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Evaluating Potential Respiratory Benefits of Forest-Based Experiences: A Regional Scale Approach

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Abstract: Background: Several studies have suggested the possibility of obtaining specific respiratory benefits by experiencing forests and other natural resources. Despite this, forests have never been considered according to such potential. This study aims to compare municipalities by considering the absence/presence of tree species generating 'above threshold' potential respiratory benefits. Methods: The autonomous Region of Friuli Venezia Giulia in Italy has been assumed as a research area. The natural resource based view (NRBV), postulating the strategic role played by natural resources in achieving both above-average (thus 'valuable') and 'concentrated' (thus 'rare' among competitors) performance, has been adopted. The literature reviews dealing with potential respiratory benefits of biogenic organic compounds (BVOCs) emitted by trees, published within the 'forest therapy' research field, have been adopted. Three analysis models rating tree species by their potential respiratory benefits in 'holistic-general' (P1), 'particular' (P2), and 'dynamic" terms (P3) have been outlined. The resulting overall potentials of tree species have been assessed by adopting the well-rooted Hollerith distance (HD) model. Tree species have been rated "1" when they satisfy one or more of 58 potential respiratory benefits. Municipalities have been ranked by considering the surface area covered by forest types whose dominant tree species achieve above-average potential respiratory benefits. QGIS software has been adopted to geographically reference the results obtained. Results: (P1) Valuable municipalities include those covered by both coniferous and deciduous forests; (P2–3) Municipalities achieving the highest potential respiratory benefits, in both particular and dynamic terms, have been mapped. Discussion: Forest-based initiatives that are running in the preselected municipalities can be both further improved and diversified in a targeted way. Conclusions: Despite some limitations mostly embedded in the concept of 'model', this study allows scholars to reduce uncertainties when locating municipalities in which to conduct local-scale experiments.

Keywords: biogenic volatile organic compounds; ecosystem services; forests; forest therapy; Hollerith model; health and wellness; information theory; life on land; SDG3; sustainable development goals

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1. Introduction

An increasing body of evidence is suggesting the benefits of nature for human health, social health, and health economics [1–4]. In the last few years, the COVID-19 pandemic has originated huge additional social costs and impacted negatively on economics worldwide [5]. At the same time, the pandemic has generated additional financial burdens [6,7], increasing poverty rates, especially in developing countries [8]. Nevertheless, despite these challenges, some opportunities have emerged in the COVID-19 era. These include the possibility to accelerate energy transition processes [9], disclose green-deal innovations [10], and most importantly for this study, increase forest visits [11]. This study deals with the possibility to improve forest ecosystem services for 'Good health and Wellbeing' purposes, representing the Sustainable Development Goal (SDG) No. 3 [12].

Several definitions of both "health" and "forests" have been given with the purpose to enlighten the key features of such complex research fields. As is widely recognized, health has been described as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" [13] (p. 1). With respect to health issues, several studies have enlightened direct relations linking reduced air pollution exposure and respiratory health improvements [14]. Forests can be described as "lands of more than 0.5 hectares, with a tree canopy cover of more than 10 percent, which is not primarily under agricultural or urban land use." [15]. The United Nations Climate Change Conference UK 2021 held on 02 November 2021 released the Declaration on Forests and Land Use regarding the strategic role played by forests in both obtaining health benefits and allowing the survival of human races on Planet Earth [16].

Primary studies expounding physiological and psychological benefits obtained through multisensorial activities carried out in forest-environments have recently been reviewed [17–23], including those focusing on the effects of experiencing the forest atmosphere [24,25]. In Japan, the latter studies have led to the adoption of the term "forest therapy" to indicate "the evidence-based medical approach supporting the healing of individuals though immersion in forests", according to the Japanese Forest Therapy Society [26], which is the landmark organization operating in this research field. The term derives from that of "forest bathing" (in Japanese "Shinrin-yoku"), which has been described as: "the act of absorbing the atmosphere of the forest" [24] (p. 27). Even more closely, taking a forest bath means "visiting forests and woods for relaxation and recreation, breathing in volatile organic substances, called phytoncides (essential wood oils), which are antimicrobial BVOCs derived from trees" [27] (p. 9). The common thread connecting those definitions is represented by the act of breathing [28]. Thus, despite the importance the five senses and that of their synergic effects, this study focuses on forest aerosols as strategic resources for respiratory benefit purposes.

The possibility has been suggested to remarkably improve poor mental health while generating considerable savings in national public health spending through visiting protected forested areas [29], and the potential role played by the forest heritage in reducing biodiversity loss and preventing zoonotic disease outbreaks has been observed [30]. The potential of forest therapy for sustainable tourism development purposes has been highlighted. Nevertheless, the relationships linking forest ecosystem services and potential respiratory benefits have only recently been explored [31,32]. Consequently, to the best of our knowledge, no definitions of forest therapy as an ecosystem service (ES) have been made available for human health purposes.

ES generically represent "benefits for human societies and for the well-being obtained from ecosystems" [33] (p. 1). More narrowly, they can be defined as the direct and indirect contributions of ecosystems to human well-being [34]. By building on these early pieces of evidence, several definitions, both superficial and in-depth, of forest therapy have been provided.

FT has been generally described as the act of "visiting a forest or engaging in various therapeutic activities in a forest environment to improve one's health and wellbeing" [35] (p. 1) or, perhaps in a misleading way, as 'guided tours' [36] (p. 36).

This study requires the definition of forest therapy ES suitable for the development of pilot projects [37,38]. For the purposes of this study, the definition of forest therapy ES is based on the above-mentioned original definition of FT. FT can be described as the ES aimed to integrate conventional therapies, having a regional-scale of interest, which can be experienced along the forest-paths where the health benefits obtained by patients have been scientifically proven.

Causal analyses investigating the role played by specific BVOCs in determining the achievement of those health benefits have been performed and reviewed. There is growing consensus on the important role played by the biogenic volatile substances (BVOCs) generated by trees in supplying those ES [39,40] which can be defined as low molecular weight and mostly lipophilic molecules that have high vapour pressure at ambient temperature [41]. The existing models aiming to assess the production of BVOCs generated by trees in forest settings are generally based on empirical analyses performed in forest settings [42]. Despite these models, the administrative units paying for health care services often operate at a regional scale and do not assess the value of forest heritage for respiratory benefits purposes at regional scale. As a consequence, decisions on why a specific forest path has been chosen for forest therapy study purposes remain somewhat ambiguous. The two pillars of this study are the importance of the act of breathing [28] and that of the socio-economic damage caused by air pollution [43]. The idea behind this paper is that the 'heterogeneity' of natural resources represents a needed but not sufficient premise of competitive advantage [44], waiting to be quantified to facilitate biological and medical investigations that are often time consuming and labour-intensive. To improve the productivity of those investigations for forest therapy purposes, there is the need to locate forests showing the highest potential.

All this considered, the main goal of this paper is to grade the mountain municipalities of the research area according to their potential for forest therapy purposes. Consequently, the following four research questions (RQ) have been considered:

RQ1: Which are the municipalities where BVOCs emitted by trees can have any potentially positive respiratory impact?

RQ2: Which are the municipalities where BVOCs emitted by trees are the most heterogeneous?

RQ3: Which are the municipalities where potential respiratory benefits of BVOCs emitted by trees are the most heterogeneous?

RQ4: are the municipalities in which forest-based activities with asthmatic patients are taking place in the research-area among those achieving the highest potential respiratory benefits?

This study aims to achieve the following research targets (RT):

RT1: locating regional municipalities in which BVOCs emitted by trees seem to best balance potentially negative and potentially positive respiratory impacts.

RT2: locating regional municipalities in which BVOCs emitted by trees, having potentially positive respiratory impacts, are most heterogeneous.

RT3: locating regional municipalities in which potentially positive respiratory impacts from BVOCs emitted by trees are the most heterogeneous.

RT4: to position regional municipalities in which forest-based, integrative medical experiences are taking place among those considered here.

The early scientific literature reviews considering primary medical studies suggesting the potential respiratory benefits of BVOCs by forest trees have been adopted for this study.

As illustrated in the following pages, forest-based activities aimed to improve health conditions of asthmatic patients are already taking place in the research-area.

Thus, the following research hypotheses (RHs) have been formulated:

RH1: the preselected municipalities are ranked among those achieving the highest potential respiratory benefits.

RH2: the regional municipalities achieving the highest potential respiratory benefits are spatially concentrated and different from those initially considered.

RH3: deciduous forests can achieve high potential respiratory benefits.

Those RHs are going to be verified in the following pages.

2. Materials and Methods

This section describes the research area. The theoretically grounded models of analysis, the database, and Hollerith model then follow. An illustration of the DB rating-ranking process concludes.

2.1. The Research Area

This study focuses on forests in the autonomous region of Friuli Venezia Giulia (FVG) in north-eastern Italy. In the last 10 years, the national wooded area has increased by about 587,000 hectares to a total of 11 million hectares [45]. The FVG Region accounts for 215 municipalities and covers 792,400 ha. It has a wooded area of approximately

316,224 ha (43.35%) in 2007 of which 93% was recorded on the mountains and about 7% on the plains [46], as shown in Figure 1.

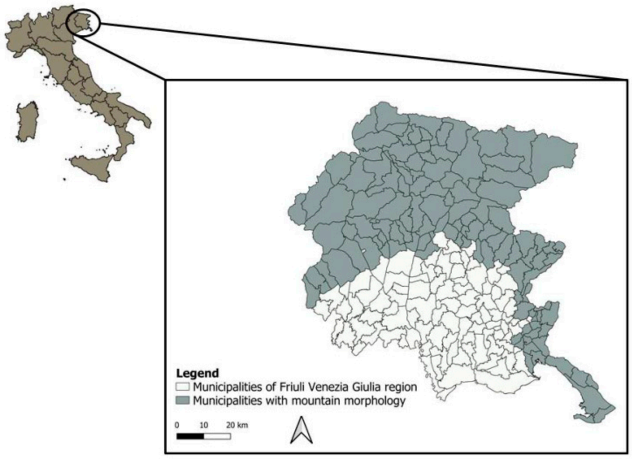

Figure 1. Municipalities of Friuli Venezia Giulia Region with mountain morphology. Source: Direzione Centrale, Commercio, Cooperazione, Risorse agricole e Forestali; Region of Friuli Venezia Giulia (I). Elaborations: authors.

Figure 2 illustrates the geographic distribution of forest categories in the research area [47]. Due to the high qualitative heterogeneity of those categories, this study concentrates on the potential respiratory benefits of forest types and tree species composing each category growing in municipalities with a mountain morphology. Forests on the plain, despite being valuable, could be considered in a forthcoming study. By adopting a qualitative viewpoint, the regional forest vegetation has been mapped since 1998. Hence, 21 dominant forest categories and 47 tree species composing 80 dominant forest types [48] indicate the availability of a highly heterogeneous forest heritage.

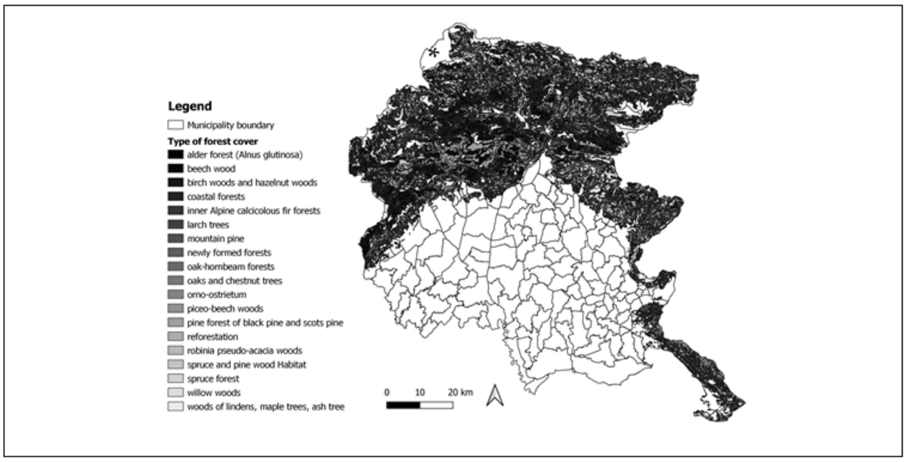

Figure 2. Source: SITFOR FVG. Geographic distribution of forest categories. Regional Infrastructure of Environmental and Territorial Data (IRDAT). * Municipality of Sappada: data unavailable.

The potential respiratory benefits of such a heterogeneous forest heritage were recognized by the medical doctors working at the regional University Hospital S. Maria della Misericordia at Udine and by the parents of their young asthmatic patients gathered together by the Non Profit 'Associazione Lotta alle Pneumopatie Infantili' (ALPI) association. In 2002, the municipalities of Sauris (1440 MASL) and Tarvisio (990 MASL) and lately San Leonardo (190 MASL) started to host climate therapy stays of different duration. Those stays and the one-day forest-based experiences allowed doctors to investigate the effects of both on the health of their patients [49–54]. Based on the early evidence highlighting positive effects, those asthmatic patients started to attend climate therapy stays of one week, as well as half-day forest bathing sessions, in the different seasons of the year [55].

As suggested by the Report on the State of Forests and Forestry in Italy, an initiative by the Ministry of Agricultural, Food, Forestry Policies (MIPAAF) and the University of Padova, "despite in its early phases, the experience running in the southern Alps area of the Region of Friuli Venezia Giulia, specifically in the Natisone Valleys, represents 'de facto' the first experience of forest-based therapy in Italy" [56] (p. 243).

In 2020, that experience was ranked as a case study of European interest by the scientific network Green4Care Alliance [57]. Moreover, the mountains are highly accessible for people suffering from respiratory diseases and living on the Po Plain, which is one of the most intensively populated and polluted areas in Europe [58]. Nevertheless, despite these achievements, the potential respiratory benefits of forests remain totally ignored at other regional mountain destinations. Building on these premises, the municipalities lying in the mountain area of the Region of Friuli Venezia Giulia have been assumed as a research area.

2.2. The Resource Based Theory

The availability of a well-established set of productive inputs is of strategic importance in economic studies [59–62]. By following the resource based theory (RBT), the possibility to achieve a competitive advantage, which can be defended against attempts at imitation by competitors, depends on the availability of productive inputs having the following five quality characteristics. Firstly, those inputs which should be capable of producing 'above-average', thus 'Valuable' performances [60,62]. Furthermore, those valuable resources should be spatially concentrated and/or available to a few competitors (thus, they should be 'rare').

This study is going to assess both forests' value for potential respiratory benefit purposes and resource *rarity* [60].

Forests' value has been quantified by considering only tree species and forest type for potential respiratory impacts which are "above-average". Forests rarity has been quantified by geographically referencing municipalities achieving high potential respiratory benefits [60].

This study jointly applies two of the most important spillovers of the RBT, the knowledge based view (KBV) and the natural resource based view (NRBV). With respect to this point, it applies scientific (evidence-based) knowledge, representing one of the most important productive resources by following the KBV [63–65]. Furthermore, it focuses on both the natural environment, representing the core of the NRBV [66], and the importance of setting up 'holistic' databases that gradually increase the biophysical realism of ecosystem data and models [67].

2.3. Data Adopted

This study adopts three databases, which have been specified as follows: data on administrative boundaries and territorial surfaces, data on forest tree species, and data on forest distribution and types.

2.3.1. Data on Administrative Boundaries and Territorial Surfaces

Data provided by the National Institute of Statistics in Italy [68] quantifying the territorial surface (square meters) covered by each of the municipalities considered in this study have been adopted. The surface of the regional FVG territory has been integrated by adding the Municipality of Sappada, which was annexed to the FVG Region in November 2017. The FVG Region accounts for a total of 215 municipalities.

Box A1 illustrates the 215 regional municipalities and the 116 endowed with any mountain morphology, considered by this study [68].

2.3.2. Data on Forest Tree Species, Forest Distribution, and Types

The Table A1 lists the 47 tree species dominating the forest heritage in the Region of Friuli Venezia Giulia [48] (pp. 18–177) and composing the vegetation database of tree species. The source of data for spatial distribution of forests in the region was the "Forest types" geodatabase available from the regional data infrastructure for environmental and territorial data [69]. This layer collects the geometries of 80 different forest types, represented at 1:5000 spatial scale and updated in 2010.

The forest land cover (ha) in each municipality was obtained in GIS environment (QGIS.org, 2021. Available online: https://qgis.org/en/site/ (accessed on 22 February 2022)) by an overlay procedure between the forest types layer and the geodatabase of the regional municipal territories, IRDAT, FVG Region. For the purposes of this study, the land covered by "other forest types" has not been considered, due to the absence of a clear description on the tree species prevailing in those forest types.

The Box A2 lists the 80 forest types composing the forest heritage in the Region of Friuli Venezia Giulia [70].

The following data have been made available for the 116 regional municipalities whose land is characterized by mountain forests. Those municipalities represent the majority (almost 54%) of the 215 regional municipalities. Despite the existence of several valuable forests located in coastal municipalities, e.g., Lignano Sabbiadoro, Grado, and Trieste, which have been not considered by the maps, but waiting to be analyzed in a forthcoming study, this data coverage seems to be statistically representative. Those maps have been further processed to transform geographically referenced data into numerical data available in tabular form through running the above-mentioned QGIS application. Such a process allowed the surface covered by each forest type to be quantified at the municipal level.

2.4. The Hollerith Distance

The concept of "distance measurement" [71], which was established in the early 1900s represents one of the most important achievements in information theory [72] and in the theory of complex systems [73]. It is based on the application of the binary code '1' or '0', indicating respectively 1 = 'presence' or 0 = 'absence' of the signal represented by pre-selected information or a quality attribute. The calculation of the Hollerith distance, one of the early research methods in forestry [74] has been described as an "inevitable technique" for describing both natural and social phenomena [75]. It requires a repeated reading of the same object of analysis in order to verify the presence/absence of multiple signals, i.e., quality attributes.

The final result obtainable from applying the Hollerith distance is similar to that obtained through the consolidated "punch card" method, consisting of a characteristic sequence (string) of values equal to 0 and equal to 1 for each subject analyzed. The maximum distance is measured through the arithmetic sum of the absolute values of the differences (distances) between maximum achievable values xi and obtained values xy. The greater the frequency with which the sought character is absent the greater the Hollerith distance (HD). In this study, the maximum HD achievable are reached where the desired signals are absent, and vice versa. For this reason, the Hollerith distance has been inversed to obtain an index representing the adherence to an 'optimal' situation. The forest types whose inversed HD exceeds the average are the only ones considered to be 'valuable', by following the RBT [59,60].

2.5. Assessing (Rating) Functional Potentials of Tree Species for Forest Therapy Purposes

According to evidence, the definition of forest therapy means exposure to and inhalation of BVOCs, which are valuable for the purpose of reaching clinically measurable benefits. Early research in this field concerns respiratory diseases such as asthma in adults and children [76]. However, airways and lungs are to be considered the entry point and an absorption surface for BVOCs whose benefit could extend to the whole body in the clinical context of several chronic diseases [27]. This process includes the establishment of models rating the functional potential of tree species.

Three different viewpoints for assessing the value of tree species have been adopted, for the purpose of answering the three above-mentioned RQs: a general, 'holistic' (HD1) model [67,77], a particular, 'atomistic' one [78], and a 'dynamic-relational' model [79]. The rating schemes for HD1, HD2, and HD3 are based on the tables provided below. Each scheme adopts a simple equal weighting component scoring approach. These models have been structured as follows.

2.5.1. Hollerith Distance: The 'Holistic' Model of Analysis HD1

Table 1 identifies the key-performances considered by the HD1 model. Current models of analysis of BVOCs emitted by trees focus on the potentially positive effects of forest aerosols inhalation for therapy purposes [80]. Nevertheless, an ecosystem considered in general terms is the set of resources, both functional and dysfunctional, determining its equilibrium [77].

Regarding BVOCs having potential respiratory benefits, given the breadth of terpenoids, this study focuses on those most frequently studied in the medical and health fields: monoterpenes and sesquiterpenes [81]. Last but not least, the model HD1 considers the capacity of tree species to make available (store) terpenes in leaves and from felled trees in their branch residues, in stumps, in logs if they are lying in the forests, in dead wood, and in the needle litter [40,82–84].

The HP1 model also evaluates some of the potentially negative effects of forest-based activities, which are rarely considered. A study [85] identifies six possible risks to be considered when assessing the potential of a natural resource for human health purposes. Following the cited study, two of these risks can create negative impacts on people with respiratory conditions. These are "the risk of an increased presence of allergens" and "the risk of a decreased air quality" (p. 242).

The HP1 model takes into account both of these risks. This has been done by considering the potentially negative effects of the inhalation of pollen produced by trees [86] and the emission of isoprene that represents a health-risk, given its capacity to form secondary organic aerosols through its atmospheric oxidation [40] (p. 768).

The HD1 model considers a total of 5 characteristics that tree species must possess for the purposes of this study: (1) they do not emit pollen producing potentially negative respiratory effects; (2) do not emit isoprene; (3) emit BVOCs having potential respiratory benefits: monoterpenes; (4) emit BVOCs having potential respiratory benefits: sesquiterpenes; and (5) possess the capacity to store monoterpenes in litter. A score equal to 1 is assigned for each of the characteristics possessed.

The HD1 index does not consider the emission of diterpenes, triterpenes, tetraterpenes or polyterpenes. This is because BVOCs having potential respiratory benefits have been identified as secondary to those possessed by monoterpenes and sesquiterpenes [81,87] (p. 95).

Table 1. HD1 Model: key-performances and sources.

N.	Key-Performances	Sources
1	No/extremely low potentially negative effects of the inhalation of pollens	[86]
2	No/extremely low potentially negative effects of inhalation of isoprene emissions	[40] (Table 2 p. 768); [88–90]
3	Monoterpenes (C atoms:10)	[40] (Table 2 p. 768); [81,88]
4	Sesquiterpenes (C atoms:15)	[40] (Table 2 p. 768); [81,88]
5	Stored MTS	[40] (Table 2 p. 768); [81,88]

(Source: [40] (Table 2 p. 768)).

Table 2. BVOC emission potentials of leaves and needles of selected major European forest tree species.

N.	Functional Aerosols	N.	Functional Aerosols	N.	Functional Aerosols
1	borneol (b) (M)	9	3-carene (a) (M)	17	β-phellandrene (a, d) (M)
2	bornyl acetate (a, b) (M)	10	perrillyl alchol (b) (M)	18	β-pinene (a, d) (M)
3	camphene (a, d) (M)	11	pinene (b) (M)	19	d-Limonene (d) (M)
4	carvone (c) (M)	12	pulegone (c) (M)	20	γ-terpinene (a, c) (M)
5	cymene (b, d) (M)	13	sabinene (a, b) (M)	21	caryophyllene (b) (S)
6	limonene (a, b) (M)	14	terpinene (b) (M)	22	1,8-Cyneole (b, d) (S)
7	linalool (b) (M)	15	α-pinene (a, d) (M)	23	1-Octanol (b) (S)
8	myrcene (a, b, d) (M)	16	β-myrcene (a) (M)		

Source: (a): [39]; (b) [91] (c) [92]. (M) monoterpenes, (S) sesquiterpenes).

In model HD1, the minimum Hollerith distance '0', indicating the maximum functional potential of the tree species, is reached when the number of key performances achieved by each forest tree species equals the number of essential performances considered (5 − 5 = 0). On the contrary, the maximum Hollerith distance ('5'), indicating the minimum functional potentials of forest trees, is reached when the number of essential performances satisfied by the tree species is equal to 0 (5 − 0 = 5).

Thus, the final result of the HD1 is constituted by a final score, in absolute terms, which positions each tree species according to the Hollerith distance reached between two opposite extremes: 0 (minimum HD = maximum potential respiratory benefits) and 5 (maximum HD = minimum potential respiratory benefits).

Differently from the HD2 and HD3 analysis models, the HD1 model considers only a few (5) very general aspects of tree emissions, having both potentially positive and potentially negative impacts for the purposes of this study. In this respect, it has been called a "holistic-general" [67] model.

2.5.2. Hollerith Distance: The Atomistic-Particular Analysis Model HD2

The heterogeneity of potentially valuable resources represents a fundamental premise for the existence of a defensible competitive advantage, by following the RBT [44]. By adopting a 'particular' approach, an ES can be represented through the set of heterogeneous elements, capabilities, and resources designed to measure its potential [78].

As previously stated, monoterpenes and sesquiterpenes constitute the resources (terpenoids) having the greatest potential for functional purposes [39,81,87,91,92]. Table 2 lists the breadth of the BVOCs potentially released by the major European forest tree species.

By following the atomistic approach, FT-ES can be represented as a medical evidence based practice, whose potential is directly related to the heterogeneity of potentially beneficial terpenoids emitted by trees.

The adoption of the HD2 model is justified by the breadth of BVOCs belonging to the two types, by the small number of studies produced on the functional properties of specific BVOCs, and by the high probability that the functional potential of new BVOCs will be elucidated in subsequent studies. Thus, the HD2 model deals with the possibilities of implementing the DB by updating scientific studies reporting the healing properties of new tree species and BVOCs emitted.

In the HD2 model, a score is assigned to each tree species equal to 1 for each monoterpene emitted (21 such molecules are considered) and for each sesquiterpene emitted (2 are considered). In this model, the value equal to "0" indicates the maximum functional potential reached by the tree species. The value equal to "0" or the number of essential benefits satisfied by the tree species is equal to the number of benefits considered (23 − 23 = 0). The maximum value equals '23', indicating the minimum potential respiratory benefitsof the tree species. In this way it is possible to position each tree species according to the Hollerith distance reached between the two opposite extremes: 0 (minimum HD2 = maximum potential respiratory benefits) and 23 (maximum HD2 = minimum potential respiratory benefits).

Differently from the HD1 and HD3 models, the HD2 analysis model focuses on heterogeneity of BVOCs emitted by forest trees having any potential for forest therapy purposes.

2.5.3. Hollerith Distance: The 'Dynamic-Relational' Approach HD3

Last but not least, a system can be described as a set of information useful for creating the relationships necessary to achieve certain results [79]. This definition focuses on the process of enhancing a resource as the one to be considered more important. By adopting this approach, FT-ES can be described as the set of information allowing general medicine practitioners (GMPs) to interact with information provided for preventive, integrative, and rehabilitative medical purposes.

Table 3 reports the heterogeneity of effects of terpenes on human health [39]. The HD3 dynamic-relational model focuses on the ability of the single tree species to produce BVOCs performing very specific (antioxidative, anti-inflammatory, neuroprotective, and immunostimulative) functions. It is therefore a model designed to facilitate interactions between forest scholars and GMPs aiming to prescribe their patients integrative medicine, preventative and rehabilitative forest-based activities.

Table 3. Reported potential respiratory benefits of specific terpenes.

N	BVOC	Antiox.	Anti-Infl.	Neuroprot.	Immunostim.
1	Borneol	X (a)	X (a)	X (a)	
2	Bornyl acetate		X (a)		
3	Camphene				
4	Carvone			X (b)	X (c)
5	Cymene		X (a)	X (a)	X (a)
6	Limonene	X (a)	X (a)		X (a,c)
7	Linalool		X (a)		
8	Myrcene		X (a)		X (a)
9	3-carene				
10	Perrillyl alchol				X (a,c)
11	Pinene	X (a)	X (a)	X (a)	X (a)
12	Pulegone			X (b)	
13	Sabinene		X (a)		
14	Terpinene		X (a)		
15	α-pinene				
16	β-myrcene				
17	β-phellandrene				
18	β-pinene				
19	d-Limonene				
20	γ-terpinene			X (b)	
21	Caryophyllene	X (a)	X (a)	X (a)	
22	1,8-Cyneole	X (a)		X (a)	
23	1-Octanol		X (a)		
	TOT BVOCs functions	5	11	8	6

(Source: (a): [93]; (b) [94]; (c) [91]).

In the HD-3 model a value of 1 is assigned for each BVOC, emitted by the tree species, with antioxidative (5 out of 5), anti-inflammatory (11 out of 11), neuroprotective (8 out of 8) functions and immunostimulants (6 out of 6). The model thus makes it possible to characterise each tree species with 30 attributes (Table 3). The range of permitted values will oscillate, according to the Hollerith distance approach, between 0 (minimum HD3 = maximum potential respiratory benefits) and 30 (maximum HD3 = minimum potential respiratory benefits).

Differently from the HD1 and HD2 models, the HD3 analysis model focuses on the heterogeneity of the potential functional effects of BVOCs emitted by forest trees according to the scientific literature.

Through the adoption of the HD1–3 complementary models, a total of 58 functional quality attributes of tree species were assessed.

2.5.4. Rating Functional Discrepancies of the 47 Tree Species by Applying the Hollerith Distance

The same rating procedure was applied to the above-mentioned three models of analysis, HD1, HD2, and HD3.

Firstly, three spreadsheets were generated, one for each model of analysis, HD1, HD2, and HD3. Then, in each spreadsheet, the matrix "Hollerith distances for tree species" was created consisting of 47 tree species and 8 rows (HD1 analysis model), 23 rows (HD2 analysis model) and 30 rows (HD3 analysis model).

Then, for each column (tree species), the sum of the "1" by each tree species was calculated and the difference between the maximum value achievable and that achieved.

For instance, in model HD1 spreadsheet "L5A-1-SPECIE46-TERP-GR7-HOLL(1)", the tree species showing no allergenic pollen emissions (1), no isoprene emissions (1), emissions of monoterpenes (1), emissions of sesquiterpenes (1), and capacity to store MTS (1) achieve a total HD1 of $5 - 5 = 0$.

2.5.5. Assessing the Potential Respiratory Benefits of the 80 Forest Types

For this purpose, further matrices were generated. The calculation of the potential respiratory benefits of forest types by adopting P1 (general) and P2 (particular) models took place through the generation of matrices 47 columns (tree species) $\times$ 80 rows (forest types).

In order to calculate functional potentials of forest types through the P3 model (dynamic), the following four matrices 47×80 were generated: P3–1 (antioxidant potentials), P3–2 (anti-inflammatory), P3–3 (neuroprotective), and P3–4 (immunostimulating). After these matrices, a summary (overall) matrix for the P3 model (called 'P3') was generated. As for rating tree species by considering their potential respiratory benefits, the structure of the matrices rating forest types was kept the same for each analysis model: P1, P2, and P3.

Forest types achieving above-average proximity indexes were rated = '1' as for dominant tree species. On the contrary, forest types achieving proximity indexes that are below-average were rated = '0'.

Moreover, the rating process of functional potentials of forest types gives the possibility to assess (rank) municipalities having the greatest surface area of those types.

2.6. The Ranking Process of the Rated Data

According to [85], the potential of ecosystem services for human health purposes should be assessed taking into account the 'scarcity' of resources supplying them (p. 239). The calculation of potential respiratory benefits of each forest type, = '0' not valuable or '1' = valuable, allowed municipalities to be ranked by considering the surface covered by each of them. This process includes: conversion of geospatial data from the cartographic to tabular form; data processing and ranking of municipalities; and geographic referencing results.

- conversion of geospatial data from the cartographic to tabular form

The maps provided by the ISTAT-DB and the SITFOR.FVG-DB were analyzed using QGIS 3.16 software "Hannover", long release version. The 'limiti01012021.zip' folder made available by the Italian National Institute of Statistics [68], WGS84 UTM32N version, was downloaded to obtain the coordinates describing the borders of both the municipalities and those of the Friuli Venezia Giulia Region, representing the research area. After that, the 'Superficie-forestale.zip' folder made available by the Geographic Information System of the Friuli Venezia Giulia Region [70] was adopted.

The polygons defining the land surfaces covered by the forest types were then superimposed on the polygons defining the administrative boundaries of the municipalities, in the regional areas with mountain morphology.

In this way, the area (Ha) covered by each forest type for each municipality was obtained in tabular form.

- data processing

The ratio between the area covered by forest types and the area covered by each municipality was then calculated as a preliminary result. The ratio between the area covered by each forest type whose value for potential respiratory benefits purposes is above average and the area covered by each municipality was then calculated, as the result of applying P1, P2, and P3 models. In this way, a continuous number 0.001–1.0 representing the rate of total surface area of forest types by municipality and the rate of total surface area covered by forest types whose potential respiratory benefits achieve above-average potential were obtained.

- geographic referencing results

Results available in tabular form were geographically referenced using the same software version.

Figure 3 summarizes the data acquisition process, their processing and the georeferencing of the results. A total number of 58 key quality attributes were considered by these models for the purposes of this study.

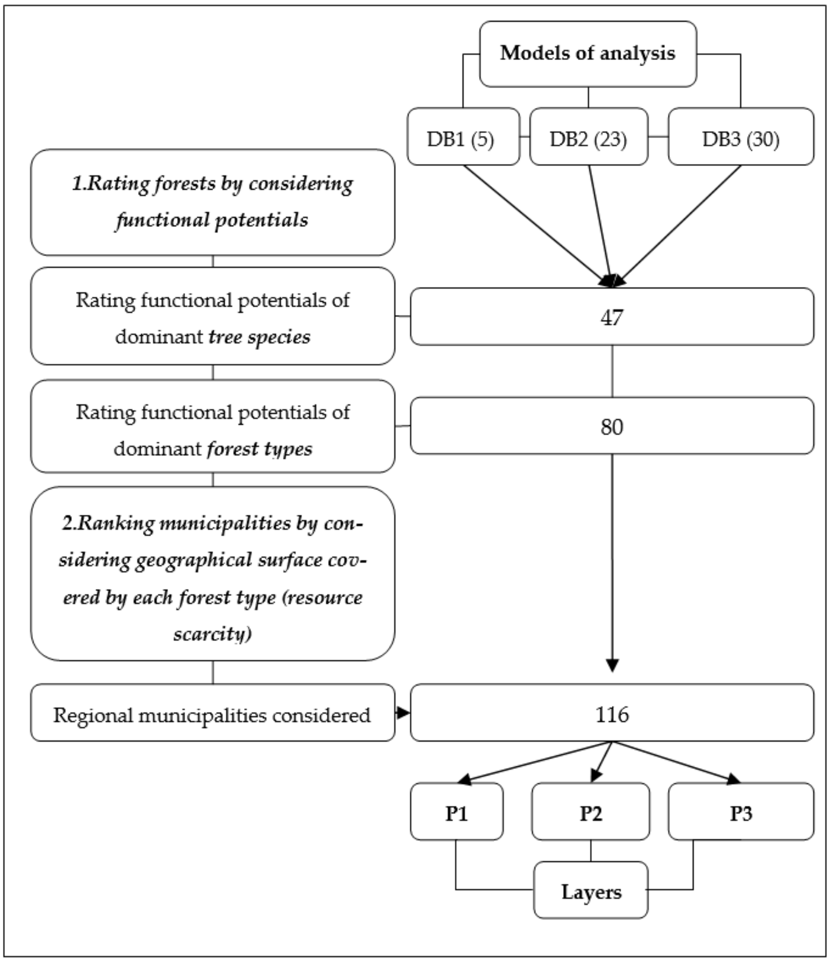

Figure 3. Rating tree species for potential respiratory benefits purposes. Source: authors.

Results thus obtained were geographically referenced by the adoption of the above mentioned QGIS software.

3. Results and Discussion

Figure 4 represents the density rates of forest heritage in the preselected regional municipalities.

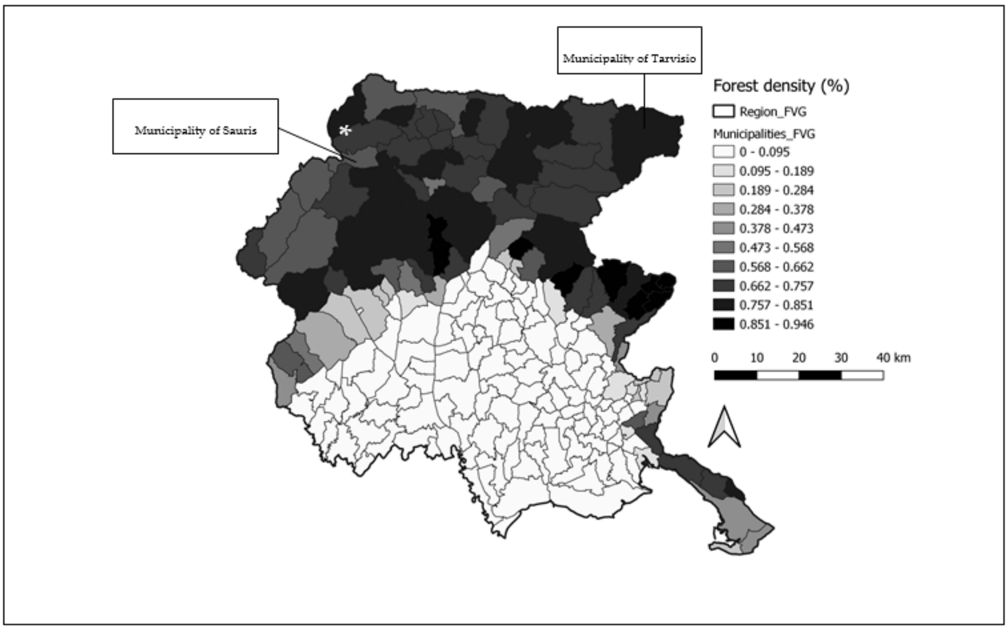

Figure 4. Source: SITFOR FVG. Forest density: % of municipal territory covered by trees. Geographic distribution of forest categories. Regional Infrastructure of Environmental and Territorial Data (IRDAT). Friuli Venezia Giulia Region. * Municipality of Sappada: unavailable data estimated by interpolation. Elaboration: authors.

The following sections illustrate the municipalities according to different potentials of respiratory impacts by adopting the above-described general-holistic approach (P1), particular-segmentary approach (P2), and dynamic-relational approach (P3).

3.1. Healing Potential of BVOCs Emitted by Regional Forests: General-Holistic Approach (P1)

RT1: locating regional municipalities in which BVOCs emitted by trees seem to best balance potentially negative and potentially positive respiratory impacts for human health purposes.

Figure 5 illustrates the distribution of regional municipalities by considering potential respiratory benefits and threats of BVOCs emitted by trees.

The municipalities whose forests best balance negative and positive potential respiratory impacts seem less heterogeneously distributed across the mountain area of the region than those portrayed by Figure 3.

Municipalities located in the northern and north-eastern areas of the Region of Friuli Venezia Giulia achieve the highest potential respiratory benefits. On the contrary, municipalities located in the southern and eastern areas achieve the lowest potential respiratory benefits when considered through applying the P1, holistic, model. The first four positions are occupied by municipalities located in Carnia, a mountain area in north-eastern FVG region.

The mountain municipalities achieving the highest potentials are located in the areas farthest from the Po Plain, which is the most polluted and intensely populated area of the whole country [95]. Nevertheless, despite this result, a few municipalities located closer to the plain achieve high or discrete potentials. These results confirm hypothesis RH3.

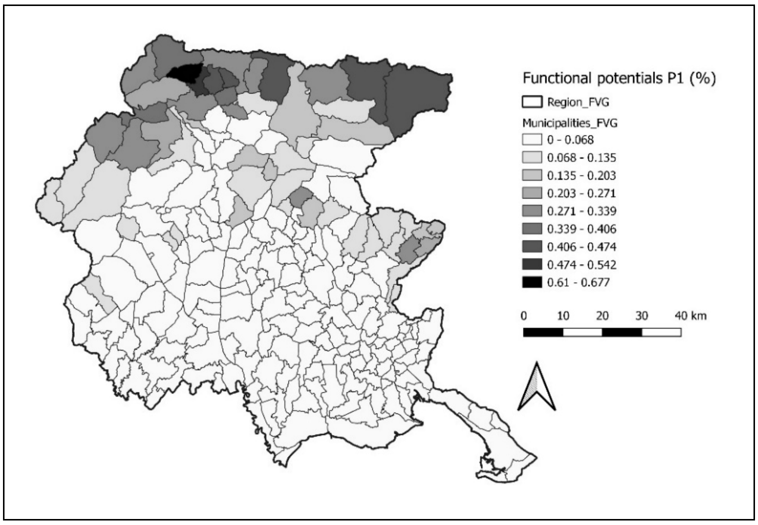

Figure 5. Potential respiratory benefits by regional forests in mountain municipalities: General-holistic approach (P1). Source: authors.

Table 4 divides the municipalities analyzed into the following three groups: (a) high, (b) medium, and (c) little or no functional potential of the forest heritage, based on the analysis model P1. As has been illustrated, by adopting the model P1, the municipality of Rigolato (in the province of Udine) and that of San Lorenzo Isontino (Gorizia) achieve the highest and lowest potential respiratory benefits, respectively. The municipalities of Tarvisio and Sauris are ranked 5th and 10th, respectively. Thus, municipalities in which forest-based activities with asthmatic patients are taking place are among those achieving high potential respiratory benefits, by adopting the P1 model. These results duly confirm hypothesis RH1.

3.2. Particular-Segmentary Approach (P2)

RT2: locating regional municipalities in which BVOCs emitted by trees, having potentially positive respiratory impacts, are most heterogeneous.

Figure 6 illustrates the distribution of regional municipalities by considering the heterogeneity of the positive respiratory impacts of BVOCs emitted by trees.

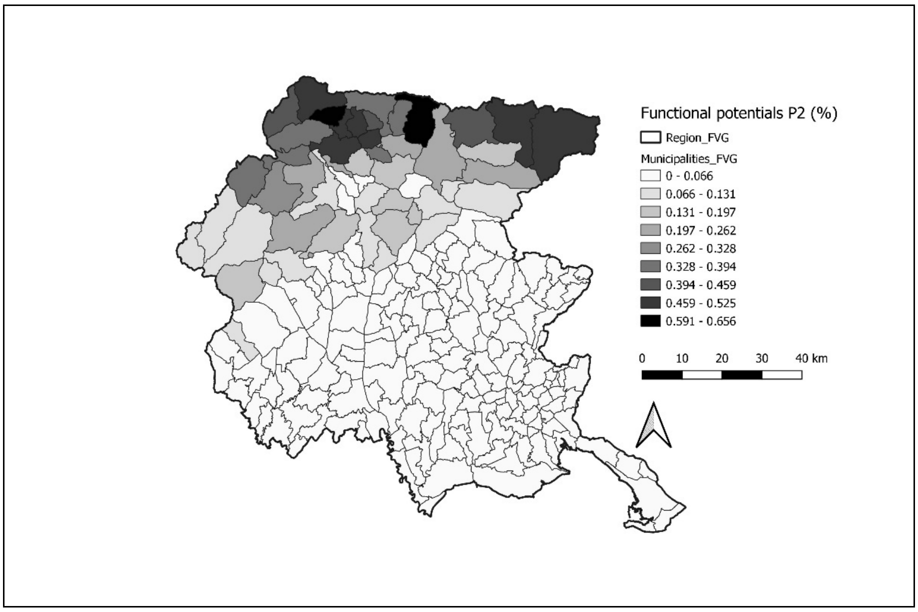

Figure 6. Potential respiratory benefits of BVOCs emitted by regional forests in mountain municipalities: Atomistic-segmentary approach (P2). Source: authors.

Table 4. Potential respiratory benefits of forest heritage by municipality—P1.

Potential Respiratory Benefits	Municipalities
(a) High (rank: 1–29), Ist quartile	RIGOLATO (0.678), COMEGLIANS (0.48), RAVASCLETTO (0.446), PAULARO (0.446), TARVISIO (0.436), CERCIVENTO (0.432), MALBORGHETTO VALBRUNA (0.429), SUTRIO (0.403), FORNI AVOLTRI (0.396), SAURIS (0.363), PONTEBBA (0.335), MONTENARS (0.333), PALUZZA (0.331), SAPPADA (0.329), OVARO (0.325), FORNI DI SOPRA (0.311), SAN LEONARDO (0.288), TREPPO-LIGOSULLO (0.287), ZUGLIO (0.285), FORNI DI SOTTO (0.283), PRATO CARNICO (0.263), AMPEZZO (0.235), STREGNA (0.225), CHIUSAFORTE (0.189), RAVEO (0.186), TARCENTO (0.178), CAVAZZO CARNICO (0.175), GRIMACCO (0.166), e FORGARIA NEL FRIULI (0.163).
(b) Medium (rank: 30–58), IInd quartile	MOGGIO UDINESE (0.161), DRENCHIA (0.157), BORDANO (0.137), ARTEGNA (0.135), TORREANO (0.133), ERTO E CASSO (0.13), TRASAGHIS(0.122), CLAUT (0.115), PULFERO (0.111), DOGNA (0.105), VENZONE (0.105), BUDOIA (0.098), ANDREIS (0.098), FANNA (0.092), CAVASSO NUOVO (0.092), GEMONA DEL FRIULI (0.091), CIMOLAIS (0.09), PREPOTTO (0.086), SAVOGNA (0.084), ARTA TERME (0.083), RESIUTTA (0.083), SOCCHIEVE (0.081), DOLEGNA DEL COLLIO (0.078), SAN PIETRO AL NATISONE (0.072),FAEDIS (0.071), NIMIS (0.071), VERZEGNIS (0.067), BARCIS (0.066), POLCENIGO (0.062).
(c) Low/No potentials (rank: 59–87); IIIrd quartile	TRAMONTI DI SOPRA (0.06), RESIA (0.054), SEQUALS (0.043), ATTIMIS (0.041), TOLMEZZO (0.041), FRISANCO (0.039), CIVIDALE DEL FRIULI (0.039), VITO D'ASIO (0.039), AVIANO (0.037), CORMONS (0.034), LUSEVERA (0.032), PINZANO AL TAGLIAMENTO (0.031), MAGNANO IN RIVIERA (0.031), PREONE (0.03), MONTEREALE VALCELLINA (0.029), LAUCO (0.026), TRAMONTI DI SOTTO (0.026), POVOLETTO (0.024), SAN FLORIANO DEL COLLIO (0.024), CASTELNOVO DEL FRIULI (0.021), CLAUZETTO (0.021), MANIAGO (0.018), TRAVESIO (0.015), ENEMONZO (0.01), CAPRIVA DEL FRIULI (0.009), GORIZIA (0.008), CANEVA (0.006), VILLA SANTINA (0.005), e SAN LORENZO ISONTINO (0.004).

(source: authors).

Municipalities located in the northern areas achieve the highest potential respiratory benefits. On the contrary, municipalities located in the central-eastern areas of the Friuli Venezia Giulia Region achieve no or very low potential respiratory benefits when assessed through applying the same model.

The municipalities assessed by adopting the P2 model seem even more spatially concentrated than those assessed through applying the P1.

Only a few municipalities achieve high and discrete functional potentials.

Table 5 lists the municipalities analyzed on the basis of three groups: high, medium, and scarce, close to zero, potentials according to the analysis model P2.

As illustrated, the municipalities of Rigolato and Lusevera achieve the highest and lowest potential respiratory benefits, respectively, when applying the P2 model.

The municipalities of Tarvisio and Sauris are ranked 7th and 15th, respectively. Thus, municipalities in which forest-based activities with asthmatic patients are taking place are among those achieving high potential respiratory benefits, by adopting the P2 model. These results confirm the hypothesis RH2.

3.3. Dynamic-Relational Approach (P3)

RT3: locating regional municipalities in which potentially positive respiratory impacts from BVOCs emitted by trees are the most heterogeneous. Figure 7 illustrates the distribution of the regional municipalities by considering potential respiratory benefits of BVOCs emitted by trees through applying the model P3.

Table 5. Potential respiratory benefits of forest heritage by municipality through applying model P2.

Potential Respiratory Benefits	Municipalities
(a) High (rank: 1–29), Ist quartile	RIGOLATO (0.656), PAULARO (0.591), OVARO (0.524), MALBORGHETTO VALBRUNA (0.519), RAVASCLETTO (0.501), SUTRIO (0.476), TARVISIO (0.475), FORNI AVOLTRI (0.47), COMEGLIANS (0.468), PONTEBBA (0.429), CERCIVENTO (0.418), SAPPADA (0.41), ZUGLIO (0.387), TREPPO-LIGOSULLO (0.384), SAURIS (0.381), PALUZZA (0.355), PRATO CARNICO (0.351), FORNI DI SOPRA (0.339), FORNI DI SOTTO (0.321), AMPEZZO (0.25), MOGGIO UDINESE (0.248), CHIUSAFORTE (0.245), RAVEO (0.21), TRAMONTI DI SOPRA (0.208), ARTA TERME (0.206), TRASAGHIS (0.194), TRAMONTI DI SOTTO (0.187), CAVAZZO CARNICO (0.181), e DOGNA (0.178).
(b) Medium (rank: 30–58), IInd quartile	TOLMEZZO (0.159), BARCIS (0.155), LAUCO (0.151), BORDANO (0.137), ERTO E CASSO (0.13), RESIUTTA (0.125), CLAUT (0.121), VENZONE (0.112), VITO D'ASIO (0.112), CIMOLAIS (0.102), RESIA (0.102), SOCCHIEVE (0.099), ANDREIS (0.098), BUDOIA (0.095), FRISANCO (0.093), GEMONA DEL FRIULI (0.092), FORGARIA NEL FRIULI (0.088), VERZEGNIS (0.082), POLCENIGO (0.061), ENEMONZO (0.043), AVIANO (0.037), PREONE (0.033), MONTEREALE VALCELLINA (0.029), AMARO (0.026), VILLA SANTINA (0.025), CLAUZETTO (0.02), MONTENARS (0.011), ARTEGNA (0.009), e CANEVA (0.006).
(c) Low/No potentials (rank: 59–87); IIIrd quartile	LUSEVERA (0.001), other municipalities = 0.

(Source: authors).

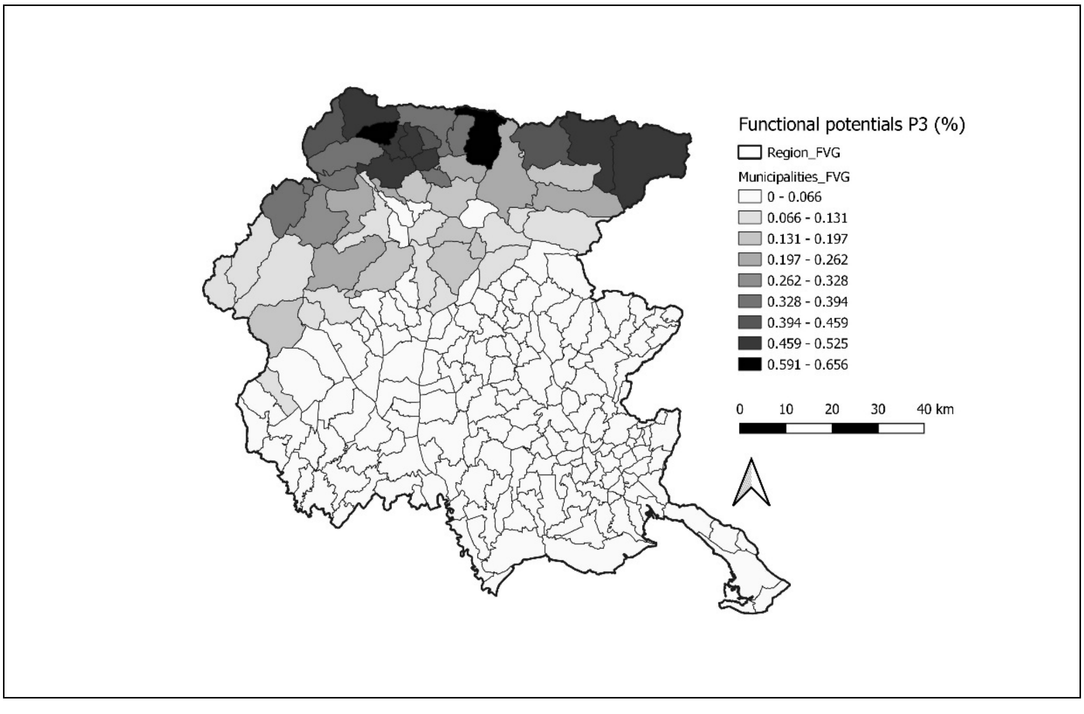

Figure 7. Potential respiratory benefits of BVOCs emitted by regional forests in mountain municipalities: Dynamic-relational approach (P3). Source: authors.

As a result of applying the P3 model, municipalities located in the central-eastern areas of the Friuli Venezia Giulia Region achieve no or very low potential respiratory benefits when assessed. Instead, municipalities located in the central mountain areas achieve the highest potential respiratory benefits. On the contrary, Amaro, located in the Province of Udine, achieves no potential.

Table 6 lists the municipalities analyzed according to three groups: high, medium, and low-to-zero potential according to the analysis model P3. Once again, the municipality of Rigolato achieves the highest potentials. Those of Vito d'Asio and Magnano in Riviera achieve the lowest ones, according with the P3 model. The municipalities of Tarvisio and Sauris are ranked 8th and 18th, respectively. Thus, municipalities in which forest-based activities with asthmatic patients are taking place are among those achieving high potential respiratory benefits, by adopting the P3 model. Other municipalities, including Rigolato, Paularo, and Ovaro, achieve the highest potential respiratory benefits. These results confirm the hypothesis RH2.

Table 6. Potential respiratory benefits of forest heritage by municipality through applying model P3.

Potential Respiratory Benefits	Municipalities
(a) High (rank: 1–29), Ist quartile	RIGOLATO (0.589), PAULARO (0.533), OVARO (0.453), MALBORGHETTO VALBRUNA (0.433), SUTRIO (0.425), FORNI AVOLTRI (0.422), ZUGLIO (0.421), TARVISIO (0.405), COMEGLIANS (0.383), CERCIVENTO (0.375), SAPPADA (0.354), TREPPO-LIGOSULLO (0.333), PONTEBBA (0.327), SAURIS (0.314), PALUZZA (0.313), RAVASCLETTO (0.313), FORNI DI SOTTO (0.297), PRATO CARNICO (0.286), FORNI DI SOPRA (0.254), AMPEZZO (0.216), RAVEO (0.21), CAVAZZO CARNICO (0.18), CHIUSAFORTE (0.156), MOGGIO UDINESE (0.154), ARTA TERME (0.152), LAUCO (0.151), ERTO E CASSO (0.13), TRASAGHIS (0.117), e VENZONE (0.111).
(b) Medium (rank: 30–58), IInd quartile	CLAUT (0.107), BORDANO (0.098), ANDREIS (0.098), DOGNA (0.095), SOCCHIEVE (0.091), FORGARIA NEL FRIULI (0.088), BUDOIA (0.08), VERZEGNIS (0.079), BARCIS (0.077), GEMONA DEL FRIULI (0.076), RESIUTTA (0.07), CIMOLAIS (0.065), TOLMEZZO (0.065), RESIA (0.061), TRAMONTI DI SOPRA (0.047), AVIANO (0.04), PREONE (0.03), MONTEREALE VALCELLINA (0.029), FRISANCO (0.029), TRAMONTI DI SOTTO (0.026), POLCENIGO (0.014), ENEMONZO (0.01), MONTENARS (0.009), VILLA SANTINA (0.009), ARTEGNA (0.002), LUSEVERA (0.001), VITO D'ASIO, and MAGNANO IN RIVIERA.
(c) Low/No potentials (rank: 59–87); IIIrd quartile	No municipalities are ranked as low/no potentials.

(source: authors).

3.4. The Overall Potentials

RT4: positioning regional municipalities in which forest-based, integrative medicine experiences are taking place among those considered here. Figure 8 positions those municipalities by considering potential respiratory benefits of BVOCs emitted by trees through applying the models P1–3.

As it can be seen, the municipalities of Sauris and Tarvisio are among those achieving high potentials for this study purposes. Despite these achievements, other regional municipalities achieve the highest potentials, as illustrated in Table 7. These results confirm the hypotheses RH1–2.

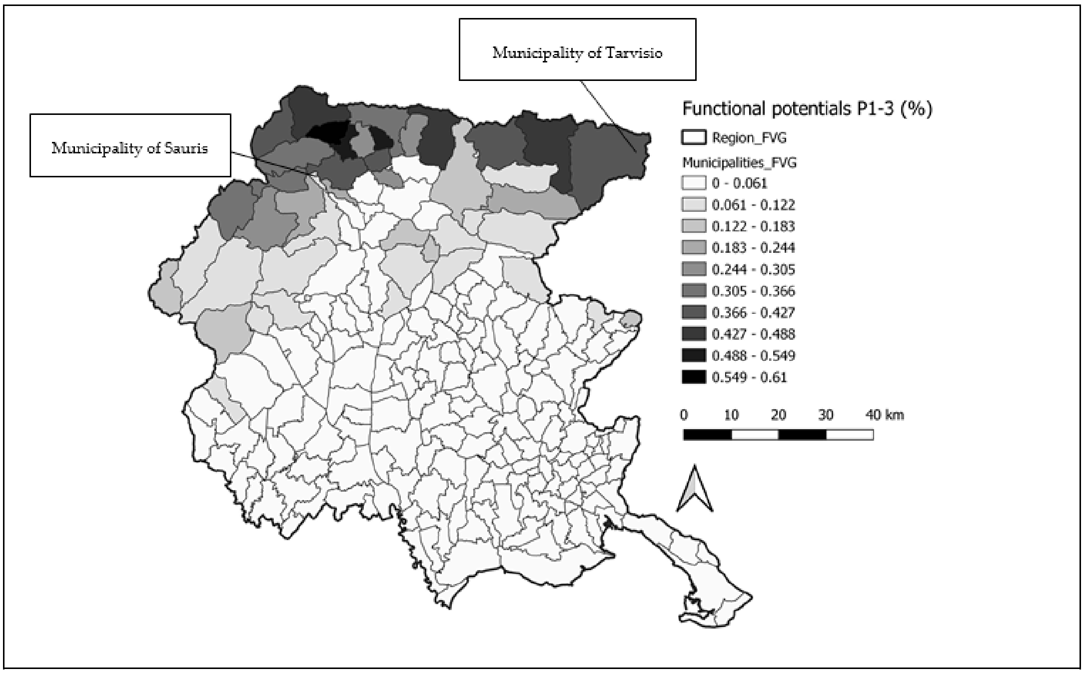

Figure 8. Overall potential respiratory benefits of BVOCs emitted by regional forests in mountain municipalities: Overall approach (P1–3). Source: authors.

Table 7. Overall potential respiratory benefits of forest heritage by municipality through applying models P1–3.

Potential Respiratory Benefits	Municipalities
(a) High (rank: 1–29), Ist quartile	RIGOLATO (0.61), COMEGLIANS (0.518), CERCIVENTO (0.503), PAULARO (0.479), MALBORGHETTO VALBRUNA (0.479), FORNI AVOLTRI (0.449), TARVISIO (0.425), SAPPADA (0.396), SUTRIO (0.392), PONTEBBA (0.377), OVARO (0.37), SAURIS (0.352), PRATO CARNICO (0.343), FORNI DI SOPRA (0.339), PALUZZA (0.337), TREPPO-LIGOSULLO (0.29), FORNI DI SOTTO (0.285), RAVASCLETTO (0.283), ZUGLIO (0.263), AMPEZZO (0.225652309), CHIUSAFORTE (0.187), RAVEO (0.186), CAVAZZO CARNICO (0.18), MOGGIO UDINESE (0.154), DRENCHIA (0.147), BORDANO (0.137), ERTO E CASSO (0.13), BARCIS (0.122), FORGARIA NEL FRIULI (0.12), and CLAUT (0.11).

(source: authors).

The Figures A1–A3 in Appendix A.2.1, Appendix A.2.2, Appendix A.2.3 list the potentials of forest-types for respiratory impact purposes by applying P1–3 models. The Figure A4 in Appendix A.3 illustrates "how many" and "which" of the above-mentioned municipalities achieving high potentials through applying the P1 model were also high in P2 and/or in P1, representing the internal consistency of information supplied by those models.

As may be noted, 23 municipalities out of the 30 achieving the highest potentials by applying P1 scored high when evaluated adopting the P2 model. Moreover, 26 municipalities out of 30 achieving the highest potentials by applying P2 scored high when evaluated adopting the P3 model.

4. Discussion

Municipalities achieving the highest potential respiratory benefits have been located. Results confirming both the RH1 and RH2 suggest that forest-based initiatives which are running in the preselected municipalities are achieving 'high' potential respiratory benefits and can be further improved. At the same time, the municipalities achieving 'the highest' potential respiratory benefits should be considered by research adopting a local-scale approach. Last but not least, confirmation of the RH3, obtained by applying the P1 model, suggests that municipalities achieving the highest potentials could include both those which are farthest from the Po Plain (highest altitude covered by coniferous forests) and those which are closest to the Po Plain (lowest altitude, covered by deciduous forest), which is somewhat counterintuitive.

Nevertheless, despite these achievements, a number of questions remain to be addressed. The target of comparing regions by considering BVOCs emission potentials, due to the heterogeneity of the tree species constituting the regional forest heritage, seems to go beyond the purposes of this study and could be considered by further interdisciplinary research. This study confirmed the RH1–3 and acknowledges the need to continuously incorporate even more accurate descriptions of forest variables [42]. The aim "to provide data for the potential use of these habitats" for forest therapy purposes falls among those preselected ones. The aims to supply data for forest management and clinical practice guidelines fall beyond the purposes of this study. The analysis models adopted here, on the one hand, did not take into account all of the variables influencing the production of BVOCs, such as phytochemical variables [96], chrono-referenced variables [97], meteorological ones [98], interactions among variables, or the degree of connectivity among variables constituting any complex system [99]. This limit seems largely embedded in the concept of the model. On the other hand, they assessed the potential respiratory benefits of specific BVOCs by leveraging both the scientific literature reporting them and by using the maps describing the forest heritage provided by the regional forest management authority.

5. Conclusions

This study has adopted geographically referenced data obtained from regional repositories and the early scientific evidence on potentials of forest heritage for respiratory purposes to evaluate potential respiratory benefits of forest-based experiences. Furthermore, it has adopted the RBT as conceptual lens to identify regional municipalities achieving 'above the average', thus "valuable" potentials.

The maps obtained by applying the models 1–3 highlight the potential of only a few, thus 'rare', municipalities out of the remarkable 116 municipalities considered here. Moreover, the maps created showed that the municipalities in which integrative medicine experiences are taking place are the ones reaching the greatest potential.

Local administrators who operate in the municipalities achieving above the average potentials can use those maps to pursue their development targets.

Those municipalities achieving valuable potentials, but who are not offering integrative medicine experiences, could be helped by regional stakeholders to recognize the strategic role plaid by the interactions linking the forest heritage for both human health and sustainable development purposes.

Municipalities in which integrative medicine experiences are taking place could be helped to recognize the importance of adopting forest aerosol-based definitions of forest bathing and the evidence-based one of the one of forest therapy when setting-up clinical interdisciplinary trials.

As suggested, the heterogeneity of BVOCs produced by tree species could provide an appropriate base for closer research on the forest–human health relationship. Public decision-makers will have the capacity to assess these issues, will not only be able provide even more accurate, updated, and cost-effective geographical information systems, but they may support, even more productively, the setting-up of new ecosystem services in the framework of human health.

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M.D.; review and editing, M.D., L.I. and M.S; visualization and supervision, L.I., M.S. and F.G.V.; project administration: L.I.; funding acquisition: M.D. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Appendix A.1

Box A1. Administrative Database: Municipalities in the Region of Friuli Venezia Giulia Listed in Alphabetical Order. * Municipalities endowed with mountain morphology.

AIELLO DEL FRIULI, AMARO *, AMPEZZO *, ANDREIS *, AQUILEIA, ARBA *, ARTA TERME *, ARTEGNA *, ATTIMIS *, AVIANO *, AZZANO DECIMO, BAGNARIA ARSA, BARCIS *, BASILIANO, BERTIOLO, BICINICCO, BORDANO *, BRUGNERA, BUDOIA *, BUJA *, BUTTRIO, CAMINO AL TAGLIAMENTO, CAMPOFORMIDO, CAMPOLONGO TAPOGLIANO, CANEVA *, CAPRIVA DEL FRIULI *, CARLINO, CASARSA DELLA DELIZIA, CASSACCO *, CASTELNOVO DEL FRIULI *, CASTIONS DI STRADA, CAVASSO NUOVO *, CAVAZZO CARNICO *, CERCIVENTO *, CERVIGNANO DEL FRIULI, CHIONS, CHIOPRIS-VISCONE, CHIUSAFORTE *, CIMOLAIS *, CIVIDALE DEL FRIULI *, CLAUT *, CLAUZETTO *, CODROIPO, COLLOREDO DI MONTE ALBANO, COMEGLIANS *, CORDENONS, CORDOVADO, CORMONS *, CORNO DI ROSAZZO *, COSEANO, DIGNANO, DOBERDO' DEL LAGO *, DOGNA *, DOLEGNA DEL COLLIO *, DRENCHIA *, DUINO-AURISINA *, ENEMONZO *, ERTO E CASSO *, FAEDIS *, FAGAGNA, FANNA *, FARRA D'ISONZO *, FIUME VENETO, FIUMICELLO VILLA VICENTINA, FLAIBANO, FOGLIANO REDIPUGLIA *, FONTANAFREDDA, FORGARIA NEL FRIULI *, FORNI AVOLTRI *, FORNI DI SOPRA *, FORNI DI SOTTO *, FRISANCO *, GEMONA DEL FRIULI *, GONARS, GORIZIA *, GRADISCA D'ISONZO *, GRADO, GRIMACCO *, LATISANA, LAUCO *, LESTIZZA, LIGNANO SABBIADORO, LUSEVERA *, MAGNANO IN RIVIERA *, MAJANO, MALBORGHETTO VALBRUNA *, MANIAGO, MANZANO, MARANO LAGUNARE, MARIANO DEL FRIULI, MARTIGNACCO, MEDEA, MEDUNO *, MERETO DI TOMBA, MOGGIO UDINESE *, MOIMACCO, MONFALCONE *, MONRUPINO *, MONTENARS *, MONTEREALE VALCELLINA *, MORARO, MORSANO AL TAGLIAMENTO, MORTEGLIANO, MORUZZO, MOSSA *, MUGGIA *, MUZZANA DEL TURGNANO, NIMIS *, OSOPPO *, OVARO *, PAGNACCO, PALAZZOLO DELLO STELLA, PALMANOVA, PALUZZA *, PASIAN DI PRATO, PASIANO DI PORDENONE, PAULARO *, PAVIA DI UDINE, PINZANO AL TAGLIAMENTO *, POCENIA, POLCENIGO *, PONTEBBA *, PORCIA, PORDENONE, PORPETTO, POVOLETTO *, POZZUOLO DEL FRIULI, PRADAMANO, PRATA DI PORDENONE, PRATO CARNICO *, PRAVISDOMINI, PRECENICCO, PREMARIACCO, PREONE *, PREPOTTO *, PULFERO *, RAGOGNA *, RAVASCLETTO *, RAVEO *, REANA DEL ROJALE *, REMANZACCO, RESIA *, RESIUTTA *, RIGOLATO *, RIVE D'ARCANO, RIVIGNANO, TEOR, ROMANS D'ISONZO, RONCHI DEI LEGIONARI *, RONCHIS, ROVEREDO IN PIANO, RUDA, SACILE, SAGRADO *, SAN CANZIAN D'ISONZO, SAN DANIELE DEL FRIULI *, SAN DORLIGO DELLA VALLE—DOLINA *, SAN FLORIANO DEL COLLIO *, SAN GIORGIO DELLA RICHINVELDA, SAN GIORGIO DI NOGARO, SAN GIOVANNI AL NATISONE, SAN LEONARDO *, SAN LORENZO ISONTINO *, SAN MARTINO AL TAGLIAMENTO, SAN PIER D'ISONZO *, SAN PIETRO AL NATISONE *, SAN QUIRINO, SAN VITO AL TAGLIAMENTO, SAN VITO AL TORRE, SAN VITO DI FAGAGNA, SANTA MARIA LA LONGA, SAPPADA, SAURIS *, SAVOGNA *, SAVOGNA D'ISONZO *, SEDEGLIANO, SEQUALS *, SESTO AL REGHENA, SGONICO *, SOCCHIEVE *, SPILIMBERGO, STARANZANO *, STREGNA *, SUTRIO *, TAIPANA *, TALMASSONS, TARCENTO *, TARVISIO *, TAVAGNACCO, TERZO DI AQUILEIA, TOLMEZZO *, TORREANO *, TORVISCOSA, TRAMONTI DI SOPRA *, TRAMONTI DI SOTTO *, TRASAGHIS *, TRAVESIO *, TREPPO GRANDE, TREPPO LIGOSULLO, TRICESIMO, TRIESTE *, TRIVIGNANO UDINESE, TURRIACO, UDINE, VAJONT, VALVASONE-ARZENE, VARMO, VENZONE *, VERZEGNIS *, VILLA SANTINA *, VILLESSE *, VISCO, VITO D'ASIO *, VIVARO, ZOPPOLA, ZUGLIO *.

Table A1. Vegetation Database: Tree Species Dominating Forests in the FVG Region: Family, Genus, Species and Common Name.

Family	Genus	Species	Common Name
Pinaceae	*Abies Lam*	*Abies alba*	*European silver fir*
Sapindaceae	*Acer*	*Acer campestre*	*Field maple*
Sapindaceae	*Acer*	*Acer monspessolanum*	*Montpellier maple*
Sapindaceae	*Acer*	*Acer platanoides*	*Norway maple*
Sapindaceae	*Acer*	*Acer pseudoplatanus*	*Sycamore maple*
Betulaceae	*Alnus*	*Alnus glutinosa*	*Common alder*
Betulaceae	*Alnus*	*Alnus incana*	*Grey alder*
Betulaceae	*Betula*	*Betula alba*	*White birch*
Betulaceae	*Betula*	*Betula pendula*	*Silver birch*
Betulaceae	*Carpinus*	*Carpinus betulus*	*European hornbeam*
Betulaceae	*Carpinus*	*Carpinus orientalis*	*Oriental hornbeam*
Fagaceae	*Castanea*	*Castanea sativa*	*Sweet chestnut*
Cannabaceae	*Celtis*	*Celtis australis*	*European nettle tree*
Fagaceae	*Fagus*	*Fagus sylvatica*	*Common beech*
Oleaceae	*Fraxinus*	*Fraxinus excelsior*	*Common ash*
Oleaceae	*Fraxinus*	*Fraxinus ornus*	*south European flowering ash*
Oleaceae	*Fraxinus*	*Fraxinus oxycarpa*	*Southern Ash tree*
Pinaceae	*Larix*	*Larix decidua*	*European larch*
Betulaceae	*Ostrya*	*Ostrya carpinifolia*	*European hop-hornbeam*
Pinaceae	*Picea*	*Picea abies*	*European spruce*
Pinaceae	*Pinus*	*Pinus halepensis sub. Brutia*	*Turkish pine*
Pinaceae	*Pinus*	*Pinus halepensis*	*n.a.*
Pinaceae	*Pinus*	*Pinus nigra*	*black pine*
Pinaceae	*Pinus*	*Pinus pinaster*	*cluster pine*
Pinaceae	*Pinus*	*Pinus pinea*	*Italian stone pine*
Pinaceae	*Pinus*	*Pinus sylvestris*	*Scots pine*
Salicaceae	*Populus*	*Populus alba*	*Silver poplar*
Salicaceae	*Populus*	*Populus nigra*	*Black poplar*
Salicaceae	*Populus*	*Populus tremula*	*Quaking aspen*
Rosaceae	*Prunus*	*Prunus avium*	*Sweet cherry*
Rosaceae	*Prunus*	*Prunus mahaleb*	*Rock cherry*
Rosaceae	*Prunus*	*Prunus padus*	*Hackberry*
Fagaceae	*Quercus*	*Quercus cerris*	*Turkey oak*
Fagaceae	*Quercus*	*Quercus ilex*	*Evergreen oak*
Fagaceae	*Quercus*	*Quercus petraea*	*Cornish*
Fagaceae	*Quercus*	*Quercus pubescens*	*Downy oak*
Fagaceae	*Quercus*	*Quercus robur*	*Common oak*
Fabaceae	*Robinia*	*Robinia pseudoacacia*	*Black locust*
Rosaceae	*Sorbus*	*Sorbus aria*	*Common whitebeam*

Table A1. *Cont.*

Family	Genus	Species	Common Name
Rosaceae	*Sorbus*	*Sorbus aucuparia*	*Mountain ash*
Rosaceae	*Sorbus*	*Sorbus domestica*	*Sorb tree*
Rosaceae	*Sorbus*	*Sorbus torminalis*	*Wild service tree*
Taxaceae	*Taxus*	*Taxus baccata*	*Common Yew*
Malvaceae	*Tilia*	*Tilia cordata*	*Small-leaved lime*
Malvaceae	*Tilia*	*Tilia platiphillos*	*Large-leaved lime*
Ulmaceae	*Ulmus*	*Ulmus glabra*	*Scots elm*
Ulmaceae	*Ulmus*	*Ulmus minor*	*Field elm*

Elaborations: authors. Source: [93] (pp. 18–177).

Box A2. Vegetation Database: the 80 Forest Types Composing the Forest Heritage in the Mountain Area of the Region of Friuli Venezia Giulia. Local Names.

Ostrio-lecceta, Lecceta con pino nero, Bosco costiero dei suoli idrici, Querco-carpineto planiziale, Querco-carpineto collinare, Carpineto tipico, Carpineto con frassino, Carpineto con ostria, Carpineto con cerro, Rovereto tipico carsico, Rovereto tipico collinare, Rovereto dei suoli acidi, Castagneto dei suoli xerici, Castagneto dei suoli mesici, Castagneto con frassino, Castagneto dei suoli acidi, Pseudomacchia con carpinella, Orno-ostrieto tipico, Ostrio-querceto tipico, Ostrio-querceto a scotano, Aceri-frassineto con ostria, Aceri-frassineto tipico, Aceri-frassineto con faggio, Aceri-frassineto con ontano nero, Faggeta submontana con ostria, Faggeta submontana tipica, Faggeta submontana dei suoli mesici carbonatici, Faggeta submontana dei suoli mesoidrici, Faggeta submontana dei suoli mesici silicatici, Faggeta submontana dei suoli acidi, Faggeta montana dei suoli xerici, Faggeta montana tipica esalpica, Faggeta montana tipica mesalpica, Faggeta montana dei suoli acidi, Faggeta montana dei suoli mesici, Faggeta altimontana tipica, Faggeta subalpina, Faggeta altimontana dei substrati silicatici, Pineta di pino nero tipica, Pineta di pino nero submontana con ostria, Pineta di pino nero con faggio, Pineta di pino nero montana con pino silvestre, Pineta di pino silvestre esalpica tipica, Pineta di pino silvestre esalpica con faggio, Pineta di pino silvestre mesalpica tipica, Pineta di pino silvestre mesalpica con faggio e abete rosso, Piceo-faggeto dei suoli xerici, Piceo-faggeto dei suoli mesici carbonatici montano, Piceo-faggeto dei suoli mesici carbonatici altimontano, Piceo-faggeto dei suoli acidi, Piceo-faggeto dei suoli mesici montano, Piceo-faggeto dei suoli mesici altimontano, Abieteto esalpico submontano, Abieteto esalpico montano, Abieti-piceo-faggeto dei substrati carbonatici montano, Abieti-piceo-faggeto dei substrati carbonatici altimontano, Abieti-piceo-faggeto dei suoli mesici montano, Abieti-piceo-faggeto dei suoli mesici altimontano, Abieti-piceo-faggeto altimontano dei suoli acidi, Piceo-abieteto dei substrati carbonatici dei suoli mesici carbonatici, Piceo-abieteto dei substrati carbonatici dei substrati gessosi, Piceo-abieteto dei suoli mesici submontano, Piceo-abieteto dei suoli mesici bassomontano, Piceo-abieteto dei suoli mesici montano, Piceo-abieteto dei suoli mesici altimontano, Piceo-abieteto dei suoli acidi montano, Piceo-abieteto dei suoli acidi altimontano, Pecceta dei substrati carbonatici altimontana, Pecceta dei substrati carbonatici subalpina, Pecceta montana dei suoli acidi tipica, Pecceta montana dei suoli acidi in successione con faggeta, Pecceta altimontana e subalpina dei substrati silicatici, Pecceta di sostituzione dei substrati gessosi, Pecceta di sostituzione dei suoli mesici, Pecceta di sostituzione dei suoli acidi, Pecceta secondaria montana, Pecceta secondaria altimontana, Pecceta azonale su alluvioni, Lariceto tipico dei substrati carbonatici, Lariceto tipico dei substrati silicatici.

Elaborations: authors. Source: [93] (pp. 18–177).

Appendix A.2 Potentials of Forest Types

Appendix A.2.1 Potential Respiratory Impacts—P1 Model

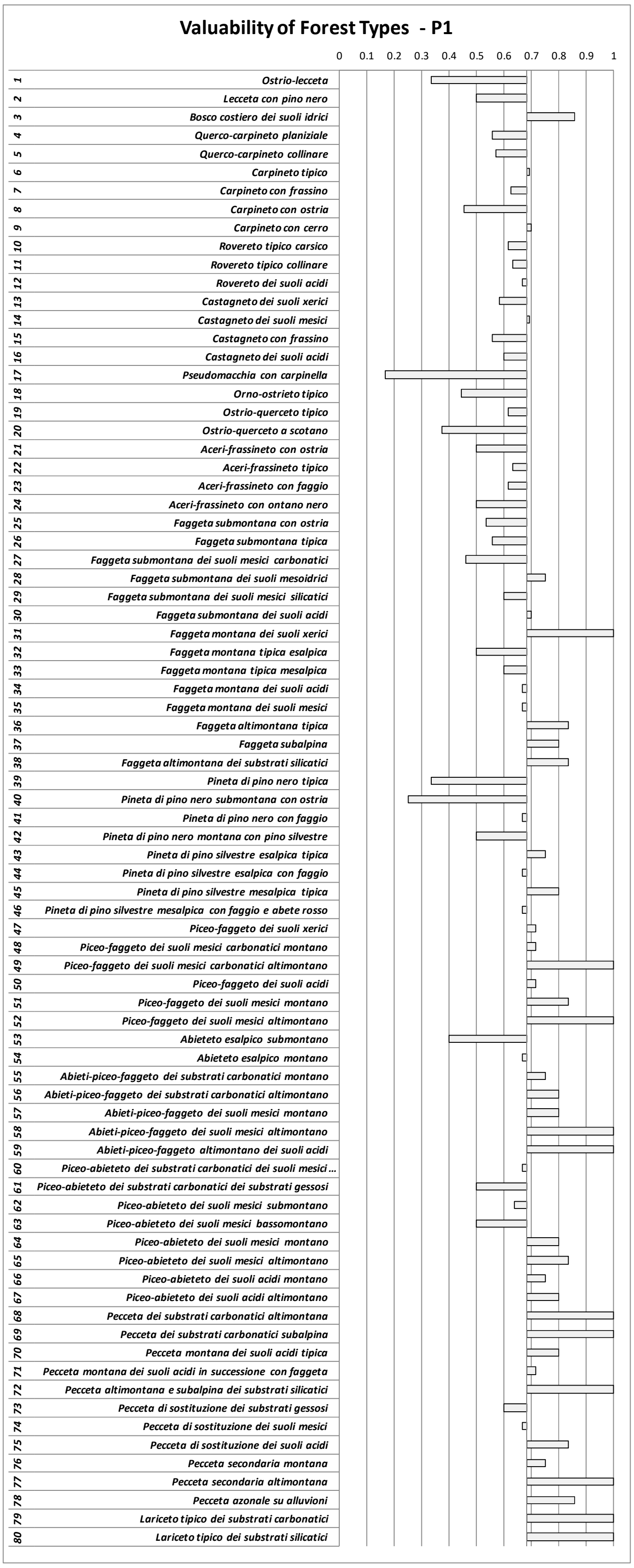

Figure A1. Forest types by increasing altitude. Average P1 value: 0.683963. Below the average = 0; Above the average = 1. Source: authors.

Appendix A.2.2 Potential Respiratory Impacts—P2 Model

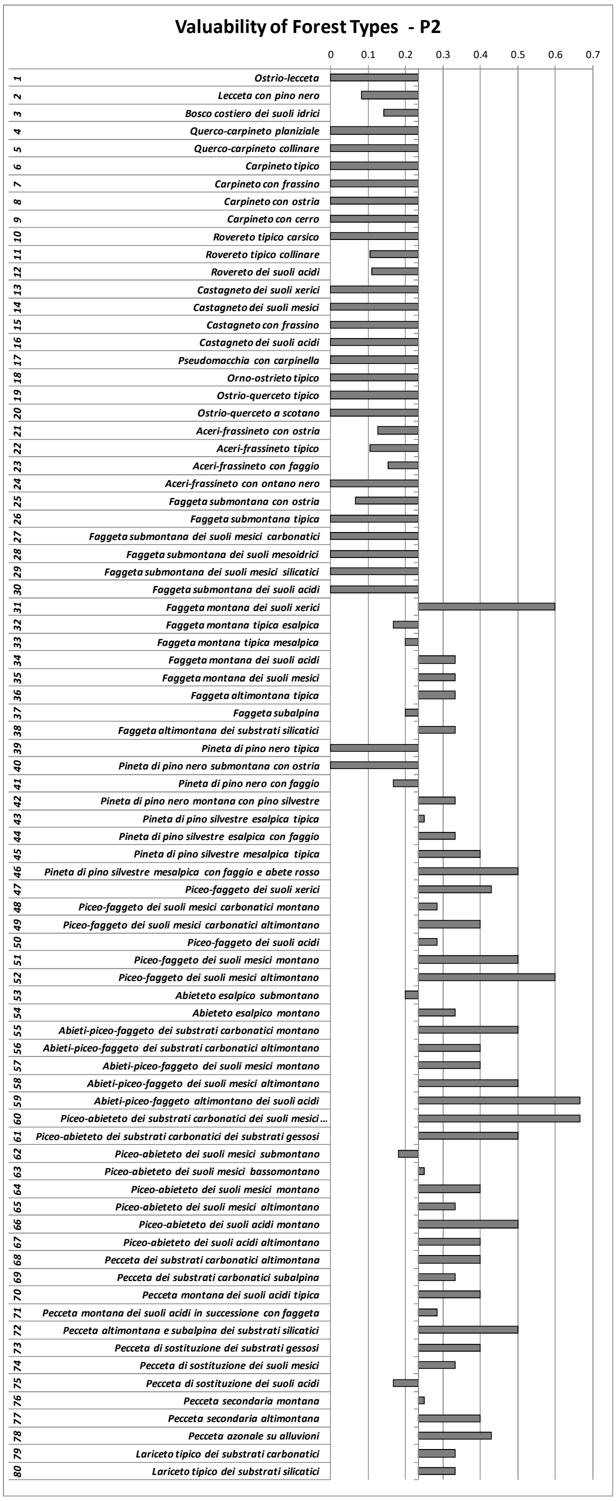

Figure A2. Forest types by increasing altitude. Average P2 value: 0.233409. Below-average = 0; Above-average = 1. Source: authors.

Appendix A.2.3 Potential Respiratory Impacts—P3 Model

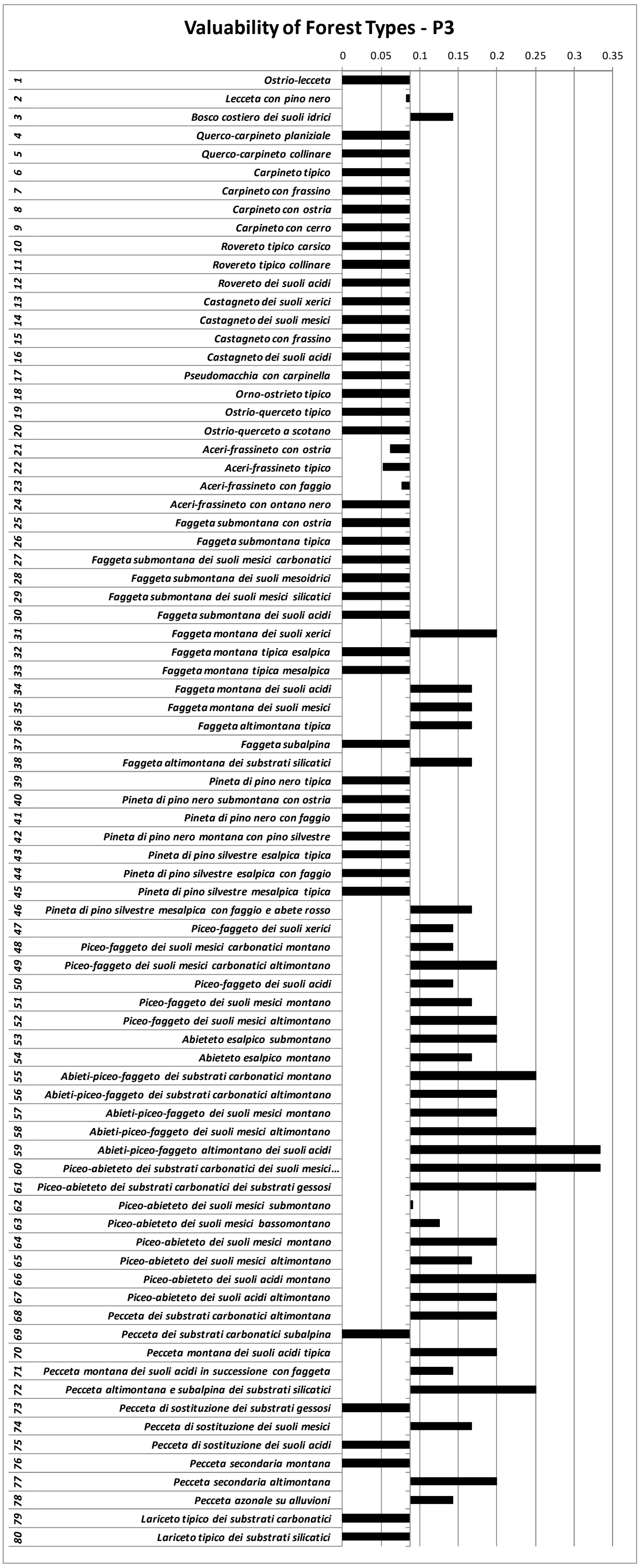

Figure A3. Forest types by increasing altitude. Average P3 value: 0.087064. Below-average = 0; Above-average = 1. Source: authors.

Appendix A.3

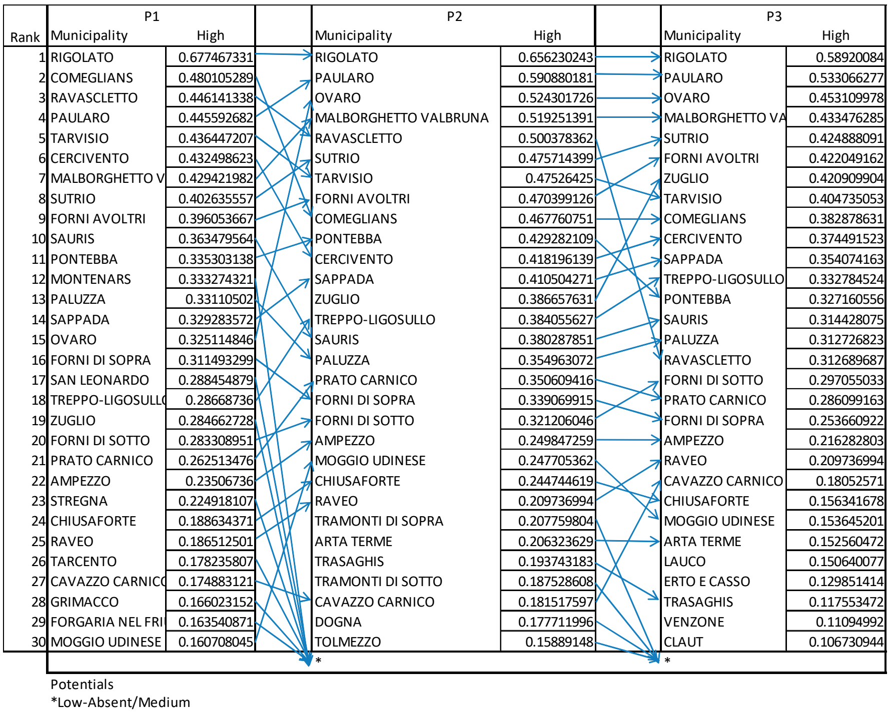

Figure A4. Internal Consistency of Information Supplied by Models P1, P2 and P3. Best 30 municipalities. (Source: authors).

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