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Ecosystem Service Trade-Offs in Peri-Urban Landscapes: Drivers, Governance Obstacles and Improvements

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Abstract: Trade-offs in ecosystem services (ESs) manifest when the enhancement of one service leads to the diminishment of another. These trade-offs pose a notable challenge, impacting the sustainability of particular socioecological system peri-urban landscapes (PULs). This issue arises from the dynamic processes associated with peri-urbanization, which threaten natural ecosystems and their services in peri-urban areas. Additionally, the escalating demand for ecosystem services in PULs contributes to these trade-offs. Policymaking and planning concerning ES trade-offs in PULs should prioritize promoting a balance between conflicting services and fostering synergies among them. However, it is noteworthy that ES trade-offs in PULs are not given high priority in policy and planning agendas. Knowledge regarding policy development and planning for ES trade-offs in PULs often remains concealed within specific country and regional case studies. Consequently, this research seeks to characterize the ES trade-offs in selected PUL case studies, with the objective of identifying potential commonalities among them. Furthermore, this study aims to identify (i) the factors driving ES trade-offs, (ii) challenges related to how policymaking and planning address ES trade-offs in PULs, and (iii) recommendations for enhancing governance practices to better manage peri-urban ES trade-offs. We designed a semi-quantitative survey and collected information about 24 case studies located across the world. The answers from this survey were analyzed using principal component analysis. The results showed that the most common trade-offs occurred between "cultural and provisioning" and "regulating and provisioning" ESs. It was found that urban development is the primary driver behind the emergence of the examined trade-offs. To address this issue at the governance level, this study recommends establishing mechanisms to facilitate collaboration among stakeholders. This should be accompanied by robust dissemination efforts and the promotion of awareness among actors regarding the fundamental concepts of ESs and PULs.

Keywords: awareness; conflict; planning; principal component analysis; similarity patterns

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1. Introduction

1.1. Ecosystem Service Trade-Offs in Peri-Urban Landscapes

Ecosystems are often modified to enhance the provision of specific services [1]. Peri-urban landscapes (PULs) are examples of specific areas where land-use changes occur in a very dynamic way, producing modifications in the provision of services of the related ecosystems. PULs are wide portions of man-modified landscapes embedded in a (semi)rural

context in a continuous spatiotemporal manner and often within large metropolitan regions [2]. PULs are characterized by a low-density urban fabric and different types and mixes of land uses and urban services, including residential, commercial, industrial, farmlands, and semi-natural areas and ecosystems [3]. Such a mixture of land uses is the result of dynamic socioecological changes, occurring faster than in other urban contexts and usually involving higher rates of soil consumption, with many environmental generated externalities [4,5]. If not correctly planned or managed, such rapid changes can often lead to trade-offs in the provision of ecosystem services (ESs). ES trade-offs represent a situation where one ES decreases as a result of the increase of another ES [6]. Very often, ES trade-offs occur in situations where two types of ESs support different objectives [1]. The specificity of ES trade-offs depends on the context in which they are identified [7]. Trade-offs also occur when there is a difference between the supply and demand for certain services, leading to an unbalanced or unfair distribution of services to people [8]. So far, ES trade-offs have been studied from different perspectives over the past decades, e.g., focusing on categories of spatial, temporal, reversible, and among-service trade-offs [9]. The typifying ES trade-offs presented in this study build on the previous research addressing explicit ES trade-offs [6] discussing them explicitly in peri-urban contexts [3]. Our study explores all pairs of trade-offs.

1.2. Drivers and Governance of Ecosystem Service Trade-Offs in Peri-Urban Landscapes

A driver is a factor related to human management activities that affects ESs [1]. Specifically, many ES trade-offs are driven by land use and land cover changes [9] or urbanization processes [10]. These processes have significant relevance in peri-urban contexts due to the dynamic changes in land use and land cover. Drivers can change dynamically over time, especially in transitioning landscapes like PULs. Thus, drivers of ES trade-offs need to be analyzed in a specific time context and cannot be generalized over time. Ignoring the history of a landscape and its related ecosystems might lead to an increase in trade-offs instead of synergies among ESs [10]. Failing to recognize and address drivers of ES trade-offs could lead to inequalities in ES provision and, to some extent, irreversible damage for some ecosystems [11]. Identifying potential trade-offs occurring in a certain landscape enables the design of effective management decisions aimed at minimizing social conflicts and possible environmental issues [12]. Nevertheless, ES trade-offs are still a problematic issue for policymakers and planners, mainly due to difficulties in assessing relationships among ESs [13], even though promoting synergies among ES trade-offs needs to be one of the priorities of current land-use policies [14]. Moreover, recent research shows that instruments for environmental management and policymaking could themselves be one of the drivers of ES trade-offs [9], classified as a socioecological group of drivers [1]. In particular, political practices, socioeconomic incentives, and technological progress are a set of drivers potentially generating ES trade-offs [15]. The interaction between different administrative and hierarchical levels of governance actors could also be seen as one of the important drivers of ES trade-offs [16], as specific services increased for higher administrative levels can be followed by losses at a more local level.

When looking at PULs, important ES trade-offs are related either to agricultural activities [17] or recreational activities, both of which intensively emerge in such landscapes [18]. Although some cities develop different policy mechanisms to address sustainable food production in PULs and reduce ES trade-offs, the efficiency of these policies is either difficult to assess or rather low [19]. The integration of top-down and bottom-up governance approaches has also been advocated [3], e.g., to achieve this goal, it is important to address influential users and context setters, as those actors are often responsible for ES trade-offs [7], and to implement more efficient spatial planning measures in PULs. Overall, spatial planning measures are needed to support the improvement of the rural–urban relationship, which represents the most typical peri-urban feature [19].

1.3. Research Gap and Research Aims

In this paper, we aim to examine real-world examples of ES trade-offs in PULs identified in 24 case study regions, with particular reference to normative instruments, policies, and plans that attempt to address some ESs in different geographical contexts. To this aim, we performed a detailed survey with regional experts on ESs to gain knowledge related to policymaking and spatial planning for the specific context of PULs. More specifically, this paper has the following specific objectives: (i) to characterize the case study regions containing PULs and analyze the ES trade-offs, identifying possible similarity patterns among them according to the administrative level, continent, and economic development level; (ii) to describe the drivers of peri-urban ES trade-offs in each case study region; (iii) to characterize the obstacles related to how ES trade-offs in PULs are addressed by policy instruments and spatial planning documents in each case study region; and (iv) based on the case studies analyzed, to describe possible improvements of how ES trade-offs could be better addressed by policymaking and planning in PULs.

2. Materials and Methods

To facilitate our research objective, we implemented and analyzed an online explorative survey. We chose the explorative method to provide the knowledge for closing the unexplored knowledge gap. This qualitative research method has several advantages mainly related to its flexibility [20], e.g., reduces interview biases, simplifies data collection, and increases the convenience of respondents [21]. Other ES-related studies have successfully implemented this method to display the advantages and risks of using the ES concept in participatory planning or to discuss the academic teaching of ESs [22]. The survey was forwarded to members of the following networks: International Association of Landscape Ecology (IALE), Global Land Programme (GLP), and IUFRO Landscape Ecology Working Party. We also used our personal scientific networks to contact scientists and peers working in governance, planning, and ESs in peri-urban contexts. The survey was forwarded with a notice of data protection and the explanation of objectives and contained a total of 25 questions (17 close-ended and 8 open-ended). Questions were organized into six sections: (i) the profile of the respondent, (ii) information of the case study region where PULs are located, (iii) ES trade-offs, (iv) ES trade-off drivers, (v) policy instruments, and (vi) planning documents. The first section allowed us to gather general information about respondent profiles. The second section contained questions about the case study region where PULs are located, with basic statistical data and details of the natural ecosystem types and ESs present in the region. Section three allowed us to gather information about the ES trade-offs in the analyzed PULs. The following pairs of ES trade-offs were analyzed: (i) cultural and provisioning, (ii) cultural and regulating, (iii) regulating and provisioning, (iv) different types of cultural ESs, (v) different types of provisioning ESs, and (vi) different types of regulating ESs. Section four contained close-ended questions about the drivers of ES trade-offs, where answers were predefined based on other studies [4]. Section five collected data about policy instruments, while section six included the planning documents that addressed the ES trade-offs in the analyzed case study regions. Open-ended questions were about (i) the obstacles related to specific policy instruments/planning documents to better address ES trade-offs (questions #18 and #24) and (ii) potential improvements to specific policy instruments/planning documents to better address ES trade-offs (questions #19 and #25). The answers to these open-ended questions were analyzed. Finally, the answers of close-ended questions were binary coded: "1" for positive answers (e.g., a selection of an available answer option by a respondent) and "0" for negative answers (e.g., a lack of selection of an available answer option by a respondent). The detailed questions together with their codes are presented in Table A1.

This approach allowed us to collect 24 diverse case studies of PULs, where a single case study was described by a separate answer to our survey. The case studies are located in different countries and regions (Table A2): ten are located in Europe (42%), six in South

America (29%), three in Asia (13%), three in Africa (13%), and two in North America (Figure 1).

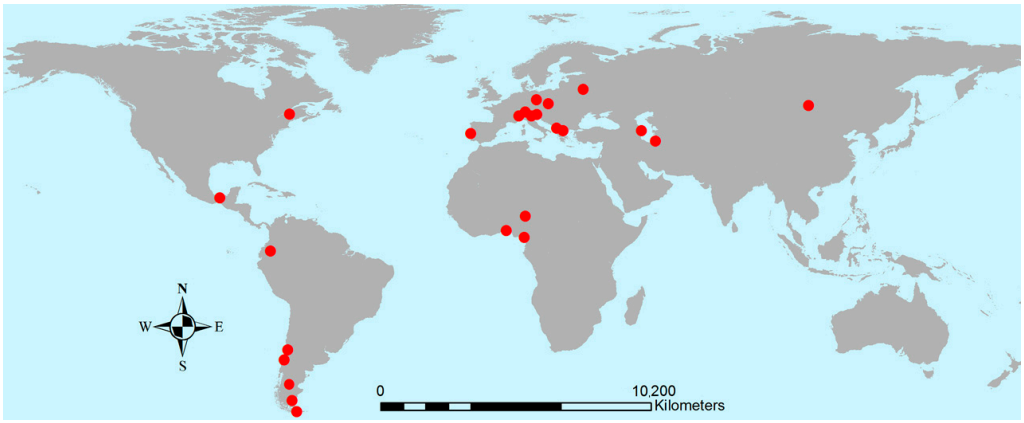

Figure 1. Localization of the case study regions (red dots).

Case studies were classified into 3 categories of administrative level: regional, metropolitan-area, and single-municipality PULs. The characterization of these case studies depended on the following factors: (1) ecosystem types (Figure A1), (ii) types of ESs (Figure A2), and (iii) types of ES trade-offs (Figure A3). The two types of ES trade-offs "cultural and provisioning" and "regulating and provisioning" were mentioned in almost all of the case studies. The data showed a relatively even distribution across the three categories of administrative level with "regional PULs" slightly more represented than the other two. The category of "different types of regulating ES trade-offs" emerged only in 54% of the case studies. It is worth noting that in more than 80% of the analyzed case studies, all types of ES trade-offs are considered challenging.

Descriptive statistics were used to characterize the case study regions and PULs. The answers provided to the open-ended questions about the obstacles related to how ES trade-offs in PULs are addressed by policy instruments and spatial planning documents (e.g., questions #18 and #24) were analyzed. The recurring aspects identified in those answers were listed and used for presenting the results (Table A3). A similar analytical procedure was applied to questions #19 and #25 regarding improvements to better address peri-urban ES trade-offs in governance and planning. To evaluate the similarities among the 24 study cases identified by respondents, we performed two separated principal component analyses (PCAs): (i) one to characterize the case studies and (ii) another for ES trade-offs. PCA reduces data multidimensionality and minimizes information losses, allowing to detect relevant characteristics to represent variability [23–25]. We used a Monte Carlo permutation test (n = 999) to assess the significance of each axis and set correlation coefficients among columns for the final cross-product matrices. For each PCA, we analyzed the whole group of responses (41 variables for characterization and 36 variables for ES trade-offs), but we only used those with a low redundancy and higher correlation with Axes 1 and 2 in the graphical representation (eigenvalues >0.200 for the two first axes). For each PCA, similarity patterns were explored in relation to (i) administrative-level types (single municipality, metropolitan area, region), (ii) continents (America, East Europe, West Europe, Africa, and Asia), and (iii) economic development levels (low, medium, high) according to their Human Development Index (HDI) [26]. For this last classification, three categories were defined: low for HDI < 0.76 (Azerbaijan, Cameroon, Ecuador, Mongolia, Nigeria), medium for HDI 0.76–0.87 (Argentina, Belarus, Chile, Iran, Mexico, Portugal), and high for HDI > 0.87 (Germany, Greece, Italy, Poland, Slovenia, US). Complementary, we used multi-response permutation procedure (MRPP) tests with Bray–Curtis distance to evaluate significant differences among groups according to geographical area types (single municipality, metropolitan area, regional), continents (America, East Europe, West Europe, Africa, Asia), and economic development levels (low, medium, high) based on the PCA analyses.

We calculated the MRPP statistic (T) with the chance-corrected within-group agreement (A) and the associated probability (p) [27]. Subsequent pairwise groupings were tested to determine the significance of the differences ($p < 0.05$) [28]. We performed the multivariate analyses in PC-ORD 5.0 software [29].

3. Results

3.1. Characterization of Case Studies

In the PCA using the case study characterization (Figure 2), the first two axes were significant (Axis 1: eigenvalue = 21.958, $p = 0.001$; Axis 2: eigenvalue = 17.399, $p = 0.001$), explaining 38.4% and 30.5% of the variance (68.9% explained accumulated variance). The more relevant characteristics were, in decreasing order, the presence of inland wetlands (B11) and inland waters (B13) among ecosystem types, as well as the domination of large (A2) or small (A3) cities, or sparse population regions (A7) (codes are explained in Table A1; eigenvectors for each variable are presented in Table A4). In the PCA about ES trade-offs (Figure 2), the first two axes (Axis 1: eigenvalue = 14.218, $p = 0.027$; Axis 2: eigenvalue = 11.138, $p = 0.010$) explained 27.6% and 21.6% of the variance (49.2% explained accumulated variance).

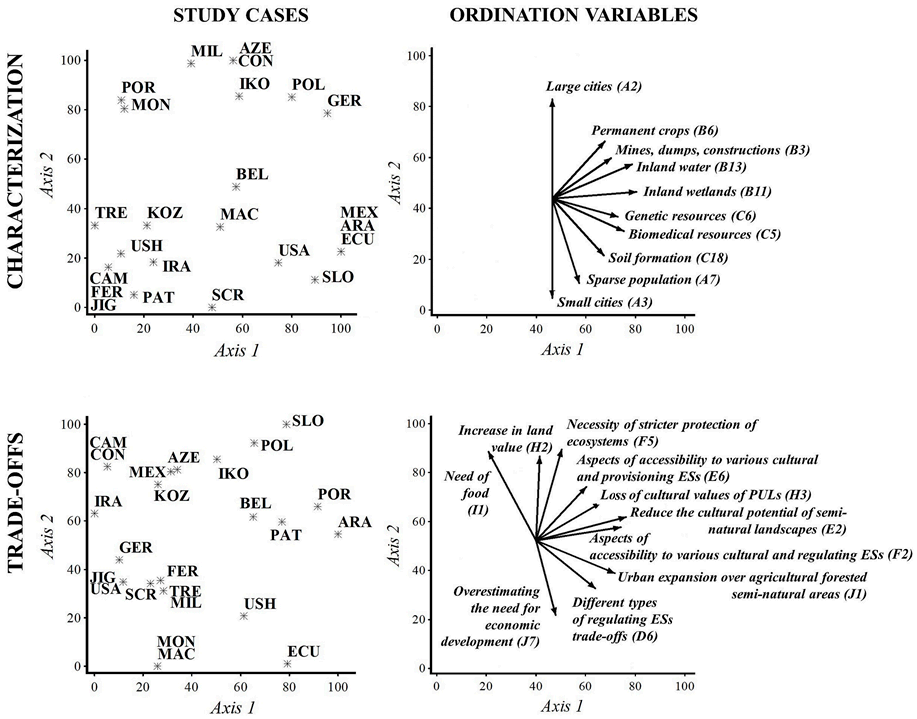

Figure 2. Case studies (**left**) and ordination variables (**right**) after principal component analysis for the characterization of case studies and trade-offs. Case studies that are closer indicate greater similarities between them; longer vectors indicate a higher influence in the case study's ordination. For the characterization analysis (**upper**), graphs are vertically flipped and 28° rotated; for the trade-off (**lower**) analysis, graphs are vertically flipped and 35° rotated. See codes for the ordination variables in Table A1. Codes explaining the location of the case studies: ARA = La Araucanía region (Chile); AZE = Greater Baku urban area (Azerbaijan); BEL = Mahiliou (Belarus); CAM = Niger Delta-Bakassi (Cameroon); CON = Concepción metropolitan area (Chile); ECU = Ecuador state (Ecuador); FER = Ferrara (Italy); GER = Berlin metropolitan area (Germany); IKO = Ikorodu (Nigeria); IRA = Gorgan (Iran); JIG = Jigawa State (Nigeria); KOZ = Kozani (Greece); MAC = West Macedonia region (Greece); MEX = Cardenas (Mexico); MIL = Southeast part of Milan metropolitan area (Italy); MON = Ulaanbaatar (Mongolia); PAT = Patagonian valleys region (Argentina); POL = Wrocław functional area (Poland); POR = Lisbon metropolitan area (Portugal); SCR = Santa Cruz province (Argentina); SLO = Osrednjeslovenska region/Central Slovenian (Slovenia); TRE = Trento (Italy); USA = Hinesburg, Vermont (United States); USH = Ushuaia urban area (Argentina).

The more relevant characteristics were, in decreasing order, the reduction in potential cultural ESs as cultural and provisioning ES trade-offs (E2), the loss of cultural ESs as a trade-off among cultural ESs (H3), the need for stricter protection of ecosystems as cultural and regulating ES trade-offs (F5), the need to provide food for a growing urban core as provisioning ES trade-offs (I1), and the emergence of regulating ESs at each case study (D6) (Table A4). In the PCA for case study characterization, the classification by geographical area type displayed the more significant grouping (Figure 3) and was validated by the MRPP results (Table A5). The three categories of case studies split by area type (single municipality, metropolitan area, and region) strongly differed among themselves ($p = 0.062$), while differences among the groups of case studies by continent or development level were not detected ($p = 0.199$) (Table A5 and Figure 3). In the PCA for ES trade-offs, the classification of case studies according to continent displayed the more significant grouping (Figure 3) and also was validated by the MRPP results (Table A5). The case studies grouped in East EU strongly differed from those in America, West EU, Africa, and Asia ($p = 0.064$), while significant differences were not detected ($p = 0.162$) among other comparisons (e.g., America and West EU, Africa or Asia) (Table A5). Likewise, a slight difference was observed between metropolitan area and regional classifications ($p = 0.092$), while weak similarities were observed for other comparisons such as geographical area categories ($p = 0.212$) and development levels ($p = 0.334$) (Table A5 and Figure 3).

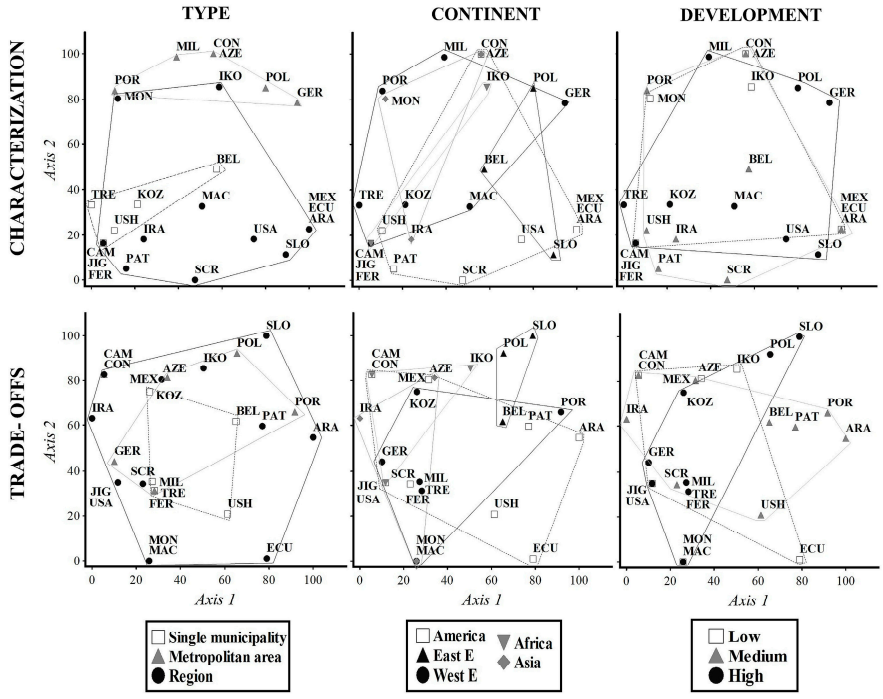

Figure 3. Classification of the case study PULs for the characterizations (**upper panel**) and trade-offs (**lower panel**). The principal component analyses (PCAs) presented in Figure 2 show geographical area type (single municipality, metropolitan area, regional), continent (America, East EU, West EU, Africa, Asia), and development level (low, medium, high).

3.2. Drivers of Ecosystem Service Trade-Offs in the Case Studies Containing Peri-Urban Landscapes

Drivers of ES trade-offs were identified by the analysis of the responses in the survey. Concerning the cultural and provisioning ES trade-offs, 71% of the respondents indicated the main driver as the conflict between current land use and those requested for ESs by local governance actors. Moreover, other drivers emerged from the survey, such as the reduction in the provision of the recreational, aesthetic, and spiritual potential of semi-natural landscapes (46%), as well as the reduction in the amenity value of the PULs (42%). The remaining groups of drivers were the reduction in the productivity of farmlands

(25%), conflicts arising from the intense recreational use of farmlands and agricultural infrastructure, unwanted trespassing, littering (21%), accessibility to other ESs (25%), and private grounds traditionally used for growing vegetables which were replaced with lawns and playgrounds (13%). When it comes to cultural and regulating ES trade-offs, the reduction in the regulating capacity of ecosystems was indicated as the most relevant driver (63%). The other drivers were aspects of accessibility to different ESs (25%), sealing surfaces (46%), decrease in water-retention potential (38%), and the need for stricter protection of ecosystems (54%). Regarding regulating and provisioning ES trade-offs, the main challenges related to forest management were the most often mentioned (63%). Other conflicts types were conflicts related to food production (50%) and the transformation of productive farmlands into public areas (green areas) (38%). For different types of cultural ES trade-offs, the most mentioned driver was related to the conflicts between new and old PUL inhabitants with different expectations of those groups (58%), while increased land value (46%) and the loss of the sense of place, aesthetics, and spiritual values of PULs (38%) were less frequently mentioned. Regarding the different types of provisioning ES trade-offs, the need to provide food for the urban core and the use of arable land for food or energy purposes were both in 42% of responses, while other drivers were the need to reduce the cost of food production (33%), the decrease in forest production (25%), and planting biofuel-related plants (17%). Regarding the different types of regulating ES trade-offs, it was observed that urban expansion over agricultural forested semi-natural areas covered 42% of case study regions. The other drivers were considered less relevant, including intensified agricultural production (13%), former heavy industrial activity (8%), lack of general awareness about ES concepts (4%), food insecurity (4%), lack of effective (strict) planning (21%), and lastly, the overestimation of the need for economic development (17%).

3.3. Obstacles in Addressing Ecosystem Service Trade-Offs by Policy and Planning

Content analysis showed the recurring aspects in the answers to the open-ended questions about the obstacles to addressing different types of ES trade-offs by policy instruments and planning documents (Table A3). The obstacles are reported in Figure 4 together with their relative frequencies. The obstacle "The proposed policy instrument/planning document (PI/PD) is not explicitly addressing ES trade-offs" emerges as the most relevant. This answer points to a lack of adequate policy instruments or planning documents that can efficiently address the existence of peri-urban ES trade-offs in each case study region. This is particularly evident in the "Metropolitan areas" as reported in Figure 4.

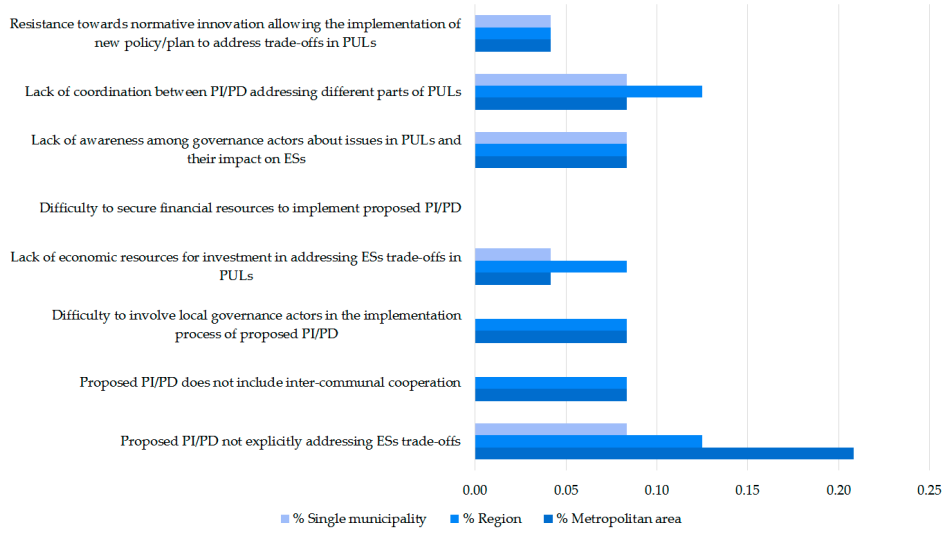

Figure 4. Type of identified possible obstacles (8 categories distributed by geographical area) related to ecosystem service (ES) trade-offs in peri urban landscapes (PULs). PD = planning document, PI = policy instrument.

In addition, a cross-analysis between the indicated obstacles and the seven categories of ES trade-offs was conducted to analyze the frequency distribution of the obstacles and categories of trade-offs (Figure A4). It can be interesting to observe how the three types of obstacles can interact with each category of ES trade-offs. In particular, the obstacle "resistance towards normative innovation" presented the highest frequencies for all categories of ES trade-offs, especially for "cultural vs. provisioning" and "regulating vs. provisioning". Further, the obstacle "it is difficult to constantly secure financial resources to implement the proposed policy instrument/planning document" has the lowest frequencies for all categories of ES trade-offs, except for the "different types of regulating ES trade-offs". In general, the latter is the category of ES trade-offs with the highest frequencies for all types of obstacles.

3.4. Improvements to Better Address Peri-Urban Ecosystem Service Trade-Offs in Policymaking and Planning

Content analysis showing the recurring aspects identified in the answers to the open-ended questions identifying improvements to better address peri-urban ES trade-offs in policymaking and planning, which are presented in Table A3. Further, we distilled several suggestions to address ES trade-offs. They are described in Figure 5 together with their relative frequencies. In terms of the type of possible improvements, it is observed that "implementation of the proposed policy instrument/planning document should be based on improved cooperation/communication of different governance actors" is the most relevant in more than 45% of the case studies.

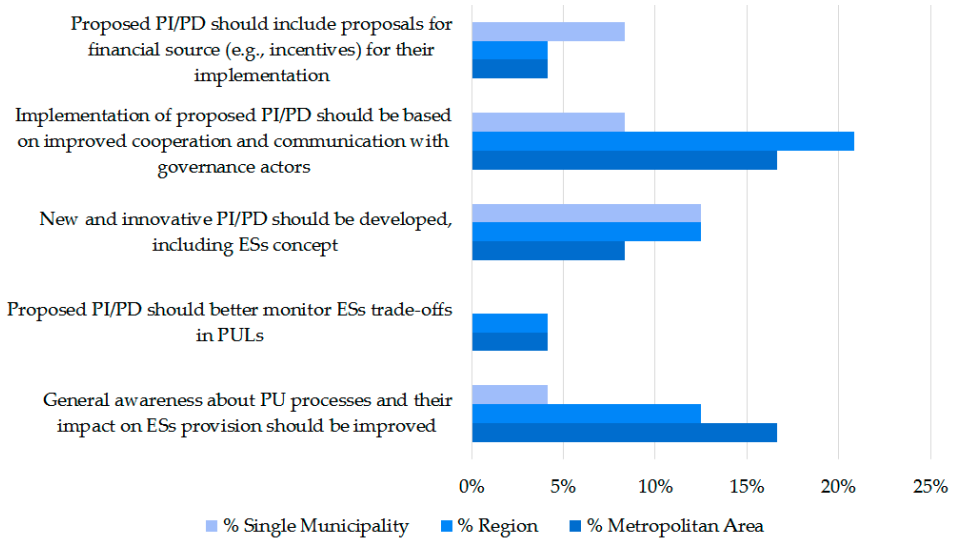

Figure 5. Types of identified improvements (categories from 1 to 5 by administrative level) proposed for better addressing ecosystem service (ES) trade-offs in peri-urban landscapes (PULs). PD = planning document, PI = policy instrument.

Moreover, the distribution of the data according to administrative level seems quite similar, where the categories "regional" and "metropolitan area" are the most preponderant ones. This study analyzed the existing connections (cross-analysis) among the types of possible improvements and categories of ES trade-offs (Figures A4 and A5). According to these results, the types of possible improvements, e.g., "general awareness about PU processes and specifically their impact on ES provision should be improved", and "new and innovative policy instrument/planning documents should be developed, which include/incorporate the ES concept based on a better understanding of this concept" have reported higher frequencies for all the categories of ES trade-offs. Furthermore, the "implementation of the proposed policy instrument/planning document should be based on the improved cooperation/communication of different governance actors" underlines the need for more interaction among all different governance actors.

4. Discussion

The supply and demand for urban ESs differ greatly across the globe [30]. In PULs, ESs are influenced by various increasing demands for food, recreation, and housing, which are driven by the characteristics of the cities and human settlements, where development policies address these demands by increasing housing and commercial site areas at the expense of agricultural and natural lands [31]. In our research, the case studies presented dissimilarities in their natural characteristics and showed different trade-offs, resulting in a greater dispersion in the multivariate analyses. The dispersion of the case studies based on natural characterization was mainly influenced by city size, e.g., large (A2) or small (A3) cities, or sparsely populated regions (A7). This dispersion was independent of the continent or development level of the country but was influenced by the geographical area size (e.g., single municipality compared to regional level). The increase in the rate of urbanization across the world, particularly in Europe, is causing ES losses, especially at the PUL level [32]. These changes affect their capacity to supply ESs [33], consequently decreasing human well-being for current and future generations [34]. While compact cities aim to reduce land consumption, densification puts pressure on the remaining green areas, influencing ES provision and ultimately the quality of life for the growing urban population [30,35]. Greater differences among geographical area types than among continents and development levels suggest that geographical area types are similar across continents (e.g., cultures) and development levels. In this sense, the characteristics of the single municipalities in these case studies were more similar to regional than metropolitan areas (e.g., SCR and JIG). Recent efforts to improve sustainability at the landscape level have increased the interest in connecting socioeconomic and biophysical systems, where cultural ESs are identified as one of the main influential factors at different spatiotemporal scales and levels of organization [36,37], e.g., the provision of ESs at the landscape level in Southern Patagonia was greatly influenced by cultural ESs, which are related to city size [36] and influence conservation and supporting ESs [38]. Additionally, another influential factor that differentiated the case studies based on their natural characteristics was the presence of water (e.g., inland wetlands and inland water). Water presence was identified as a powerful proxy for ES provision [31]. Water bodies influence cultural ESs [36] and have a positive effect on aesthetic values [39] and recreation due to the phenomenon of hydrophilia [40,41]. However, the magnitude of their influence is related to their abundance in the landscape, e.g., they influence cultural ESs more where they are scarce (e.g., arid landscapes in Southern Patagonia) and aesthetic values more where they are frequent (e.g., Tierra del Fuego mountain landscapes) [36].

The differences among the case studies based on trade-offs were less evident in the multivariate analyses. The most important factors distinguishing the case studies were the need for stricter protection of ecosystems as cultural and regulating ES trade-offs (F5), the need to provide food for a growing urban core as provisioning ES trade-offs (I1), and the emergence of regulating ESs in each case study (D6) (see Table A3). The second axis highlights the reduction in potential cultural ESs as cultural and provisioning ES trade-offs (E2), and the loss of cultural ESs as a trade-off among cultural ESs (H3). Cueva et al. [32] recommend that trade-off patterns among ESs in PULs must be considered in the management and design of city planning, where more multifunctional and climate-resilient areas must guarantee ESs and human well-being. These factors had a greater influence in East EU compared to the rest of the world (America, West EU, Africa, Asia), despite their geographical area type (single municipality, metropolitan area, regional) or development level (low, medium, high). This could suggest specific patterns of peri-urban development within East EU. This aspect would require more studies comparing PULs in East EU and other regions or concerning the peri-urbanization of Europe [42]. The differences among European PULs could be related to development patterns in both parts of the continent and planning traditions [43]. ES interactions need to be carefully managed by integrating different policy fields at regional and local levels to sustain ES provision in peri-urban areas [31].

4.1. Drivers of Ecosystem Service Trade-Offs in Peri-Urban Landscapes

Drivers in the context of ESs are understood as the direct factors influencing specific changes in ESs [44]. Respondents to the survey identified specific drivers but did not mention large-scale drivers related to the implementation of large-scale policies or plans, e.g., policies for nature conservation or national planning requirements. Many of the drivers identified in our study were characteristic of peri-urbanization processes. Similar to other studies on peri-urban issues [3,5], our results highlight that peri-urbanization processes like sealing surfaces, growth of an urban core, intensification of agricultural production, and transformation of productive farmlands into public areas are important drivers of ES trade-offs. Moreover, other processes not addressed by our study but still resulting from peri-urban development, such as increased land value or decreased water-retention potential, generate specific ES trade-offs in PULs. Aspects related to land use or land cover changes are also seen by other authors as significant drivers [9,45]. From the analysis of survey responses, different conflicts emerged, e.g., misunderstandings about land-use management, the promotion of specific ESs by governance actors, or tensions between new and old residents. This finding confirms how PULs are vulnerable to land use, socioeconomic, ethnic, and human–wildlife conflicts [46].

4.2. Governance of Ecosystem Service Trade-Offs in Peri-Urban Landscapes

As shown in the results section, ES trade-offs in PULs are related to various drivers. Among those drivers, different types of conflicts form a significant group. Mitigating peri-urban conflicts is an important task on the way from ES trade-offs to ES synergies in such contexts [46]. The results showed several obstacles concerning how ES trade-offs are addressed by policy instruments and spatial planning documents. Specifically, the lack of adequate policies or planning documents dealing with ES trade-offs was the most common obstacle. Currently, the scientific debate is looking at aspects of PUL governance and planning in a general way [47], with limited knowledge related to practical tools or policy experiences to mitigate ES trade-offs. Such knowledge is hidden in specific niches of governance, by local planners and policymakers implementing policy and planning on-site [3]. In terms of suggestions to improve the inclusion of ES trade-offs in policymaking and planning, the results suggest that there is a need to develop sufficient and effective methods for the cooperation of governance actors to pave the way from trade-offs to synergies. Thus, a way to improve ES trade-off governance should be based on identifying the variety of actors responsible for such trade-offs. The identification and cooperation of all groups of governance actors, such as planners, householders, citizens, farmers, students, and scientists, is very important for the successful implementation of sustainable development goals in peri-urban contexts [48]. Such cooperation can be implemented with the support of the Delphi method, which has shown its usefulness in consensus-building processes in PULs [49].

An initial step in establishing and implementing cooperation methods could be based on raising awareness about trade-offs. As other studies show, the ES concept proves its usefulness in participatory planning processes and can be used as a common language to communicate about the various benefits that people obtain from landscapes. To this end, basic training on the ES concept represents a fundamental step in raising awareness [22]. This is in line with our results, showing that more awareness is needed not only concerning the ES concept but also peri-urbanization as a multifaceted and open process. PULs, like other landscapes, need to be conceptualized in a holistic way. As displayed in the literature for several decades, holistic approaches have shown their usefulness in governance and planning [50]. To this end, addressing the social perspective of landscapes and specifically understanding that place-specific peri-urban flows and the way in which they are understood and managed by governance actors is a basis for human well-being could be a good starting point to mitigate ES trade-offs.

One of the basic challenges in developing and implementing governance instruments in PULs relies on the difficulty of delimiting such landscapes in a geographic and/or

administrative way [51]. This challenge aligns with the discussion about the most effective administrative level where peri-urban systems can be governed [52]. As they are part of wider metropolitan systems where cross-administrative boundary issues exist, there is a need for more complex and advanced planning schemes and instruments. Links among different planning levels should be revised and strengthened, from the master-plan level to zoning. It has been advocated that a combination of different governance tools (e.g., traditional and innovative, top-down and bottom-up) can be used at different and integrated scales, from the more strategic (e.g., the regional/metropolitan) to the more operational (urban/district). However, such a combination requires full coordination among different planning levels, which can be achieved only with a strong normative framework. Finally, it should be underlined that none of the respondents mentioned the possible use of more specific mechanisms or management approaches to address ES trade-offs, such as multicriteria decision analysis via participatory approaches, which can be a valuable practical instrument to facilitate the learning of ES trade-offs and the explicit identification and evaluation of stakeholders' preferences [53].

4.3. Limitations and Outlook

Our results are based on a relatively small number of analyzed case studies. Moreover, our set of case studies is dominated by European ones, with several located quite close to each other (e.g., case studies from northern Italy). Thus, it is important to keep in mind that the generalizations provided in this study must acknowledge this aspect. On the other hand, our online survey method allowed us to gather experiences directly related to specific governance activities implemented in the case study regions, which concern the governance of ES trade-offs in PULs. To further develop this study, methods allowing direct discussion with local governance actors who took part in policy or planning processes should be included. When selecting the case studies, we aimed to collect as many diverse examples of PULs as possible where ES trade-offs are described as problematic from the planning perspective. We chose this explorative approach because we believe more scholarship is needed to compare various processes related to ES trade-offs in peri-urban contexts across developed and less-developed regions. To the best of our knowledge, this study is a pioneer in this regard which can open a broader scientific discussion concerning the different urbanization and peri-urbanization processes taking place in the Global North and South regions. In our opinion, interesting scientific insights and useful planning and governance results can emerge from such research, which will be important for understanding and addressing different sustainability challenges, including ES trade-offs.

5. Conclusions

This research conducted an analysis of 24 regional case studies situated in peri-urban landscapes. It involved characterizing these landscapes, identifying similarity patterns, and offering insights into existing ES trade-offs. A notable clustering of case studies was observed based on geographical area type. Similar ES trade-offs were noted among North America, Western Europe, Africa, and Asia, with the most prevalent trade-offs being categorized as "cultural and provisioning" and "regulating and provisioning". The primary drivers of these trade-offs were directly linked to peri-urbanization, encompassing factors such as surface sealing, urban core expansion, and increased agricultural production intensity. Specific drivers were associated with various conflicts emerging in PULs. A significant challenge was the lack of identification and mitigation of these conflicts. This research identified a critical issue, e.g., the absence of explicit policy or planning documents addressing ES trade-offs in PULs, highlighting the need for innovative forms of governance. Furthermore, it emphasized the necessity of developing methods for fostering cooperation among governance actors to address these trade-offs in PULs. This collaborative effort should be rooted in a comprehensive dissemination and understanding of concepts such as ESs and PULs.

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Appendix A

Table A1. List of questions presented in the online survey.

Profile of the respondent
1. Country of residence
2. Type of institution
• University
• Research institute
• NGO
• Consultancy
• Public administration
• Company
• Other
Information about case study region
3. Characteristic of the case study region
A1 Urban region
A2 Region dominated by large cities (more than 500 K inhabitants) and metropolitan areas
A3 Region dominated by small (less than 100 K) and medium sized cities (100–500 K)
A4 Rural region
A5 Region dominated by natural ecosystems
A6 Densely populated region
A7 Sparsely populated region
4. Natural ecosystem types present in the case study region
Please provide multiple answers. The names are equivalent with CORINE land cover classes, level 2; see: https://land.copernicus.eu/user-corner/technical-library/corine-land-cover-nomenclature-guidelines/html, accessed on 1 December 2022.
B1 Urban fabric
B2 Industrial, commercial and transportation units
B3 Mine, dump and construction sites
B4 Artificial, non-agricultural vegetated areas
B5 Arable land
B6 Permanent crops
B7 Pastures
B8 Heterogeneous agricultural areas
B9 Forests, scrub and/or herbaceous vegetation associations
B10 Open spaces with little or no vegetation
B11 Inland wetlands
B12 Maritime wetlands
B13 Inland waters
B14 Marine waters

Table A1. *Cont.*

5. What types of ecosystem services (ESs) exist in your case study region?
Based on MEA—Millennium Ecosystem Assessment
C1 Provisioning: food
C2 Provisioning: fresh water
C3 Provisioning: fuelwood
C4 Provisioning: fiber
C5 Provisioning: biochemicals
C6 Provisioning: genetic resources
C7 Regulating: climate regulation
C8 Regulating: disease regulation
C9 Regulating: water regulation
C10 Regulating: water purification
C11 Cultural: spiritual and religious
C12 Cultural: recreation and ecotourism
C13 Cultural: aesthetics
C14 Cultural: inspirational
C15 Cultural: educational
C16 Cultural: sense of place
C17 Cultural: cultural heritage
C18 Supporting: soil formation
C19 Supporting: nutrient cycling
C20 Supporting: primary production

Ecosystem service (ES) trade-offs

6. Are ES trade-offs in PULs a challenge in your region which needs to be better addressed with policymaking and planning?
- Yes
- No

7. What kind of ES trade-offs emerge in your region? Please classify the trade-offs into:
D1 Cultural and provisioning ES trade-offs
D2 Cultural and regulating ES trade-offs
D3 Regulating and provisioning ES trade-offs
D4 Different types of cultural ES trade-offs
D5 Different types of provisioning ES trade-offs
D6 Different types of regulating ES trade-offs

8. Please explain why cultural and provisioning ES trade-offs in PULs are challenging in your region.
E1 Conflicting land uses and local governance actors advocating specific ESs
E2 Reduce the provision of the recreational, aesthetic and spiritual potential of semi-natural landscapes
E3 Reduce the amenity value of the PULs
E4 Reduce the productivity of farmlands
E5 Conflicts arising from intense recreational use of the farmland and agricultural infrastructure, unwanted trespassing, littering
E6 Aspects of accessibility to various ESs
E7 Private grounds traditionally used for growing vegetables have been replaced with lawns and playgrounds

9. Please explain why cultural and regulating ES trade-offs in PULs are challenging in your region.
F1 Hamper the regulating capacity of ecosystems
F2 Aspects of accessibility to various ESs
F3 Sealing surfaces
F4 Decrease in water-retention potential
F5 Necessity for stricter protection of ecosystems

10. Please explain why regulating and provisioning ES trade-offs in PULs are challenging in your region.
G1 Challenges related to forest management
G2 Conflicts related to food production
G3 Transformations of productive farmlands into public areas (green areas)

11. Please explain why different types of cultural ES trade-offs in PULs are challenging in your region.
H1 Conflicts between new and old PUL inhabitants related to the different expectations of those groups
H2 Increase in land value
H3 Loss of the sense of place, aesthetics, and spiritual values of PULs

12. Please explain why different types of provisioning ES trade-offs in PULs are challenging in your region.
I1 The need to provide food for a growing urban core
I2 The need to reduce the cost of food production
I3 Decrease in forest production
I4 The use of arable land for food or energy purposes
I5 Planting biofuel-related plants

Table A1. *Cont.*

13. Please explain why different types of regulating ES trade-offs in PULs are challenging in your region. **J1** Urban expansion over agricultural forested semi-natural areas **J2** Intensify agricultural production **J3** Former heavy industrial activity **J4** Lack of general awareness about the ES concept **J5** Food insecurity **J6** Lack of effective (strict) planning **J7** Overestimating the need for economic development
Policy instrument (PI) **14.** Please name the existing PI in your region which addresses ES trade-offs in PULs. **15.** Please shortly describe the existing PI in your region which addresses ES trade-offs in PULs. **16.** Please name the governance actors involved in the implementation of the PI. *Stakeholders defined as having a particular interest as they represent a community or group interest (stake); citizens/laymen as as the group being affected, but not organized to represent a shared interest; experts/scientists defined as objective knowledge holders* • Stakeholders • Citizens • Experts/scientists **17.** Please assess the efficiency of a specific PI in addressing the ES trade-offs in PULs. *Assessment on the Likert scale: 1—not efficient at all to 5—very efficient* **18.** What are the main obstacles related to this PI in better addressing ES trade-offs in PULs? *Please name the driver as described in questions 1.2–1.7 and please provide a short obstacle description for the chosen driver* **19.** What are the necessary improvements to your PI to better address ES trade-offs in PULs? *Please name the driver as described in questions 1.2–1.7 and please provide a short improvement description for the chosen driver*
Planning document (PD) **20.** Please name the existing PD in your region which addresses ES trade-offs in PULs **21.** Please shortly describe the existing PD in your region which addresses ES trade-offs in PULs **22.** Please name the governance actors involved in the implementation of the PD *Stakeholders defined as having a particular interest as they represent a community or group interest (stake); citizens/laymen as as the group being affected, but not organized to represent a shared interest; experts/scientists defined as objective knowledge holders* • Stakeholders • Citizens • Experts/scientists **23.** Please assess the efficiency of a specific PD in addressing the ES trade-offs in PULs *Assessment on the Likert scale: 1—not efficient at all to 5—very efficient* **24.** What are the main obstacles related to this PD in better addressing ES trade-offs in PULs? *Please name the driver as described in questions 1.2–1.7 and please provide a short obstacle description for the chosen driver* **25.** What are the necessary improvements to your PD to better address ES trade-offs in PULs? *Please name the driver as described in questions 1.2–1.7 and please provide a short improvement description for the chosen driver*

Table A2. List of peri-urban regions which are part of the study.

	Name of the Case Study Region	Country	Geographic Area
1	Ushuaia	Argentina	Single municipality
2	Patagonia valleys	Argentina	Regional
3	Kozani	Greece	Single municipality
4	Ferrara	Italy	Single municipality
5	Santa Cruz	Argentina	Regional
6	West Macedonia	Greece	Regional
7	Hinesburg, Vermont	United States	Regional
8	La Araucanía	Chile	Regional
9	Berlin Metro Area	Germany	Metropolitan area
10	Jigawa State	Nigeria	Regional
11	Area Metropolitana de Concepcion	Chile	Metropolitan area
12	Osrednjeslovenska region/Central Slovenian	Slovenia	Regional
13	Ulaanbaatar	Mongolia	Single municipality
14	Cardenas	Mexico	Regional
15	Greater Baku urban area.	Azerbaijan	Metropolitan area
16	Southern-east of Milan Metropolitan area	Italy	Metropolitan area
17	Mahiliou	Belarus	Single municipality
18	Wrocław Functional Area (WFA)	Poland	Metropolitan area
19	Ecuador	Ecuador	Regional
20	Trento	Italy	Single municipality
21	Gorgán Según	Iran	Regional
22	Niger Delta—Bakassi	Cameroon	Regional
23	Ikorodu	Nigeria	Regional
24	Metropolitan Area of Lisbon	Portugal	Metropolitan area

Table A3. Results of the content analysis of open-ended questions #18, #19, #24, and #25.

Section	Question with Its Number	Recurring Aspects Identified in the Answers to the Open-Ended Questions
Policy instrument (PI)	18. What are the main obstacles related to this PI in better addressing ES trade-offs in PULs?	1. The proposed PI is not explicitly addressing ES trade-offs 2. The proposed PI does include inter-communal cooperation 3. It is difficult to involve local governance actors in the implementation process of the proposed PI 4. There is an existing lack of economic resources for investment in addressing ES trade-offs in PULs 5. It is difficult to constantly secure financial resources to implement the proposed PI 6. There is a lack of awareness among governance actors about issues in PULs and specifically their impact on ES provision 7. There is a lack of coordination between different PIs that are addressing different parts of PULs 8. There is a resistance (for political or bureaucratic reasons) in normative innovation that would allow the implementation of a new policy/plan to address trade-offs in PULs
	19. What are the necessary improvements to your PI to better address ES trade-offs in PULs?	1. General awareness about peri-urbanization processes and specifically their impact on ES provision should be improved 2. The proposed PI should better monitor ES trade-offs in PULs 3. New and innovative PIs should be developed, which include/incorporate the ES concept (based on a better understanding of this concept) 4. Implementation of the proposed PI should be based on the improved cooperation/communication of different governance actors 5. The proposed PI should include options/proposals for financial sources (incentives, other economic/fiscal mechanisms) for their actual implementation
Planning document (PD)	24. What are the main obstacles related to this PD in better addressing ES trade-offs in PULs?	1. The proposed PD is not explicitly addressing ES trade-offs 2. The proposed PI does include inter-communal cooperation 3. It is difficult to involve local governance actors in the implementation process of the proposed PD 4. There is an existing lack of economic resources for investment in addressing ES trade-offs in PULs 5. It is difficult to constantly secure financial resources to implement the proposed PD 6. There is lack of awareness among governance actors about issues in PULs and specifically their impact on ES provision 7. There is a lack of coordination between different PDs that are addressing different parts of PULs 8. There is a resistance (for political or bureaucratic reasons) in normative innovation that would allow the implementation of a new policy/plan to address trade-offs in PULs
	25. What are the necessary improvements to your PD to better address ES trade-offs in PULs?	1. General awareness about peri-urbanization processes and specifically their impact on ES provision should be improved 2. The proposed PD should better monitor ES trade-offs in PULs 3. New and innovative PDs should be developed, which include/incorporate the ES concept (based on a better understanding of this concept) 4. Implementation of the proposed PD should be based on the improved cooperation/communication of different governance actors 5. The proposed PD should include options/proposals for financial sources (incentives, other economic/fiscal mechanisms) for their actual implementation

Table A4. Relevant ordination variables and eigenvector for Axes 1 and 2, according to characterization and ecosystem service (ES) trade-off PCA, performed for the 24 study cases. See codes for ordination variables in Table A1.

Characterization PCA			ES Trade-Off PCA		
Ordination Variable	**Eigenvector 1**	**Eigenvector 2**	**Ordination Variable**	**Eigenvector 1**	**Eigenvector 2**
A2	0.2403	−0.4514	D6	0.1174	0.3842
A3	−0.2403	0.4514	EE2	0.4642	0.1750
A7	−0.0743	0.4551	EE6	0.3799	−0.0747
B3	0.3885	−0.0313	F2	0.4116	0.2020
B6	0.3959	−0.1242	F5	0.3820	−0.3087
B11	0.4282	0.1888	H2	0.2655	−0.3465
B13	0.4736	0.0522	H3	0.3971	0.0373
C5	0.2713	0.3333	I1	0.0544	−0.5247
C6	0.2770	0.2548	J1	0.2477	0.3780
C18	0.1156	0.3934	J7	−0.1363	0.3748

Table A5. Multi-response permutation procedure (MRPP) results to compare differences in groups according to area type (single municipality—SM, metropolitan area—MA, regional—R), continent (America—AM, East Europe—EE, West Europe—WE, Africa—AFR, Asia—AS), and development level (low, medium, high), for the characterization and ecosystem service trade-offs informed by the 24 case studies, using a matrix with the more relevant ordination variables detected by PCA (Table A3).

Evaluation	Factor	Group Comparison	T	A	*p*
Characterization	Area type	Overall	−5.7936	0.2375	0.0002
		SM vs. MA	−5.3135	0.3816	0.0016
		SM vs. R	−1.7527	0.0593	0.0622
		MA vs. R	−5.8024	0.2189	0.0006
	Continent	Overall	−0.3613	0.0225	0.3265
		AM vs. EE	−0.2873	0.0197	0.3145
		AM vs. WE	−0.6628	0.0296	0.2090
		AM vs. AFR	−0.3652	0.0296	0.2838
		AM vs. AS	−0.4771	0.0368	0.2625
		EE vs. WE	−0.5960	0.0403	0.2423
		EE vs. AFR	−0.7851	0.1478	0.1988
		EE vs. AS	0.2068	−0.0241	0.5324
		WE vs. AFR	0.4552	−0.0414	0.6023
		WE vs. AS	0.8596	−0.0617	0.8069
		AFR vs. AS	−0.2455	0.0408	0.2984
	Development level	Overall	1.0592	−0.0427	0.8864
		low vs. medium	0.2140	−0.0100	0.9566
		low vs. high	0.8851	−0.0446	0.8588
		medium vs. high	1.1407	−0.0401	0.9566
ES trade-offs	Geographic area type	Overall	−0.9641	0.0282	0.1620
		SM vs. MA	0.5121	−0.0248	0.6704
		SM vs. R	−0.7101	0.0195	0.2115
		MA vs. R	−1.4056	0.0373	0.0922
	Continent	Overall	−1.1085	0.0493	0.1353
		AM vs. EE	−2.2379	0.0957	0.0220
		AM vs. WE	−0.8133	0.0247	0.1963
		AM vs. AFR	−0.0393	0.0023	0.4161
		AM vs. AS	0.7748	−0.0378	0.7685
		EE vs. WE	−2.1406	0.1221	0.0327
		EE vs. AFR	−2.4655	0.2530	0.0255
		EE vs. AS	−1.6393	0.1227	0.0643
		WE vs. AFR	−0.9495	0.0554	0.1624
		WE vs. AS	0.8070	−0.0539	0.7814
		AFR vs. AS	1.3425	−0.1332	0.9194
	Development level	Overall	0.2219	−0.0064	0.5457
		low vs. medium	−0.2400	0.0080	0.3345
		low vs. high	0.9391	−0.0347	0.8322
		medium vs. high	−0.3246	0.0080	0.3380

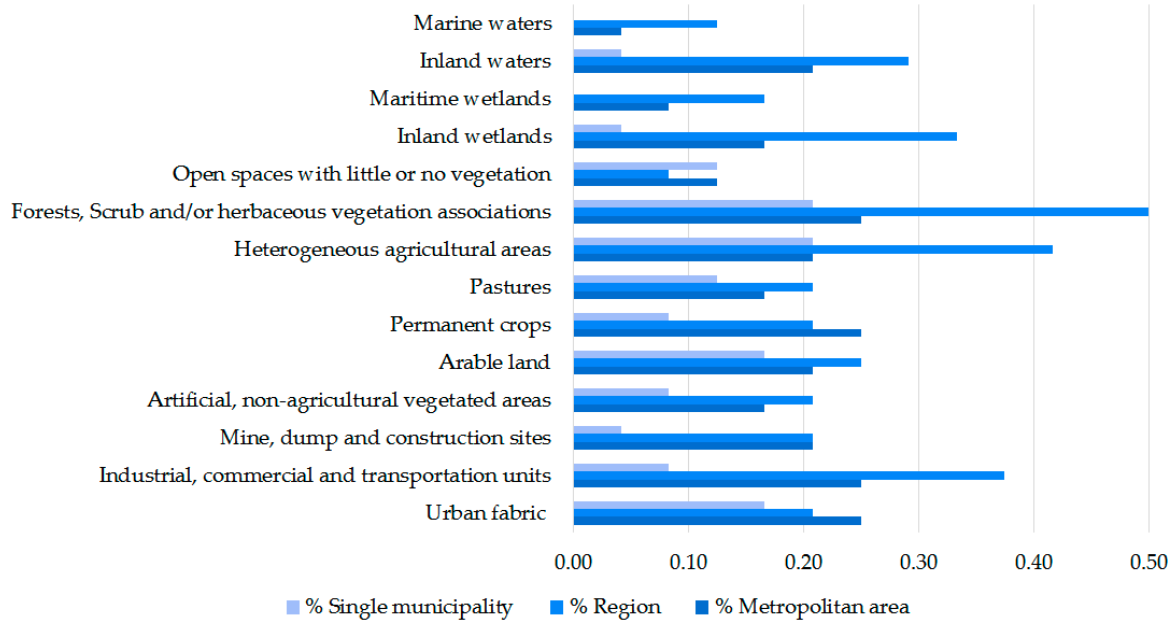

Figure A1. Distribution of the relative frequency of data on the types of ecosystems present in the case study regions.

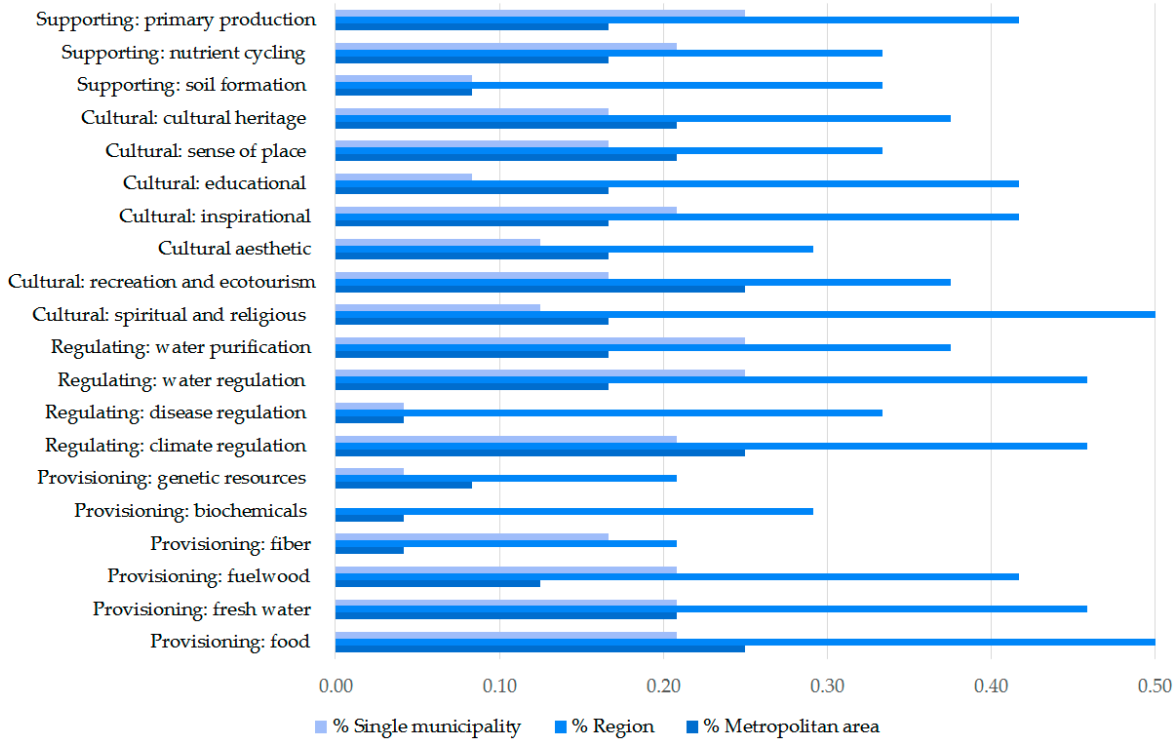

Figure A2. Relative frequency of the data distribution concerning the types of ecosystem services in the case study regions.

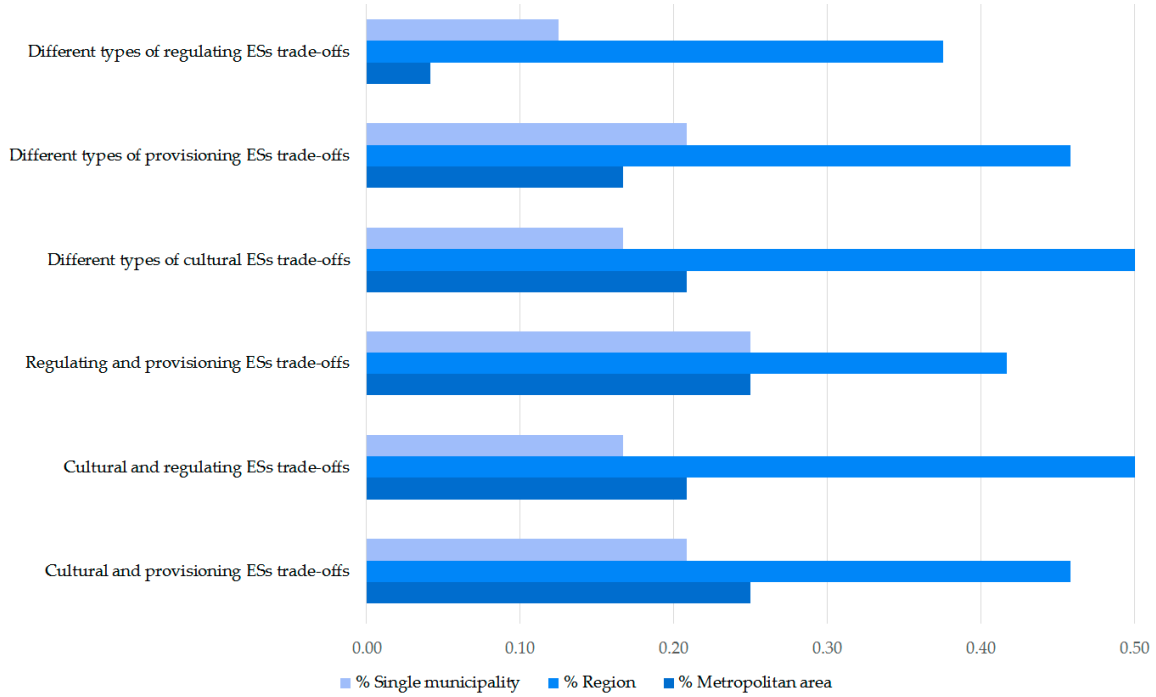

Figure A3. Relative frequency of the data distribution concerning the pairs of peri-urban ecosystem service trade-offs in the case study regions, across the geographic area categories.

	Resistance towards normative innovation that would allow the implementation of new policy/plan to address trade-offs in PULs	Lack of coordination between PI/PD addressing different parts of PULs	Lack of awareness among governance actors about issues in PULs and their impact on ESs provision	Difficulty to secure financial resources to implement proposed PI/PD	Lack of economic resources for investment in addressing ESs trade-offs in PULs	Difficulty to involve local governance actors in the implementation process of proposed PI/PD	Proposed PI/PD does not include inter-communal cooperation	Proposed PI/PD is not explicitly addressing ESs trade-offs
Cultural and provisioning ESs trade-offs	3	6	5	0	3	3	3	10
Cultural and regulating ESs trade-offs	3	6	5	0	3	4	3	8
Regulating and provisioning ESs trade-offs	2	6	6	0	3	3	3	10
Different types of cultural ESs trade-offs	3	6	5	0	3	4	3	8
Different types of provisioning ESs trade-offs	3	4	6	0	4	3	1	7
Different types of regulating ESs trade-offs	2	5	3	0	3	3	2	5

Figure A4. Cross-analysis between the identified obstacles concerning how ecosystem service (ES) trade-offs in peri-urban landscapes (PULs) are addressed by policy instruments and spatial planning documents and the seven categories of ES trade-offs. PD = planning document, PI = policy instrument. Colors varied from minimum (green) to maximum (red).

	Proposed PI/PD should include options for financial sources (e.g., incentives) for their implementation	Implementation of the proposed PI/PD should be based on improved cooperation and communication of different governance	New and innovative PI/PD should be developed including ESs concept	Proposed PI/PD should better monitor ESs trade-offs in PULs	General awareness about PU processes and their impact on ESs provision should be improved
Cultural and provisioning ESs trade-offs	3	9	8	2	8
Cultural and regulating ESs trade-offs	3	8	7	1	7
Regulating and provisioning ESs trade-offs	3	10	8	2	8
Different types of cultural ESs trade-offs	3	8	8	2	8
Different types of provisioning ESs trade-offs	4	7	7	1	7
Different types of regulating ESs trade-offs	3	4	6	1	3

Figure A5. Cross-analysis between the identified improvements to better address peri-urban ecosystem service (ES) trade-offs in policymaking and planning and the seven categories of ES trade-offs. PD = planning document, PI = policy instrument. Colors varied from minimum (green) to maximum (red).

References

1. Bennett, E.M.; Peterson, G.D.; Gordon, L.J. Understanding relationships among multiple ecosystem services. *Ecol. Let.* **2009**, *12*, 1394–1404. [CrossRef] [PubMed]
2. Piorr, A.; Ravetz, J.; Tosics, I. Peri-Urbanisation in Europe. Towards European Policies to Sustain Urban-Rural Futures. Synthesis Report. 2011. Available online: https://www.openspace.eca.ed.ac.uk (accessed on 30 May 2024).
3. Spyra, M.; La Rosa, D.; Zasada, I.; Sylla, M.; Shkaruba, A. Governance of ecosystem services trade-offs in peri-urban landscapes. *Land Use Pol.* **2020**, *95*, e104617. [CrossRef]
4. Pinto-Correia, T.; Primdahl, J.; Pedroli, B. *European Landscapes in Transition: Implications for Policy and Practice*; Cambridge University Press: Cambridge, UK, 2018. [CrossRef]
5. Spyra, M.; Kleemann, J.; Caló, N.C.; Schürmann, A.; Fürst, C. Protection of peri-urban open spaces at the level of regional policy-making: Examples from six European regions. *Land Use Pol.* **2021**, *107*, e105480. [CrossRef]
6. Rodríguez, J.P.; Beard, T.D., Jr.; Bennett, E.M.; Cumming, G.S.; Cork, S.J.; Agard, J.; Dobson, A.P.; Peterson, G.D. Trade-offs across space, time, and ecosystem services. *Ecol. Soc.* **2006**, *11*, e28. [CrossRef]
7. Turkelboom, F.; Leone, M.; Jacobs, S.; Kelemen, E.; García-Llorente, M.; Baró, F.; Termansen, M.; Barton, D.N.; Berry, P.; Stange, E.; et al. When we cannot have it all: Ecosystem services trade-offs in the context of spatial planning. *Ecosyst. Serv.* **2018**, *29*, 566–578. [CrossRef]
8. Zhou, W.; Yu, W.; Qian, Y.; Han, L.; Pickett, S.; Wang, J.; Li, W.; Ouyang, Z. Beyond city expansion: Multi-scale environmental impacts of urban megaregion formation in China. *Natl. Sci. Rev.* **2022**, *9*, 1–13. [CrossRef] [PubMed]
9. Zheng, H.; Wang, L.; Wu, T. Coordinating ecosystem service trade-offs to achieve win–win outcomes: A review of the approaches. *J. Environ. Sci.* **2019**, *82*, 103–112. [CrossRef] [PubMed]
10. Tomscha, S.A.; Gergel, S.E. Ecosystem service trade-offs and synergies misunderstood without landscape history. *Ecol. Soc.* **2016**, *21*, e43. [CrossRef]
11. Dade, M.C.; Mitchell, M.; McAlpine, C.A.; Rhodes, J.R. Assessing ecosystem service trade-offs and synergies: The need for a more mechanistic approach. *Ambio* **2019**, *48*, 1116–1128. [CrossRef]
12. Wong, C.P.; Jiang, B.; Kinzig, A.P.; Lee, K.N.; Ouyang, Z. Linking ecosystem characteristics to final ecosystem services for public policy. *Ecol. Let.* **2015**, *18*, 108–118. [CrossRef]
13. Deng, X.; Li, Z.; Gibson, J.A. Review on trade-off analysis of ecosystem services for sustainable land-use management. *J. Geogr. Sci.* **2016**, *26*, 953–968. [CrossRef]
14. Yang, S.; Zhao, W.; Liu, Y.; Wang, S.; Wang, J.; Zhai, R. Influence of land use change on the ecosystem service trade-offs in the ecological restoration area: Dynamics and scenarios in the Yanhe watershed, China. *Sci. Total Environ.* **2018**, *644*, 556–566. [CrossRef] [PubMed]

15. Nelson, E.; Mendoza, G.; Regetz, J.; Polasky, S.; Tallis, H.; Cameron, D.; Chan, K.M.; Daily, G.C.; Goldstein, J.; Kareiva, P.M.; et al. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and trade-offs at landscape scales. *Front. Ecol. Environ.* **2009**, *7*, 4–11. [CrossRef]
16. Howe, C.; Suich, H.; Vira, B.; Mace, G.M. Creating win-wins from trade-offs? Ecosystem services for human well-being: A meta-analysis of ecosystem service trade-offs and synergies in the real World. *Glob. Environ. Change* **2014**, *28*, 263–275. [CrossRef]
17. Montoya, D.; Haegeman, B.; Gaba, S.; De Mazancourt, C.; Bretagnolle, V.; Loreau, M. Trade-offs in the provisioning and stability of ecosystem services in agroecosystems. *Ecol. Appl.* **2019**, *29*, e01853. [CrossRef] [PubMed]
18. Ko, H.; Son, Y. Perceptions of cultural ecosystem services in urban green spaces: A case study in Gwacheon, Republic of Korea. *Ecol. Indic.* **2018**, *91*, 299–306. [CrossRef]
19. Olsson, E.; Kerselaers, E.; Søderkvist Kristensen, L.; Primdahl, J.; Rogge, E.; Wästfelt, A. Peri-urban food production and its relation to urban resilience. *Sustainability* **2016**, *8*, e1340. [CrossRef]
20. Braun, V.; Clarke, V.; Boulton, E.; Davey, L.; McEvoy, C. The online survey as a qualitative research tool. *Int. J. Soc. Res. Methodol.* **2021**, *24*, 641–654. [CrossRef]
21. van Selm, M.; Jankowski, N.W. Conducting online surveys. *Qual. Quant.* **2006**, *40*, 435–456. [CrossRef]
22. Palacios-Agundez, I.; Rodríguez-Loinaz, G.; Hagemann, N.; Sylla, M.; Spyra, M. Teaching the ecosystem service concept: Experience from Academia. *Ecol. Soc.* **2022**, *27*, e2. [CrossRef]
23. Jolliffe, I.T.; Cadima, J. Principal Component Analysis: A review and recent developments. *Philos. Trans. R. Soc. Math. Phys. Eng. Sci.* **2016**, *374*, e2065. [CrossRef] [PubMed]
24. Jolliffe, I. *Principal Component Analysis*; Springer: New York, NY, USA, 2002.
25. Pearson, K. On lines and planes of closest fit to systems of points in space. *Lond. Edinb. Dublin Philos. Mag. J. Sci.* **1901**, *2*, 559–572. [CrossRef]
26. UNDP—United Nations Development Programme. *Human Development Reports the Next Frontier: Human Development and the Anthropocene*; UNDP: New York, NY, USA, 2020; p. 412. Available online: https://hdr.undp.org (accessed on 30 May 2024).
27. McCune, B.; Grace, J.B. *Analysis of Ecological Communities*; MjM Software Design: Gleneden Beach, OR, USA, 2002.
28. Zimmerman, G.M.; Goetz, H.; Mielke, P.W. Use of an improved statistical method for group comparisons to study effects of prairie fire. *Ecology* **1985**, *66*, 606–611. [CrossRef]
29. McCune, B.; Mefford, M.J. *PC-ORD: Multivariate Analysis of Ecological Data*; MjM Software Design: Gleneden Beach, OR, USA, 1999.
30. Grêt-Regamey, A.; Galleguillos-Torres, M.; Dissegna, A.; Weibel, B. How urban densification influences ecosystem services: Comparison between a temperate and a tropical city. *Environ. Res. Let.* **2020**, *15*, e075001. [CrossRef]
31. Sylla, M.; Hagemann, N.; Szewrański, S. Mapping trade-offs and synergies among peri-urban ecosystem services to address spatial policy. *Environ. Sci. Pol.* **2020**, *112*, 79–90. [CrossRef]
32. Cueva, J.; Yakouchenkova, I.A.; Fröhlich, K.; Dermann, A.F.; Dermann, F.; Köhler, M.; Grossmann, J.; Meier, W.; Bauhus, J.; Schröder, D.; et al. Synergies and trade-offs in ecosystem services from urban and peri-urban forests and their implication to sustainable city design and planning. *Sustain. Cities Soc.* **2022**, *82*, e103903. [CrossRef]
33. Hirokawa, K.H. Sustainability and the urban forest: An ecosystem services perspective. *SSRN Electron. J.* **2011**, *11*, 233–259. [CrossRef]
34. de Groot, R.S.; Alkemade, R.; Braat, L.; Hein, L.; Willemen, L. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecol. Complex.* **2010**, *7*, 260–272. [CrossRef]
35. Li, B.; Chen, D.; Wu, S.; Zhou, S.; Wang, T.; Chen, H. Spatio-temporal assessment of urbanization impacts on ecosystem services: Case study of Nanjing city, China. *Ecol. Indic.* **2016**, *71*, 416–427. [CrossRef]
36. Martínez Pastur, G.; Peri, P.L.; Lencinas, M.V.; García-Llorente, M.; Martín-López, B. Spatial patterns of cultural ecosystem services provision in Southern Patagonia. *Land. Ecol.* **2016**, *31*, 383–399. [CrossRef]
37. Zoeller, K.C.; Gurney, G.G.; Cumming, G.S. The influence of landscape context on the production of cultural ecosystem services. *Land. Ecol.* **2022**, *37*, 883–894. [CrossRef]
38. Rosas, Y.M.; Peri, P.L.; Lencinas, M.V.; Lizarraga, L.; Martínez Pastur, G. Multi-taxon biodiversity assessment of Southern Patagonia: Supporting conservation strategies at different landscapes. *J. Environ. Manag.* **2022**, *307*, e114578. [CrossRef] [PubMed]
39. García-Llorente, M.; Martín-López, B.; Iniesta-Arandia, I.; López-Santiago, C.A.; Aguilera, P.A.; Montes, C. The role of multi-functionality in social preferences toward semi-arid rural landscapes: An ecosystem service approach. *Environ. Sci. Pol.* **2012**, *19–20*, 136–146. [CrossRef]
40. Abildtrup, J.; Garcia, S.; Olsen, S.B.; Stenger, A. Spatial preference heterogeneity in forest recreation. *Ecol. Econ.* **2013**, *92*, 67–77. [CrossRef]
41. Termansen, M.; McClean, C.J.; Skov-Petersen, H. Recreational site choice modelling using high-resolution spatial data. *Environ. Plan.* **2004**, *36*, 1085–1099. [CrossRef]
42. Shaw, B.J.; van Vliet, J.; Verburg, P.H. The peri-urbanization of Europe: A systematic review of a multifaceted process. *Land. Urban Plan.* **2020**, *196*, e103733. [CrossRef]
43. Hoggart, K. *The City's Hinterland: Dynamism and Divergence in Europe's Peri-Urban Territories*; Routledge: London, UK, 2016.
44. Cord, A.F.; Bartkowski, B.; Beckmann, M.; Dittrich, A.; Hermans-Neumann, K.; Kaim, A.; Lienhoop, N.; Locher-Krause, K.; Priess, J.; Schröter-Schlaack, C.; et al. Towards systematic analyses of ecosystem service trade-offs and synergies: Main concepts, methods and the road ahead. *Ecosyst. Serv.* **2017**, *28*, 264–272. [CrossRef]
45. Wang, L.; Zheng, H.; Wen, Z.; Liu, L.; Robinson, B.E.; Li, R.; Li, C.; Kong, L. Ecosystem service synergies/trade-offs informing the supply-demand match of ecosystem services: Framework and application. *Ecosyst. Serv.* **2019**, *37*, e100939. [CrossRef]

46. Kleemann, J.; Struve, B.; Spyra, M. Conflicts in urban peripheries in Europe. *Land Use Pol.* **2023**, *133*, e106849. [CrossRef]
47. Tan, J.; Gu, K.; Zheng, Y. Peri-urban planning: A landscape perspective. *Plan. Theory* **2024**, *23*, 42–63. [CrossRef]
48. Rozas-Vásquez, D.; Spyra, M.; Jorquera, F.; Molina, S.; Caló, N.C. Ecosystem services supply from peri-urban landscapes and their contribution to the sustainable development goals: A global perspective. *Land* **2022**, *11*, e2006. [CrossRef]
49. Gomes, S.L.; Hermans, L.M.; Butsch, C.; Banerjee, P.S.; Luft, S.; Chakraborty, S.A. Delphi-based methodology for participatory adaptation pathways building with local stakeholders: Methodological considerations and an illustrative application in peri-urban India. *Environ. Dev.* **2023**, *46*, e100822. [CrossRef]
50. Antrop, M.; van Eetvelde, V. Holistic aspects of suburban landscapes: Visual image interpretation and landscape metrics. *Land. Urban Plan.* **2000**, *50*, 43–58. [CrossRef]
51. Sahana, M.; Ravetz, J.; Patel, P.P.; Dadashpoor, H.; Follmann, A. Where is the peri-urban? A systematic re-view of peri-urban research and approaches for its identification and demarcation worldwide. *Rem. Sen.* **2023**, *15*, e1316. [CrossRef]
52. Kline, J.D.; Thiers, P.; Ozawa, C.P.; Alan Yeakley, J.; Gordon, S.N. How well has land-use planning worked under different governance regimes? A case study in the Portland, OR-Vancouver, WA Metropolitan area, USA. *Land. Urban Plan.* **2014**, *131*, 51–63. [CrossRef]
53. Saarikoski, H.; Mustajoki, J.; Hjerppe, T.; Aapala, K. Participatory multi-criteria decision analysis in valuing peatland ecosystem services: Trade-offs related to peat extraction vs. pristine peatlands in southern Finland. *Ecol. Econ.* **2019**, *162*, 17–28. [CrossRef]