East-South (SE), at South-West (W) and at North-East (NE)	%		General	COPERNICUS DEM
	Humidity relative of biotopes	It calculates the average value between the indicators of solar exposure, relative humidity and ecotones length barriers	%		General	COPERNICUS DEM, COS 2015, PT CLIMATE DATA

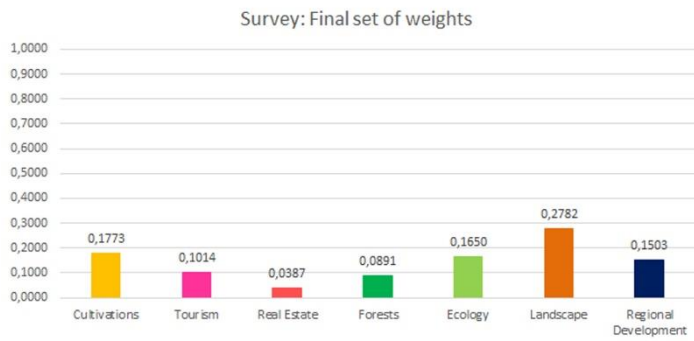
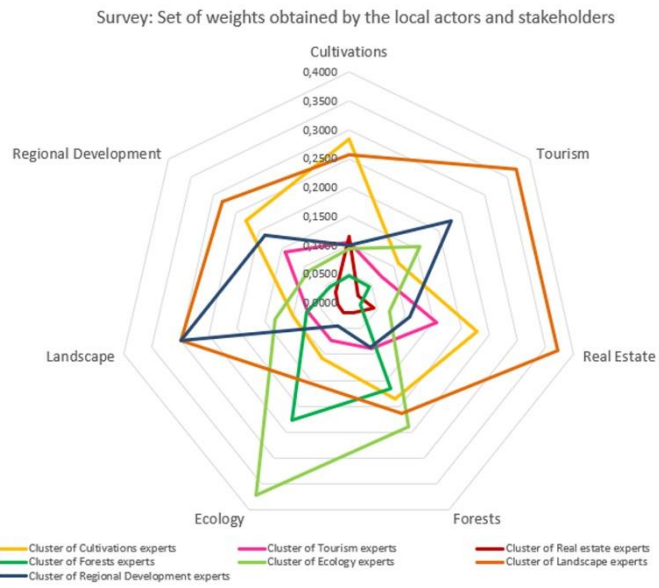
**Table A.5.** Set of resilience indicators: Ecology component.

LANDSCAPE						
Criteria	Indicators	Description	um	Preference	Type	Source
Value	Density of terrestrial protected areas	The indicator calculates the extension of protected areas related to the territorial surface.	%	max	General	CCDR-N
	Density of Natura 2000 sites	It considers the extension of Natura 2000 sites in the considered territory, related to the total number of the region/nation.	%		General	CCDR-N
	Density of protected cultural assets	It considers the number of protected cultural assets with respect to the total cultural assets in the territory.	%		General	CCDR-N
	Landscape viewpoints	It considers the number of high scenic value viewpoints from that is possible to appreciate the aesthetic value of the considered landscape	No.		General	CIM DOURO
	Accessibility from PORTO	It estimates the time distance from Porto to reach Douro Municipalities. The indicator is closely related to the degree of infrastructure accessibility and regional integration.	minutes	min	Site-specific	Guida Michelin
Vulnerability	Skyline disturbances	It records the presence of visive disturbances that may compromise the perception of landscape (e.g. pylons, wind turbines, highway)	No.	min	General	EDP distribuição
	Non-protected cultural heritage	It considers the incidence of non-protected cultural assets with respect to the overall cultural heritage in the considered territory	%		General	IGEO
	Landscape fragmentation	It considers the degree of heterogeneity of the territory by calculating the Shannon index. When the value is near to 1, it means the landscape composition is homogeneous and this favours the continuity and conservation, whereas when the value is near to 0 this means there is a high landscape diversity	%		General	COS 2015
Adaptability	Environmental associations	It measures the incidence of environmental associations with respect to the overall associations in the considered territory.	No.	max	General	PORDATA
	Municipal investments for protected areas and biodiversity	It refers to the amount of municipal investments for preserving and enhancing protected areas and biodiversity	€/y		General	CCDR-N
	Group of Local Actions (GAL)	It records the number of Groups of Local Actions (GAL) as public-private partnerships for the local development of rural areas.	No		General	ENRD

Table A.6. Set of resilience indicators: Landscape component.

REGIONAL DEVELOPMENT						
Criteria	Indicators	Description	um	Preference	Type	Source
Value	Cohesion between actors and stakeholders	It calculates the density of relations between the local actors and the stakeholders with respect to the resilience of the territory	%	max	General	Computed after Dente 2014
	Population with high education degree	It considers the residents with high education degree with respect to the total population in the territory	%		General	CCDR-N
	Accessibility to services	It considers the time distance to reach primary services (e.g. hospitals, schools) as indirect measure of the urban life quality	minutes		General	Google Maps, OSM, KITCASP
	Gross value added by economic activities	It measures the gross value added that is generated by economic activities and non-financial firms	%		General	CCDR-N
	Renewable energy production	It considers the incidence of renewable energy with respect to the annual energy production in the territory	%		General	CCDR-N
	Incidence of recycled waste	It considers the production of recycled waste with respect to the overall waste production in the territory.	%		General	CCDR-N
	ICT enterprises	It considers the number of ICT enterprises as new frontier for the regional and local economy.	No.		General	CCDR-N
Vulnerability	Inactive population (<15 yo and >65 yo)	It summarizes the residents with age under 15 yo and over 65 yo as the part of population that is most exposed to risks	No.	min	General	CCDR-N
	Incidence of Population flows	It measures the population flows in terms of in-migration and outmigration.	%		General	CCDR-N
	Greenhouse gas emissions	It measures the green-house emissions released in the atmosphere in the considered territory	kt		General	APA ambiente
	Flood risk area	It considers the area affected by flood risk with respect to the total municipal surface.	%		General	SNIamb
	Non-occupation rate	It measures the percentage of people that is searching for a job with respect to the labour force of the territory	%		General	CCDR-N
Adaptability	Projects presented in the program Norte 2020	It considers the number of projects approved in the Norte2020 program to sustain the regional development	No.	max	Site-specific	Norte2020
	Adoption of Climate planning	It considers the number of climate plans at local scale adopted in the territory	No.		General	Municipalities websites
	Projects of sustainable mobility	It refers to the Municipalities participation to the project "Accessibility for all" for increasing the sustainable mobility	0; 1		Site-specific	MPT Dept. Portugal
	Projects presented by citizens	It considers the projects presented by citizens to empower the territorial local development.	No		Site-specific	OPP 2017
	EIA and SEA procedures approved	It refers to the EIA and ESA evaluation procedures approved in the territory.	No.		General	APA ambiente
	Municipal plans updated (last 10 years)	It considers the number of municipal plans updated in the last 10 years.	0; 1		General	Municipalities websites

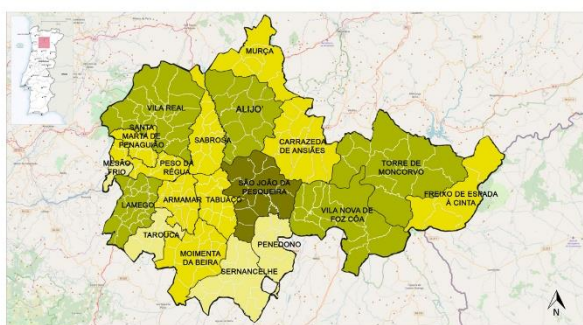
**Table A.7.** Set of resilience indicators: Regional development component.



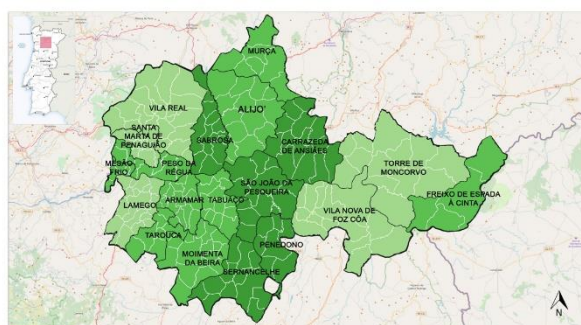
678  
679

**Figure A.1** Illustration of the evaluations of the single experts (a) and final set of weights (b).

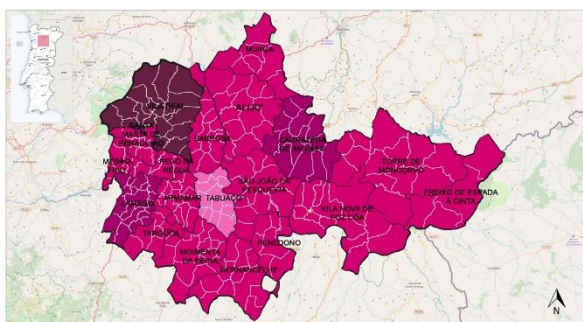
THEMATIC MAPS



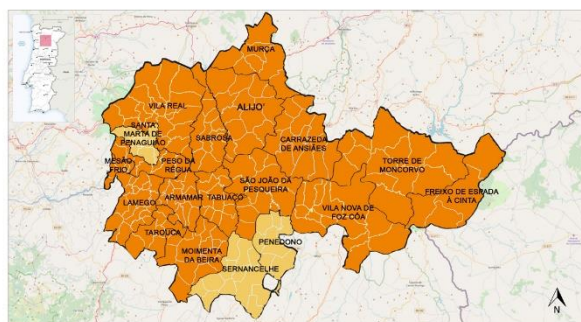
**Cultivations map - Classes of values**  
 > 0,2 Very low value   0,2 - 0,4 Low value   0,4 - 0,6 Medium value   0,6 - 0,8 - High value   0,8 > Very high value



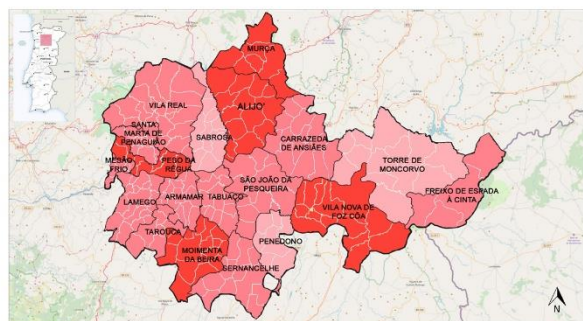
**Ecology map - Classes of values**  
 > 0,2 Very low value   0,2 - 0,4 Low value   0,4 - 0,6 Medium value   0,6 - 0,8 - High value   < 0,8 Very high value



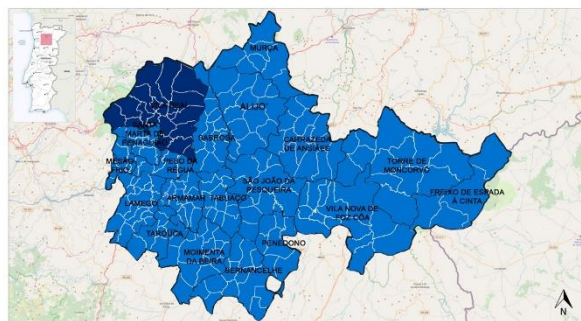
**Tourism map - Classes of values**  
 > 0,2 Very low value   0,2 - 0,4 Low value   0,4 - 0,6 Medium value   0,6 - 0,8 - High value   < 0,8 Very high value



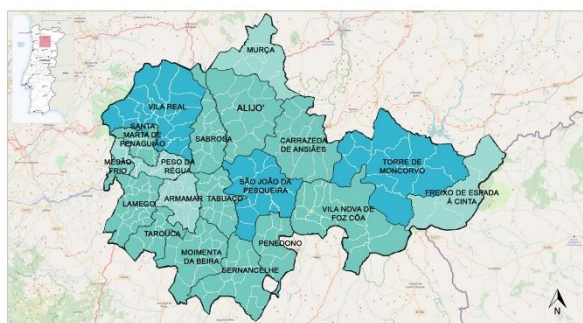
**Landscape map - Classes of values**  
 > 0,2 Very low value   0,2 - 0,4 Low value   0,4 - 0,6 Medium value   0,6 - 0,8 High value   < 0,8 Very high value



**Real estate map - Classes of values**  
 > 0,2 Very low value   0,2 - 0,4 Low value   0,4 - 0,6 Medium value   0,6 - 0,8 High value   0,8 > Very high value



**Regional development map - Classes of values**  
 > 0,2 Very Low value   0,2 - 0,4 Low value   0,4 - 0,6 Medium value   0,6 - 0,8 High value   < 0,8 Very high value



**Forests map - Classes of values**  
 > 0,2 Very low value   0,2 - 0,4 Low value   0,4 - 0,6 Medium value   0,6 - 0,8 - High value   < 0,8 Very high value

680

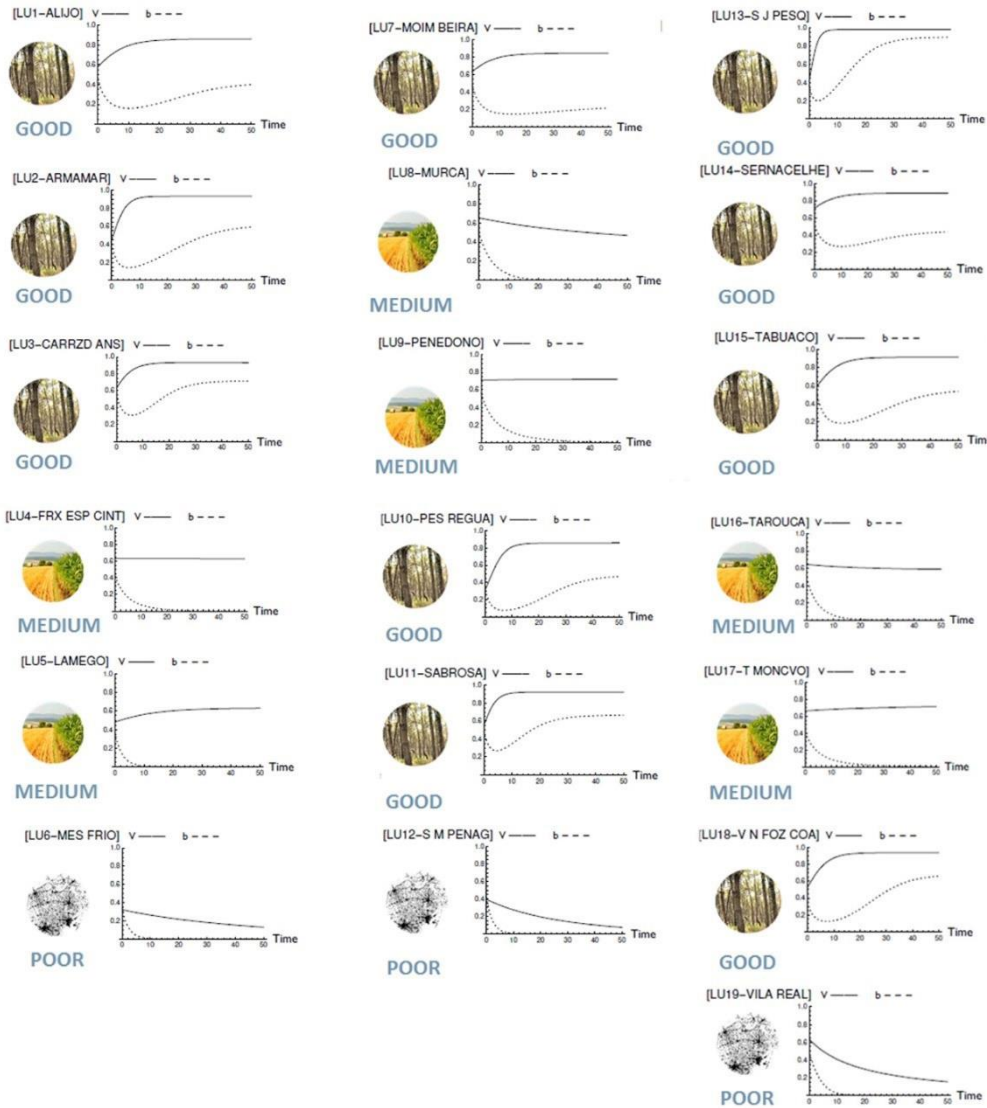
681

**Figure A.2.** Thematic maps of the seven components.

LU	Municipalities	$V_{i0}$	$b_{i0}$	$U_i$	$a_i$	$d_i$	$\varphi_i$	$S_i$	$P_i$	Equilibria
1	Alijó	0.5780	0.4699	0.0289	0,2415	0.6781	0.3059	29760	310.34	<b>3</b> (1), (2)
2	Armamar	0.4544	0.4096	0.0272	0,1694	0.6343	0.6688	11720	222.91	<b>3</b> (1), (2)
3	Carrazeda de Ansiães	0.6344	0.5594	0.0178	0,2333	0.6792	0.3944	27920	306.43	<b>3</b> (1), (2)
4	Freixo de Espada à Cinta	0.6335	0.4205	0.0085	0,2407	0.5707	0.0400	24410	169.97	<b>(2)</b> (1)
5	Lamego	0.4816	0.3745	0.0551	0,1256	0.6353	0.2356	16540	312.14	<b>(2)</b> (1)
6	Mesão Frio	0.3212	0.3476	0.0366	0,3030	0.6865	0.0338	2660	68.28	<b>(1)</b>
7	Moimenta da Beira	0.6304	0.4827	0.0316	0,2087	0.6986	0.2907	22000	277.74	<b>3</b> (1), (2)
8	Murça	0.6552	0.5161	0.0221	0,2109	0.6348	0.0533	18940	179.27	<b>(2)</b> (1)
9	Penedono	0.7128	0.5663	0.0209	0,1965	0.7133	0.1049	13370	153.34	<b>(2)</b> (1)
10	Peso da Régua	0.3243	0.3150	0.0570	0,2753	0.6078	0.6571	9490	180.64	<b>3</b> (1), (2)
11	Sabrosa	0.5522	0.4870	0.0334	0,2314	0.6671	0.6472	15690	224.67	<b>3</b> (1), (2)
12	Santa Marta de Penaguião	0.3946	0.4196	0.0512	0,2189	0.5760	0.0373	6930	278.92	<b>(1)</b>
13	São João da Pesqueira	0.4128	0.3763	0.0133	0,1844	0.6550	1.0982	26610	154.36	<b>3</b> (1), (2)
14	Sernancelhe	0.7113	0.5080	0.0217	0,2054	0.6754	0.2853	22860	264.77	<b>3</b> (1), (2)
15	Tabuaço	0.5996	0.4928	0.0195	0,1946	0.6100	0.3744	13390	211.52	<b>3</b> (1), (2)
16	Tarouca	0.6432	0.4925	0.0317	0,1884	0.6809	0.1118	10010	135.75	<b>2</b> (1)
17	Torre de Moncorvo	0.6641	0.4071	0.0129	0,2138	0.5834	0.0804	53160	414.91	<b>2</b> (1)
18	Vila Nova de Foz Côa	0.5295	0.3511	0.0158	0,1953	0.5809	0.4366	39820	379.36	<b>3</b> (1), (2)
19	Vila Real	0.6330	0.4808	0.0810	0,2464	0.6676	0.1124	37880	450.00	<b>(1)</b>

Table A.8. Model parameters and equilibria.

TIME DIAGRAMS



685

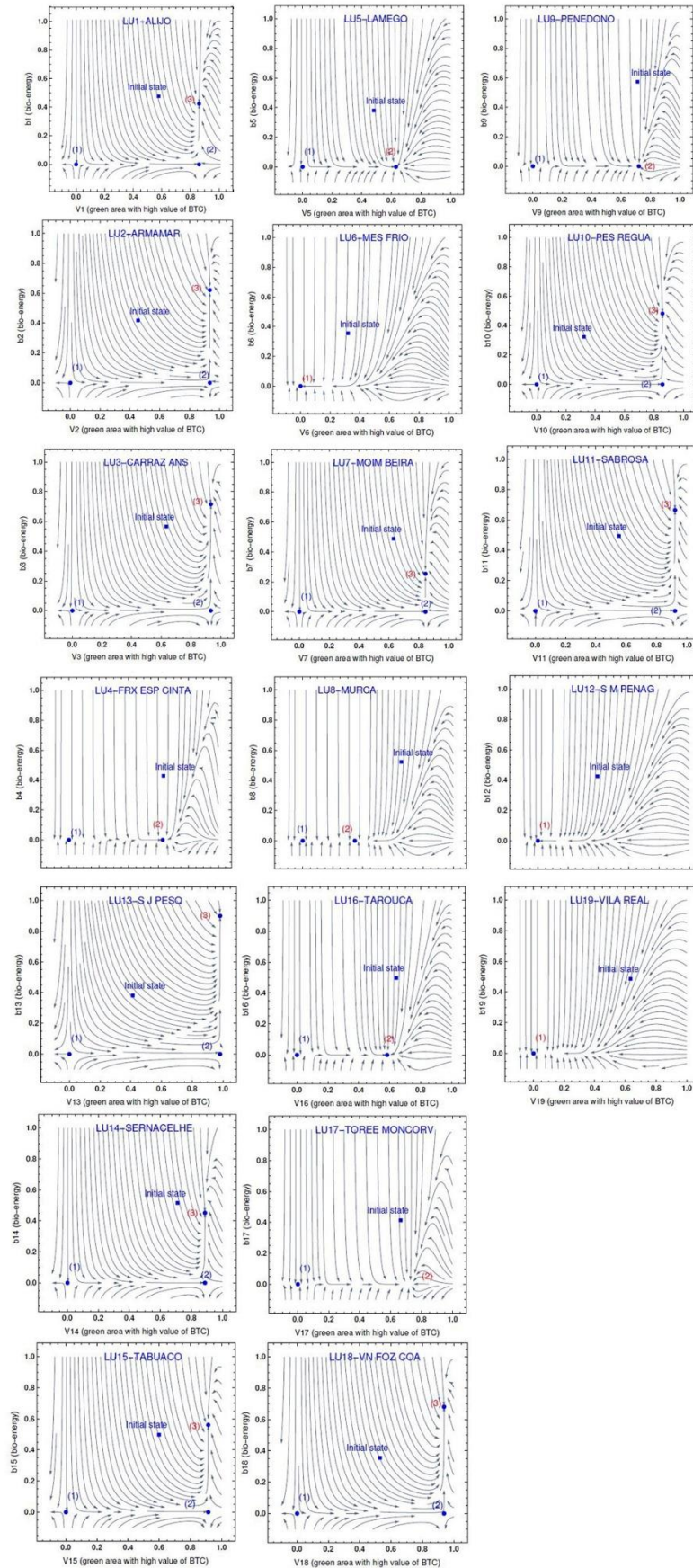
686

687

688

**Figure A.3** Time diagrams of the 19 LUs. Elaborations made with Mathematica Software, 2019

PHASE DIAGRAMS



689

690

Figure A.4. Phase diagrams of the 19 LUs. Elaborations made with Mathematica Software, 2019