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► To cite this version:

Ileana Pătru-Stupariu, Ana-Maria Calotă, Mathieu Santonja, Paulina Anastasiu, Ioana Stoicescu, et al.. Do wind turbines impact plant community properties in mountain region?. *Biologia*, 2019, 74 (12), pp.1613-1619. 10.2478/s11756-019-00333-9 . hal-02265112

HAL Id: hal-02265112

<https://amu.hal.science/hal-02265112>

Submitted on 15 Dec 2019

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1 **Title: Do wind turbines impact plant community properties in mountain region?**

2

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26

27 **Abstract**

28 The emergence of renewable energy infrastructures calls for a better understanding of their
29 impact on biodiversity. The aim of the present study was to investigate in a mountain region
30 the impact of a wind turbine on plant communities in their vicinity. A field survey was
31 conducted in a wind farm situated in the Southern Romanian Carpathians, five years after the
32 turbines were installed. We tested for the effects of the presence of the turbine and the distance
33 to the turbine on plant species richness, on five plant ecological indicators and on the quality of
34 the pastures. Overall, 33 plant species belonging to 16 families were recorded, and among them
35 21 were recorded in both the presence and the absence of wind turbine. The presence of a
36 turbine did not affect the structure of the plant community, as the majority of the plots exhibited
37 similar plant species richness and composition. Finally, the values of the ecological indicators
38 and the pasture quality were not altered by the presence of the turbine. Such analyses could be
39 extended over longer time periods so as to capture potential long-term effects and by integrating
40 other environmental factors such as microclimatic conditions or soil properties.

41

42 **Key words:** wind energy, mountain pasture, plant ecological indicators, pastoral value

43

44 **1. Introduction**

45 Over time, the landscape of Europe has undergone radical changes that have induced
46 specific phenomena such as habitat fragmentation and loss (Lindenmayer and Fischer 2006),
47 thus giving rise to a major problem for what concerns biodiversity (Fahrig 2003; Didham 2010;
48 Pătru-Stupariu et al. 2015). A new challenge is the potential environmental impact of the
49 renewable energy sources and their supporting infrastructures. Assessing their impact is a target
50 within the framework of international policy instruments and treaties, such as the Pan-European
51 Biological and Landscape Diversity Strategy (EEA 2005) or the European Landscape

52 Convention (Council of Europe 2000). For instance, wind farms situated in mountain regions
53 are of particular interest (Hastik et al. 2015) because they potentially affect ecosystems such as
54 pastures or wood-pastures, representing hotspots of biodiversity (Hartel et al. 2013). Thus, if
55 such farms are going to be constructed in a near future in regions with a complex topography,
56 such as in mountains, they have to be developed within the existing landscape and integrated
57 with a minimum impact on biodiversity (Fang et al. 2018), and avoid potential land-use
58 conflicts (Huber et al. 2017). The ecosystem service approach could represent an appropriate
59 framework for finding suitable trade-offs between the production of renewable energy and the
60 conservation of natural values (Egli et al. 2017). Therefore, one needs to better understand how
61 to integrate this type of infrastructure in sites with high natural value, while maintaining the
62 benefits gained from the natural environment and mitigating the disturbances on biodiversity
63 (Davis et al. 2018). Particularly, it is a subject of interest to know how the presence of wind
64 farms affects specific functions and values of the natural environment.

65 Several perspectives were already discussed, and specific issues were addressed in
66 previous studies. The extensive development of the wind farms brought into attention an
67 important but rather subjective perspective, referring to landscape aesthetics and people's
68 perception (Thayer and Freeman 1987; Layne 2018). Over time, the focus was extended
69 towards problems related to measurements and field observations related to changes in local-
70 scale meteorology and ground-level microclimate (Petersen et al. 1998; Baidya Roy et al. 2004;
71 Baidya Roy and Traiteur 2010; Armstrong et al. 2014), impact on soil (Wang et al. 2015) and
72 fauna (Pruett et al. 2009; Bastos et al. 2016; Silva et al. 2017). Recent studies brought into
73 attention the impact of wind turbines on vegetation on the basis of satellite data analysis (Li et
74 al. 2016; Tang et al. 2017; Xia and Zhou 2017) or simulations that were conducted for
75 understanding the interplay between wind and vegetation under various scenarios of
76 development (Peringer et al. 2016; Fang et al. 2018). Even more recently, the influence of wind

77 farms on vegetation structure at local scale was analysed by performing systematic field
78 surveys. For example, Urziceanu et al. (2018) inventoried the presence of rare and vascular
79 plants, while Pustkowiak et al. (2018) linked the pollinator diversity to the plant species
80 composition.

81 The aim of the present study was to assess the impact of a wind turbine on its
82 surrounding environment and vegetation, based on *in situ* measurements in the vicinity of the
83 installation and at various distances from the turbine. We focused on a wind farm situated in a
84 mountainous region in Romania, which is among the top ten European countries with technical
85 potential for wind energy in mountainous areas (EEA Report 2009). We tested whether the
86 presence of a turbine after five years of operation alters the vegetation, which we assessed by
87 means of the plant species composition and the quality of the pasture, as well as using several
88 plant ecological indicators (for light, temperature, soil moisture, soil reaction, and soil nitrogen)
89 for characterizing the environmental conditions.

90

91 **2. Material and methods**

92

93 **2.1. Study site**

94 We selected an area situated in the south-western part of Romania, which was
95 acknowledged as having high wind energy potential (Dragomir et al. 2016). The study site
96 (Topleț) was located in the SW Romanian Carpathians, in the Mts. Mehedinți (Supplementary
97 Fig. S1), in the neighbourhood of the Peak Meteriz-Dranic (800 m a.s.l., coordinates: 44°46'24"
98 N, 22°25'19" E). In the site, the mean annual temperature is 8.5 °C and the average precipitation
99 ranges from 650 to 750 mm per year. The mean wind speed is 6.5 m.s⁻¹ and occasionally values
100 of 20 m.s⁻¹ were measured (EIA 2012). The vegetation is a mixture of pastures and forest
101 patches, which represent a traditional form of semi-open natural landscape (Buttler et al. 2009)

102 that has a high biodiversity (Gillet 2008). The wind farm has two Vestas 112-3.0 MW turbines
103 functional since 2011.

104

105 ***2.2. Experimental design***

106 We considered two transects (TI and TII) passing through the turbine location, called
107 “turbine transects”, and two transects (CI and CII) situated at a 300 m distance from the turbine
108 transects, called “control transects” (Supplementary Fig. S2). This specific sampling design,
109 including a spatial repartition of the plots along two transects, took into account the expected
110 wind direction and therefore transects TI and TII delineated an angle centred at the turbine. The
111 directions of TI and CI and of TII and CII coincided, the aim being to generate a ‘copy’ of the
112 two turbine transects. Each transect was composed of five 1×1 m plots with a 50 m distance
113 between plots (Supplementary Fig. S2). The four transects included one plot situated on the
114 upwind side (i.e. -50 m) and three plots situated on the downwind side (i.e. +50, +100 and +150
115 m) of the turbine tower (Supplementary Fig. S2). The downwind closest plot to the intersection
116 of the transects was expected to be most influenced by the air flow induced by the rotation of
117 the turbine blades. All together there were eight plots on the turbine transects and eight on their
118 control counterparts.

119

120 ***2.3. Plant inventory***

121 Firstly, an inventory of the plant species present in each of the sixteen plots was
122 performed in May 2015. Secondly, we assessed the ecological preferences of all the plant
123 species. We used the method of Sârbu et al. (2013), adapted from the method of Ellenberg et
124 al. (1992) for the specific soil and climatic characteristics of Romania. The ecological indicators
125 considered were those for light, temperature, soil moisture, soil reaction and soil nitrogen. For
126 each indicator, a value (ranging from 0 to 10) was assigned to each plant species

127 (Supplementary Tables S1 and S2), reflecting habitat requirements of that species to the
128 corresponding ecological factor. For each indicator, a mean value per plot was calculated as the
129 arithmetic mean of the values associated to each species present in the considered plot. Thirdly,
130 the pastoral values of the plant species were assessed by a 5-class ranking system according to
131 the herbivore consumption preferences (Supplementary Table S2): graminee fodder, feed
132 fodder, other fodder plants, non-consumable plants, and plants damaging the grassy rug of the
133 meadows (Maruşca et al. 2014). For each category, a mean pastoral value for each plot was
134 calculated as the ratio between the number of species in a considered category and the total
135 number of species in the plot.

136

137 **2.4. Statistical analysis**

138 Statistical analyses were performed with the R software (version 3.3.1), using package
139 “*vegan*”. Significance was evaluated in all cases at $P < 0.05$. A linear model approach was used
140 to test for the effects of the turbine presence, the distance to the turbine (ranging from -50 m
141 upwind to $+150$ m downwind), and their interactions on plant species richness, on the five
142 ecological indicators (light, temperature, soil moisture, soil reaction, and soil nitrogen) and on
143 the five pastoral value indicators (graminee fodder, feed fodder, other fodder plants, non-
144 consumable plants, and plants damaging the grassy rug of the meadows). Then, a
145 correspondence analysis (CA) was conducted using the presence/absence data of the thirty-
146 three plant species to see whether the presence of the turbine induces a shift in the plant
147 community. Finally, in order to test for the difference of species composition between both
148 plant communities (wind turbine *vs.* no wind turbine presence), an analysis of similarities
149 (ANOSIM) was performed.

150

151 **3. Results**

152 Overall, 33 plant species belonging to 16 families were recorded across the 16 plots
153 (Supplementary Table S2). Among them, 21 species were found in both the presence and the
154 absence of the turbine. Six plant species (*Dactylis glomerata*, *Genista sagittalis*, *Leucanthemum*
155 *vulgare*, *Lotus corniculatus*, *Ranunculus bulbosus*, *Rorippa kernerii*) were found only in
156 absence of a turbine, while six plant species (*Capsella bursa pastoris*, *Convolvulus arvensis*,
157 *Echium vulgare*, *Erodium cicutarium*, *Pimpinella saxifraga*, *Poa bulbosa*) were found only in
158 presence of a turbine. The presence of a turbine did not affect the plot plant species richness,
159 with a mean of 11 plant species recorded both in the presence and the absence of a turbine
160 (Tables 1 and 2). Additionally, the presence of a turbine did not affect the structure of the plant
161 community (ANOSIM, $R = -0.13$, $P = 0.99$; Supplementary Fig. S3), as the majority of the
162 sixteen plots exhibited a similar plant species composition (Fig. 1).

163 Based on the average scores of the five ecological indicators (Table 1), the study site
164 was characterized by a strong light exposition, a cold and dry climate, and a slightly acid soil
165 with no nitrogen limitation (Table 1, Supplementary Table S1). The values of the five ecological
166 indicators were similar in presence and in absence of a turbine (Tables 1 and 2), and we
167 observed only a significant influence ($P = 0.045$) of the Turbine \times Distance interaction factor
168 for the soil reaction parameter. This suggests an increase of soil reaction from upwind to
169 downwind in presence of a turbine and, in the opposite, a decrease of soil reaction from upwind
170 to downwind in absence of a turbine (Table 2, Supplementary Fig. S4).

171 With respect to the pastoral value, the species identified in the sixteen plots belonged to
172 six categories, namely graminee fodder, feed fodder, other fodder plants, non-consumable
173 plants, plants damaging the grassy rug of the meadows and toxic and harmful species. The
174 corresponding mean values of the six categories were similar between the turbine and control
175 transects (Tables 1 and 2). The majority of the plants were fodder species (belonging to the
176 graminee, feed or other fodder plant categories) and the quality of the pasture was not altered

177 by the presence of the turbine (in Table 1, the mean values for fodder species sum to 0.62 and
178 to 0.65, indicating a percentage of 62% vs. 65% of fodder plants in absence and presence of a
179 turbine, respectively).

180

181 **4. Discussion**

182 Since renewable energy (e.g. wind power) can be a part of the solution to the carbon
183 and climate issues (Pacala and Socolow 2004), it is crucial to understand the reciprocal
184 interferences between presence of wind turbines and vegetation development, especially for
185 optimizing future developments of wind parks. The results obtained in the present study are
186 related to the influence of wind turbine on plant communities after five years of operation. We
187 analysed the plant species characteristics, with a focus on the ecological preferences of plant
188 species and their pastoral value.

189 The outcomes of the analyses indicate that there is no significant difference between the
190 characteristics of the vegetation and its environment in the presence of the turbine as compared
191 to its absence. Thus, we reported for the first time an absence of wind turbine impact on the
192 neighbouring vegetation after five years of wind farm operation in the studied mountain region,
193 and no effect neither on the pastoral value of the grassland. These results go along with the
194 findings of Urziceanu et al. (2018), which indicated that even rare and threatened vascular
195 plants can be found in the neighbourhood of a wind farm in the studied hilly region. Similarly,
196 in a case study conducted in a homogeneous agricultural landscape, Pustkowiak et al. (2018)
197 indicated that plant species richness around wind turbines was comparable or even higher to
198 that found in grassland patches or in neighbouring cropland.

199 Conversely, several other studies showed that changes in plant community structure
200 after the installation and operation of a wind turbine can occur. Such changes were due mainly
201 to shading (Saidur et al. 2011) or drying (Baidya Roy et al. 2004) effects and can have cascading

202 effects on the physiology of plants and the soil properties (Armstrong et al. 2014; Dodd et al.
203 2005). Since microclimate changes may affect the vegetation characteristics such as the pastoral
204 value of the grassland (Durau et al. 2010), it is worth to systematically investigate how spatial
205 variability of local climate and other environmental factors such as topography (Šrůtek and
206 Doležal 2003) and soils (Gobat et al. 1989) can induce, in interaction with the presence of wind
207 turbines, effects on vegetation development (Riesch et al. 2018). In the present study, we
208 reported an absence of impact of the turbine as assessed by plant ecological indicators,
209 suggesting that the wind farm did not significantly alter the environmental characteristics in the
210 studied mountain region. We saw an effect on the soil reaction, a pattern which could be related
211 to the downwind turbulences influencing the rain distribution and the snowpack, which in turn
212 can affect soil processes (Gavazov et al. 2017, Robroek et al. 2013). Nevertheless, we
213 acknowledge that the investigation of more wind farm sites would be needed to make the
214 statistical comparison more robust.

215 Time could be a key factor for investigating how the changes induced by wind turbines
216 on microclimate (Baidya Roy and Traiteur, 2010) may cascade to changes in vegetation
217 structure (Brand et al. 2011). Here, we reported the absence of wind turbine impact after five
218 years of wind farm operation. However, as simulations showed, vegetation occurring in the
219 neighbourhood of wind turbines could also have a long-term feedback effect on wind resource
220 distribution in mountainous regions (Porté-Agel et al. 2011; Fang et al. 2018). This calls for
221 long time monitoring of the interdependencies between wind turbine efficiency, local
222 meteorological conditions, soil properties and vegetation characteristics. In a broader context,
223 such integrated approaches could contribute to mitigate the negative effects of wind turbines on
224 the environment and to maintain the fragile ecological equilibrium in valuable landscapes
225 (Burton et al. 2011; Zhou et al. 2012).

226

227 **5. Conclusion**

228 We conducted a field survey to investigate the impact of a wind turbine five years after
229 its installation on plant communities in their vicinity in a mountainous region. The statistical
230 analyses indicated no significant differences between the two conditions (turbine presence vs.
231 turbine absence) on both plant species richness and composition, their relationships to
232 environmental factors and their pastoral value. The values of five ecological indicators were, in
233 general, not altered by the presence of the turbine and a slight effect on the soil reaction was
234 noticed.

235 Such analyses could be extended by investigating whether, over longer time periods, the
236 wind turbines could influence the microclimatic conditions or the soil properties and, in turn,
237 vegetation development (growth, patterning, structural properties), the distribution of the
238 different species and their pastoral value, as well as potential feedback effects on the wind
239 turbine efficiency. Such inter-disciplinary analyses could help to predict potential
240 environmental changes and avoid the harmful impact on biodiversity.

241

242 **Acknowledgements**

243 This work was partially supported by the Swiss Enlargement Contribution in the framework of
244 the Romanian-Swiss Research Programme, project WindLand, project code: IZERZO
245 142168/1 and 22 RO-CH/RSRP. We thank the reviewers for the very constructive comments.

246

247 **Conflict of Interest** The authors declare that they have no conflict of interest.

248

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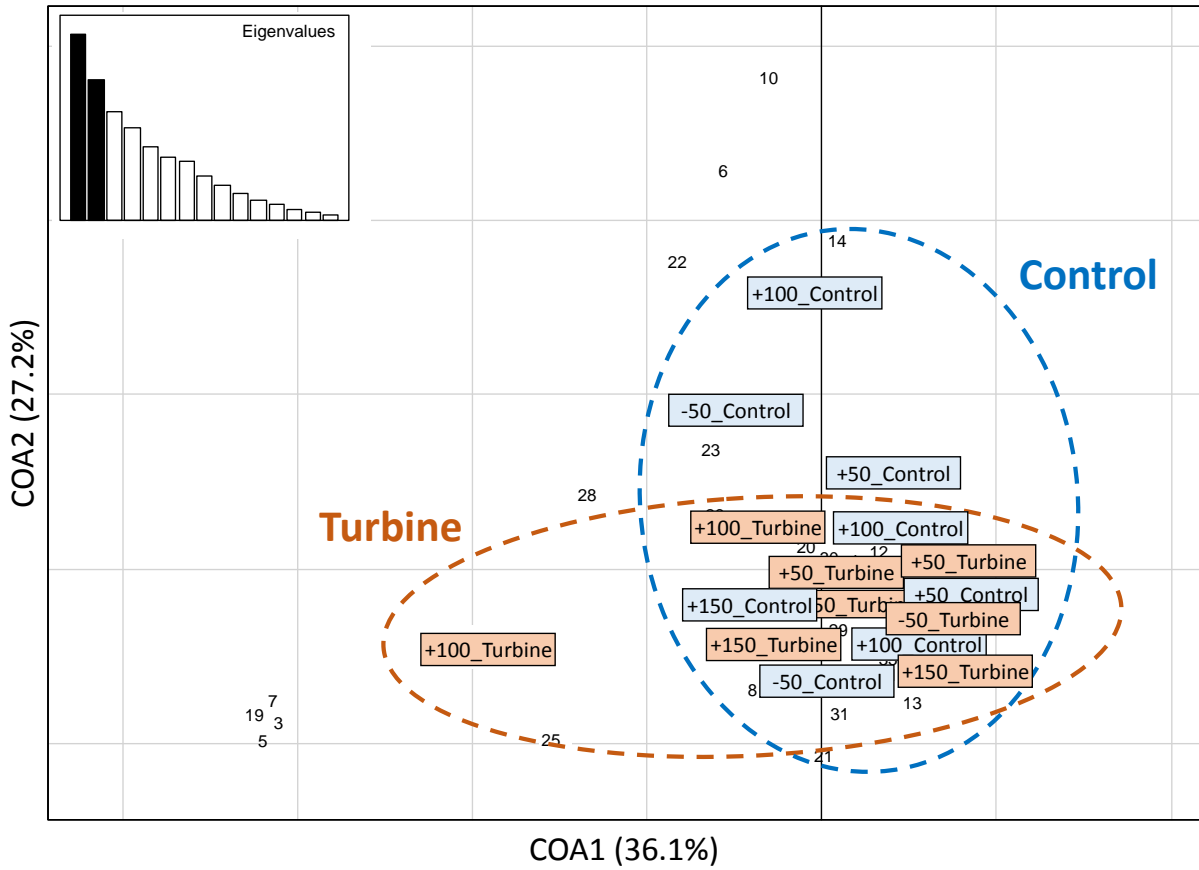
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394 **Fig. 1.** Correspondence analysis (CA) based on the presence/absence of thirty-three plant
 395 species recorded in eight plots close to the wind turbine and eight plots without turbine
 396 (control). Variance explained by each principal component are shown in brackets.

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401 **Table 1.** Mean values \pm SD (n= 8) of plant species richness, 5 ecological indicators and 5
 402 pastoral value indicators in presence/absence of turbine. GF= graminee fodder; FF= feed
 403 fodder; OFP= other fodder plants; NCP= non-consumable plants; PD= plants damaging the
 404 grassy rug of the meadows.
 405

	With turbine	Without turbine
	Mean \pm SD	Mean \pm SD
Plant species richness	11.13 \pm 2.30	11.50 \pm 3.16
Ecological indicators		
<i>Light</i>	7.71 \pm 0.24	7.69 \pm 0.19
<i>Temperature</i>	2.61 \pm 0.65	2.51 \pm 0.92
<i>Soil moisture</i>	2.66 \pm 0.43	2.76 \pm 0.59
<i>Soil reaction</i>	3.19 \pm 0.69	3.15 \pm 0.81
<i>Soil nitrogen</i>	5.14 \pm 0.49	5.26 \pm 0.66
Plant pastoral value		
<i>GF</i>	0.14 \pm 0.05	0.14 \pm 0.04
<i>FF</i>	0.16 \pm 0.06	0.19 \pm 0.09
<i>OFP</i>	0.32 \pm 0.07	0.32 \pm 0.09
<i>NCP</i>	0.17 \pm 0.10	0.17 \pm 0.09
<i>PD</i>	0.22 \pm 0.08	0.18 \pm 0.12

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409 **Table 2.** Effects of the turbine presence, the distance to the turbine, and their interactions on
 410 plant species richness, 5 ecological indicators and 5 pastoral value indicators. *T*-values and
 411 associated *P*-values are indicated. GF= graminee fodder; FF= feed fodder; FP= other fodder
 412 plants; NCP= non-consumable plants; PD= plants damaging the grassy rug of the meadows.
 413

	Turbine		Distance		Turbine × Distance	
	<i>t</i> -value	<i>P</i> -value	<i>t</i> -value	<i>P</i> -value	<i>t</i> -value	<i>P</i> -value
Plant species richness	-0.15	0.881	-0.67	0.517	0.07	0.942
Ecological indicators						
<i>Light</i>	0.06	0.952	0.41	0.693	0.08	0.934
<i>Temperature</i>	-0.78	0.452	-1.14	0.276	1.53	0.153
<i>Soil moisture</i>	-0.25	0.804	0.83	0.424	-0.03	0.977
<i>Soil reaction</i>	-1.36	0.200	-1.92	0.079	2.24	0.045
<i>Soil nitrogen</i>	-0.33	0.747	-0.35	0.731	0.04	0.973
Plant pastoral value						
<i>GF</i>	0.29	0.777	1.18	0.260	-0.81	0.437
<i>FF</i>	-0.71	0.494	-0.37	0.715	0.29	0.777
<i>OFP</i>	-0.04	0.968	0.79	0.445	0.08	0.935
<i>NCP</i>	0.19	0.850	-0.32	0.757	-0.27	0.790
<i>PD</i>	0.50	0.624	-0.23	0.826	0.09	0.928

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