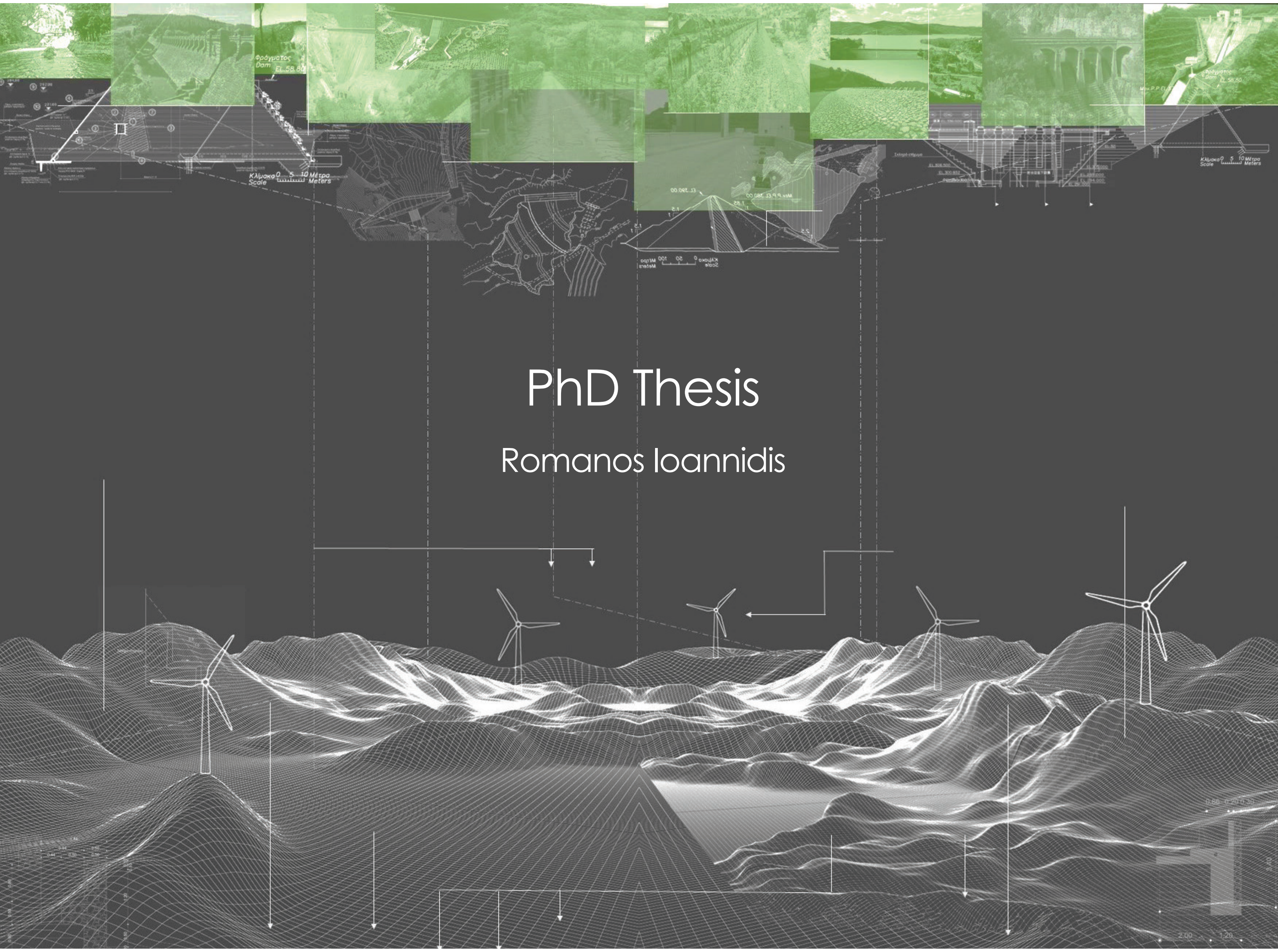
SPATIAL PLANNING AND ARCHITECTURAL DESIGN FOR THE INTEGRATION OF CIVIL INFRASTRUCTURE INTO LANDSCAPES

Inferences from renewable energy works and dams



PhD Thesis

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ΧΩΡΙΚΟΣ ΚΑΙ ΑΡΧΙΤΕΚΤΟΝΙΚΟΣ ΣΧΕΔΙΑΣΜΟΣ ΓΙΑ ΤΗΝ ΕΝΤΑΞΗ ΤΩΝ ΕΡΓΩΝ ΥΠΟΔΟΜΗΣ ΣΤΟ ΤΟΠΙΟ

Συμπεράσματα από τα έργα ανανεώσιμης ενέργειας και τα φράγματα

Διδακτορική διατριβή

Ρωμανός Ιωαννίδης

EXTENDED ABSTRACT

The case of renewable energy (RE) has demonstrated that the integration of civil infrastructure into landscapes can be a major challenge. Negligence over impacts to natural and cultural characteristics of landscapes and marginalization of communities affected by those impacts, can lead to a vicious cycle of public unrest and developmental disorder. In this work, we initially investigate how civil infrastructure transforms landscapes, both quantitatively-spatially and qualitatively-perceptually. Then, utilizing the results of this investigation we proceed with proposing upgrades to spatial planning and architectural design of infrastructure, aiming for its improved integration into landscapes. The study goes into more detail in the study of wind, solar, hydroelectric energy works and dams but the inferences drawn refer to all major infrastructure works. The analysis is structured in three hierarchical levels of analysis at gradually decreasing spatial scales:

(A) Global scale – Comparative assessment of the generic landscape impacts of different types of infrastructure works:

Stakeholders in the development of infrastructure are often uncertain about whether landscape impacts are a genuine and objective issue or whether they should be attributed to biased NIMBY (not in my back yard) dispositions by the public. This uncertainty eventually conflicts with the development of optimal design methods for the mitigation of impacts. For this reason, our analysis initiates with an investigation of whether the extents and the severity of landscape impacts of different types of infrastructure can be generically and objectively quantified and compared. RE works were analysed in detail in this regard, utilizing literature and data from realized projects, from global sources. Three established metrics of landscape impacts were elected as insightful indicators of landscape impacts: land use, visibility and public perception. Through the investigation of these metrics, it was demonstrated that wind energy works have been, on average, the most impactful to landscapes, per unit energy generation, followed by solar photovoltaic projects and hydroelectric dams, respectively. More broadly, it was concluded that different types of infrastructure indeed have different generic landscape impacts and therefore different mitigation approaches are suitable in each case. These approaches are highly dependent on: (i) whether the examined infrastructure-type is perceived negatively by the public, within landscapes, (ii) the spatial extents of its visual impacts and land-use requirements and (iii) its receptivity or not of architectural treatment.

(B) National & regional scale - Improving spatial planning for landscape integration of infrastucture:

At this scale, emphasis is given on the treatment of types of infrastructure works that receive strong criticism over their visual impacts. So far, visibility analysis has been established as the

primary tool that informs the siting of projects, in order to reduce their visibility from within scenic landscapes. However, conventional visibility analyses have limited utility as a planning tool since they can only be applied in late planning stages when project's locations have already been finalized. This is due to the fact that they require those locations as input. We thus propose reversing visibility analyses by using the locations of protected landscape elements as their input. This methodological shift allows for the generation of fixed landscape-protection maps surrounding important landscape elements. Such maps enjoy the advantages of: (i) proactiveness, as they can be used to anticipate landscape impacts from earlier planning stages, before projects' locations have been finalized, (ii) time-saving, as they only need to be calculated once within a region or country, discarding the requirement for individual visibility analyses for each new project and (iii) better compatibility with participatory planning processes. The implementation of reverse visibility analysis was also investigated in practice, in the region of Thessaly, Greece, where Reverse – Zone of Theoretical Visibility (R-ZTV) maps were formed and used to project visual impacts from planned wind energy projects to the protected landscape elements of the region.

(C) Project's site scale – The utility, costs and potential of architectural and landscape design:

At this scale, we investigated the architectural treatment of infrastructure works, in the context of mitigating their landscape impacts. To this aim, we formulated a typology of global practices of architectural and landscape design in dams and analyzed them from a cost-benefit perspective. The analysis demonstrated that the implementation of architectural and landscape design (i) can measurably improve the public perception of infrastructure and (ii) that there are no insurmountable technical or cost-associated limitations to its wider implementation. It is thus overall argued that architectural and landscape design studies could and should be implemented more widely to infrastructure projects that can receive such treatment.

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SELECTED PUBLICATIONS

1. Ioannidis, R., & Koutsoyiannis, D. (2020). A review of land use, visibility and public perception of renewable energy in the context of landscape impact. *Applied Energy*, *276*, 115367.
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2. Ioannidis, R., Mamassis, N., Efstratiadis, A., & Koutsoyiannis, D. (2022). Reversing visibility analysis: Towards an accelerated a priori assessment of landscape impacts of renewable energy projects. *Renewable and Sustainable Energy Reviews*, *161*, 112389. https://doi.org/10.1016/j.rser.2022.112389
3. Ioannidis, R., Sargentis, G. F., & Koutsoyiannis, D. (2022). Landscape design in infrastructure projects-is it an extravagance? A cost-benefit investigation of practices in dams. *Landscape Research*, 1-18.
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The complete list of publications carried out during this PhD research are presented in Appendix H

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CONTENTS

1 INTRODUCTION

1.1 Research context and aims

What are landscape impacts and how are they related to infrastructure projects?

In the community of engineers, the term "landscape" is often confused as a synonym for the term "environment". Thus, landscape impacts are falsely considered identical to environmental-ecological impacts (Ananiadou-Tzimopoulou, 2013; Chen et al., 2018; De Block et al., 2019). The basic difference between the two concepts however, is that environmental impacts refer to changes to the environment while landscape impacts refer to how such changes are perceived by people (Moraitis, 2012). This is explicitly described in the definition of landscape by the European Landscape Convention: "Landscape means an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors" (Council of Europe, 2000); the "as perceived by people" clause expresses exactly this point. In the case of infrastructure projects, we could specify the definition of their landscape impacts to: changes to how areas are perceived by the public after the transformation of their natural and/or cultural characteristics by works of infrastructure.

During the last two decades, the landscape impacts of infrastructure projects have been the subject of increasing numbers of scientific studies as do the methods that can be applied for their mitigation. This emergent research interest has evidently been induced by the significant landscape-associated issues that have been met during the development of renewable energy (RE). These issues have acted as an alert that the integration of civil infrastructure to landscapes can be a major challenge which can easily become the source of developmental issues. In the case of RE, in particular, landscape impacts have often been identified as the primary or one of the major drivers of opposition movements against new projects (Jefferson, 2018; Pasqualetti, 2011; Wolsink, 2007a). The impacts of RE works to the natural and cultural character of landscapes are in many cases perceived as intrusive by local communities, causing unrest both about potential economic impacts and potential degradation of the aspects of their quality of life that are associated with landscape quality. This worry over impeding landscape impacts has been inciting public opposition against projects, which in turn causes social unrest and delays or even cancellations of projects (Azau, 2011; Ioannidis and Koutsoyiannis, 2020; Scherhaufer et al., 2017).

The aim of this research is to contribute to the improvement of the planning and design methods for the mitigation of landscape impacts of infrastructure. The anticipated utility of this effort is (a) the minimization of impacts to the quality of life of communities in the proximity of infrastructure projects and (b) the prevention of conflicts of local communities with the public or private bodies that develop infrastructure projects and consequently the facilitation of the development of infrastructure. It is noted that when targeted strategies and measures for the mitigation of landscape impacts are not implemented, the resultant conflicts can become lose-lose for both ends, i.e., project opposition and project backers. In the case of Renewable Energy for example, the inadequate implementation of landscape protection measures has led on the one hand, to the delayed development of RE due to opposition induced by fear of landscape-impacts while on the other, to landscapes actually being significantly impacted by RE infrastructure. This perpetuates a cycle of conflict, unrest, developmental problems and negative effects on the quality of life of local communities. It is therefore reasonable to argue that, overall, effective measures for the mitigation of landscape impacts can contribute both to safeguarding the quality of life of affected communities and to the efficient development of infrastructure.

In the remaining Sections of the introduction, the theoretical and empirical context of the study is analysed in more detail. In particular, in Section 1.2 the case of RE is presented in more detail as a practice-oriented example of the negative developmental and social impacts from neglecting the landscape integration of infrastructure works, in Section 1.3 the utility of landscape integration of civil infrastructure is analysed from a theoretical perspective, with a focus on its correlation with quality of life of communities in the proximity of projects, in Section 1.4 the research questions of the study are presented in detail and finally, in Section 1.6 the structure of the remaining parts of the thesis is presented.

1.2 In practice: Landscape impact as a cause of public unrest and developmental disorder - the case of renewable energy

Problems associated with the integration of infrastructure into landscapes have been studied in academic literature in various points in time and for various different types of infrastructure. Early references of landscape impacts of infrastructure include various types of works that emerged after the industrial revolution, such as transmission lines (Priestley and Evans, 1996), roadworks (Fischer et al., 2000) and dams (Christofides et al., 2005). In the last few decades, however, issues of landscape integration of infrastructure have come to be at the forefront of academic research more than ever before, with the spotlight aimed at renewable energy projects (Chiabrando et al., 2009; Fischer et al., 2000; Stevenson and Griffiths, 1994). The observation of this ongoing transformation to landscapes from RE works is what prompted the present research. From a social perspective, RE is subject to a major contradiction. On the one hand, there seems to be general support for renewables (Mirasgedis et al., 2014; Tegou et al., 2010; Wolsink, 2007b), yet on the other strong oppositions movements against numerous projects under development persist (Ioannidis and Koutsoyiannis, 2020). In this Section, we aim to further illuminate this issue, as it is considered an insightful example of how the landscape impacts of infrastructure can intertwine with its expansion, both in terms of inciting public unrest and causing developmental disorder.

Opposition movements against RE developments on grounds of landscape-impacts, have been causing delays and cancellations which have been linked with significant economic ramifications. The relevant examples are abundant. In the USA, for example, lawsuits with legal arguments related to landscape, visibility and aesthetics have been consistently filed against wind and, to a lesser extent. solar energy developments[1] (Brown and Escobar, 2007; Butler, 2009; Elkind et al., 2018; Lewis, 2014; Pasqualetti and Stremke, 2018; Phadke, 2009). As a result, renewable energy projects constitute a significant percentage of the large number of projects that have been challenged on environmental grounds, with reference to the National Environmental Protection Act, federal Environmental Quality Acts and Environmental Protection Acts (Pociask and Fuhr Jr, 2011; Schneider and Takahashi, 2011). As indicative to the economic impact of such litigations, we present the 2010 study by the US Chamber of Commerce, in which 351 challenged and delayed projects were compiled and analysed. In that study, it was estimated that the US economy was deprived of a $1.1 trillion short-term economic boost and of 1.9 million jobs annually, due to the examined legal challenges (Pociask and Fuhr Jr, 2011). It has to be noted though that neither all of the examined projects were RE projects (45% of them were RE projects) nor a specific percentage of the litigations that were grounded on legal arguments over visual and landscape impacts was provided. Nevertheless, the numbers presented are indicative of the large-scale economic repercussions from the cancellation or delay of large-scale energy projects.

Similar problems have also emerged in the European Union (Nadaï and Labussière, 2017; Pasqualetti, 2011; Uyterlinde et al., 2017; Wolsink, 2000). We present the case of Greece in more detail as an example (Kaldellis et al., 2012). In Greece, in 2017 and 2018, the installed capacity of only some of the major wind energy projects that were challenged summed 1237.7 MW (Table 1). Even though landscape impacts were not mentioned in all of the relevant litigations, it was often evident from the channels of communication of the opposing groups (public statements and webpages) that landscape impacts are a significant, or maybe even the most significant, implicit motivation for opposition; it has to be noted that in many cases, legal arguments target particular other sections of environmental impact assessment studies that are more technical and are therefore considered more objective than landscape impacts, in the context of legal action. Such legal arguments over environmental impacts are commonly expected to increase the odds of winning the cases (Lee, 2017). Nevertheless, various legal challenges against wind energy developments that explicitly included arguments over landscape impacts, have also been handled, for example, by the Hellenic Council of state (Council of State and Administrative Justice, 2015, 2013a, 2013b, 2012a, 2012b, 2011).

The developmental consequences of opposition against RE, in Greece, are demonstrated by the fact that even though the national target set for installed capacity of wind energy by 2020 was 7500 MW (Ministry of Environment, Energy & Climate Change, 2009)[2] only 4114 MW had actually been installed by that time. Given that several hundred of MW have been put on hold due to opposition movements, with strong reference to landscape impacts, it is reasonable to argue about the developmental and economic impact of the issue of landscape integration of RE. In this regard, it also has to be noted that the delay or cancellation of projects that leads to falling behind European Union's energy targets will also potentially prompt the imposition of fines to member states. For reference, in a relevant study for Ireland, which was almost double the

[1] The term developments or works was used in this research for reference to wind and solar projects rather than the term "farms", in agreement with the critique of Jefferson (2018) that the term "farms" is an euphemism.

[2] In accordance to directives from the European Union (European Union, 2009).

percentage of Greece away from the target of RE utilization in 2017, the fines were anticipated in the range of €300-600 million (Renewable Energy Consumers and Producers [RECAP], 2017).

Table 1. Examples of challenged wind energy projects in Greece in 2017 and 2018.

Location	Installed capacity (MW)	Number of turbines	Type of opposition
Paros, Naxos, Tinos and Andros	218.5	95	Legal action from local government
Samothrace	110.7	39	Votes by groups of citizens and associations
Vermio	465	174	Negative decision from local government
Agrafa	86	40	Legal action from citizens
Sitia	81	27	Negative decision from local authorities
Karistos	167.9	73	Legal action from local government
Mani	103.2	48	Legal action from citizens and associations
Monemvasia	5.4	5	Legal action from local government

Data were collected from news articles in the websites of national media (links are presented in the order of reference in the table): http://www.kathimerini.gr; https://www.ert.gr/; http://www.alterthess.gr/; https://www.efsyn.gr/; https://www.efsyn.gr/; https://www.alfavita.gr/; http://www.kathimerini.gr; https://www.rizospastis.gr/.

However, the challenges of landscape integration of infrastructure should not be solely viewed through the lenses of economic and developmental impacts. In the long term, it is evident that RE works will indeed be the cause of massive landscape changes. It is the first time in human history that energy generation has so high land-use demands (Apostol et al., 2016; Stremke and van den Dobbelsteen, 2012; Trainor et al., 2016; van Zalk and Behrens, 2018) and that the required infrastructure generates such extensive visual impacts (Degórski et al., 2012; Möller, 2010; Scottish Natural Heritage [SNH], 2014). The scale of the landscape and visual impacts that are generated from RE, is excellently demonstrated in the calculations of zones of theoretical visibility (ZTV) that have been carried out for wind energy. Results from large-scale ZTV analyses in the literature showed that wind turbines were visible from approximately 17% of the land area of Spain[3]

[3] From the examination of a hypothetical scenario of wind energy utilization in Spain, referring to national installed capacity nearly equal to the current installed capacity of wind energy in Spain.

(Rodrigues et al., 2010), 21% of the Netherlands (Statistics Netherlands [CBS] et al., 2014), 46% of Scotland (Scottish Natural Heritage [SNH], 2014) and 96% of the region of North Jutland, in Denmark (Möller, 2010). Furthermore, the global effort to increase energy generation from RE, will inevitably further perplex the problematic relationship between energy generation and landscapes. In Europe, for example, the share of RE in energy consumption, which in 2018 was 18%, is planned to be increased to 27%, by 2030 (European Council, General Secretariat of the Council, 2014). It thus reasonable to assume that the RE transition will continue to be one the greatest forces of transformation of European landscapes in the following decades. Moreover, this transformation is expected to be even more perceivable than the transition from 18% to 27% might indicate. This is due to the fact that RE projects will gradually have to be sited closer to more sensitive locations, from a landscape impact perspective, as suitable locations have been decreasing under the current RE expansion (Deshaies and Herrero-Luque, 2015; Kaldellis et al., 2012; Nitsch et al., 2004).

1.3 In theory: the utility of the landscape integration of civil infrastructure

In this Section, we investigate the utility of the landscape integration of infrastructure from a theoretical perspective. We focus on how the quality of landscapes is associated with human needs and how the landscape impacts of infrastructure can impact those needs and also make some initial comments on the potential role of design and planning in the mitigation of such impacts.

First of all, it is self-evident that landscape integration is not a prerequisite for the design of infrastructure. The primary purposes of infrastructure works refer to the fulfilment of physiological needs of humans, such as the needs for water, food and energy (Sargentis, 2022; Sargentis et al., 2022), which do not depend on the integration of the associated infrastructure into landscapes but on the function of infrastructure per se. Yet, as societies progress and the basic physiological needs of humans are being fulfilled with consistency and security, their quality of life becomes increasingly connected with the fulfilment of social, cognitive and psychological needs (Maslow, 1943) that are dependent, among other parameters, on the natural, cultural and aesthetic qualities of their surroundings (Moraitis and Rassia, 2019; Tsoukala et al., 2015). At that point, negative effects to the quality of living spaces become more perceptible and have a more measurable effect to quality of life. Demonstrating care (Li and Nassauer, 2020) for the integration of infrastructure to its natural and cultural surroundings contributes to improving the public perception of the built environment (Moraitis, 2016) and furthermore, architectural and landscape design of works also facilitates secondary uses of infrastructure such as recreational and educational uses or ecosystem services.

It is our observation however, that in the community of infrastructure engineers, the above-mentioned benefits originating from the successful integration of infrastructure works into landscapes are neither always understood nor supported. Therefore, we dedicated the following paragraphs to expand further into the contribution of landscape design and planning of infrastructure to human's quality of life and the fulfilment of human needs. To this aim, we built on the foundations of relevant social science literature, mostly referring to Maslow's hierarchy of needs (Maslow, 1943; McLeod, 2020; Zhang and Dong, 2009). The hierarchy is presented in one of its latest versions (Maslow, 1970) in Figure 1, in the form of a pyramid[4]. The basic logic of this representation is that the more fundamental the need the lower it is presented in the pyramid. Hence, the lowest level refers to the physiological needs of humans and the upper levels refer to needs such as self-actualization and transcendence.

While the major objective of infrastructure projects concerns the primary human needs that are presented at the base of the pyramid, i.e., safety and physiological needs, we believe that landscape integration of infrastructure is related to subsequent human needs for safety, esteem, cognitive and aesthetic needs (highlighted in the pyramid of Figure 1). In the following paragraphs, the correlation of landscape integration with these needs is analysed in more detail, meanwhile considering how landscape planning and architectural design can contribute to their fulfilment:

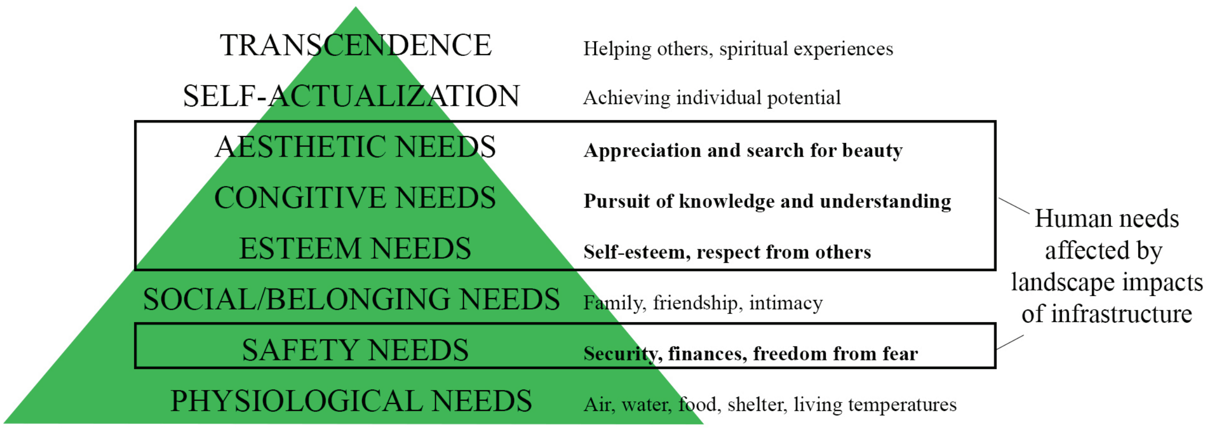


Figure 1. Maslow's hierarchy of human needs (Maslow, 1970) presented as a pyramid, highlighting human needs affected by landscape impacts of infrastructure works.

Safety Needs: Humans have the need to be free of fear, whether this concerns their well-being, their finances, etc. or fear of tyranny, injustice, etc. New infrastructure projects can interfere with this sense of safety of individuals in affected communities for many reasons, one of which is landscape change. This is the case especially for people whose occupation is related with landscape and nature, e.g. in professions in the areas of tourism (Riddington et al., 2008), real-estate (Walker et al., 2014), livestock, farming (Sargentis et al., 2021c), etc. Individuals in these occupations are more sensitive to landscape transformations as they can potentially affect their income and more broadly the stability of their professional life. Additionally, their choice of occupation might be related with preference for working and living in scenic or pristine natural landscapes. It is thus reasonable to argue that the significant and rapid landscape transformations that are associated with the development of major infrastructure can affect the sense of safety of local communities both in terms of occupation and income as well as in relation with their long-

[4] It should be noted that the representation of A. Maslow's hierarchy in the form of a pyramid was not the way he presented his work but was rather carried out by readers of his work. Maslow himself noted that the hierarchy is not a rigid structure with disassociated levels but “any behavior tends to be determined by several or all of the basic needs simultaneously" (Maslow, 1987).

term plans for living in landscapes with particular features associated with their natural qualities, history or scenicness (Fast et al., 2015; McKenna et al., 2021). Furthermore, as all human needs are interrelated and do not follow a strict hierarchical form, as Maslow himself suggested (Maslow, 1987), problems initiating from perceptions of industrialization, intrusion, authoritarian imposition of infrastructure on landscapes and more broadly over negative perception of population over their living spaces can also be the cause of psychological and physiological stresses (Hanie et al., 2010; Ricci, 2018; Stigsdotter, 2005). Overall, targeted courses of action for the mitigation of landscape impacts could arguably contribute to the minimization of the aforementioned impacts that are associated with human safety needs. Such actions range from improved architectural design and landscape planning of infrastructure to better communication with local communities before the implementation of new projects or their inclusion in relevant discourse and planning procedures (Berry et al., 2011; Devine-Wright, 2014; Moraitis, 2011; Wolsink, 2000).

Esteem Needs: Esteem needs refer to the need of humans for self-confidence and respect from others. Major infrastructure projects can generate issues associated with the esteem needs of the individuals and communities that live in their proximity. Major infrastructure works have the inherent characteristic that while they provide for needs for energy, water, sanitation, etc. of large spatial units, most of their landscape and environmental impacts concern a much smaller area adjacent to the required works (Sargentis et al., 2019b). It is reasonable that this "injustice" of impacts in comparison to utilities can provoke negative sentiment to local communities and a sense of disregard from authorities that develop infrastructure projects (Wolsink, 2020a, 2018). Arguably, indicative measures for the mitigation of this sense include the adequate communication of the spatial reasoning for the siting of projects to local communities (Kazak et al., 2017; Langer et al., 2016) and the practical demonstration of respect to the culture and the way of living of local communities (Ioannidis, 2015; Ioannidis and Koutsoyiannis, 2017a; Rojanamon et al., 2012). Focusing mostly on the role of landscape in this issue, we note that the proper landscape planning can aid in the former (Moraitis, 2011; Mostegl et al., 2017) and landscape design can aid in the latter (Moraitis, 2012; Moraitis, 2012; Moraitis, 2019). In particular, landscape studies can be used to integrate aspects of local culture and way of living in the infrastructure works through targeted architectural and landscape interventions. Unfortunately, as is later analysed in detail in Section 2.4.3, not all types of infrastructure projects are receptive of architectural design so this is not an option for every type of infrastructure. Nevertheless, this is an important, yet usually untapped, potentiality for many infrastructure works. Moreover, even in cases when architectural studies cannot be applied directly to the infrastructure, they can be implemented in auxiliary works and landscaping or in other compensatory works that are in some cases implemented in the proximity of major projects. On the whole, the integration of elements from local architectural culture or of local architectural preferences (possibly after public discourse) in infrastructure works, can act as demonstration of respect to the local community and contribute to the reduction of the negative perception of new infrastructure, even leading to positive perception (Ioannidis et al., 2022; Pérez et al., 2013).

Cognitive Needs: Cognitive needs refer to the pursuit of humans for knowledge and understanding. This natural drive is that which sets individuals on a critical stance towards their social and political environment. In the examined issue, this drive manifests in the will of local communities to be informed about the processes that lead to the transformation of their environments (Moraitis, 2015) by infrastructure projects as well as about the utility of these infrastructure works. The academic literature suggests that such issues can be primarily dealt through communication and engagement with local communities and with groups involved in environmental and societal issues associated with infrastructure development and planning of projects (Bidwell, 2013; Devine-Wright, 2014; Jerpåsen and Larsen, 2011; Llewellyn et al., 2017). It is reasonable that the more the uncertainty about the necessity of a project and of the reasons for the selection of a particular location - the more likely it is that the project will be perceived negatively.

Furthermore, considerations over the utility and the planning processes of projects do not cease with their completion but persist during their life span (Delicado et al., 2016; Stine, 2003). Among others, people who engage in activities in the proximity of built infrastructure works, e.g., hikers confronting a dam or local students who regularly cross a bridge, will also be faced with questions of the same kind. Thus, other than solely interacting with local communities throughout the planning and construction phases of projects, information about the utility and design of projects should optimally be provided during the life span of projects. One of the primary ways to achieve this is the implementation of informative elements, such as information boards, inscriptions, use of art and symbolisms, etc. (Ioannidis et al., 2022) or the development of small museums in the works' areas (Alfrey and Putnam, 2003). In some cases, the works themselves can also be used as the centre of guided tours, acquiring in this way and more educational and informative role. All of the above are either dependent on the incorporation of architectural and landscape studies in infrastructure works or would be significantly supported by the incorporation of such studies.

Aesthetic Needs: Aesthetic needs refer to the appreciation of beauty and its pursuit by people. Maslow identifies aesthetic needs as an "uncomfortable" area for scientists, due to the lack of knowledge regarding them, but also acknowledges aesthetic needs as "a truly basic . . . need" for some individuals (Maslow, 1987). In the context of the discussion on landscape transformations caused by infrastructure, aesthetic needs and the pursuit of beauty can be translated as the need for the preservation of a pleasant a living environment (Navarrete-Hernandez and Laffan, 2019). Landscape transformations caused by works of infrastructure, can be perceived as significant source of degradation of living environments, by local communities, and as the cause of direct impacts to their quality of life (Gavrilidis et al., 2016; Hartig and Kahn Jr, 2016; Stigsdotter, 2005). For the mitigation of the purely aesthetic aspect of landscape impacts of infrastructure two different courses of action can be identified. The first would be to try to conceal impactful infrastructure through spatial planning and landscape design methods, such as visibility analysis etc. The second, to implement landscape and architectural studies in order to integrate infrastructure works into their natural or cultural surroundings and rehabilitate their impacts to the natural landscape (from excavation, abutments, roadworks, appurtenant structures, etc.).

Finally, even though in this Section we presented the effort for landscape integration of infrastructure as one that is more relevant to contemporary highly developed societies, we have to note that economic development is not necessarily the primary driver of appreciation for the built and natural environment. From the examination of the perception of landscape and architecture throughout history, e.g. the Hellenistic Era (Iliopoulou, 2019, 2015), it could be argued that landscape is not necessarily valued in societies with high technological and economic development but rather on those with high cultural development. Furthermore, in one of the earliest historical references to principles of construction surviving to-date, the Ancient Roman architect and engineer Vitruvius identified three principles for high-quality building: "Firmitas (construction - sturdiness), utilitas (functional utility) and venustas (beauty)". In contemporary times, these principles are still acknowledged as the foundations of the design of human structures (Brophy and Lewis, 2012; Jones, 2014; Patterson, 1997). Even though the first principle of Vitruvius, structural integrity (firmitas), is not associated with the landscape integration of engineering works, the other two principles can be both considered relevant to it, to different extents. This is certainly these for the "venustas" principle, but can also be argued for the "utilitas" principle, since as we already analysed in the previous paragraphs, the landscape integration of infrastructure can lead to additional secondary uses of infrastructure works.

1.4 Research questions, focus and limitations

1.4.1 Research questions

Landscape impacts of infrastructure are described both by spatial variables that can be objectively quantified, such as land use, and by perceptual variables that are more subjective, such as metrics of public perception. This dual quantitative-spatial and qualitative-perceptual nature of landscape impacts, renders their quantification and mitigation a challenging problem, requiring interdisciplinary analysis, involving elements from both engineering and social sciences. In this study, the landscape integration of infrastructure is approached from the perspective of spatial planning and design or infrastructure works. Thus, the primary scientific areas involved are civil engineering, spatial planning and architectural-landscape design. The interfaces of issues of landscape integration of infrastructure with the fields of social sciences and humanities, which are also important, are primarily mentioned in the initial theoretical introduction and are also acknowledged and referenced throughout the study but are not expanded beyond current state-of-the-art.

The main part of the research initiates from a global investigation on the assessment of the type and extents of landscape impacts from different works of infrastructure, focusing particularly on renewable energy. This first level of analysis is based on the compilation and analysis of data from international literature as well as data from realized infrastructure projects compiled from various sources globally. The results of this first level of analysis in the global scale, are then utilized to propose improved spatial planning techniques, at the national and regional scale, and upgrades to architectural and landscape design practices in the project-site scale. In more detail, the particular research questions of each level of analysis can be separated and grouped accordingly, in each scale of the analysis:

> 1: Global scale: How can landscape impacts of infrastructure be quantified and how do such impacts differ among different types of infrastructure works? Can we generically rank different types of infrastructure, e.g., wind, solar and hydroelectric energy works, in terms of their landscape impact? What is the influence of the spatial, aesthetic and cultural characteristics of different types of infrastructure on their perception by the public within landscapes?
>
> 2: National or regional scale: From the global analysis it is demonstrated that some infrastructure works are by definition visible to larger areas of land than others or are

perceived more negatively by the public. Various spatial planning methods have been developed for the mitigation of the so called "visual impacts" from such works. Is there potential for improvement of the utilized methods, taking advantage of the experience from more than two decades of relevant applications and the realization of their shortcomings? For example, is the current preference for application of visibility analysis of projects in the project-site justified or would its implementation in larger spatial scales, e.g., national or regional, be preferable? Can the latest advances in the availability of landscape-related spatial data contribute to advances in this regard?

3: Project-site scale: While for some types of infrastructure works architectural treatment is not possible, for others it is a, largely untapped, potentiality. It can thus be hypothesized that the implementation of full scale architectural and landscape design studies in infrastructure works could potentially improve their integration into landscapes and enforce their positive perception. But, have such studies in fact improved the perception of infrastructure when they have been applied? Is the wider implementation of such studies economically and technically feasible?

1.4.2 Renewable Energy works and dams: Why?

As described in Section 1.2, RE has been identified as the major contemporary driver of change to global landscapes by infrastructure. Therefore, it is currently in the spotlight of research on landscape impacts of major infrastructure. The significant issues that have been met in matters of landscape integration of RE works have rendered research in this direction a priority both for (a) the mitigation of impacts to landscapes, which have an unprecedented spatial scale, and (b) the facilitation of the development of projects, which are often delayed or cancelled due to resultant opposition movements. Additionally, due to the increased scientific interest in regard to the landscape impacts of RE works there is currently an abundancy of relevant literature and data sets from scientific organizations, which can be utilized to formulate novel analyses and comparisons.

Furthermore, the various types of RE works differ both in terms of the spatial and architectural characteristics of their impacts and also in terms of the perception of those impacts by the public and therefore their investigation was expected to generate varied and informative conclusions. Indicatively, as is later analysed in detail in Section 2: (a) wind and solar energy works are perceived most negatively due to their extensive land use and visibility as well as their perception us industrial machines while (b) hydroelectric works also receive criticism, in terms of landscape impacts, but the investigation demonstrated, early on, a significant attribute of hydroelectric projects that was considered to require further investigation, i.e., their capability for architectural and landscape design treatment.

The above-mentioned differentiation of impacts, which is analysed in more detail in Section 2, led to the eventual split of infrastructure works into two different categories in terms of their landscape integration potential. The first category refers to works that are largely predefined by industrial or technical specifications that render the architectural treatment of their fundamental parts impossible, e.g., wind turbines, solar panels, power transmission lines and, with some exceptions, highways. The forms of these types of infrastructure works cannot be modified in the context of architectural studies and were thus named as "non-architecture-friendly" infrastructure. The second category refers to works that are compatible with architectural or landscape design studies, e.g., dams, bridges, water supply works, water and wastewater treatment plants, etc. Such works have partly or fully modifiable forms and hence can be treated architecturally and were therefore named "architecture-friendly" infrastructure. In the later parts of our research, in Section 3, wind energy projects are studied in detail as indicative of "non-architecture-friendly" infrastructure and, in Section 4, dams were studied as works indicative of "architecture-friendly" infrastructure. Hydroelectric dams were initially identified in the comparison of RE works of Section 2 as "architecture-friendly" infrastructure, but since hydroelectric dams have common structural parts with dams of other uses, the relevant investigation of Section 4, was expanded to include dams of all uses, so that more data could be utilized.

1.4.3 Limitations and considerations

As was described in the discussion over the utility of the landscape integration of infrastructure, the fundamental role of civil infrastructure within a society is providing for the fulfilment of the physiological needs of the population (Figure 1). It is clear that the integration of projects into landscapes does not directly improve how infrastructure provides to citizens for the fulfilment of their basic physiological needs for drinking water, food or energy. Therefore, the issue of landscape integration of infrastructure projects is identified as a matter of optimization of their design which does not affect their basic functions per se.

It can be observed that the larger the effectiveness of societies in providing individuals with water, food and shelter; the greater their concern about the quality of landscapes. In a global context, this is demonstrated by the fact that countries with developed economies and high human-development indexes are the ones that lead internationally in matters of landscape planning and architectural design (Buchan, 2002; Denn, 1995; Scottish Natural Heritage [SNH], 2017). Therefore, the discussion over landscape integration of infrastructure is more relevant to countries that have already catered for the basic physiological needs of their citizens and can allocate resources to the optimization of infrastructure works. This means that in countries with economies in transition or developing economies (United Nations Department for Economic and Social Affairs, 2019), where fulfilment of physiological needs of the population is not a given for large percentages of the population, design for landscape integration might be a relative "luxury" that might not be possible to be afforded yet (Ioannidis et al., 2022). Nevertheless, the present research includes cases of exemplary integration of projects into landscape from countries with economies in various levels of development and demonstrates that the integration of infrastructure into landscape is not necessarily associated with measurable increases to projects' costs.

Within a country, landscape impacts of infrastructure affect the quality of life of people that live in the proximity of works of infrastructure. Meanwhile, the same works provide for the needs of thousands or millions of individuals living in distant areas (Koutsoyiannis, 2011; Sargentis et al., 2019b). It is therefore reasonable that the social utility of infrastructure in providing for societies' fundamental living needs should be acknowledged before proceeding to the discussion of the landscape impacts of infrastructure. Furthermore, since landscape impacts of infrastructure in many cases cannot be completely mitigated, understanding and good will from local communities should also be present when the potential cancellation or delay of projects is imminent; especially so when measures for landscape integration of projects have been implemented and the local communities have been involved in the relevant discourse. On the other hand, stakeholders in the development of infrastructure projects should take into account the fact that local communities are the "few" who are called upon to endure significant life changes for the good of the "many". Thus, the minimization of impacts to the communities that encounter works of infrastructure in their everyday lives should be an important design consideration, in the context of optimized design and planning of infrastructure.

1.5 Innovation Points

The major innovation points of the study are the following:

A. As already established, the current uncertainty regarding the rationality and the spatial extents of the so called "landscape impacts" of infrastructure, has been perplexing their efficient mitigation and has been contributing to the continuation of a vicious cycle of public unrest and developmental disorder. An initial novelty point of the present research, is the formulation of a methodology for the joint quantification of both the spatial and the perceptual aspects of landscape impacts of infrastructure and the comparison of such impacts between different types of infrastructure works (as presented in detail in Section 2). This innovation was made possible by identifying three representative metrics of landscape impacts from global literature, namely land-use, visibility and public perception, and reviewing those metrics to quantify and compare the landscape impacts of major RE works, i.e., hydroelectric dams, wind and solar energy works. This analysis eventually led to the measurable and generic assessment of the severity of the landscape impacts of these different types of works, resolving the current uncertainty over them. The conclusions of the analysis are presented in detail in Section 5.1 of the Conclusions.

B. In regard to spatial planning for the integration of infrastructure into landscape the thesis innovates in the identification of its current shortcomings and the proposal of targeted improvements to overcome them (as presented in detail in Section 3). In particular, the reversal of conventional practice of visibility analysis is proposed and examined in detail as a methodological upgrade that can lead to overcoming various of its issues of timing, utility and time-consumption. It is also argued that even though visibility analysis has so far been implemented in a project-site spatial scale it would be more useful as a planning tool if it was implemented at the regional or national scale, which is however impossible in its conventional format. In particular, the research demonstrates through both theoretical and practical investigations that reverse visibility analysis (i) enables the timely anticipation of landscape-visual impacts in earlier stages of development than was possible so far (ii) renders the requirement for individual visibility analysis for each RE unnecessary, thus potentially accelerating project planning an licensing, (iii) is more compatible with, the widely supported in the academic literature, participatory planning processes (iv) enables the integration of maps informed by visibility analysis in multi-criteria planning studies in large spatial scales and (v) generates maps that can also be utilized independently by various stakeholders in the development of infrastructure projects, either in the planning of projects or in the protection of landscapes. These advantages are also analyzed in more detail in Section 5.2 of the Conclusions.

C. Another novelty of the thesis, is the evaluation of the utility of applications of architectural and landscape design in infrastructure works and the critical investigation of the potential for future expandability of such applications, from a cost-benefit perspective. The investigation of this aspect of the design of infrastructure works was considered crucial, since, so far, the architectural treatment of infrastructure has been scarce and both its benefits and its technical and economic requirements have not been analyzed in detail. To this aim, an assessment of architectural and landscape design practice in infrastructure works was carried out, focusing on dams (as presented in detail in Section 3). In this investigation, both the capacity of architectural treatment to actually improve the public perception of infrastructure was evaluated and also its future potential for expansion was investigated, considering the potential costs and technical challenges. As presented in detail in Section 5.3 of the Conclusions, the investigation demonstrated that the implementation of architectural and landscape design studies measurably improves the public perception of infrastructure and that it is not necessarily linked with significant additional costs or technical challenges.

D. Finally, the research subject per se can also be considered as one of the major innovations of the study. So far, even though the integration of major civil infrastructure into landscapes has been investigated in various scientific works, this has mostly been done in a fragmentary fashion, focused on individual projects or particular issues. The formation of a unified methodology – strategy, referring to various (a) spatial scales, (b) scientific disciplines and (c) types of infrastructure works has not been researched. In the present thesis, a holistic framework is proposed for the integration of civil infrastructure into landscapes that combines all of the above (a to c). In particular, the thesis combines the analysis of available data and scientific literature - in global scale, spatial planning - in the regional or national scale, and architectural design - in the project site-scale. That way the complete spectrum of associated analysis, planning and design procedures is covered and is eventually unified into a structured strategy (see Section 5.4 of the Conclusions) that can be utilized for improving the landscape integration of any type of major infrastructure work.

1.6 Content structure

In Section 1 of the thesis, the aims, motivation, context, research questions and limitations of the research are presented. Particular focus is given on establishing the societal and developmental utility of improving the integration of major infrastructure into landscape, in terms of sustaining/improving the quality of life of citizens and accelerating the development of infrastructure.

In Section 2, the empirical and theoretical foundation is set for the improvement-proposals to spatial planning and architectural practices for landscape impact mitigation, in Sections 3 and 4. Global practice and literature were analysed in order to identify whether landscape impacts of different types of infrastructure are characterized by generic corresponding levels of severity. The identification and description of such a standard differentiation between different types of infrastructure can lead to ranking different types of infrastructure in terms of landscape impacts and the targeting of their individual problems, eventually leading to improved anticipation and mitigation of their landscape impacts. The study of RE works in particular, allowed carrying out this comparison using data from realized projects with comparable characteristics, in terms of purpose. Namely, hydroelectric dams, wind energy and solar energy works were examined. Three metrics were identified as determinants of the severity of their landscape impacts and investigated in detail: land use, visibility and public perception of projects. These metrics allowed for the assessment of both the quantifiable-spatial aspect of landscape impacts as well as their qualitative-perceptual aspect.

The third Section continues from the identification the extents of the visibility of infrastructure within landscapes as one of the most important origins of negative perception by the public in Section 2. This was particularly noted in Section 2 for the types of works that are perceived to be intrusively industrial, e.g., works whose shape is rigidly defined by industrial specifications and cannot be modified through architectural design, as is the case with wind turbines and solar panels. In Section 3, the methods that have been used so far to minimize the visual impacts originating from such types of works were investigated and improvements to them were proposed. In particular, we proposed reversing the conventional-mainstream format of visibility analyses by shifting their focus from the elements that generate visual impacts (e.g., wind turbines, or electric power transmission works) to areas that are to be protected from such impacts (e.g., archaeological/historical sites, settlements, etc.). The benefits and the challenges of the proposed methodological shift were then investigated in detail. Emphasis was given on the fact that reverse visibility analysis enables (i) the inclusion of the parameter of landscape impacts in multicriteria analyses in the form of visibility maps, something that has so far been impossible, and (ii) also accelerates the assessment of the potential landscape impacts from planned projects, as the maps that are generated from reverse visibility analysis are fixed around protected areas and can therefore be used by multiple projects under development within it. Furthermore, an exemplary application of reverse visibility analysis was carried out for the region of Thessaly, Greece. Reverse – Zone of Theoretical Visibility analysis (R-ZTV) were calculated and then used to assess the potential landscape impacts to protected landscape element of the Region from wind energy projects that are currently under development. The implementation verified the advantages of reverse visibility analyses that were initially described theoretically and demonstrated the practical challenges of carrying out such analyses and how these challenges can be surpassed, through various different approaches.

In Section 4, the significance of the architectural and landscape design of infrastructure, which was highlighted in the second Section, was investigated in more detail and analysed in terms of its future potential. In the second Section, hydroelectric dams were identified as less impactful than other RE works and one of the most important factors for this was their capability for architectural treatment. Similarly, there also other types of infrastructure works whose exterior is not rigidly defined by industrial or technical specifications and in which architectural and landscape studies can be applied, in order to improve their integration in their natural and cultural surroundings. Such works include dams, bridges, water treatment works, etc. In this Section of the study, we focused on global practice of architectural and landscape design studies in the example of dams, in order to (i) assess the contribution of such studies to improving the public perception of projects and (ii) to investigate whether architectural and landscape studies could be applied more widely in infrastructure projects or if this possibility is halted by economical and technical limitations.

In Section 5, the key findings of each Section of the study are summarized and the conclusions of the study on how the integration of civil infrastructure into landscapes can be improved through spatial planning and architectural design are presented. The conclusions include both (i) the corresponding conclusions of Sections 2, 3 and 4 as well as (ii) general strategic inferences for policy and practice that aims for the mitigation of landscape impacts of infrastructure works, informed by the results and the conclusions of sections 2, 3 and 4. Furthermore, some thoughts in regard to future research are also presented.

In Section 6, the figure and table lists are presented and in Section 7, the references of the research are listed.

In the final Section, Section 8, the appendices and the supplementary material of the study are presented. In Appendix A, additional considerations over the data screening and the selection of metrics and technologies that were analysed in Section 2 are presented, in Appendix B an in-depth analysis of older estimates of hydroelectric land use is presented, following the identification of some relevant data infelicities, in Appendix C the detailed methodology and results of the perception analysis of Section 2 are presented, in Appendix D the link to the excel tables of the perception analysis of the same Section is provided, in Appendix E the table of La Brena II dam landscape detailed design costs is presented, in Appendix F, the table of the detailed costs for the case study of the Greek dam in Section 4 is presented, in Appendix G a summary of the thesis in Greek language is presented and finally in Appendix H the complete list of publications of R. Ioannidis associated with this thesis is presented.

2 GLOBAL SCALE: COMPARATIVE ASSESSMENT OF LANDSCAPE IMPACT SEVERITY OF DIFFERENT TYPES OF INFRASTRUCTURE WORKS

2.1 Introduction

2.1.1 Research questions and scientific aims

Among stakeholders in the development of infrastructure, arguments over landscape impacts are often perceived with uncertainty on whether they are a genuine and objective issue or if they are just manifestations of biased NIMBY (not in my back yard) dispositions by the public. This uncertainty eventually conflicts with the development and implementation of optimal planning and design methods for the mitigation of landscape impacts. For this reason, our analysis initiates from the investigation of the following question that can shed light into these issues: Are the extents and the severity of landscape impacts of different types of infrastructure in fact different? Are there objective ways in which landscape impacts of projects can be quantified and compared?

For this investigation we formulate and carry out a comparative assessment of the generic landscape impacts of different types of infrastructure works. RE works were selected as the focus of this investigation, due to the fact that renewable energy projects have been the recipient of significant criticism in regard to their landscape impacts in the last decades. Thus, significant effort has been put into estimating, managing and reducing the landscape impacts of RE projects, generating a lot of relevant data and literature. However, so far, research on landscape impacts of RE has mostly focused on localized analyses of impacts rather than generic cumulative analyses. With global RE capacity reaching more than 1856 GW (World Energy Council [WEC], 2016a, 2016b, 2016c) at the moment, extensive national and regional data for RE have emerged, allowing for large-scale fact-based analyses of landscape impacts that were so far impossible. This Section focuses in this exact direction, through the review of literature and data on established metrics of landscape impact. In the context of the analysis of RE works the general research questions are specified to the following: What are the typical landscape impacts of major RE technologies and how do they differentiate? What is the generic ranking of major RE technologies, in terms of landscape impact, based on data from realized projects?

Through the investigation of these questions, the distinct characteristics that render each RE technology impactful are identified and quantified. This identification of similarities and differences between different types of works, allows for a clearer and more universal definition of the nature of landscape impacts of infrastructure works, laying the proper scientific foundations for its mitigation. This concerns both the formulation of better informed and fact-based spatial planning policies as well as the demonstration of novel directions for research on managing and minimizing landscape impacts (Frolova et al., 2015b; Pasqualetti and Stremke, 2018). Even though some level of landscape impact from the development of RE or infrastructure is in general unavoidable, there is arguably still room for optimization of the spatial and architectural design of infrastructure, especially in cases where cultural or natural heritage is affected and key elements of local economies, such as tourism or real estate, are threatened (Wolsink, 2007a).

2.1.2 Observations and hypothesis

An initial observation which demonstrated that RE would be an interesting case study for the investigation of differences and similarities between the landscape impacts of different type of infrastructure works was that the various RE technologies have been disproportionately researched over their landscape impacts. In particular, wind turbines seemed to be the basic topic in the majority of literature (Baraja-Rodríguez et al., 2015; Nadaï and Van Der Horst, 2010; Wüstenhagen et al., 2007), design guidelines (Buchan, 2002; Carlisle City Council, 2011; Frantál et al., 2018; Horner + Maclennan and Envision, 2006; Stevenson and Griffiths, 1994), institutional publications (Coleman, 2003; Henningsson et al., 2013; Parliamentary Commissioner for the Environment [PCE], 2006; Riddington et al., 2008; Wood, 2010) and news articles (Devine-Wright, 2011; Pasqualetti, 2011; Weiss, 2017) on landscape impact, followed by solar panels (Elkind et al., 2018; Mérida-Rodríguez et al., 2015a) and lastly hydroelectric dams. This observation was partially counter-intuitive due to the fact that the type of RE with the highest installed capacity globally is hydroelectricity, followed by wind energy and lastly, solar energy, which could suggest that research interest would be analogous. Since that was not the case, a hypothesis was formed, that this disproportionate distribution of scientific interest, might be indicative of differences between the severity of landscape impacts generated from each technology. If this hypothesis was true, then the current status of literature would demonstrate that wind energy would be expected to generate the largest impact, followed by solar and hydroelectric energy, in order. Even though parts of this conclusion have already been produced in literature (Cohen et al., 2014; Frolova et al., 2015a; Koutsoyiannis and Ioannidis, 2017; Sovacool, 2009), it is a subject that has neither been completely formulated yet nor been investigated through specialized analysis of large-scale datasets.

2.1.3 Section structure

In Section 2, we investigate the first research question of the study (see Section 1.4.1) using renewable energy as a case study. In the introductory Section 2.1, the context of the investigations of this Section, the research questions and the initial observations and hypothesis are presented. In Section 2.2, we review three metrics that have been consistently used in the analysis of landscape impacts from RE: land use, visibility and public perception. In particular, in Section 2.2.1, we describe the study-screening procedures and subsequently, in Sections 2.2.2, 2.2.3 and 2.2.4, we describe the literature analysed, the methods used and the results obtained for each of the three metrics, in sequence. Then, in Section 2.3, we present the resultant generic estimates for the landscape impacts of major RE technologies based on the utilization of scientific analyses whose results were distinguished for their generic applicability and on statistical perception analysis. In Section 2.4 we discuss the results and explore their significance and their correlations with existing literature. Finally, we present the conclusions in Section 2.5.

2.2 Methods and Results

In this Section, we review three metrics that have been extensively used in the analysis of landscape impacts of RE: land use, visibility and public perception. Through the review of these metrics, we form a typology of impacts for major RE technologies and a generic landscape-impact ranking, based on the quantification of average impacts from realized projects. The analysis highlights the strengths and weaknesses of each technology, in a landscape impact context, and demonstrates that, depending on landscape attributes, any technology can potentially be the least impactful. The analysis also sets the foundation for the following Sections, in which the generated knowledge of Section 2 is utilized in order to develop novel methodologies for mitigation of landscape impacts of RE.

2.2.1 Study screening

2.2.1.1 Primary screening

This Section describes study screening methods for land-use and visibility, which was more complex, while study screening for public perception is described within the corresponding Section (Section 2.2.4). For the collection of data and studies, searches were carried out on Google Scholar, Elsevier, Wiley and Taylor & Francis data bases using the search strings "hydroelectric energy/ wind energy/ solar energy land use", "hydroelectric energy/ wind energy/ solar energy visibility" and "hydroelectric energy/ wind energy/ solar energy visual impact". The results of the search engines were searched for relevant studies until more than ten consequent results with irrelevant titles were found. Additional individual searches were carried out for articles and reports of interest that were referenced within the studies that were originally found.

2.2.1.2 Secondary screening

In addition to presenting the overview of literature we also distinguished estimates with generic applicability to be used for the calculation of generic estimates of land use and visibility. Since not all of the estimates that were compiled through the primary screening process could be used to this aim, due to biases that rendered their results non-generalizable, additional secondary screening criteria were required. These criteria were focused on the following parameters that were believed to affect the generic applicability of the estimates:

Scale of data sets: The problem of landscape impact of RE was examined at the level of large-scale energy generation that is the most altering to landscapes (Apostol et al., 2016; Stremke and van den Dobbelsteen, 2012). In accordance to this logic, literature referring to large-scale energy generation was prioritized, i.e., studies analysing large data sets compiled globally nationally or regionally were preferred, in order of reference.

Terrain: Land use and visibility of RE developments are greatly dependent on terrain topography. Therefore, to reach generic and unbiased conclusions, data from areas of moderate terrain were preferred over data from extremely mountainous or flat areas. In order to distinguish countries with moderate from countries with extreme terrain, an index was required. The topographic ruggedness index of Nunn and Puga (2010) was utilized to this end. Ruggedness is defined as the average slope of a country's land area and is calculated by Nunn and Puga by averaging the elevation of adjacent 30 by 30 arc-second cells in the GTOPO30 global elevation data set. In Figure 2, all countries from which terrain-related data were discussed in the present research are pinpointed, with reference to this index. Results from countries with extreme terrain, are mentioned in the study but were not included in the generic estimations.

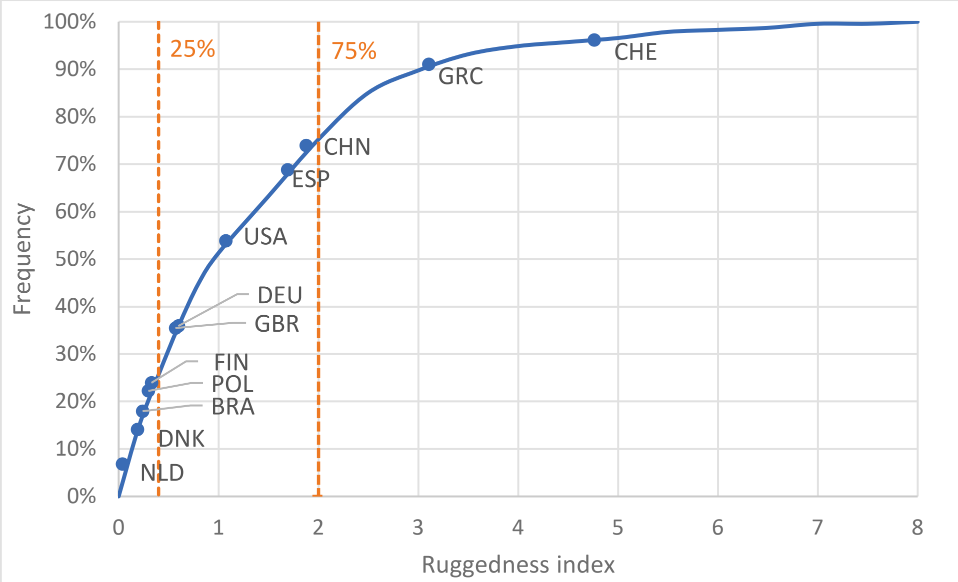


Figure 2. Cumulative frequency chart of the ruggedness indexes of countries. The countries that are referenced in this study are presented using their isocodes. The countries whose ruggedness index was within the frequencies of 25% and 75% were considered of moderate topography. Original data from Nunn and Puga (2010).

Energy generation efficiency: Land use and visibility of RE are commonly expressed as ratios of the affected area to either installed capacity or energy generation. Energy generation (in GWh) was considered preferable over installed capacity (in MW), as the denominator of the ratio, in the context of this analysis. Otherwise, if installed capacity was the denominator, the affected area would be overestimated for more efficient technologies, which generate more GWh of energy per MW of installed capacity.

Realized data vs. theoretical estimates: Hydroelectric, wind and solar energy have already developed significantly and thus data from realized projects were preferred over theoretical estimates. This concerned both the estimates of land use and visibility but also the capacity factors (CFs). Rather than using theoretical estimates, realized CFs were utilized in all conversions of installed capacity to expected energy generation. In particular, global average CFs were calculated, using global data sets from realized projects from the World Energy Council (World Energy Council [WEC], 2016a, 2016b, 2016c) (Table 2).

National economic status: Studies utilizing data from countries with developed economies were prioritized over those that utilized data from countries with developing economies. It is the opinion of the authors that the problem of minimizing landscape impacts from energy generation is, at the moment, more relevant to developed countries that have the ability to allocate resources for such efforts and have already developed extensive institutional and legal procedures for this purpose. Additionally, due to differences in project planning, related to regimes, social structures, and corruption indexes, such an analysis for developing countries would require separate and specialized research.

Additional details regarding primary and secondary screening are provided on Appendix A.

Table 2. Capacity factors of major renewable energy technologies. Global data of installed capacity and energy generation were retrieved from the World Energy Council ((World Energy Council [WEC], 2016a)- Hydropower, (World Energy Council [WEC], 2016b)- Wind and (World Energy Council [WEC], 2016c)- Solar).

Type of renewable energy	Total installed capacity of data set (GW)	Comments on data set	Capacity factor
Hydroelectric	1212	includes pumped storage	0.37
Wind	432	includes onshore and offshore	0.22
Solar	222	includes PV and CSP	0.13

2.2.2 Land Use

The land area that is used by RE developments is certainly altered from a landscape perspective, either directly or visually (Trainor et al., 2016). Thus, land use has been extensively used as a spatial metric of landscape impact (Denholm et al., 2009; Hertwich et al., 2016; Ong et al., 2013; Stremke and van den Dobbelsteen, 2012; Trainor et al., 2016). Land use is additionally identified as the least subjective out of the three metrics that are analysed, as it is the least dependent on personal opinions and biases, in contrast to visibility and public perception.

Overall, the literature review demonstrated a general consensus in estimates of solar and wind energy land use and an adequacy of studies utilizing large and credible data sets. The review of hydroelectric land use however, was more complex, due to discrepancy in estimates and lack of in-depth studies. The discrepancy of hydroelectric land use estimates is demonstrated excellently in the data compiled from literature by Trainor et al. (2016). Out of the estimates compiled in this study, the ratio of largest to smallest estimate was 13.5 in the case of hydroelectricity, larger by almost one order of magnitude to the ratios of wind and solar energy, which were 4 and 1.4.

2.2.2.1 Solar and wind energy land use

In literature, land use of solar and wind energy is measured in two forms: (a) Direct land use, which is the area that is directly occupied by RE equipment, facilities and works of infrastructure and (b) total land use, which is the land area of the property that is used by the projects (Denholm et al., 2009; Ong et al., 2013). Total land use, which is the most extensive of the two types of land use, was preferred as a metric, in the context of landscape impact. This was due to the fact that wind turbines and solar panels are visually and aesthetically dominant within the property they are installed(Trainor et al., 2016), for different reasons in each case, as described subsequently.

In the case of solar energy, direct and total land are almost equal. For major solar photovoltaic (PV) projects direct land use constitutes of approximately 90% of the total land use area, as is demonstrated, for example, by Ong et al. (2013) who estimate 13 759 m^2/GWh for average total land-use and 12 545 m^2/GWh for average direct land-use. This is to be expected since solar panels do not have extensive spacing requirements like wind turbines (as described below). As a result, the land properties required for their installation need only accommodate the panels, access roads and small auxiliary facilities and are thus almost completely filled. It is therefore reasonable to assume that the panels are dominant from a landscape perspective within the totality of the used area, mainly due to their visibility but also due to glare effects, which are stronger in their proximity (Chiabrando et al., 2009).

In the case of wind energy, the difference between direct and total land use is larger. Indicatively, as described by Denholm et al. (2009), direct land-use of wind developments is 3000 ± 3000 m^2/MW and total land-use is 340 000 ± 220 000 m^2/MW. This difference is justified by the fact that wind turbines are sited in distances of 3 to 10 rotor diameters apart (120-900 m for 40-90 m blades) to optimize the absorption of wind energy. This generates the requirement for larger and more complex land properties for wind energy projects. But even though turbines and works of infrastructure only occupy a small percentage of the properties used, literature suggests that their presence is perceivable in a much larger area due to their size, the movement of their blades and the noise they generate under certain conditions (Manwell et al., 2002; Shen et al., 2019).

In particular, relevant studies suggest that the visual/landscape prominence or domination of wind turbines exceeds 1 to 6.4 km away from their location. Indicatively, The Sinclair – Thomas matrices (Select Committee appointed to consider European Union documents and other matters relating to the European Union, 1999) (as cited by Buchan (Buchan, 2002)) present 4 km as the radius of dominant impact for wind turbines with heights of 90 to 100 m. Similarly, Sullivan et al. present 6.4 km as the radius in which a wind turbine is considered a "commanding visual presence that may completely fill or exceed the visible horizon in the direction of view"(Sullivan et al., 2012). Finally, Bishop, Stevenson and Griffiths, SNH and Buchan all agree on a distance of 2 km as distance in which a wind turbine is dominant visually (Bishop, 2002; Buchan, 2002; Scottish Natural Heritage [SNH], 2009; Stevenson and Griffiths, 1994) and Vissering et al. (Vissering et al., 2011) conclude that the greatest impact is expected at up to 800 m and impact on "the integral part of scenic view" at up to 4 km.

In an investigation of the relation of the area of landscape dominance to the area of total land use, a simplified calculation of the theoretical visual impact of a common 3 MW wind turbine of 2019 was carried out. Such a turbine (with a rotor diameter of 80 m, tower height of 90 m and tower diameter of 6 m) occupies 50 m^2 at its base (Smith and Mahmoud, 2016), but is expected to be visually dominating, in an area larger than its total land use equivalent, even when the smallest distance of dominant visibility from literature is used. Using 800 m (Vissering et al., 2011) as the radius of a circle of visual dominance around the turbine, the area of impact was calculated 670 000 m^2/MW. Even if the turbine is not fully visible in this area due to concealment from terrain, tall buildings etc., this estimate significantly surpasses the average total land-use estimate of wind energy that is 176 000 m^2/MW (Table 3). The distance of 800 m, which is used in this example, is also equal to the distance of 10 rotor diameters, which is a common distance for the siting of adjacent turbines in a wind energy development. Thus, the reduction to the average area of visual impact due to overlapping of visual impact from adjacent turbines is not expected to affect this estimation. Furthermore, if the larger distances of visual dominance from the previous paragraph are used, the difference is even larger. For example, if a radius of 2 km is used (Bishop, 2002; Buchan, 2002; Scottish Natural Heritage [SNH], 2009; Stevenson and Griffiths, 1994) the area of maximum theoretical impact of a single turbine is 4 188 790 m^2/MW.

Hence, with total land use established as the type of land use that is more relevant to landscape impact, we proceeded on analysing relevant literature and concluding on generic estimates. Since literature on the subject was sufficient and in-agreement, own verification of additional data collection was not required. Two NREL reports from USA (Denholm et al., 2009; Ong et al., 2013), whose results have already been cited in relevant studies (Hertwich et al., 2016; Trainor et al., 2016), stood out and were distinguished as suitable for generic use. The reason for their selection was that they were the best match to the screening criteria of Section 2.2.1 In detail, (i) the datasets analysed were large and nationwide, (ii) the ruggedness index of USA is very close to the global average (Figure 2) and therefore the results are not expected to be biased due to terrain topography, (iii) they were presented in terms of installed capacity and therefore allowed for the use of the global CFs of Table 2 for their conversion to expected energy generation (iv) they originated from realized wind and solar energy projects and did not embody theoretical estimates and finally (v) USA has a developed economy status. Furthermore, since the studies were specifically conducted to measure land use, they are very meticulous, allowing for a thorough review of the methods used. Their results were also in general agreement with the other estimates in literature. Indicatively, the estimates of other studies, which are also are presented individually in the next paragraph, average 163 300 m^2/GWh for total land use of wind energy, while Denholm et al. estimated 176 000 m^2/GWh (Denholm et al., 2009); and 46 204 m^2/GWh for solar energy while Ong et al. estimated 28 000 m^2/GWh (Ong et al., 2013). In Table 3, we present the results of this Section as well as the estimates of Ong et al. and Denholm et al. in m^2/MW (before their conversion to m^2/GWh, with the use of the CFs of Table 2).

In other literature, total land use of wind energy, was estimated at 126 920 m^2/GWh by Trainor et al. (Trainor et al., 2016), 103 777 ± 51 889 m^2/GWh by Ledec et al. (Ledec et al., 2011) and 25 000 to 110 000 m^2/GWh by Gagnon et al. (Gagnon et al., 2002). In the study of Hertwich et al. (Hertwich et al., 2016), the results of five studies on total land use were compiled, ranging from 43 240 to 475 646 m^2/MW (Jacobson, 2009; MacKay, 2009; McDonald et al., 2009; Scheidel and Sorman, 2012; US Department of Energy [DOE], 2008) or 22 437 to 246 807 m^2/GWh, when converted in terms of energy generation, and averaging 191 508 m^2/GWh. Van Zalk and Behrens (van Zalk and Behrens, 2018) estimated average total land use of wind energy at 326 797 m^2/MW, i.e. similarly, 169 571 m^2/GWh, analysing literature from the USA. Finally, the estimates from the more recent studies of Fritsche et al. (Fritsche et al., 2017) and IINAS (International Institute for Sustainability Analysis and Strategy [IINAS], 2017), which are much smaller, 1000 m^2/GWh and 700m^2/GWh respectively, refer to direct land use which, as previously mentioned, is indeed very small in the case of wind energy.

Regarding total land use of solar energy, Gagnon et al. (2002) presented the highest and lowest estimates found in literature in 2002, which were 30 000 and 45 000 m^2/GWh respectively, Trainor et al. (2016) estimated it at 15 100 m^2/GWh, while Van Zalk and Behrens produced the largest estimate so far, 126 582 m^2/MW (van Zalk and Behrens, 2018), or 111 154 m^2/GWh (converted using the CF of Table 2). Finally in the website of UCS it was estimated in the range of 14 164 to 40 469 m^2/MW, which averages 21 063 m^2/GWh (converted using the CF of Table 2) (2013) . Lastly, Fritsche estimated 10 000 m^2/GWh (Fritsche et al., 2017) and IINAS 8700 m^2/GWh (International Institute for Sustainability Analysis and Strategy [IINAS], 2017) for direct land use of solar energy, which is in fact smaller than total land use.

Table 3. Estimates of total land use requirements of wind, solar and hydroelectric energy. The estimates were singled out from literature on the basis of highest generic applicability.

Type of renewable energy technology	Total land use per unit installed capacity (m^2/MW)	Total installed capacity of data sets used (GW)	Source of total land-use data per unit installed capacity	Total land use per unit energy generation (m^2/GWh) [a]
Wind (Onshore >20 MW)	340 000	25	(Denholm et al., 2009)	176 000 [b]
Solar (PV >20 MW)	31 970	3.6	(Ong et al., 2013)	28 000 [b c]
Hydro (Large hydroelectric dams (non-multipurpose reservoirs))	-	Unknown [d]	(Trainor et al., 2016)	900

a. Results rounded up to one thousand.

b. Conversion of installed capacity to energy with the use of corresponding CF's of Table 2

c. CSP land-use presents a slight difference to PV land-use in the report of Ong et al. (Ong et al., 2013).

d. Data set consists of 50 randomly selected hydroelectric reservoirs from the USA (Trainor et al., 2016). The estimate was verified by own calculations based on data sets of 9.7 GW of installed capacity from Spanish and Greek hydroelectric reservoirs (Table 5).

2.2.2.2 *Hydroelectric energy land use*

Land use of hydroelectric projects is measured through the area covered by hydroelectric reservoirs. In reality, land is also used by the dam, the power plant and other appurtenant structures, but the reservoir area is larger by several orders of magnitude, rendering these additional land-uses negligible[5]. Hydroelectric land use, as measured through the reservoir area, can be considered an adequate metric of landscape impact for the following reasons: (a) The major landscape transformation of hydroelectric projects is, in fact, the inundation of sections of river valleys, for the creation of artificial lakes and (b) as described in detail in the next Subsection, negative visual impact from reservoirs and hydroelectric facilities has not been reported in literature.

However, a generic estimate of hydroelectric land use was harder to reach, in comparison to solar and wind energy, as there was no consensus in literature. This prevented a quick and definitive conclusion and instead generated the requirement for in-depth analysis of published research and supplementary own calculations. All compiled estimates of hydroelectric land use, based on national or global data, are presented in Table 4. The estimates present a wide range, the lowest and highest being 2000 m^2/GWh and 768 234 m^2/GWh. For comparison, the range defined by

[5] This is verified by calculations of land use of hydroelectric infrastructure in Section 2.2.2.2.

these estimates was 766 234 m^2/GWh, while the corresponding ranges for solar and wind energy land use, were 35 000 and 221 807 m^2/GWh, respectively.

2.2.2.2.1 Investigation of the discrepancy

A level of variability is generally justified in estimates of land use from hydroelectric projects, since the average surface area of hydroelectric reservoirs is dependent both on the average terrain topography of the examined area and on the exact locations selected for the projects, within this area. However, the following two observations, indicated that the discrepancy in estimates of hydroelectric land use might be caused or exaggerated by additional factors. In summary, the two basic observations were (a) the lack of correlation of estimates to topographical relief, i.e., flat countries having smaller ratios of average reservoir area to energy generation and more mountainous countries having larger ratios, and (b) several irregularities in the data selection processes, especially in older literature over hydroelectric land use.

In more detail, the first possible explanation that was examined in the investigation of this discrepancy was the aforementioned sensitivity of hydroelectric land use to terrain topography. However, no correlation of average reservoir surface with the countries' terrain was identified in the compiled estimates. Indicatively, even two studies on the extremes of the range of the estimates (IINAS – 3500 m^2/GWh (International Institute for Sustainability Analysis and Strategy [IINAS], 2017) and Pimentel et al. 750 000 m^2/GWh (Pimentel et al., 2002)), analysed data from countries with similar and, in fact, close to average terrain; with ruggedness indexes 0.6 (Germany) and 1.1 (USA), respectively (Figure 2). Furthermore, even two studies that utilized data from the same country reached conclusions on average reservoir area that differ greatly; Pimentel et al. estimated 750 000 m^2/GWh (Pimentel et al., 2002) and Trainor et al. 16 900 m^2/GWh (Trainor et al., 2016) for hydroelectric land use in the USA. Unexpectantly, their difference, 733 100 m^2/ GWh, is almost as large as the total range of estimates of Table 3, i.e., 748 234 m^2/GWh.

The second possible explanation that was investigated, was the presence of estimates that overestimated or underestimated hydroelectric land use. To explore this scenario the studies of Table 3 were examined in detail, placing emphasis on the data used in each case. Unfortunately, accessibility to the datasets that were used was limited in the more recent studies (Fritsche et al., 2017; International Institute for Sustainability Analysis and Strategy [IINAS], 2017; Trainor et al., 2016), since the presented estimates were generic and were not associated with specific datasets. The older studies of Gagnon and van de Vate, Goodland, and Ledec and Quintero (Gagnon and van de Vate, 1997; Goodland, 1995; Ledec and Quintero, 2003) were more descriptive over data selection but important irregularities were identified during their review. In particular, the datasets used, which were largely common between the three studies, were found to be partial to reservoirs with bad environmental design. In the studies of Ledec and Quintero and Goodland (Goodland, 1995; Ledec and Quintero, 2003), 96% and 94% of the projects analysed, respectively, originate from developing countries. Additionally, Ledec and Quintero include some particularly small projects in their calculations, whose average reservoir area is larger by two orders of magnitude than the largest estimate of hydroelectric land use. This is justified by the fact that the aim of these studies was the analysis of extreme environmental impacts from hydroelectric projects, rather than the estimation of an average of hydroelectric land use. Furthermore, several of the reservoirs used in the calculations are not exclusively hydroelectric but are multipurpose reservoirs, which is expected to contribute to overestimations. It has to be noted that Goodland, in contrast to Ledec et al., does not claim to have reached an estimate of global average of hydroelectric land use, with the use of these data. The study of Gagnon and van de Vate (Gagnon and van de Vate, 1997), referenced several other data sources in addition to Goodland (Goodland, 1995) but unfortunately the majority of the cited studies could not be accessed. On the basis of the preceding arguments as well as the further in-depth analysis of the three aforementioned studies, presented in Appendix B, their results were not considered suitable for use in a generic estimation of hydroelectric land use.

Table 4. Estimates of hydroelectric land-use in literature (estimates that used national data or compilations of data from various countries)

Geographic origin of data set	Dataset details	Land use per unit energy generation (m^2/GWh)	Source
N/a	Generic estimate by authors	10 000	(Fritsche et al., 2017)
Germany	Na	3500	(International Institute for Sustainability Analysis and Strategy [IINAS], 2017) as cited in (Fritsche et al., 2017)
USA	47 hydroelectric dams randomly selected from the National Hydrography Dataset	16 900	(Trainor et al., 2016)
China	Representing 22.1 GW of installed capacity	24 000	(Ziqiang et al., 1996) as cited in (Gagnon and van de Vate, 1997)
Switzerland	Representing 11.8 GW of installed capacity	2000	(Dones and Gantner, 1996) as cited in (Gagnon and van de Vate, 1997)
N/a	Personal communication of Ledec and Quintero with J. Goldemberg	185 117	(Ledec and Quintero, 2003)
USA	Based on a random sample of 50 hydropower reservoirs in the USA	750 000	(Pimentel et al., 2002)
Asia & Africa & Latin America	189 projects: Many small dams in Africa	86 872[a]	(Goodland, 1995) as cited in (Gagnon and van de Vate, 1997)

Various	Estimated using data from the World Bank (Goodland,1995), which is based upon a survey of nearly 200 plants.	98 729-768 234[b]	(Goodland, 1995) as cited in (Williams and Porter, 2006)
Various	Calculated using the sum of installed capacity and reservoir area of all referenced projects	34 181[c]	(Goodland, 1995)

a. Weighted average of the three cited figures.

b. Original data of Williams and Porter(2006) was in m^2/MW and was converted to m^2/GWh using the CF of Table 2.

c. The CF of Table 2 was used for conversion from m^2/MW to m^2/GWh.

2.2.2.2.2 Challenges in calculating hydroelectric land use

The irregularities found in the older studies referenced in the previous Subsection (Gagnon and van de Vate, 1997; Goodland, 1995; Ledec and Quintero, 2003), demonstrated the need to examine the data sets used in each study thoroughly. However, since detailed data sets were not found in the remaining studies (Fritsche et al., 2017; International Institute for Sustainability Analysis and Strategy [IINAS], 2017; Pimentel et al., 2002; Trainor et al., 2016), we concluded that it was necessary to perform own verifying calculations. During this process, some inherent challenges in the estimation of hydroelectric land use were identified (Holdren et al., 1980). These might be partially responsible for the difficulty of the scientific community in reaching consensus on hydroelectric land use. Calculation of hydroelectric land-use is more complex than solar and wind energy land-use, since it does not only depend on two variables; namely, the size of area used by the projects and their energy generation or installed capacity. For hydroelectric reservoirs, other than the surface area of the reservoir and the energy generation or installed capacity of the hydroelectric power plant, the same calculation additionally requires:

- Identification and separation of single-purpose hydroelectric reservoirs and multipurpose hydroelectric reservoirs: It is common for hydroelectric projects to be combined with other water uses as part of multi-purpose reservoirs (Gagnon et al., 2002; Papoulakos et al., 2017). In particular, according to data from the International Commission on Large Dams, out of the 5786 hydroelectric dams globally 3932 are multi-purpose dams (International Commission on Large Dams, 2018). However, to avoid overestimating hydroelectric land use, reservoirs with additional uses that affect the volume of water storage, such as water supply, irrigation, industrial use and flood control, should not be included in the calculations.

- Understanding of the multiple (in some cases) components of hydroelectric complexes: The structure of a hydroelectric complex is not always binary, consisting of a single reservoir and a single power station. On the contrary, it can be a very complicated system consisting of several reservoirs and power stations, in distance (Koutsoyiannis et al., 2002). Tracking all the components of a hydroelectric complex can be challenging, since they are spatially dispersed and they differ in size, but their omission can alter the results significantly. For example, if a pumped storage reservoir upstream or an additional power station downstream of the main dam is omitted, the installed capacity and the land use of the hydroelectric complex will be miscalculated. In extensive calculations that include multiple hydroelectric projects avoiding such omissions requires meticulousness and in-depth knowledge of the examined hydroelectric complexes.

Gagnon et al. highlighted cases in which these challenges were not fully addressed, in their literature review (Gagnon et al., 2002), and furthermore, in this article, the studies of Ledec and Quintero and Goodland (Goodland, 1995; Ledec and Quintero, 2003) were highlighted for similar omissions (see Appendix B). To avoid biased estimates, if studies did not clarify whether they dealt with these challenges or if their data sets could not be accessed and inspected (Ledec and Quintero, 2003; Pimentel et al., 2002; Ziqiang et al., 1996), they were considered potentially prone to not having addressed them and where therefore not included in the generic estimation of hydroelectric land use.

2.2.2.2.3 Conclusion on hydroelectric land use

In recent analyses, Trainor (Trainor et al., 2016), Fritsche (Fritsche et al., 2017) and IINAS (as cited in (Fritsche et al., 2017)), estimate hydroelectric land use in the range of 3000-16 900 m^2/GWh. Out of these studies, the study of Trainor et al., which is based on a random sample of 47 hydroelectric projects in the USA, was found to suit the secondary screening criteria of Section 2.2.1 and the additional considerations over hydroelectric land use calculations the best. In detail: (i) all projects used were single-purpose hydroelectric projects (Trainor, personal communication, Mar 27, 2019) randomly compiled in a national scale, (ii) data originated from USA that has moderate terrain topography (Figure 2), (iii) data were presented in terms of energy generation (iv) based on realized energy generation data and finally, (v) USA has developed economy status. Thus, 16 900 m^2/GWh was selected as the estimate with the best generic applicability regarding land use of hydroelectric reservoirs. The older estimate of Pimentel et al. (Pimentel et al., 2002) (Table 4) that was also based on a random sample of 50 hydroelectric reservoirs from the USA, was not used, since it was not clarified whether these were multipurpose reservoirs or not (personal communication efforts proved unsuccessful). As a result, based on the arguments for the previous Subsection it was not considered suitable. Despite the consensus in more recent studies, the data set that supports the estimate of Trainor is not very extensive and both Fritsche (Fritsche et al., 2017) and IINAS (as cited in (Fritsche et al., 2017)) do not provide detailed data-sets. Therefore, some additional calculations were carried out for verification purposes. The projects used for verifying calculations were (a) Spanish hydroelectric dams of installed capacity larger than 100 MW (García Marín and Espejo Marín, 2010; Sistema Nacional de Cartografía de Zonas Inundable [SNCZI], 2017) and (b) the complete list of Greek hydroelectric dams. Greece is a country with relatively high terrain ruggedness, and therefore Greek hydroelectric reservoirs were expected to require smaller land use than the global average. Nonetheless, they were included as a secondary verification, because of the accessibility of the datasets to the authors and their in-depth knowledge of them. The results are presented in Table 5 and are close to the estimate of Trainor et al.

Table 5. Spanish and Greek hydroelectric reservoir land-use data.

Data set examined	Land use per unit installed capacity (m^2/MW)	Installed capacity of projects (GW)	Data source	Land use per unit energy generation (m^2/GWh)[a]
Greek hydroelectric dams	44 291	1.1[b]	(Greek Committee on Large Dams [GCOLD] and TEE Larissa, 2012)	14 000
Spanish hydroelectric dams	41 304	8.6[c]	(García Marín and Espejo Marín, 2010; Sistema Nacional de Cartografía de Zonas Inundable [SNCZI], 2017) [d]	13 000

a. Includes reservoir area and an additional 200 m^2/GWh for appurtenant structures. Estimates are rounded up to one thousand.

b. Total hydroelectric capacity examined was 3.3 GW, 1.1 GW of which was from single-purpose hydroelectric reservoirs.

c. Total hydroelectric capacity examined was 11 GW, 8.6 GW of which was from single-purpose hydroelectric reservoirs.

d. García Marín and Espejo Marín as source for installed capacity and SNCZI as source for reservoir area.

Other than the reservoir area, additional land-uses of hydroelectric projects were also calculated to investigate their contribution to total land use, since relevant data were not found in literature. In particular, the sum of the area of the main dam, auxiliary dams (when present), modified slopes, power stations, visible pipelines and other auxiliary structures was measured, for Greek single-purpose hydroelectric reservoirs, using Google Earth. The average land required for these uses was 200 m^2/GWh, which is insignificant in the scale of the calculation of hydroelectric land use (Figure 3).

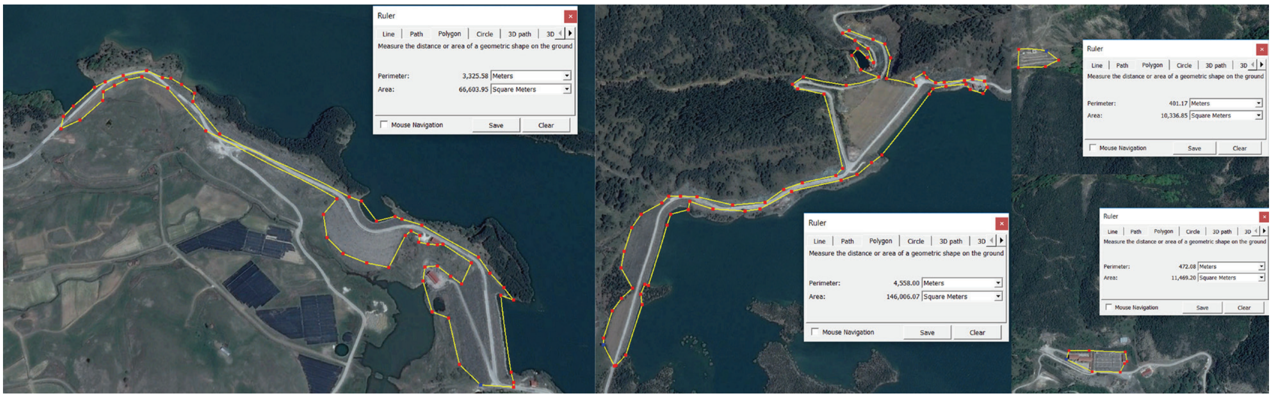


Figure 3. Example of measurement of land use from appurtenant structures and engineering works in a hydroelectric project. The project presented, Piges Aoou dam, had the most extensive non-reservoir land use out of the examined Greek hydroelectric dams. This included the power station, main dam, auxiliary dams and other appurtenant structures.

2.2.3 Visibility

Other than the direct impact on landscapes, which is measured by land-use, landscape impacts are also generated due to visibility of renewable energy projects. These so-called visual impacts, although more subjective, can extend several kilometres away from the project's locations. Hence, they have been thoroughly analysed in scientific literature (Apostol et al., 2016; Frolova et al., 2015b; Stevenson and Griffiths, 1994; Stremke and van den Dobbelsteen, 2012; Vissering et al., 2011) but also in institutional environmental-impact-assessment guidelines, which include measures to quantify and reduce these impacts, primarily for wind energy projects (Hellenic Ministry of Environment, Energy & Climate Change, 2008; Horner + Maclennan and Envision, 2006; New South Wales Government [NSW Government], 2016).

The various methods that have been developed to estimate and quantify visual impact, range from photomontage and digital representation to GIS-based viewshed analyses (Fernandez-Jimenez et al., 2015; Hurtado et al., 2004; Minelli et al., 2014; Sklenicka and Zouhar, 2018; Tsoutsos et al., 2006). Since the aims of this Section are the review of literature on visual impacts of major RE technologies and the elicitation of generic estimates, priority was given to methods of estimating visual impact that have been applied widely in national or regional scale, with similar or comparable technical assumptions. The methodology that fulfilled these criteria the best was the so called "viewshed analysis" and in particular, the calculation of "zone of theoretical visibility" (ZTV) (Hankinson, 1999) or "zone of visual impact/influence"(Wood, 2000), as it is also called. ZTV is calculated with GIS technology in the form of a binary map presenting the areas from which an object, e.g., a wind turbine, is visible and the areas from which it is not. Even though this method describes deterministically a phenomenon which is not deterministic (Möller, 2006), i.e. the discernibility of an object changes according to weather conditions, time of the day, eyesight of viewer etc., it was preferred in relation to other methods for the following two reasons: (a) It is the only technique that has been applied, in several cases, on estimations of landscape impact on a large scale (national or regional), and (b) it is a strictly spatial quantification of visual impact, in which visibility is determined based on terrain morphology and viewing distance. This is in contrast to several other common methods of evaluating visual impact, such as the Quechee Test (Vermont Agency of Natural Resources and Department of Public Service and Agency of Agriculture, Food and Markets, 2015), multicriteria analyses (Grêt-Regamey and Wissen Hayek, 2013; Sibille et al., 2009), visualization and image analysis techniques (Sargentis et al., 2019a; Schöbel et al., 2012) the Spanish method (Hurtado et al., 2004), etc. that intertwine spatial analysis with perception analysis; e.g. with inclusion of the perception of samples of individuals on the viewed elements. Even though the combination of spatial and perceptual analysis renders such methodologies more complete, it also renders them more complex and more difficult to scale up, to analyse visual impact on large scale. Furthermore, since within this Section perception on landscape impact of RE technologies is analysed separately in the next Subsection, the analysis of visibility in this Subsection is primarily focused on its spatial quantification rather that its perceptual analysis.

All types of viewshed and ZTV analyses are characterized by a common calculation process; a digital elevation model of the area of interest is used in which the locations of the objects that cause visual impact are pinpointed and their visibility is calculated radially with a line-of-sight test. When examined more thoroughly though, different analyses present variation on the setup of several parameters that potentially affect the size of the calculated ZTV. The majority of the analysed published studied, presented differences in the setup of these parameters, however most of them were considered minor and were not analysed in depth. An exception to this was the maximum distance of visibility of wind turbines. Maximum distance of visibility was considered a major differentiating parameter among studies on visibility of wind energy projects as it ranged from 10 km to 35 km, which was expected to have a significant effect on the size of the generated ZTVs. Before proceeding on the detailed analysis of the maximum distance of visibility we present some examples of minor differences in the setup of ZTV analyses, which were not analysed further. These were: the adjustment of elevation according to land-use height (Rodrigues et al., 2010), the inclusion of visibility of wind turbines from regions sharing borders with the area examined (Möller, 2010), observer height and observed object height (Scottish Natural Heritage [SNH], 2014).

Maximum distance of visibility or visual threshold[6] defines the spatial extends of the area that is investigated for visibility and is thus, arguably the parameter that affects the results of a ZTV calculation the most. In literature, the maximum distance of visibility of a wind turbine in clear weather conditions from an "unaided eye" is reported as long as 5[8] (Sullivan et al., 2012) or 42 km (for offshore wind turbines) (Sullivan et al., 2013). In ZTV analyses however, the distance used is usually shorter, but varies greatly from study to study. The distance in which visual nuisance is considered significant, ranges from 3 to 40 km (in less than 2 to 3 km the visibility is considered dominant). For example, SNH and Buchan indicate 2 km as maximum distance of visual dominance of a wind turbine (Buchan, 2002; Scottish Natural Heritage [SNH], 2009) while Bishop (Bishop, 2002) describes that "visual impact remains `in the eye of the beholder' but may well become minimal beyond 5 km to 7 km". Similarly, the Thomas Matrix and Sinclair Matrix, as cited by Sullivan et al. (Sullivan et al., 2012), present distances of 3-4 km and 7.5-12 km, respectively, as distances of moderate impact but potentially intrusive. Betakova et al. propose visual thresholds of the same scale, 10 km for landscapes with "high aesthetic values" and 5 km in "less-attractive landscapes" (Betakova et al., 2015). This correlation of visual impact perception with the quality of the examined landscape, has also been supported in other studies, e.g. by Molnarova et al. (Molnarova et al., 2012). Sullivan et al. estimate the distance of major perceived contrast at 16 km (Sullivan et al., 2012) and generally the trend in more recent studies, is the promotion of larger distances for the calculation of ZTV for average-sized wind turbines. For example, 48 km is proposed by Sullivan et al. (Sullivan et al., 2012), 20 km by Bishop (Bishop, 2002) and 16 to 40 km by Vissering et al. (Vissering et al., 2011). Moreover, in the recent version of guidelines from SNH, which are considered to be among the most reliable in the scientific field of visual-impact analysis (Churchward, 2013) and have been applied extensively (Degórski et al., 2012; Scottish Natural Heritage [SNH], 2014), the use of a 35 km threshold is suggested for ZTV analyses of modern wind turbines, with heights of 101-130 m (Scottish Natural Heritage [SNH], 2017).

As can be observed in Table 6, the maximum visibility threshold in the large-scale ZTV studies that were compiled from literature ranged from 10 to 35 km. To mitigate the fluctuation that is expected in the results of ZTV analyses based on this variation of the visibility threshold and allow

[6] It is also referenced in literature as discernibility range (Rodrigues et al., 2010).

for a fairer comparison of the compiled studies, a simplified homogenization of their results was carried out. The homogenization was made by scaling the ZTV area calculated in each study with a weight based on the ratio of the visual threshold used in each study to the average visual threshold of all studies[7] that was 20.83 km. The homogenized estimates are presented in Figure 4 and Figure 5, which explore the spatial evolution of ZTV in relation to installed capacity and energy generation.

Table 6. Data and results from national and regional-scale viewshed analyses of wind energy projects.

Name of country/region	Installed capacity (MW)	Zone of theoretical visibility (km^2)	Visibility threshold (km)	Source	ZTV per unit energy generation (km^2/GWh)
Spain	23 066	85 736	35[a]	(Rodrigues et al., 2010)	1.71
Netherlands	2206	7121	10	(Statistics Netherlands [CBS] et al., 2014)	1.69
Poland (Kuyavia-Pomerania)	282	11 033	30	(Degórski et al., 2012)	20.30
Denmark (North Jutland)	513	7616	30	(Möller, 2010)	7.37
Spain (Andalucia)	2992	87 555	15	(Díaz Cuevas et al., 2016)	1.18
Scotland	4776	78 809	30	(Scottish Natural Heritage [SNH], 2014)	3.24
Greece (South Aegean)	95	1453	10	(Tsilimigkas et al., 2018)	7.94

a. Rodrigues et al. (Rodrigues et al., 2010) did not use a fixed number but an equation for the calculation of the visibility threshold of turbines according to their height. The equation was used here for a V63 – Vestas wind turbine (91.8 m total height; https://en.wind-turbineb models.com/turbines/821-vestas-v63), which was considered representative of the average wind turbine in Spain.

It is noteworthy that Table 6 includes ZTV analyses exclusively from wind energy projects. This is due to the fact that large-scale visibility analyses have only been carried out for wind energy; with one exception, the ZTV analysis of Rodrigues et al. (2010) that also included solar energy

[7] Except the study of Rodrigues et al. (Rodrigues et al., 2010), who did not use a universal visual threshold, but calculated a unique visual threshold for each renewable energy facility examined.

developments. This lack of research interest for solar and hydroelectric energy, is to be expected based on the initial observations of Section 2.1.2 and the differences of the examined technologies in regard to perception of landscape impact are analysed in detail in the next Section and the discussion. However, differences in terms of topographical extents of visibility are also present and significantly affect visual impacts. In particular:

- Solar panels are more easily concealed within terrain forms and as a result they generate much smaller visual impact than wind turbines. The height of PV panels is usually less than 5 m whereas the height of wind turbines, with current technology, ranges from 125 to 247 m (Vestas Wind Systems A/S, 2019) (heights of models V90-2.0 MW IEC S and V162-5.6 MW DIBt S of Vestas, respectively). The spatial differences of visual impacts from solar and wind energy are also demonstrated by Rodrigues et al. (2010). In their study, Rodrigues et al. estimated the visually affected area from wind energy approximately 3.6 times larger than the visually affected area from solar energy, in two scenarios of similar energy generation from wind and solar energy in Spain (50 TWh/year from wind energy and 53 TWh/year from solar energy). In a study on the visual threshold of solar energy projects, by Sullivan et al. (Sullivan et al., 2012), the threshold was estimated to range between 24 and 35 km. This illustrates that were there not for the small height of solar panels, they would probably produce comparable visual impact to wind energy projects.
- Even though reservoirs are definitely the cause of major direct-transformation to landscapes (Leturcq, 2019), hydroelectric dams have attracted very limited research interest regarding the visual aspect of their impact to landscapes (Cohen et al., 2014). From a spatial standpoint, this is justified by the fact that hydroelectric facilities and reservoirs are usually concealed in valley terrain. Even though large-scale ZTV analyses have not been carried out for hydroelectric projects, this is excellently demonstrated in the study by Dehkordi and Nakagoshi (Dehkordi and Nakagoshi, 2004), where it is shown that the ZTV of the infrastructure and reservoir of Haizuka dam, in Japan, is confined within the borders defined by the ridges of the valley where the project is constructed. Similar arguments have also been formed by Cohen et. al. (Cohen et al., 2014). Visual impact from reservoirs has also been analysed by Christofides et al. (Christofides et al., 2005) and Sargentis et al. (Sargentis et al., 2005) but on another context; i.e. investigating the aesthetics of a reservoir depending on water level with the aim of optimizing the view from touristic facilities —which were developed because of the reservoir— rather than calculating a visually affected area.

Ultimately, generic estimates of visibility were calculated or selected utilizing the results of the ZTV analyses that fulfilled the secondary screening criteria developed in Section 2.2.1.2 In detail, the distinguished studies (i) were based on regional or national data sets, (ii) analysed data from countries with moderate terrain (Spain and UK), according to Figure 2, (iii) did not embody theoretical capacity factors in the calculations, (iv) did not produce theoretical estimates[8] but

[8] It has to be noted that the two estimates of Rodrigues et al. for wind and solar energy, refer to hypothetical scenarios of energy generation. These scenarios were considered realistic however, based on

analysed data from realized projects and finally, (v) analysed data from countries with developed economies. For wind energy, the three studies of Table 6 that fulfilled the aforementioned criteria were averaged. These studies utilized data from Spain (Rodrigues et al., 2010), Scotland (Scottish Natural Heritage [SNH], 2014)[9] and the region of Andalusia (Díaz Cuevas et al., 2016)[10] and their average was 2.01 km^2/GWh. For solar energy, the generic estimate produced was 0.45 km^2/GWh, based on the only available large-scale ZTV study of Rodrigues et al. (Rodrigues et al., 2010). Finally, for hydroelectric energy no large-scale ZTV analysis or other type of visibility analysis was found in literature.

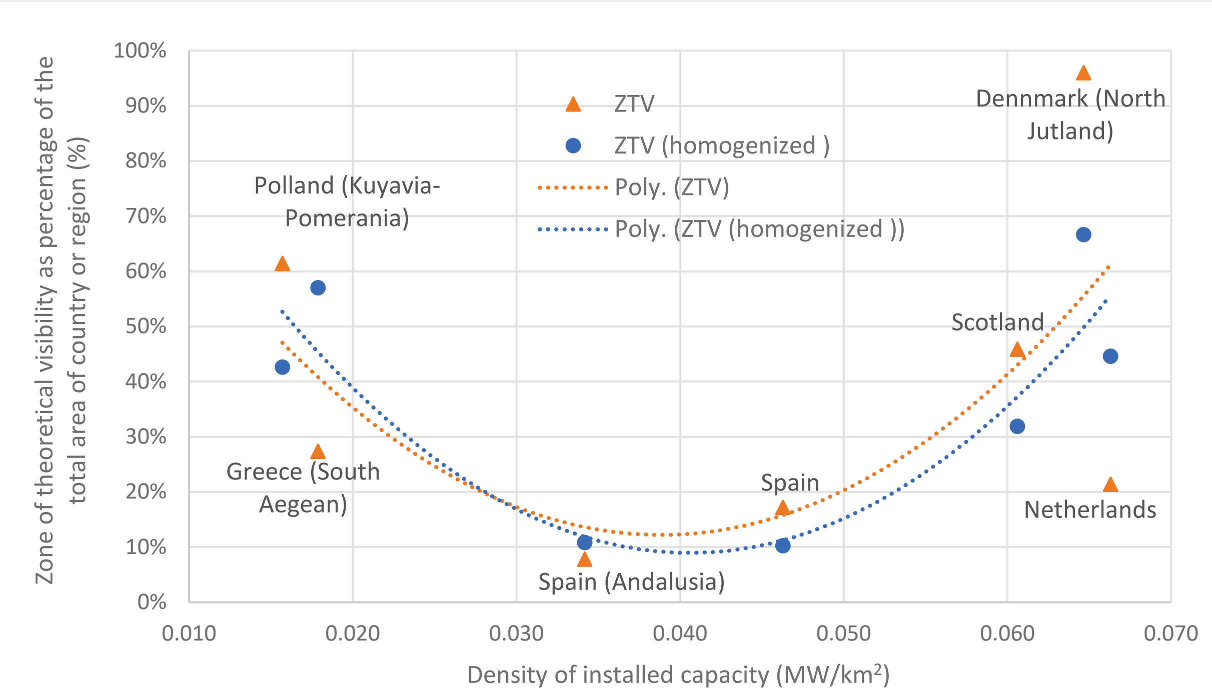


Figure 4. Percentages of the area of countries and regions from which wind turbines are theoretically visible vs. density of installed capacity. Sources of visibility data are presented in Table 6. A homogenized version of the results, based on the average visual threshold used in the studies, is also plotted as a meta-analysis of the visibility threshold.

their proximity to actual energy generation in Spain and the incorporation of parameters related to energy efficiency, terrain and protected areas in their generation.

[9] Scotland is expected to have a higher ruggedness index, than UK (the study on Nunn and Puga (2010) only provided the ruggedness index for the total of the UK and thus this was the index that was used) but is not expected to be higher than 2, which is the equivalent of 75% in Figure 2.

[10] There is no indication that the ruggedness index should be significantly larger than the national average of Spain which is close to the limit frequency of 75%.

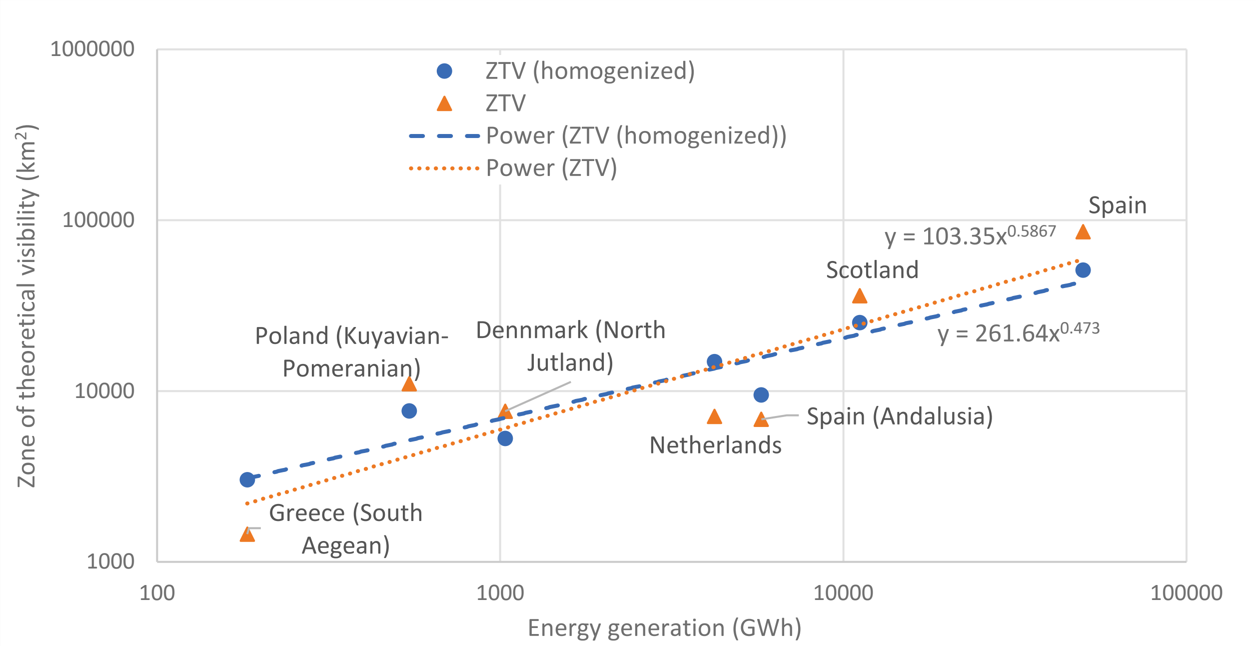


Figure 5. Zones of theoretical visibility of wind turbines vs. energy generation. Sources of visibility data are presented in Table 6. A homogenized version of the results, based on the average visual threshold used in the studies, is also plotted as a meta-analysis of the visibility threshold.

2.2.4 Public perception

The greatest difficulty in quantifying the impact of RE on landscapes is the innate subjectivity of analyses related to aesthetics. This is excellently demonstrated by the following discrepancy: On the one hand, part of the public views wind turbines as beautiful new elements in landscapes and perceives them as elements of human progress and sustainability (Nadaï and Van Der Horst, 2010; Pasqualetti and Stremke, 2018; Thayer and Freeman, 1987). On the other hand, wind turbines are also viewed as disturbing structures, unrelated to the historical and natural characteristics of landscapes, and perceived as symbols of industrialization (Fast et al., 2015; Lee, 2017; Nadaï and Van Der Horst, 2010; Phadke, 2011; Sklenicka and Zouhar, 2018). Generally, this kind of subjectivity is always present in the analysis of landscapes and is to be expected based on the definition of landscape by the Council of Europe (Council of Europe, 2000): "Landscape means an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors". The phrase "as perceived by people" demonstrates this subjectivity of public attitudes, as it links the understanding of landscape with one's own perception of it. Perception is neither exclusively emotional nor rational, but is defined in each person by a mixture of several factors (Devine-Wright, 2005), some of which are formed by emotion and others by rationale. To some, the view of a RE project might be unpleasant purely because of aesthetics and emotion (Cass and Walker, 2009) while to others because of a rational analysis based on personal ideologies (West et al., 2010).

Concepts like landscape impact-perception have in several occasions been downgraded and omitted from planning analyses (de Waal and Stremke, 2014; Holdren et al., 1980; Prados, 2010). In this analysis however, public perception is identified as an integral element of the discussion on landscape impact of RE; at least of equal importance with the other two metrics analysed. Even though public perception on landscape impact is subjective and difficult to quantify, its effect on the development of RE has been quite objective and quantifiable. This has been proved by the various cases in which public perception on landscape impact determined the emergence of opposition and thus the approval, delay or cancellation of RE schemes, as presented in the introduction of the study. More generally, the overall management of public attitudes on RE has been recognized as a prerequisite for sustainable design (Devine-Wright, 2014) and perception on landscape-impact is one of their main determinants. Additionally, the perception on the aesthetics of RE installations is also directly related to the spatial aspect of landscape impact, since it determines the negative perception of visibility and therefore the existence of visual impacts, in addition to the indisputable direct impacts to land surface (Stremke and van den Dobbelsteen, 2012).

So far, public perception on RE projects —in general, including but not limited to perception on landscape impacts— has mostly been quantified through statistical analyses with sample data originating from surveys. The surveys are carried out through questionnaires and interviews with people living in proximity to RE developments (Hoen et al., 2018; Kontogianni et al., 2014, 2013; Phadke, 2011; Scherhaufer et al., 2017; Sütterlin and Siegrist, 2017; Walker, 1995; Wolsink, 2000), experts (Langer et al., 2016; Sheikh et al., 2016) or stakeholders (Jobert A. et al., 2007; Phadke, 2011; Scherhaufer et al., 2017). Some of the surveys are additionally accompanied with pictorial stimuli (Ladenburg, 2009; Maehr et al., 2015), for the participants to specifically evaluate impact on landscape. In literature, the vast majority of studies refer to wind energy and fewer to solar energy (Sheikh et al., 2016; Späth, 2018; Sütterlin and Siegrist, 2017) and hydroelectric energy (Sütterlin and Siegrist, 2017; Walker, 1995). Visual intrusion or landscape impact are broadly recognized as fundamental components of negative perception for wind energy and are also mentioned in a smaller extent for solar energy as well. In the case of hydroelectric energy, negative perception is mostly attributed to other environmental and social impacts.

To quantify public perception on landscape impact we carried out a statistical perception analysis of literature on the topic of landscape-impact from RE and extracted indexes of perception. Relevant literature has proliferated over the past 20 years, ensuring the availability of a sufficiently large sample of studies. The basic logic for the implementation of this approach was that it allowed for the integration of both (a) the perception of the scientific community and (b) the perception of the general public. In particular, the perception of the general public is indirectly included, through surveys and questionnaires used in the analysed studies. Indicatively, several of the articles examined present results from research made using questionnaires on samples of citizens, decision makers and stakeholders affected by RE schemes (Baraja-Rodríguez et al., 2015; Betakova et al., 2016; Brahimi et al., 2018; Burton et al., 2001; Grima Murcia et al., 2017; Maehr et al., 2015; Mérida-Rodríguez et al., 2015b; Pagnussatt et al., 2018; Scherhaufer et al., 2017; Sherren et al., 2016; Sklenicka and Zouhar, 2018) or analysing media coverage on the landscape impact of RE (Delicado et al., 2016; Ferrario and Castiglioni, 2017; Nordman et al., 2015; Weiss, 2017). Hence, we believe that an elitist approach is avoided and the perception of the public is covered though a wide spectrum of opinions.

In more detail, the statistical analysis started with the collection of scientific articles from the search engines of Elsevier, Wiley and Springer online databases. We used the search strings "hydroelectric energy landscape impact", "wind energy landscape impact" and "solar energy landscape impact". For each search string the first twenty results from each data-base were collected, leading to the collection of a total of 60 publications per RE technology. The publications were read through and searched with an algorithmic procedure for sentences that were statements of perception, i.e., phrases that stated that the RE technology examined has a negative or positive effect to landscapes. According to these sentences, publications were then categorized as being positive, mixed or negative towards the landscape impact of each of the three RE technologies examined (Figure 6). The exact algorithmic procedure followed and the publications analysed are presented in Appendix C and in the supplementary material.

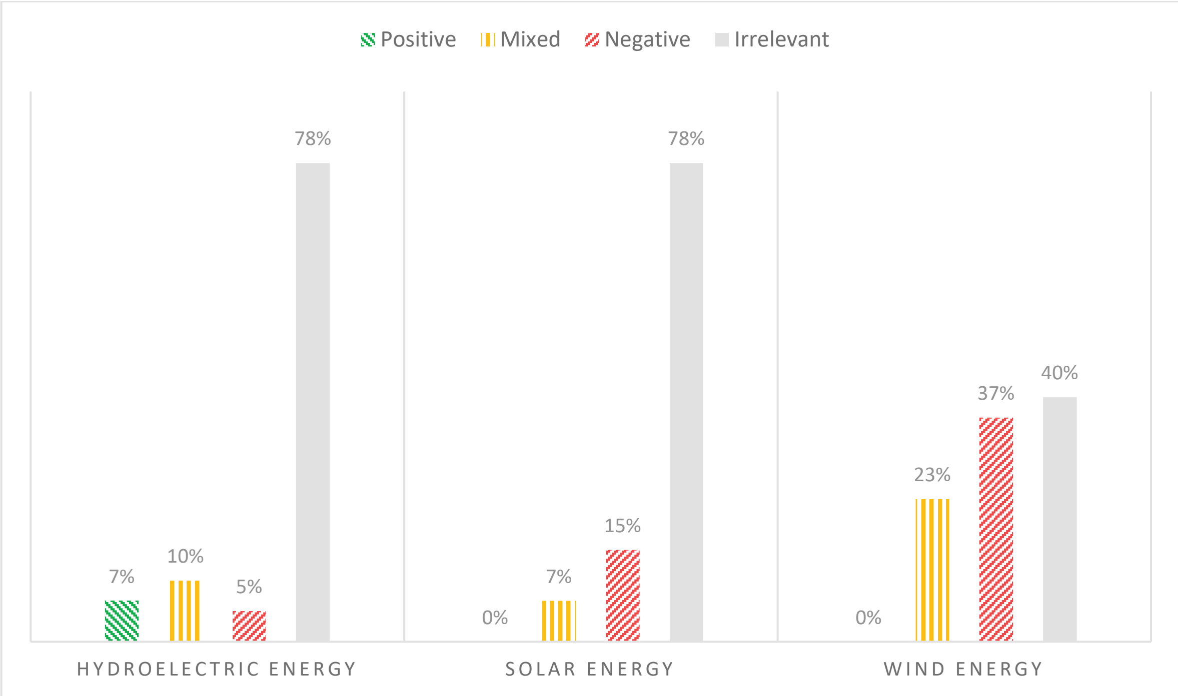


Figure 6. Percentages of articles labelled as positive, negative, mixed or irrelevant in the statistical perception analysis of literature on the landscape impact of major renewable energy technologies (more details on the publications labelled are presented in Appendix C and the supplementary material).

To present the results of the perception analysis in a simple format, we calculated an index of perception for each RE technology. This index was calculated as the percentage of publications labelled "Negative" minus the percentage of publications labelled "Positive". Publications labelled as "Mixed" include both negative and positive references and were not added to that sum, since they were considered neutralized. The index of perception was thus calculated -2% (meaning slightly positive perception) for hydroelectric energy, 15% for solar energy and 37% for wind energy. A second index was also extracted from the results to specifically quantify perception of negative landscape impact. It was named index of negative perception and was calculated by summing the percentages of articles that were labelled as "Mixed" or "Negative", as both of these labels required negative remarks on the landscape impact of the technology examined. In this index hydroelectric energy scored 15%, solar energy 22% and wind energy 60%.

2.3 Generic results

Table 7 summarizes the generic estimates of land use, visibility and public perception of hydroelectric, wind and solar energy that were compiled or calculated from literature. The generic applicability of the results is based on (a) the implementation of the additional secondary screening criteria of Section 2.2.1.2 for land use and visibility and (b) the quantification of public perception through statistical analysis of literature.

Table 7. Generic estimates of land use, visibility and public perception of RE, in the context of landscape impact.

Type of RE technology	Total Land Use (m^2/GWh)	Visibility (m^2/GWh)	Index of Negative Perception in Literature (%)
Wind (onshore)	176 000	2 014 800	60%
Solar (PV)	28 000	451 500	22%
Hydro (large)	16 900	N/A	15%

2.4 Discussion

Initiating the discussion, we present a visualization of the results in Figure 7, to allow for a better understanding of the spatial extents of landscape impacts from each analysed technology.

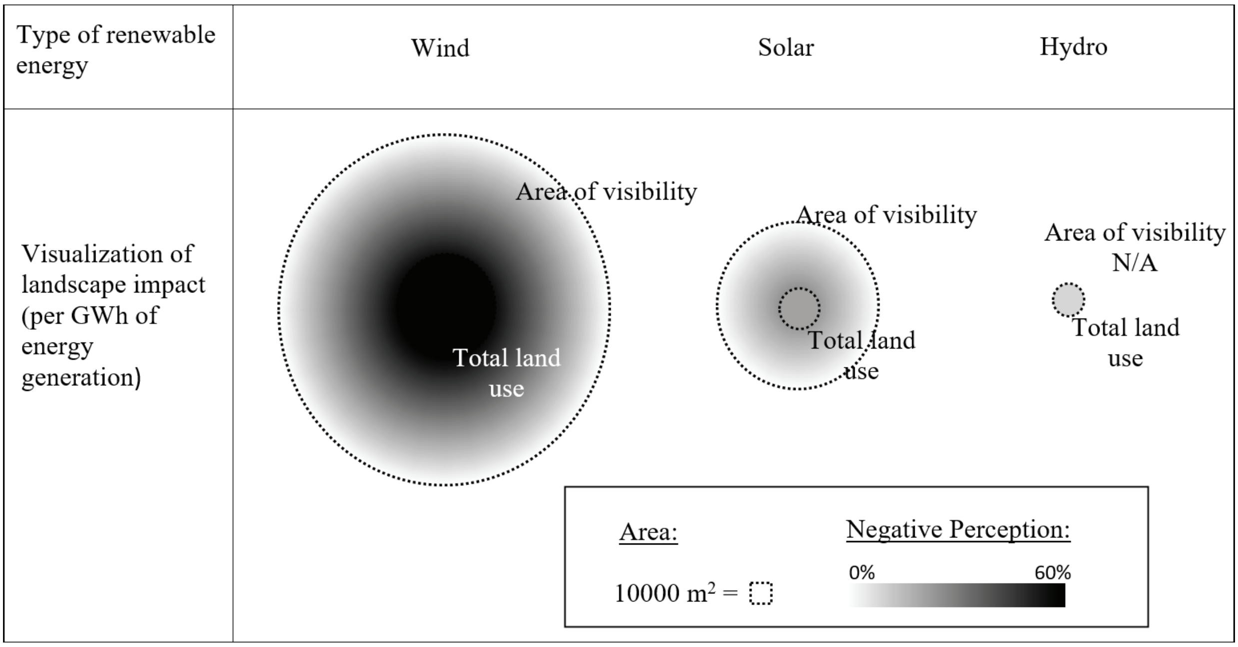


Figure 7. Visualization of results of Table 7: (a) Land use is presented with a continuous fill of colour. (b) Visibility is presented with a gradient fill starting from the inner circle that represents land use and fading radially towards the outer circle that represents the limits of visibility. This representation expresses the fact that visual impact deteriorates with distance. (c) Perception is visualized through the shade of the colour used in each case, which is based on the calculated indexes of negative perception.

2.4.1 Solar vs. wind energy

The main criticism to both solar and wind energy concerns the industrialization of landscapes, through the installation and dispersion of mechanical machines and equipment (wind turbines and solar PV panels) in extensive land areas (Barry et al., 2008; de Andrés-Ruiz et al., 2015; Fast et al., 2015; Lee, 2017; Mérida-Rodríguez et al., 2015a, 2015b; Nadaï and Van Der Horst, 2010; Phadke, 2011; Sklenicka and Zouhar, 2018). However, from both a qualitative and a quantitative standpoint, wind turbines are identified as the most impactful of the two, as they introduce industrial elements in larger areas of land and are also perceived more negatively.

Wind turbines are taller than PV panels, cannot be easily hidden in terrain and are thus visible from longer distances. As a result, the area they affect visually is larger. This is demonstrated in the results of Section 2.2.3 on visibility, where it is shown that wind energy developments are visible from approximately four times larger land area than solar energy developments, for equal energy generation. From a landscape perspective, this differentiation is significant, but nonetheless, visibility is not the only criterion of landscape impact. Wind turbines have smaller direct land-use requirements than solar PV installations, meaning that solar installations alter landscapes more, in a land-cover level. Indicatively, direct land use was calculated at 26 000 m^2/GWh for solar energy (land-use data from Ong et al. (2013) and CF of Table 2) and 3600 m^2/GWh for wind energy (land-use data from Denholm et al. (Denholm et al., 2009) and CF of Table 2). As is made evident, solar energy requires the most land area for the installation of machinery per unit energy generation, remarkably even more than average hydroelectric reservoir area, which was estimated at 16 900 m^2/GWh. Overall however, the great visual impact of wind energy is considered sufficient for its characterization as more impactful spatially (quantitatively), noting the exception of landscapes in which impacts on land-cover might be considered more important than visual impacts.

From a perceptual (qualitative) standpoint as well, wind energy is perceived more negatively than solar energy regarding landscape impact, as is demonstrated by the results of Section 2.2.4 Even though this difference is certainly affected by the fact that wind energy projects generate more extensive visual impact, which is a quantitative difference, it is also aggravated by differences in the qualitative aspect of the reported landscape impacts. In particular, wind turbines are considered more noticeable than solar panels due to blade movement, noise generation and night lighting requirements (Sklenicka and Zouhar, 2018). Solar panels on the contrary, are static, do not generate noise or significant light pollution and the only specific visual phenomenon associated with them is the generation of glare from light reflections, which however has not received as much criticism, in literature, as the other phenomena discussed. Additionally, wind energy works have also received criticism regarding the roadworks that are required to allow for their installation in hilltops and mountains Such roads are often required to pass through areas such as forests and mountain fields and slopes and, in Greece for example, they often cause impacts to pristine mountainous or island landscapes.

2.4.2 Hydroelectric vs. solar & wind energy

The reviewed metrics indicate that both qualitatively and quantitatively hydroelectric energy generates less impact to landscapes than solar and wind energy. In our perspective, this is justified by the fact that hydroelectric dams are not considered responsible for landscape industrialization; at least to the same extent as solar and wind energy developments. Indicatively, criticism on industrial transformation, in the context of landscape, has not been raised as an issue of hydroelectric projects, in scientific literature. This is demonstrated, in the results, by the perception index of hydroelectric energy. The index was calculated -2%, indicating that, in literature, positive perception prevails over negative. Furthermore, it is also demonstrated by the fact that even though hydroelectric energy is an older technology that has been utilized more than solar and wind energy globally (World Energy Council [WEC], 2016a, 2016b, 2016c), visual impact from hydroelectric projects has hardly been referenced in literature.

The landscape impact of hydroelectric dams becomes more considerable in cases of inundation of monuments of cultural or natural heritage by reservoirs (Garrett, 2010). Data for the estimation of a global average of reservoirs that inundated monuments, landscapes of cultural significance, etc. was not found. It was observed however, that the problem is more common in countries with high density of cultural monuments and especially when governed by authoritative regimes, which are less sensitive to potential public opposition to such projects. In Greece, for example, it has not been a significant issue while in Spain, mentions of at least 20 reservoirs that inundated important cultural heritage were found[11] (out of a total of 1230 reservoirs), many of which were built during the regime of Francisco Franco. The inundation of built monuments has in some cases been avoided, e.g. in the cases of Aswan dam in Egypt (Hassan, 2007) or the Hilarion dam in Greece (Sako et al., 2019), though the transportation of the monuments at risk.

2.4.3 The distinct role of hydroelectric dams for renewable energy landscapes

In a holistic assessment of the aesthetics of RE landscapes, hydroelectric energy stands out as the only major technology that generates landscape transformations with potential for unanimously positive perception. Pointedly, in the perception analysis of literature in Section 2.2.4, articles with reference to exclusively positive landscape contribution were only found for hydroelectricity (Figure 6). This can arguably be attributed to the fact that installation and dispersion of industrial machines in landscapes, which is reported as the origin of impacts in the cases of solar and wind energy, is very limited in hydroelectric energy developments; the major impact being the reservoir, which is comparable to natural lakes. Furthermore, various examples internationally (Ioannidis and Koutsoyiannis, 2017a; Kreuzer, 2011) demonstrate that dams can create aesthetically impressive results and can even be established as landmarks. This is the case especially when their architectural potential is utilized (Figure 8) but has also been observed in cases of standardized technical design without additional architectural interventions; various academic (Ananiadou-Tzimopoulou and Nana, 2015; Callis, 2015; Ferrario and Castiglioni, 2017; Frolova et al., 2015a; Keilty et al., 2016; Matveev, 1988) and institutional publications, e.g. from Spain (Pérez et al., 2013), Norway (Nynäs, 2013) and Scotland (Fleetwood, 2010), have analysed the positive impacts of dams and power stations to landscapes. In these publications, dams were highlighted for their architectural and landscape design and their contribution to creating scenic landscapes, enhancing built heritage and creating touristic attractions.

[11] Data gathered from Spanish media articles and Wikipedia:
https://www.escapadarural.com, https://www.traveler.es, https://en.wikipedia.org/wiki/List_of_submerged_places_in_Spain,

Figure 8. Example of architecturally designed dam (Marathon dam in Greece). Picture of the downstream face of the dam, which is overlaid with marble from the mine of Penteli that was also used to build the Temple of Parthenon, including pictures of architecturally designed appurtenant structures: (A) water intake tower, with similar design with the downstream face of the dam and (B) reservoir control building at the base of the dam, built to resemble the ancient temple-like structure called Thesaurus (treasure) and built after the victorious battle of Marathon (480 BCE) in Delphi. The new building was given this form in order to symbolize the victory of modern Athens in the battle against water scarcity. The dam of Marathon is not a hydroelectric dam but is indicative of the architectural adaptability of dams and their appurtenant structures, that can, and has been utilized in hundreds of hydroelectric dams internationally. Technical information on Marathon dam can be found in Soulis et al. (Soulis et al., 2019).

2.4.4 Visibility of wind energy developments

In the review of large-scale visual impact estimations for wind energy, the following two observations were made regarding the spatial evolution of the visibility of developments in relation to installed capacity. Firstly, the percentage of a country or region from which wind energy installations become visible ascends to double-digits even in regions with low to medium wind energy utilization. Such examples are Kuyavia-Pomerania (Poland) (Degórski et al., 2012), South Aegean (Greece) (Tsilimigkas et al., 2018) and the Netherlands (Statistics Netherlands [CBS] et al., 2014). These regions/countries have low densities of installed capacity (smaller than 0.035 MW/km^2 except for Netherlands) but average visually affected areas of more than 20% of their respective total areas (Figure 4). In regard to the extent of the utilization of wind energy in these cases, the shares of wind energy in national power generation are 5.8%, 2.6% and 4.8%, respectively. Secondly, the rate of generation of visual impact is generated decreases with the increase of installed capacity (Figure 5). This trend is, in our understanding, justified by the fact that visibility of multiple wind farms overlaps after a certain point of utilization of wind energy within a country or a region. Given this explanation of the phenomenon, the rate of creation of visual impact does not actually lessen, as in reality there is a saturation of wind turbine visibility, that is untraceable from ZTV analyses. So far, zones of theoretical visibility are primarily used to calculate the area from which at least one wind turbine is visible and not the density of visible turbines; with the exceptions of Möller (Möller, 2010) and SNH (Scottish Natural Heritage [SNH], 2014) that have also included graphical demonstrations of cumulative visual impact. It should be noted that this cumulative effect is also demonstrated when analysing the results of Rodrigues et al. (2010); in several different energy utilization scenarios they examined, the ratio of visually affected area to installed capacity declined the larger the number of wind turbines installed.

2.5 Inferences from the comparative quantification of landscape impacts of Renewable Energy works

In this Section, three established metrics of landscape impact of renewable energy were reviewed: (a) land use, (b) visibility and (c) public perception. The aims of the analysis were the generic quantification of landscape impacts caused by major renewable energy technologies, i.e., hydroelectric dams, wind turbines and solar panels, and the identification of the distinct characteristics of these impacts. Through the investigation of the selected metrics both the quantitative (spatial) and the qualitative (perceptual) aspects of RE landscape impact were addressed. The exact variables that were used to address each of the examined metrics were respectively: direct and total land use, visibility analyses carried out in geographic information systems (in particular, zone-of-theoretical-visibility estimations) and indexes of perception over landscape impacts of renewable energy, extracted through the statistical analysis of literature. Out of the compiled estimates, a selected few were distinguished based on their generic applicability. The generic applicability of these estimates was determined through the application of the following criteria: (a) use of data from areas of moderate terrain topography, since visibility and land use are highly dependent on terrain (b) utilization of large datasets originating from realized projects, (c) use of data from developed countries, (d) use of original data without embodied theoretical estimates, when possible, and (e) use of data expressed in terms of energy generation, or data that allowed for conversion to expected energy generation, thus avoiding biases associated with the energy-generation efficiency of the compared technologies (which would be present if comparisons were carried out in terms of installed capacity). Additional own calculations were only carried out for verification purposes, in the investigation of the discrepancy in estimates of hydroelectric land use.

2.5.1 Landscape impact typology of renewable energy

Based on the examined metrics, wind energy was identified as the most impactful to landscapes, on average, both spatially and perceptually, followed by solar and hydroelectric energy, respectively. This conclusion provides the essence of scientific literature on landscape impact of renewable energy in a condensed and simple format but is not an undisputable universal truth. On the contrary, the distinct characteristics of the discussed technologies that are presented below, highlight the origins of this landscape impact ranking and also demonstrate that any of the examined technologies can potentially be the least impactful in particular landscapes or terrains:

2.5.1.1 Wind energy

(+) Small direct land use: Smaller transformation to land surface and land cover is generated compared to hydroelectric and solar energy.

(-) Extensive total land use: Due to the requirement for dispersed installation of turbines, large land properties are used for wind energy developments. Within these areas the turbines are highly noticeable, both visually and due to periodic acoustic nuisance.

(-) Extensive visibility: Visual impacts are widely reported in literature. Wind energy developments have altered the visual scenery of countries or regions in a range of 8% to 96% of their respective total areas. These percentages have reached 27% or 61% even in cases of low wind energy utilization.

(-) Most negative public perception: Based on the perception analysis of scientific literature, wind energy is perceived as the most impactful to landscapes, with references from the academia, policy frameworks and the public. The identification of wind turbines as industrial elements as well as their increased discernibility due to size, blade movement, noise and night lights are regularly mentioned in this regard.

2.5.1.2 Solar energy

(+-) Moderate visibility: Utility scale solar panels do not exceed 5 m in height and therefore solar energy developments generate smaller zones of visibility than wind energy developments. Visual landscape impacts from solar energy have been reported in literature but to a much lesser extent than the visual impacts from wind energy.

(+-) Moderately negative perception: Based on the perception analysis of scientific literature, solar energy ranks second in terms of negative perception. Similarly to wind turbines, the main origin of negative perception for solar panels is their identification as industrial elements. In comparison to wind turbines however, solar panels are less noticeable due to the fact that they are shorter, static, they do not generate noise and they have less night-lighting requirements.

(-) Extensive land use: Significant transformations to land surface and land cover are generated due to the extensive direct land use requirements of solar energy developments.

2.5.1.3 Hydroelectric energy

(+) Neutral visibility: Visual impact from reservoirs and hydroelectric facilities has not been reported in literature. The view of reservoirs is comparable to the view of natural lakes and the hydroelectric dam and its appurtenant structures are spatially austere and usually concealed within ravine topography. Thus, the need to quantify the visibility of hydroelectric developments has not emerged.

(+-) Least negative perception: The perception analysis demonstrated that hydroelectric energy has received the least number of negative remarks in literature relating to landscape impact. The milder perception of landscape impacts of hydroelectric developments is mainly attributed to the fact that they have not been associated with landscape industrialization, in contrast to solar and wind energy developments. Furthermore, hydroelectric dams are the only type of renewable energy technology for which studies focusing on its positive landscape and architectural heritage contribution on landscapes were found.

(-) Impactful direct land use: Reservoirs generate impactful direct transformations to land surface and land cover due to inundation. This impact becomes particularly significant, in a landscape-impact context, in cases of inundation of cultural or natural heritage.

Overall, the essence of the analysis is not the competition between different technologies, but the improvement of the sustainability of renewable energy and the minimization of landscape impacts and associated economic and developmental ramifications. It becomes evident from the conclusions that all of the discussed technologies could be utilized in an effort for optimal landscape integration of renewable energy. Indicatively: (a) Wind turbines can potentially be the least impactful in cases were protection of elements of land surface/cover is of highest priority in a landscape, since their direct land use is relatively limited. (b) Solar panels can be preferable to hydroelectric dams in areas with flat terrain due to the fact that their visibility is limited in such terrain. (c) Finally, hydroelectric dams, which, in general, can be considered the least impactful, can also be detrimental to landscapes and are not the optimal solution for every landscape, e.g., in areas with particularly flat terrain, where extremely large reservoirs are generated, or when monuments of cultural or natural value are inundated by reservoirs.

2.5.2 Landscape impact and NIMBYism

Early cases of landscape-impact motivated opposition against renewable energy developments were widely attributed to the NIMBY (not in my back yard) attitude; a correlation that gradually began to be disputed (Barry et al., 2008; Betakova et al., 2015; Cass and Walker, 2009; Devine-Wright, 2005; Jones and Eiser, 2009; Petrova, 2013; Wolsink, 2000). The results of this Section introduce practical data in the scientific debate over the emotionality or rationality of landscape-impact opposition and its relation with the NIMBY phenomenon. In particular, the results demonstrate that the quantitative (spatial) aspect of landscape impact is directly correlated to the qualitative (perceptual) one. In other words, the technologies that introduce industrial elements into larger areas and produce the most extensive visual impact are the ones that are perceived more negatively. This conclusion, in general, reinforces the view that landscape impact opposition is actually justified by differences in the impacts of the various RE technologies. In that logic, uncritical attribution of landscape-impact opposition to underlying NIMBY predispositions should be avoided. Instead, the discussion should be focused on whether significant landscape impacts are in fact imminent, which can be assessed case-to-case with data-driven impact evaluation.

3 NATIONAL & REGIONAL SCALE: A PRIORI AND ACCELERATED SPATIAL PLANNING FOR LANDSCAPE INTEGRATION USING REVERSE VISIBILITY ANALYSIS

3.1 Introduction

3.1.1 Scientific aims

In Section 3, we investigate how the process of mitigating landscape impacts of types of infrastructure works that are perceived as visually intrusive can be improved and accelerated, through a re-conceptualization of visibility analyses. The primary limitation of conventional visibility analyses is that they cannot be implemented in early planning phases of projects as they require the finalized locations of their components as input. Hence, visual impacts to landscapes cannot be assessed until late in development, when licensing procedures have already begun and projects' locations have already been finalized. In order to overcome this issue and facilitate the earlier identification of impactful projects we investigate the reversal of visibility analyses. By shifting the focus of visibility analyses from the infrastructure that generates visual impacts to the areas that have to be protected from these impacts, the analyses no longer require projects' locations as input.

This methodological shift is initially investigated theoretically and then practically. Wind energy is set as the focus of the study due to the fact that currently wind energy projects, as described in Section 2, are the type of infrastructure that receives the most critique in regard to its visual impact, rendering the mitigation of this impact a contemporary challenge. After the theoretical development of the methodological differentiations, perks and challenges of reversing visibility analysis, an exemplary reverse visibility analysis is implemented in the region of Thessaly, Greece. Reverse - Zones of Theoretical Visibility (R-ZTVs) are computed in the for important landscape elements of the region and are then used to project visual impacts to them by planned wind energy projects. The investigation proposes and alternative to mainstream-conventional visibility analyses that (a) enables the creation of R-ZTV-type maps which facilitate the anticipation of landscape impacts of projects from earlier planning stages and (b) discards the requirement for individual visibility analyses for each new project, thus accelerating project development. Furthermore, the potential of R-ZTV maps to be utilized in participatory planning processes is also investigated. Overall, the proposed method can be applied to any infrastructure work type but is understood us a crucial planning tool particularly for infrastructure that is perceived negatively visually, as is the case with wind energy infrastructure (Jefferson, 2018; Wolsink, 2007a) but also solar energy (de Andrés-Ruiz et al., 2015; Mérida-Rodríguez et al., 2015b), overhead power transmission lines (Cohen et al., 2014) and other types of infrastructure that might be perceived as industrial intrusions to landscapes.

3.1.2 Visual impacts of infrastructure works – the case of wind energy

In the last two decades, the expansion of renewable energy (RE) has imposed extensive land use requirements (Denholm et al., 2009; Ong et al., 2013; Sargentis et al., 2021c; Trainor et al., 2016) and resulted to major transformations of the visual character of landscapes (Apostol et al., 2016; Frolova et al., 2019, 2015c; Sebestyén, 2021). Since the design of the RE equipment is mostly predefined by industrial specifications and cannot be adapted to architectural traditions and local landscape features, RE projects have been strongly criticized for industrializing landscapes (Ioannidis and Koutsoyiannis, 2020). This is primarily the case for wind turbines, but also applies to photovoltaic solar panels (Ioannidis et al., 2022; Ioannidis and Koutsoyiannis, 2017a; Mamassis et al., 2021) and might also be possible for other types of infrastructure such as overhead power transmission lines, or highways, etc. In the case of wind energy in particular, landscape impacts have been identified as one of the major motivators for opposition against new projects (Frolova et al., 2015c; Ioannidis and Koutsoyiannis, 2020; Jefferson, 2018).

Indicatively, in Europe, the conflict between wind energy development and landscape quality is demonstrated in the following two ways:

A) Public opposition against wind energy on landscape-protection grounds has significantly delayed its desirable penetration into the energy mix. Even though wind energy has been associated with significant impacts to the natural (Jefferson, 2018), cultural (Phillips, 2015; Roth et al., 2018) and aesthetic (R. Ioannidis et al., 2019; Sibille et al., 2009) character of landscapes, so far spatial planning of RE systems for the mitigation of landscape impacts has been given a secondary role (Hurtado et al., 2004). As a result, landscape impacts have become a major cause of public opposition to wind energy and, consequently, of delays in the pan-European effort to make renewables the key player in energy production and to move beyond the goal of a minimum 32% share for RE in the energy mix, under the so-called "2030 Climate and Energy Framework". In Greece, for example, there has been significant opposition to wind energy projects from activist initiatives (Manta et al., 2020) and local communities (Ioannidis and Koutsoyiannis, 2020) that has even escalated to clashes between police and opposing groups. The installed capacity of the major projects that have been challenged, using various arguments – including landscape impacts – adds up to more than 1200 MW (Ioannidis and Koutsoyiannis, 2020). For comparison, in 2020 Greece was 3512 MW below (Regulatory Authority for Energy, 2015) its target for 7050 MW for wind power capacity in 2030 (Greek Democracy - Ministry of Environment and Energy, 2019). Similarly, in the rest of Europe, landscape quality degradation due to RE has been identified as a major issue (Frolova et al., 2019, 2015c) that has arguably contributed to opposition and that is eventually associated with the failure of more than half of the member states in meeting RE development targets based on the EU directives.

B) While the penetration of wind energy is a broadly desirable goal, a non-controllable expansion of infrastructure is expected to cause significant transformations to the character of European landscapes. Arguably, Europe has a very high density of scenic landscapes that are associated with architectural and cultural monuments and historical built environments. The protection of this heritage is of high priority not only for its preservation and its connection to the sense of place, cultural identity and quality of life of European citizens, but also due to its direct link with touristic and, consequently, economic development. Using one of the most informative quantifications for the extents of visual intrusion of wind energy projects to landscapes, viewshed analysis, it was estimated that the portion of the land area from which wind turbines were clearly visible was 18% in Spain, 21% in the Netherlands and even 96% in Denmark (Jutland region) (Möller, 2010; Rodrigues et al., 2010; Statistics Netherlands [CBS] et al., 2014). Such extensive impacts require specific mitigation strategies, especially when they are carried out in the vicinity of protected cultural (Jerpåsen and Larsen, 2011) or natural landscapes (Spielhofer et al., 2021), and also given that suitable locations for the siting of projects are currently diminishing.

3.1.3 Spatial planning for the mitigation of landscape impacts

Given the results of Section 2, as well as the fact that literature has disapproved of the well-known NIMBY ("not in my back yard") disposition as the primary source of social oppositions against RE (Betakova et al., 2015; Cass and Walker, 2009; Ioannidis and Koutsoyiannis, 2020; Petrova, 2013; Wolsink, 2007b, 2000), their root should be looked for in planning methods and procedures instead of "biased" public attitudes. Thus far, large-scale multi-criteria analyses have supported the siting decisions for infrastructure projects based on technical issues, such as resource availability, distance from the electricity grid and the road network, and various socio-environmental restrictions (Bertsiou et al., 2021; Chalakatevaki et al., 2017; Detsika et al., 2018; Dimitriadis et al., 2016; Latinopoulos and Kechagia, 2015; Osorio-Aravena et al., 2020; Pappa et al., 2014; Shao et al., 2020; Watson and Hudson, 2015). However, such analyses rarely account for landscape protection and when they do so, they have not managed to fully integrate calculations of project visibility and visual impacts in their assessments (Kruse et al., 2019), with very rare exceptions (Tegou et al., 2010). Of course, the visibility of infrastructure projects is not always perceived negatively. In the case of Renewable Energy for example, it is reported that considerable percentages of observers have neutral or even positive perception in the view of works, due to aesthetic (Sargentis et al., 2021a; Thayer and Freeman, 1987), cultural (Frolova et al., 2015a; Kazak et al., 2017) or other reasons (Baraja-Rodríguez et al., 2015; Pasqualetti and Stremke, 2018). Indicatively, in Section 2 of the present study, it was found that 34% of articles investigating landscape impacts of wind energy and 22% of articles regarding solar energy works also included references to positive perception of the examined landscape transformations, on top of negative ones. Interestingly, in the case of hydroelectric energy, several articles including solely positive views regarding their landscape transformations were also found (Ioannidis and Koutsoyiannis, 2020). Nevertheless, it is overall made clear from the above-mentioned percentages that, especially in the case of wind and solar energy, negative opinions are predominant.

For the minimization of this footprint through planning and the mitigation of landscape impacts, visibility analysis has been established as the best practice (Hurtado et al., 2004; Manchado et al., 2015; Scottish Natural Heritage [SNH], 2017). In this vein, it can be generally hypothesized that the lack of utilization of such analyses at the early planning stages of RE projects present a significant limitation to the projection, assessment and mitigation of landscape impacts, and may be responsible for the emergence of public opposition (Ioannidis and Koutsoyiannis, 2020). The present study investigates the reversal of visibility analyses as a methodological shift that can enable the earlier identification and mitigation of potential landscape impacts of new infrastructure projects. In this regard, the facilitation of pre-emptive visibility analysis is proposed, by employing the concept of Reverse - Zones of Theoretical Visibility (R-ZTVs). R-ZTVs can be used to consult the siting of RE infrastructures, in terms of minimizing their visual impacts, at earlier stages of their planning or conception. Overall, the method aims to improve the practices of mitigating impacts to the cultural, natural and aesthetic character of landscapes and thus to reduce associated impacts, as perceived by humans, and public opposition.

3.1.4 Section structure

In Section 3.1, the introduction of the present Section is provided: in particular, in Section 3.1.1 the scientific aims of the investigation are presented, in Section 3.1.2, the necessary theoretical background regarding issues of visual-landscape impacts of infrastructure works is presented, then in Section 3.1.3, the methods that are used for the mitigation of such impacts are presented and finally in Section 3.1.4 the structure of the Section is presented. In Section 3.2, the materials and methods of the investigation are presented, beginning with Section 3.2.1, in which we carry out a literature review for state-of-the-art in visibility analysis of infrastructure works. Then, continuing with Section 3.2.2, we present critique regarding the limitations of current conventional practices of visibility analysis and finish with Section 3.2.3, in which we describe the methodological and practical advantages of a transition to reverse visibility analyses. In Section 3.3 we present an implementation of reverse visibility analysis in the region of Thessaly, Greece, showcasing the implementation of the concept of R-ZTV maps. In the next Section, Section 3.4, we present the results of the analysis (Section 3.4.1) followed by an exemplary use of the generated R-ZTV maps of the protected landscape elements of the region o Thessaly to assess potential future impacts from proposed wind energy projects in the Region (Section 3.4.2). Finally, in Section 3.5 the results of the analysis are discussed both in terms of their utility (Section 3.5.1) and their limitations (Section 3.5.2) and in Section 3.6 the conclusions of the investigation are presented.

3.2 Materials and methods

3.2.1 Visibility analysis in spatial planning of infrastructure – Current practice in renewable energy

With the emergence of landscape impacts as a major cause of opposition to RE, significant effort has been put into their mitigation, through planning policy and targeted guidelines (Möller, 2010; Scottish Natural Heritage, 2006; Statistics Netherlands [CBS] et al., 2014; Toke et al., 2008). In this endeavour, various visual impact assessment (VIA) methods (Kruse et al., 2019) have been developed. Among them, visibility maps have been established as the basis for the quantitative assessment of landscape impacts (Gobster et al., 2019); e.g. in the prominent Scottish SNH guidance (Scottish Natural Heritage, 2006; Scottish Natural Heritage [SNH], 2017) and the Spanish Method (Hurtado et al., 2004; Manchado et al., 2015). Arguably, the most widely used mapping method for visual impacts of RE projects in the academic literature (Ioannidis and Koutsoyiannis, 2020; Tsilimigkas et al., 2018), planning practice (Scottish Natural Heritage [SNH], 2017; Sullivan et al., 2012) and institutional reports (Degórski et al., 2012; Scottish Natural Heritage [SNH], 2014; Statistics Netherlands [CBS] et al., 2014), are the so-called Zones of Theoretical Visibility (ZTV) (Hankinson, 1999). A ZTV is defined as the sum of all locations from which particular examined objects are theoretically visible, and is calculated with the use of spatial analysis tools of Geographic Information Systems (GIS). In this respect, the locations of an array of examined objects that generate visual impacts, e.g., wind turbines, are inserted in a digital elevation (or terrain) model, and a line-of-sight test is carried out, producing a binary map indicating the locations from which the objects are visible and the locations from which they are not. In a more in-depth review of terminology and methodology, ZTV mapping has also been recognized as similar (Hankinson, 1999) or interchangeable (Buchan, 2002) with the so called Zones of Visual

Influence/Impact (Wood, 2000). Furthermore, from our literature review, it can be noticed that the ZTV method shares the common foundation of requiring the calculation of cumulative viewshed (Möller, 2010) with various other methods for mapping the visibility of projects, e.g. maps of visually affected areas (Rodrigues et al., 2010; Statistics Netherlands [CBS] et al., 2014) or maps of visual influence (Scottish Natural Heritage [SNH], 2014).

3.2.2 Reflections on the timing of visibility analyses

In spite of the identification of landscape impacts of RE as one of the major causes of social opposition against RE projects (Frolova et al., 2015c; Ioannidis and Koutsoyiannis, 2020; Jefferson, 2018), the quantitative tools for their assessment have been so far generally left out from the early stages of RE planning. Indicatively, ZTV analysis, which is the most widely used quantitative method for visual impact quantification, has been implemented not earlier than the Environmental Impact Assessment (EIA) studies, which typically follow the technical, i.e., planning and design, ones. In the spatial scale of EIA, however, this analysis loses its capacity to act as a decision support tool that can detect siting alternatives, in order to mitigate potential landscape impacts, and it is downgraded to a modelling procedure for assessing the impacts of a particular project in its finalized location. Therefore, at this phase, visibility analysis should be considered a principally *a posteriori* calculation, for the *ad hoc* evaluation of landscape impacts of projects after their preliminary or final siting (Hurtado et al., 2004; Manchado et al., 2015; Scottish Natural Heritage [SNH], 2017). This is the case especially with wind energy projects, since wind turbines cannot be concealed in the natural terrain through short-distance siting adjustments, which are the sole available option at that stage of planning; in the case of solar panels though, this may be feasible to some extent (Romanos Ioannidis et al., 2019; Ioannidis and Koutsoyiannis, 2020; Oudes and Stremke, 2021). Furthermore, even though ZTV-type visibility analyses can be carried out in large spatial scales, this has only been done in *a posteriori* studies, for the assessment of cumulative visual impacts of already constructed RE projects, at the regional (Degórski et al., 2012; Möller, 2010, 2006; Tsilimigkas et al., 2018) or national scale (Scottish Natural Heritage [SNH], 2014; Statistics Netherlands [CBS] et al., 2014). It is possible that a ZTV-type visibility analysis can also be carried out *a priori*, but only under the condition that hypothetical-potential locations for examined projects have to be determined beforehand, such us in the study of Rodrigues et al. (Rodrigues et al., 2010).

Overall, in the investigation of the early-stage and large-spatial-scale planning analyses (Osorio-Aravena et al., 2020; Shao et al., 2020) or strategic environmental impact assessment studies (Pang et al., 2014) that support decisions on RE siting studies, it can be observed that ZTV and viewshed analyses have been hardly utilized. Indicatively, in the systematic review by Shao et al. (Shao et al., 2020) on multi-criteria decision making methods, only eight out of 85 studies mentioned visual impacts, and only three of them actually included any form of viewshed or visibility analysis (Gamboa and Munda, 2007; Ramírez-Rosado et al., 2008; Tegou et al., 2010). In particular, only Tegou et al. (Tegou et al., 2010) have explicitly utilized viewshed analysis in the planning procedure, by employing an interesting mixture of reverse viewshed calculations and buffer zones, to produce a generic map for visual impact assessment of potential projects in the examined island. In another review of spatial planning of renewable energy (Osorio-Aravena et al., 2020), out of 12 compiled studies only two discuss the importance of integrating visual impact assessment into RE planning (Mostegl et al., 2017; Scognamiglio, 2016), yet without making reference to practical methods for addressing this issue.

On the other hand, other multi-criteria approaches that actually consider visual impacts, are subject to important limitations. For example, in the studies by Daskalou et al. and Gigović et al. (Daskalou et al., 2016; Gigović et al., 2017), the evaluation of the visibility criterion is simplified to the application of buffer zones around protected areas, without the use of viewshed analyses. In the analysis by Kazak et al. (Kazak et al., 2017), visual impacts were evaluated in more detail, by using viewshed-type visibility analysis; nevertheless, its implementation was limited to the examination of already highlighted potential positions for projects. This is reasonable, since viewshed analysis requires the siting of the proposed projects as input. Altogether, the integration of landscape impact indexes informed by complete visibility analyses is found to be almost completely absent from early-stage and large-scale spatial planning analyses, where the project locations are not yet specified.

3.2.3 Reversing visibility analyses

Even though there is precedent for visual impact assessment with predictive characteristics (Alphan, 2021; GeoData Institute, University of Southampton, 2013; Tegou et al., 2010), which could be utilized to handle the above-mentioned issues, the significance and methodological differentiation of these tools has not been emphasized, leading to their scarce and rather inconsistent application, as described in Section 3.2.2 In order to support the transition from the current practice of *a posteriori* landscape impact assessment, i.e., after the design phase, to *a priori* assessment, i.e., in early planning stages, the essential modifications to existing landscape impact assessment methods need to be explicitly explained and realized.

The major shortcoming of mainstream visibility analyses that makes the early prediction of landscape impacts too difficult, is that they require project-specific information as their input (Gobster et al., 2019); namely, the finalized layout of the RE system and the exact micro-siting of its components (e.g., wind turbines, solar panels) is required in order to carry out viewshed analyses. In contrast, a map of projected landscape impacts that would be compatible with the format of spatial planning studies would need to be generic and independent of project-specific information, as are all spatial data that are commonly used in such studies, such as spatial layers on resource availability, buffer distances from road and electricity grids, etc. (Katikas and Kontos, 2018; Shao et al., 2020; Tegou et al., 2010). These are all generic spatial information that can be used to guide the planning of RE projects in advance, without requiring a finalized design of RE infrastructures.

To overcome this obstacle, we propose reversing the running paradigm of visibility analysis, by shifting its focus from the proposed infrastructure to the landscape sites that need to be protected. In conventional Zone of Theoretical Visibility (ZTV) method (Möller, 2010; Rodrigues et al., 2010; Statistics Netherlands [CBS] et al., 2014), the RE system is the focal point of the analysis and the generated map represents an extent around each infrastructure component. Conversely, we propose the so-called Reverse Zone of Theoretical Visibility (R-ZTV) analysis, in which the focal points are the protected landscape elements themselves. Thus, an R-ZTV map illustrates all the locations around protected landscape elements from where a given type of RE infrastructure would be visible to those elements (Figure 9). The use of ZTVs in planning, consists of (a) computing the ZTV using the predetermined location of the RE project of interest as input and then (b) looking for potential overlap of the ZTV with important landscape elements, which would indicate the generation of significant visual impacts. In the proposed concept, R-ZTVs are a priori computed for selected landscape elements and then these R-ZTV areas can be "avoided" during the planning procedure, in order to protect the selected landscape elements from non-desirable visual impacts. In GIS terms, ZTV is based on calculations of viewshed, while R-ZTV is based on reverse viewshed. In hindsight, it is reasonable that landscape elements should be the focal point of the analysis, during the planning procedure, because they have the advantage of being static and in fixed positions (Kavouras, 2001), while the RE projects under study are the ones that can be moved and be sited according to the results of the planning procedure.

By means of R-ZTV maps, visibility analysis can be utilized pre-emptively to indicate the areas to be preferred for the installation of RE projects, under the primal (yet not exclusive) criterion of minimizing landscape impacts. The protected landscape elements to be included in the calculation of R-ZTV maps can include any selection of areas and landscape features of cultural or natural significance that is considered important for the protection of landscapes' quality: e.g. historical or archaeological sites, traditional settlements (Giannakopoulou et al., 2017), tourism-related infrastructure (Efstratiadis and Hadjibiros, 2011; Sargentis et al., 2021b), etc. It also has to be noted that in in the context of strategic planning, the spatial scale of R-ZTV maps should be relatively extensive, since such studies are by definition carried out across large scales; e.g. multi-criteria planning analyses are usually implemented at the regional or national scale (Katikas and Kontos, 2018; Koukouvinos et al., 2015; Osorio-Aravena et al., 2020; Shao et al., 2020). The scale of application is another key difference with typical visibility analyses, which essentially refer to the specific project-site scale. Through reversing visibility analyses, the implementation of visibility analysis in large spatial scales becomes possible, as it is no longer dependent on the siting details of single projects, but can be carried out for multiple landscape elements at once, stretching over whole regions or even countries. Contemporary spatial planning frameworks usually include maps of such elements at these spatial scales. Such maps can be used as inputs to R-ZTV analyses.

The early anticipation of landscape impacts of RE projects can facilitate the timely dismissal of problematic locations and thus contribute both to the mitigation of landscape impacts and the reduction of associated public opposition. In theory, maps that expedite the prediction of visual impacts could be used for guidance in the sitting of projects at the initial development stages before conflicts emerge, that way lowering the risks of investment plans (Bazilian et al., 2013) and limiting the time and effort that is lost when projects are rejected at the stage of EIA. For example, it is a common regulatory requirement for proposed projects that mean wind speeds have been recorded in the examined location for more than one year and that complete business plans have been submitted (Daskalou et al., 2016; Papastamatiou et al., 2019); all this effort is wasted if the projects are later rejected in the stage of EIA, which is quite often; for example, in the case in Greece (Papastamatiou et al., 2019).

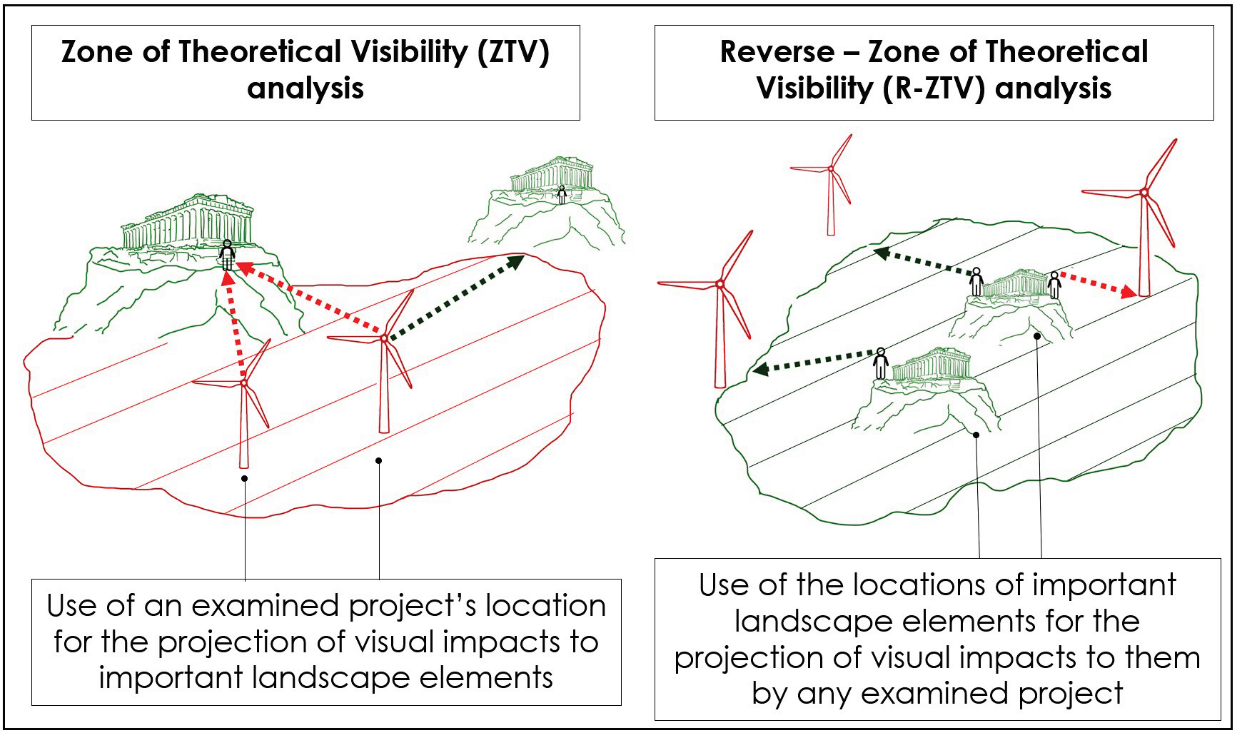


Figure 9. Graphical presentation of differences of conventional ZTV vs. proposed R-ZTV analysis.

3.3 Implementation of R-ZTV analysis at the regional scale: Case of wind energy development in the Region of Thessaly

In order to reveal the methodological requirements of reversing visibility analyses within large-scale RE planning, the proposed method was applied in the region of Thessaly, Central Greece, which extends over an area of 14 000 km^2. In this context, R-ZTV maps were generated from the perspective of already specified important landscape elements, in order to be used for the projection of potential impacts to them by proposed wind energy projects. The region of Thessaly was selected due to two reasons. On the one hand, because various wind energy projects, at different stages of maturity, are already planned within the region (Regulatory Authority for Energy, 2015). On the other hand, because it is one the few regions of Greece having established a complete Regional Spatial Planning Framework, that maps various locations and areas of importance for the regional landscape (Government Gazette, 2020). The associated data are available through an online GIS platform (http://mapsportal.ypen.gr/maps/694).

The first step for the computation of R-ZTVs for wind energy projects in Thessaly was the implementation of reverse viewshed analyses for the important landscape elements of the region. The computations of reverse viewshed were selected to be binary, or boolean as they are also called, in order to maintain the reciprocity between viewshed and reverse viewshed calculation (Caha, 2018). The required inputs in GIS were the digital elevation model (DEM), the observer's height, the observed object's height and the maximum distance of the observer's visibility. In our analysis, we utilized a DEM of the region of Thessaly with a cell size of 25 m, the height of the observer was set at two meters above the z-value of the observation point, and the height of wind turbines was set at 90 m (Lagaros and Karlaftis, 2016), which is representative of the size of turbine towers used in recent wind energy projects in Greece.

The maximum distance of visibility, also called visibility threshold or discernibility range, was identified as the most important parameter of reverse viewshed analysis, thus requiring a thorough justification over its selection. The visibility threshold defines the radius of the analysis, i.e., the distance limit used when investigating which areas are visible from each observation point, and therefore has a significant impact on the size of generated viewshed zones. In the literature, the visibility of a wind turbine under clear weather conditions is reported as long as 58 (Sullivan et al., 2012) or 42 km (Sullivan et al., 2013). On the other hand, the estimations of distances of moderate visibility of wind turbines exhibit a wide range of 3 to 40 km (Bishop, 2002; Buchan, 2002; Scottish Natural Heritage [SNH], 2009; Sullivan et al., 2012). For distances of less than 2 to 3 km, the visibility is considered dominant (Buchan, 2002; Scottish Natural Heritage [SNH], 2009; Stevenson and Griffiths, 1994). In viewshed analyses from recent studies, it is more common that distances on the highest end of the spectrum are preferred. For instance, Sullivan et al. (Sullivan et al., 2012) propose distances ranging from 16 to 48 km, Bishop (Bishop, 2002) 20 km, and Vissering et al. (Vissering et al., 2011) from 16 to 40 km. Moreover, in the latest version of the acclaimed SNH guidelines (Ioannidis and Koutsoyiannis, 2020), the use of a 35 km distance is proposed for ZTV analyses of modern wind turbines from 101 to 130 m heights. In our analysis, we carried out two applications of reverse viewshed analysis, one for a 10 km and one of 30 km visibility threshold. This decisions was made so that the broad range of visual thresholds that are reported in the literature was covered, and also because these are the most common thresholds that have been used so far in studies that include large-scale ZTV-type analyses (Ioannidis and Koutsoyiannis, 2020).

In regard to the data sets used to represent the protected landscape elements in the reverse viewshed calculations, the following spatial layers were selected from the Regional Spatial Planning Framework of Thessaly (Government Gazette, 2020), as they were identified to be relevant to the protection of the cultural and natural landscape of the Region: (i) "Archaeology/landscape" in which the delimited archaeological sites of the region are mapped, (ii) "Cultural routes" that includes a section of the E4 European long distance path as well as other proposed routes of natural and cultural interest, (iii) "Traditional settlements", and (iv) "Natural/Cultural Heritage and Landscape" that includes proposed important lands of cultural heritage and natural environment (iv-a) as well as landmarks of international, national or regional touristic interest (iv-b). The above-mentioned landscape elements of the region of Thessaly are depicted in Figure 10.

Since the spatial information for the protected landscape elements was represented in various forms in GIS (points, polylines and polygons), different assumptions had to be made in reverse viewshed computations, regarding the position of theoretical observers within these areas. The basic logic for the placement of theoretical observers was covering the spectrum of visibility of indicative visitors within the examined areas. In the case of the polygon layer (layer i), theoretical observers were placed in each angle of their perimeter as well as the mid points of each side. The analysis was not carried out for theoretical observer points within the polygons, since these areas were considered to be by definition less preferable for wind energy projects, provided that they are already demarcated as archaeological sites-landscapes. In the case of the polyline layer (layer ii), theoretical observers were placed every 500 m along the length of the paths. Finally, in the case of point-type layers (layers iii and iv), the points themselves were used as locations of the theoretical observers.

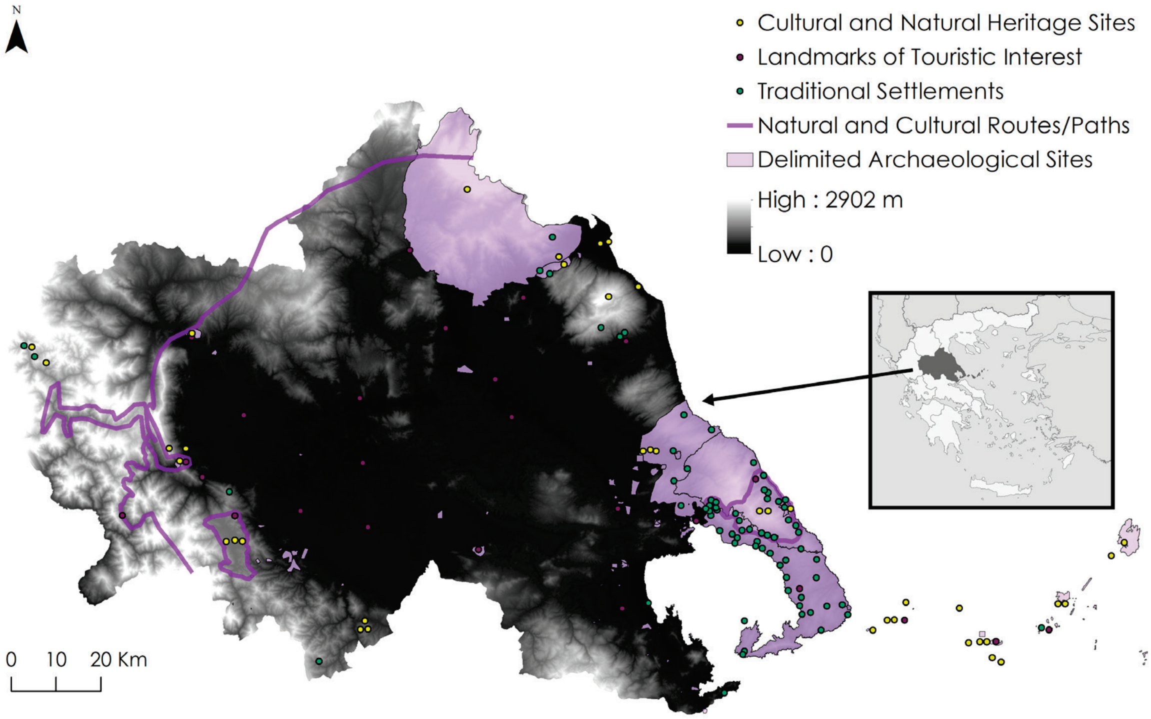


Figure 10. Map of the landscape elements of the region of Thessaly that were used in the R-ZTV analysis. Source of data: Regional Spatial Planning Framework of Thessaly (Government Gazette, 2020).

3.4 Results

3.4.1 Reverse Zone of Theoretical Visibility (R-ZTV) maps

The reverse viewshed calculations for all examined spatial data were merged together in the final R-ZTV maps. The generated R-ZTV maps and the results of the individual reverse viewshed analyses that were carried out for each of the protected landscape elements are presented in Figure 11. The coloured areas demarcate all locations from which an installed wind turbine would be visible to any of the protected elements. The results of all reverse viewshed computations for the five types of landscape elements of Figure 10 are presented as spatial layers with a 50% transparency in Figure 11, so that the overlap of reverse viewsheds can be discernible in the cumulative R-ZTV map.

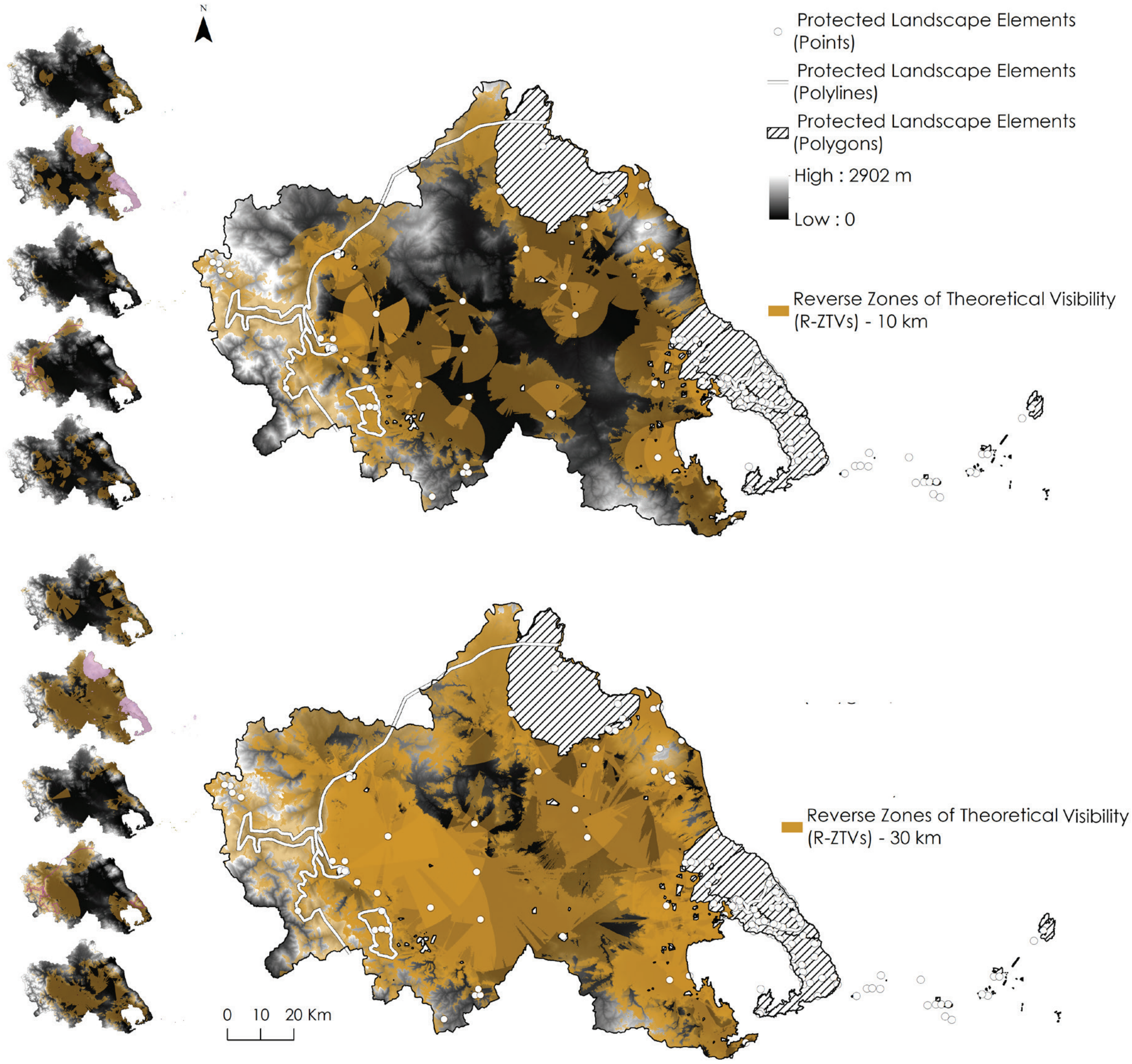


Figure 11. R-ZTVs maps of protected landscape elements in the region of Thessaly for the case of wind energy projects (right), and reverse viewshed calculations of the examined landscape elements (left). The upper and lower maps refer to visibility thresholds of 10 and 30 km, respectively.

In theory, the areas calculated through R-ZTV analysis could potentially expand to outside the borders of the examined region, as presented in Figure 12. It is thus demonstrated that offshore projects or projects in adjacent regions could also have some impact to the protected landscape elements within the region of Thessaly. However, in the context of the present research, the investigation was focused to the planning of projects within the borders of the region and hence, within the mainland. This was both due to limited data availability for adjacent regions and lack of information regarding the emergent field of marine spatial planning (Chalastani et al., 2021; Katikas, 2022; Katikas and Kontos, 2018). Nevertheless, to our knowledge, the exploitation of the actually large offshore wind energy potential of the country involves marine areas that are far away from the region of interest (Katikas, 2022; Spyridonidou et al., 2020).

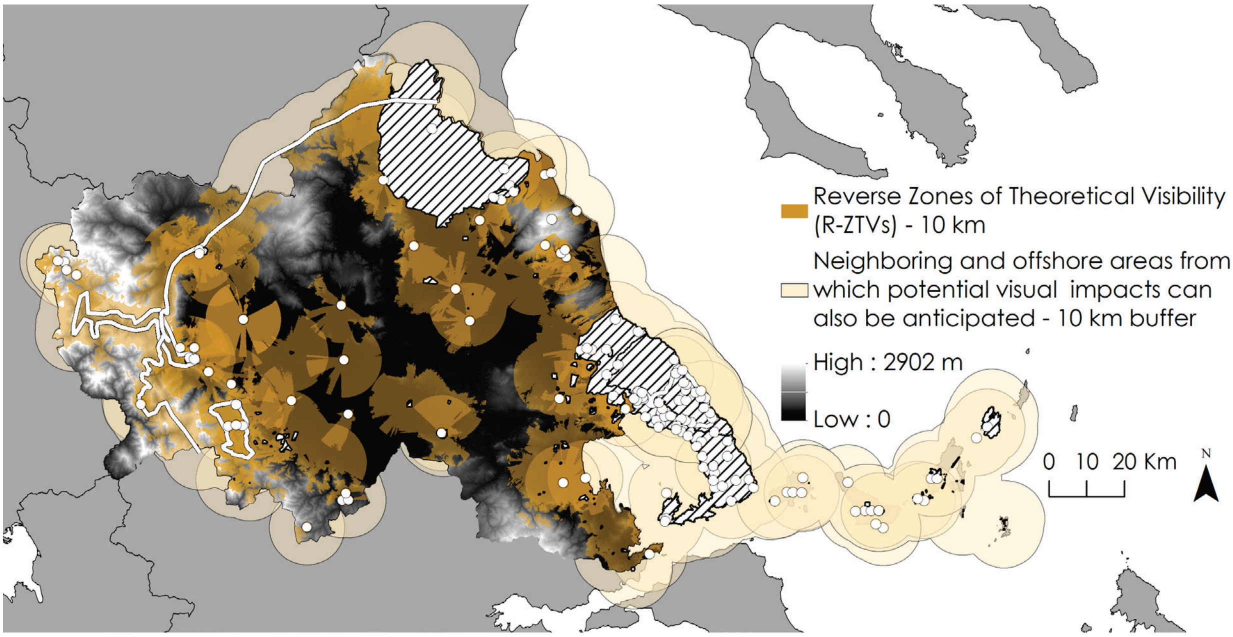


Figure 12. Expansion of R-ZTVs calculated for the protected landscape elements in the region of Thessaly (Figure 10) beyond the region's borders to offshore areas and to adjacent regions with the use of 10 km buffer zones.

3.4.2 Utilization of R-ZTV maps in spatial planning

The overall purpose of R-ZTV maps is their utilization for the *a priori* assessment of landscape impacts of renewable energy projects, with emphasis on early-stage spatial planning analyses and decision making. In this Section, the method is investigated in regard to its capacity to provide information that can support these aims and facilitate the mitigation of landscape impacts.

Initially, we investigate how R-ZTVs can be optimally mapped, in order to be compatible with multi-criteria spatial planning analyses and, more broadly, to be comprehensible and useful to stakeholders in the mitigation of landscape impacts of renewable energy.

As was expected, from the results of Section 3.4.1 we conclude that the visibility threshold used in the reverse viewshed analyses has a significant influence on the size of the generated R-ZTVs. In particular, as shown in Figure 11, with the use of a 10 km visibility threshold, 37% of the land area of the region of Thessaly would be suitable for the installation of new wind energy projects without causing any visual impact to the protected landscape elements of the region. However, this percentage is reduced to only 12% of the region if a 30 km visibility threshold is applied. As expected, the 10 km R-ZTVs allow for a wider freedom for site selection under the goal of minimizing landscape impacts. However, since both visibility thresholds (10 or 30 km) have been used widely in literature (Ioannidis and Koutsoyiannis, 2020), and also given that various other thresholds are also regularly used, as discussed in Section 3.3, it is clear that R-ZTVs should be compatible with both large and small visibility thresholds, in order to be useful in the spatial planning of RE.

To this aim, two different logics of implementation can be proposed, depending on the selected size of the visibility threshold:

(i) When smaller visibility thresholds are applied, such as 10 km, R-ZTVs can be used as a binary map demonstrating in which spatial units the installation of RE infrastructure would cause visual impacts to important landscape elements, as demonstrated in Figure 13. This binary R-ZTV is generated through the union of the reverse viewsheds of the protected landscape elements.

(ii) When larger visibility thresholds are adopted, such as 30 km, R-ZTVs can be used as a weighted map in which each pixel is characterized by the level of visual impact that would be generated to protected landscape elements if RE infrastructure was installed within it. The weighted R-ZTVs can be generated, for example, by overlaying the reverse viewsheds of protected landscape elements and giving each pixel a weight according to the number of overlaying reverse viewsheds within it. In the example of Figure 14, we present an adjusted R-ZTV map for wind energy projects in Thessaly, weighted by the number of reverse viewsheds of the protected landscape elements that overlay in each cell of the map.

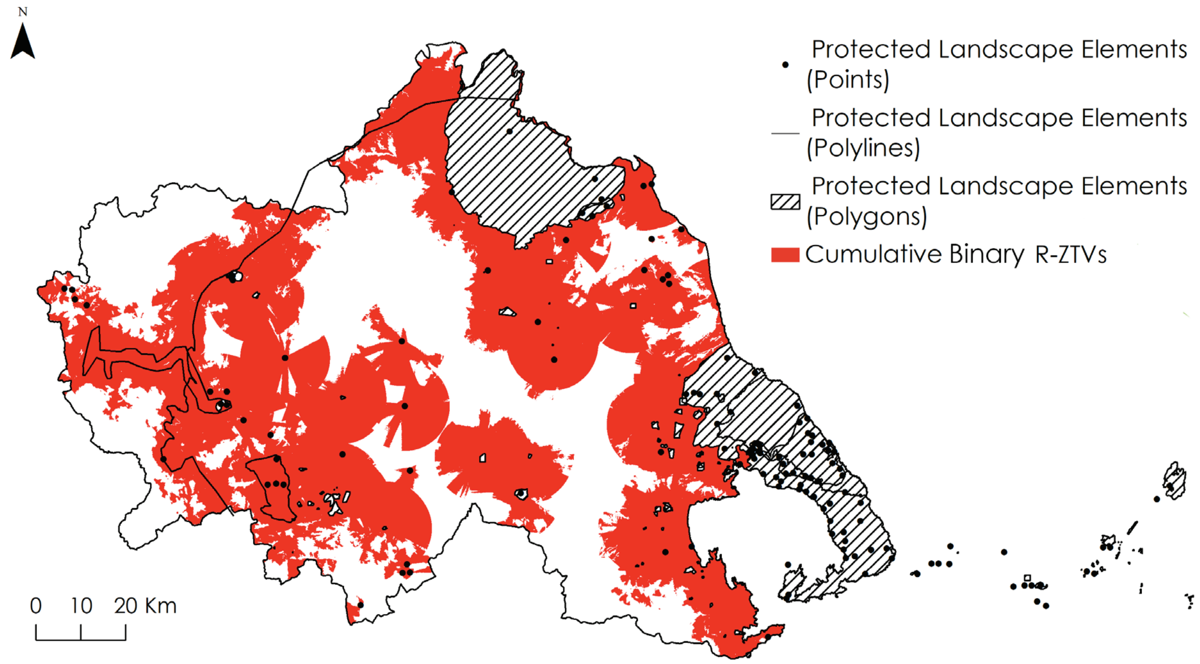


Figure 13. Binary R-ZTVs (with the use of 10 km visibility threshold)

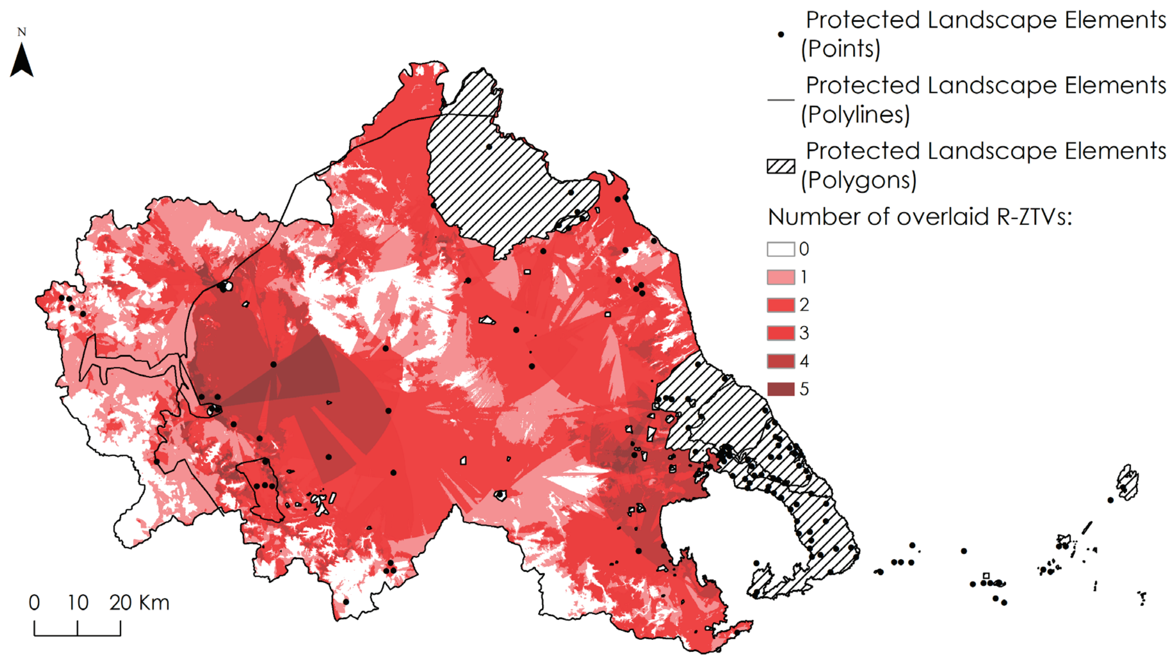


Figure 14. Weighted R-ZTVs (with the use of 30 km visibility threshold)

As a first assessment of the utility of R-ZTVs in a real-world planning scenario, the R-ZTV maps of Figure 13 and Figure 14 were used to evaluate the potential impacts of proposed wind energy projects in the region of Thessaly. Spatial data on wind energy projects in various stages of development were collected from the Greek Regulatory Authority for Energy (RAE) (Regulatory Authority for Energy, 2015). We note that the examined wind energy projects were already in advanced stages of their licensing procedure, while R-ZTV maps are able to be used even in earlier stages before the licensing processes of projects have begun. However, even in this case, the use of R-ZTV maps is again useful as it discards the requirement for carrying out individual visibility studies for all the examined projects, since now one map (e.g., the maps Figure 13 and Figure 14) can be used for the evaluation of the visual impacts of all of them at once (Figure 15).

We also remark that projects that are referenced by RAE as rejected during the licensing procedures (for various reasons, including environmental and legal justification), were also included in the analysis. On the other hand, proposed projects located inside the delimited archaeological areas that are presented in Figure 10 were excluded, as the severity of their landscape impacts was considered as self-evident.

The final list of examined projects, that sum 4.3 GW of nominal power capacity, was incorporated in the aforementioned maps, to evaluate the R-ZTV method over its capability to propose favourable locations for the installation of wind turbines, under the criterion of landscape protection. Figure 15, the R-ZTV maps of Figure 13 and Figure 14 are presented in combination with the projects of the region that are currently under development. Next, the results in regard to the overlap of the locations of the wind energy projects with the R-ZTVs are presented in Table 8 and Table 9.

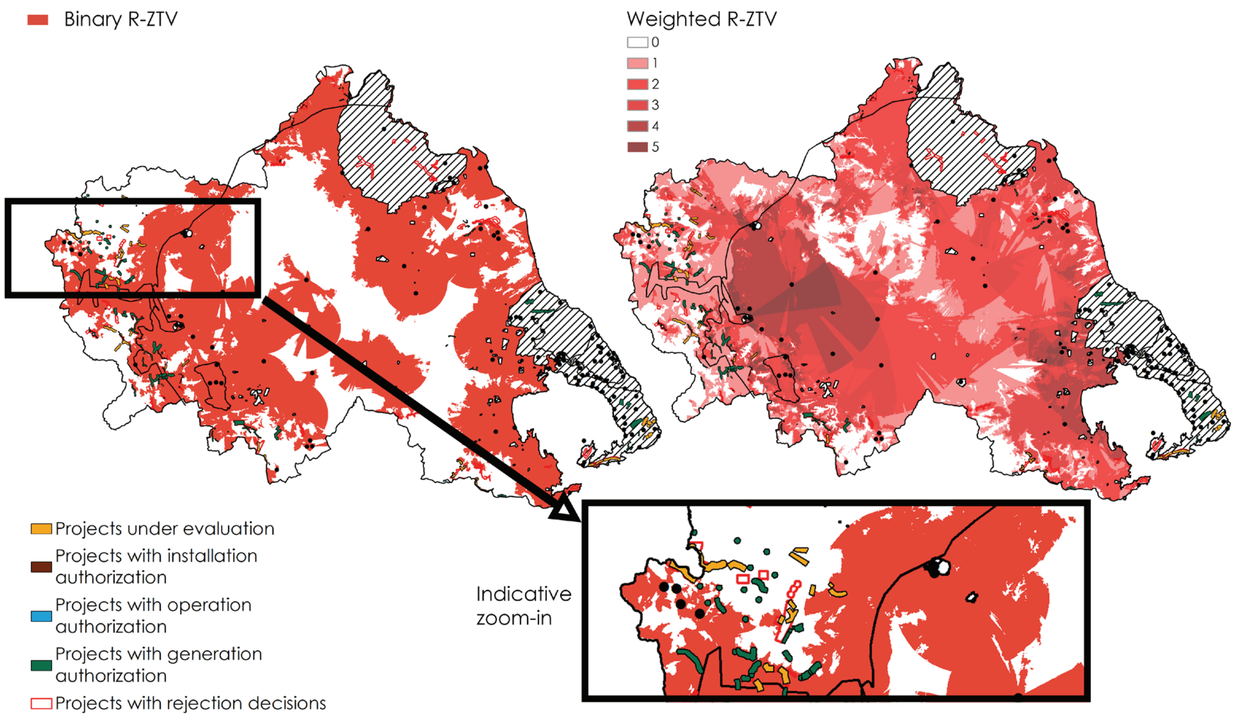


Figure 15. Wind projects in Thessaly region (in various development stages) assigned to R-ZTV maps (Figure 13 and Figure 14).

In the case of the binary R-ZTVs with a 10 km visual threshold, 29.2% of the examined wind energy projects were outside its borders and would thus be considered to be causing minimal impacts to the protected landscape sites (Table 8). In the case of the weighted R-ZTVs with a 30 km visual threshold, the projects that are completely outside the borders of the R-ZTV were only 2.2% of the total set, mainly located in the North-Western and Southern border areas of the region. However, this is not to say that site selection would have to be limited to these areas. In fact, the weighted R-ZTV map demonstrates the number of protected landscape elements that would be impacted from the installation of wind energy projects within each cell of the DEM. Therefore, weighted R-ZTVs could be used, for example, to prioritize locations that generate visual impacts to a smaller amount of protected landscape elements (Sargentis et al., 2021b). With the use of weighted R-ZTVs, we can compute that 19.7% of the analysed projects would be visible by only one protected landscape element, while another 34.2% would be visible by two elements (Table 9). Overall, the weighted R-ZTVs seem to be better suited to the setup of mainstream multi-criteria spatial planning analyses, in which various criteria have to be rated and taken into account, while the binary R-ZTVs could be utilized, possibly in the context of policy, for the computation of exclusion zones or for independent guidance to stakeholders on significant anticipated landscape impacts. An additional observation that might be indicative to the utility of R-ZTV analyses is that rejected projects in the datasets of RAE present a slightly increased overlap with R-ZTV zones than projects in other stages of development. In particular, in Table 8 there is a 77.4% overlap of rejected projects with the R-ZTV, in contrast to 70.8% for the rest of projects. Additionally, in Table 9 the sum of rejected projects in overlap with zones 3, 4 and 5 is 55.9%, in contrast to 43.1% for the same sum in non-rejected ones. This could be a first indication that R-ZTVs can anticipate problematic locations, but this is certainly not definitive, since a detailed investigation of the reasons of rejection of these projects would be required in order to verify this.

Overall, the results demonstrate that R-ZTV maps can be utilized for the anticipation of potential landscape impacts by RE projects, applying both large or small visibility thresholds. The inclusion of projections of landscape impacts that are informed by visibility analysis in early strategic planning and decision making, in general, and in operational multi-criteria siting studies, in particular, would be an improvement over the current practices. We remind that visual impacts so far are typically neither projected nor mapped in these stages (Osorio-Aravena et al., 2020; Shao et al., 2020), and if they are in fact assessed, it is usually the form of predominantly qualitative rather than quantitative assessments (Gamboa and Munda, 2007; Kaya and Kahraman, 2010; Mostegl et al., 2017; Scognamiglio, 2016).

Table 8. Wind energy projects under development in Thessaly region vs. binary R-ZTVs of Figure 13.

Project authorization stage	Number of projects in category	Number of projects overlapping with the binary R-ZTVs	Percentage of projects overlapping with the binary R-ZTVs
1 - Under evaluation	38	23	60.5%
2 - Generation authorization	92	70	76.1%
3 - Installation authorization	5	3	60.0%
4 - Operation authorization	2	1	50.0%
Totals of not rejected projects	137	97	70.8%
Rejected projects (rejection decision)	84	65	77.4%

Table 9. Wind energy projects of Thessaly region under development vs. weighted R-ZTVs of Figure 14.

Project authorization stage	Number of projects in category	Percentages of projects overlapping with the following number of protected landscape element types					
		0	1	2	3	4	5
1 - Under evaluation	38	2.6%	10.5%	36.8%	34.2%	13.2%	2.6%
2 - Generation authorization	92	1.1%	22.8%	35.9%	21.7%	15.2%	3.3%
3 - Installation authorization	5	20.0%	40.0%	0.0%	0.0%	20.0%	20.0%
4 - Operation authorization	2	50.0%	0.0%	0.0%	0.0%	0.0%	50.0%

Totals of not rejected projects	137	2.9%	19.7%	34.3%	24.1%	14.6%	4.4%
Rejected projects (rejection decision)	84	1.2%	11.9%	31.0%	33.3%	20.2%	2.4%

3.5 Discussion

3.5.1 The shift from *a posteriori* to *a priori* assessment of landscape impacts

The aim of reversing visibility analyses of RE is to allow for an early assessment of potential landscape impacts and to enable the timely dismissal of highly impactful locations, thus reducing conflicts and social opposition, and eventually favouring the development of RE.

So far, visibility analysis has been a very useful tool for the quantification of landscape impacts of RE projects across various spatial scales (Ioannidis and Koutsoyiannis, 2020; Scottish Natural Heritage [SNH], 2017). The reconceptualization of this tool so that it can be incorporated in the earliest stages of planning for RE can consequently be considered an important step towards the optimal mitigation of landscape impacts. Until this point, the *a priori* application of visibility analysis, e.g. from the stage of multi-criteria planning, for RE investments and in large spatial scales has been very rare (Osorio-Aravena et al., 2020; Shao et al., 2020). Visibility analyses have either been carried out in large scale but *a prosteriori* (Möller, 2006; Rodrigues et al., 2010; Scottish Natural Heritage [SNH], 2014; Statistics Netherlands [CBS] et al., 2014; Tsilimigkas et al., 2018), therefore mostly having academic rather than planning utility, or *a priori* but in the project's site-scale, reviewing an individual project's location *ad hoc* during the process of EIA (Buchan, 2002; Jerpåsen and Larsen, 2011; Scottish Natural Heritage, 2006; Scottish Natural Heritage [SNH], 2017). However, this timing is not optimal, both for investors and the local communities, since at that stage there are very limited options for modifying the siting of projects. Furthermore, given the fact that public discourse (Devine-Wright, 2005; Eltham et al., 2008; Langer et al., 2016; Wolsink, 2007b, 2000) and co-production (Wolsink, 2020a, 2018) have been identified as essential means to improve the social acceptance of RE projects, technological updates will be required for the facilitation of public participation in the planning phase of RE projects, in a meaningful way. It has to be noted that a well-justified siting is actually the only major way to mitigate the landscape impacts of RE projects. In contrast to other types of infrastructure works in which landscape integration can be improved through architectural design (Ioannidis et al., 2022), this not a potentiality for two out of the three primary types of RE projects, since their shape is predefined by industrial specifications and cannot be modified (Ioannidis and Koutsoyiannis, 2020). In particular, wind turbines and utility-scale solar panels have a predetermined form that cannot be altered, in contrast to works like bridges or dams that be treated architecturally through architectural and landscape studies (Daskalou et al., 2016; Koutsoyiannis and Ioannidis, 2017). Out of RE works, architectural and landscape design is only applicable to civil engineering infrastructures that are associated with hydroelectric projects, such as dams and their appurtenant structures (Ioannidis et al., 2022). Parts of wind turbines have also started to be used for architectural purposes (Leahy et al., 2021; Nagle et al., 2022), but this becomes possible after their decommission and does not refer to wind projects thereof.

R-ZTV analysis is shaped particularly to allow for *a priori* and *large-scale* assessment of potential landscape impacts of RE projects. The facilitation of this shift is the major challenge of this research, since it can enable the inclusion of landscape impact projections, by means of visibility analysis, at the very early stages of project planning, and apparently far before their design (and therefore siting) study. Through the proposed R-ZTV maps: (a) landscape impacts can be included in the well-established planning method of multi-criteria analysis among other criteria that have so far been commonly utilized (Osorio-Aravena et al., 2020; Shao et al., 2020), and (b) can be used even earlier than the beginning of licensing stages (e.g. for wind energy: suitability studies for mean wind speeds and efficacy of intended turbines, etc.), thus saving significant time and effort for projects that would potentially later face important landscape-impact induced opposition. Regarding the shortcomings of current practices in RE planning, it is indicative that in a 2016 multi-criteria spatial planning study for the examined region of Thessaly (Daskalou et al., 2016), the mitigation of landscape impacts was addressed with 1 km buffer zones around protected landscape sites. This is one of the relatively lenient and simplistic measures for landscape protection suggested by the Greek Framework for Spatial Planning and Sustainable Development of RE (Hellenic Ministry of Environment, Energy & Climate Change, 2008), that has also been used in other studies in Greece (Latinopoulos and Kechagia, 2015). We remark that similar practices are reported in multi-criteria studies in other countries, as well (Watson and Hudson, 2015).

The outcomes of this analysis, as presented in Figure 13, Figure 14 and Figure 15 and Table 8 and Table 9, demonstrate how R-ZTV maps can indeed facilitate the incorporation of visibility analysis in RE planning, at the regional or even coarser spatial levels. The format of R-ZTV maps, i.e., a generic spatial layer calculated for a whole region or country, is compatible with spatial multi-criteria analyses (Efstratiadis and Koutsoyiannis, 2010; Osorio-Aravena et al., 2020; Shao et al., 2020) or strategic environmental impact assessment studies (Pang et al., 2014) that are commonly used for RE planning across such scales. R-ZTV maps can improve the assessment of landscape impacts within such well-established design and planning practices, since they are based on accurate reverse viewshed calculations. By reducing subjectivities, such tools can facilitate decision-making for the social environmental and techno-economic optimization of RE projects. An additional advantage of R-ZTV maps is that after their single calculation at the regional or national scale for any selected protected landscape features (historical and cultural monuments, traditional settlements, touristic areas, etc.) they can be re-used for any project with similar characteristics in the proximity of these protected areas. This is possible due to the fact that the implementation of visibility analysis does not longer depend on the locations of particular examined projects, as has been the case so far. Therefore, R-ZTV-type analyses have the potential to reduce the load of EIA and thus to simplify policy, if utilized in large spatial scales. The use of visibility analyses based on reverse viewshed calculations in early stages of development is also supported by the similar yet even more generic method of Zones of Potential Visual Impact on Protected Landscapes presented by Natural England (GeoData Institute, University of Southampton, 2013) or the already mentioned study by Tegou et al. (Tegou et al., 2010). Finally, reverse visibility analyses are quite easily expandable, whenever additional information has to be added (e.g., new features of interest or new restrictions), by means of overlapping layers.

R-ZTV maps are relevant to private or state-owned enterprises involved in the development of RE, as well as to institutions and local authorities that are active in cultural heritage management and landscape planning and preservation. In this respect, these maps can be used for the anticipation of impacts either as part of multi-criteria planning studies for independent consultation, especially from the investors' point of view, who usually lack on local knowledge. In fact, many companies that are active in the field of RE development are multinational and have limited information about landscape-quality issues, such as cultural heritage, tourism, etc. As a result, in many cases, conflicts with local communities and opposition that emerges over landscape effects could have potentially been avoided if tools for early projection of these impacts were available. Furthermore, the R-ZTV maps can be used for the classification of cases of projects in regard to their landscape impacts and additionally relevant institutions can also have an active role in the selection of protected landscape sites that will be used to generate the R-ZTVs. This last point can be of particular significance given the broadly accepted importance of public participation in RE planning (Devine-Wright, 2005; Eltham et al., 2008; Wolsink, 2000), and also illustrates a potential for synergies with participatory GIS tools (Brown and Raymond, 2014; Picchi et al., 2019). Lastly, R-ZTV maps can facilitate the communication between stakeholders, by providing spatial quantification and classification of impacts; they can be used to aid in the justification of objections, trade-offs or compromises, overall easing the handling of conflicting objectives in the planning process of projects (Efstratiadis and Hadjibiros, 2011) and contributing to reducing the social turmoil, delays and costs associated with conflicts over landscape impacts.

3.5.2 Limitations

Even though R-ZTV mapping can contribute to improved projections of landscape impacts of RE during planning procedures, it should not be considered as an indisputable quantification, similarly to any method of quantifying landscape and visual impacts. Even though the calculation of visibility is relatively accurate, visibility cannot be considered equivalent to visual impact (Wolsink, 2020b). Visual impact is a rather qualitative than quantitative concept, which is subject to personal opinions and biases (Kontogianni et al., 2014, 2013; Lee, 2017; Nadaï and Van Der Horst, 2010; Phadke, 2011) and therefore depends on multiple other factors besides visibility; for example, on the perception of individuals on the quality (Molnarova et al., 2012; van der Horst, 2007) or the scenicness (Weinand et al., 2021) of the transformed landscapes prior to their transformation, on place attachment (Buchmayr et al., 2021), etc. Additionally, various other project-related or site-specific visual phenomena, such as glare from PV panels (Chiabrando et al., 2009) or movement of turbine blades (Bishop and Miller, 2007), can also affect the visual impacts of RE projects. Finally, viewshed calculations and the ZTV method, which are the foundations of R-ZTV, also have additional computational flaws of their own (Ioannidis et al., 2020; Johnson, 2014). Thus, the proposed method of R-ZTV mapping is not manifested as a definite quantification of landscape impacts. It is rather a tool that can be used to support planning practices or policy frameworks and national directives for RE planning, in terms of improving the quantitative aspect of their landscape impact assessments.

In addition to the aforementioned shortcomings of visibility analyses in general, the R-ZTV method has some additional more specific prerequisites and limitations. In particular, the basic requirement for its implementation in the large scale (national and regional), where it is more meaningful, is that sites of landscape importance must have been already designated and mapped and be available in GIS compatible formats. In some countries, such data are already mapped in those scales by environmental and cultural institutions and agencies (GeoData Institute, University of Southampton, 2013; Watson and Hudson, 2015). However, this is not necessarily the norm. For instance, in Greece, only three out of the 13 basic administrative regions have published such data in GIS format.

Lastly, there are additional limitations that are specific to the present analysis and are related to its technical assumptions and decisions. The first one is that a DEM (Digital Elevation Model) was used for the analysis rather than a DSM (Digital Surface Model) that includes adjusted land surface heights according to land uses (Minelli et al., 2014) or land cover (Grekousis et al., 2015), since the latter was not found for the examined region. Nevertheless, the differences between a DEM and a DSM in the scale of examination of our investigation are not expected to be significant. We remark though, that the use of DEMs is approved by practice guidelines for ZTV analysis (Scottish Natural Heritage, 2006). Secondly, another space for improvement involves the positioning of theoretical observers within protected areas. For example, traditional settlements were presented as points within the utilized data sets, while more accurate representations of them would allow for the inclusion of more theoretical observers, thus improving the accuracy of the derived R-ZTV maps. Differences between R-ZTVs could also be investigated by means of using centroids or peripheral points or combinations of the two for calculations in polygon type protected areas. The number of points that are generated to represent a structure in the landscape have already found to affect the calculation of area of visibility (Caha, 2018) in R-ZTV analyses at smaller spatial scales and may also have some impact, probably less significant, in larger scales.

3.6 The utility of reverse visibility analysis

The inability to integrate visibility analyses into the strategic planning of RE projects has hindered the timely projection of landscape impacts, thus impeding their mitigation and arguably contributing to significant landscape-impact induced public opposition. In this Section, the realization of a methodological shift in visibility analyses was proposed as a solution to the above-mentioned shortcoming: shifting the focus of visibility analysis from RE infrastructures that cause visual impacts to the landscape elements that should be protected from such impacts. With this modification, R-ZTVs (Reverse Zones of Theoretical Visibility) can be calculated and be used to anticipate landscape impacts of projects, much before their design studies and before the crucial steps of licensing and EIA.

The practical challenges of this shift were investigated in the region of Thessaly, Greece, where R-ZTV analysis was implemented at a regional scale of 14.000 km^2. This proof-of-concept demonstrated how the proposed reverse visibility analysis can be used to support the sitting of projects is various levels of maturity (initial evaluation of wind speeds and business plans, EIA, finalized licensing, etc.) with the landscape-protection criterion, *a priori* and in large spatial scales. It has to be noted though that the generated maps can also be used for the prediction of landscape impacts of future proposed projects within the region, even in earlier preliminary stages of development, namely in early planning or conception.

Through both the theoretical and the practical investigations of this Section it was demonstrated that the reversal of visibility analyses can lead to overcoming common landscape-associated difficulties of RE planning, in the following ways:

1) The reversal of visibility analyses enables their integration into the early planning stages of RE, which has been impractical so far. Mainstream ZTV and viewshed analyses could not be carried out at these stages since they require the detailed project layout as input, while at that time the project design (including its micro-siting) is still under investigation. However, since important landscape elements (historical-archaeological sites, cultural monuments, touristic areas, etc.) are in already known locations, visibility analysis can be instead carried out from their perspective in the form of reverse viewshed, using their locations as input. The combination of the computed reverse viewsheds in R-ZTV-type maps formulates a new type of map that can be used to project potential visual impacts to the examined landscape elements. This map can be used as early as in the conception phase or can be integrated into multi-criteria strategic planning studies, along with other technical, economic and environmental criteria, thus allowing for the early anticipation of potential landscape impacts.
2) After a single calculation, R-ZTV maps of protected landscape elements can then be used in the future for any planned RE project in their proximity. Hence, in terms of their policy implications, R-ZTV maps can potentially render the requirement for individual visibility analyses for each new project obsolete, overall accelerating the EIA of RE. Since protected landscape sites are static, the computation of the reverse viewshed of every site is only required once, and would not need to be re-calculated for each new project, as is the case with conventional visibility analyses. A new implementation will only be required if basic geometrical features of the examined RE projects, such as wind turbine or solar photovoltaic panel heights, are modified significantly.
3) Finally, R-ZTV maps have potential for synergy with participatory planning processes and can also be used independently by stakeholders and investors in RE. R-ZTV maps can be used independently by any of the stakeholders in the development of RE, in the early planning phases of RE development, when the siting or projects is still under consideration, therefore allowing for better-informed siting decisions. From the perspective of investors, R-ZTV maps can be used for the selection of locations with low anticipated landscape impacts, thus reducing investment risks. From the perspective of stakeholders that are active in the protection of landscapes, R-ZTV maps can provide quantitative data that can be used to facilitate communication and public discourse over projected landscape impacts. Finally, R-ZTV maps can be co-produced with local communities and landscape protection institutions, who can be involved in the selection of landscape features to be included in the R-ZTV analysis.

Overall, it can be expected that the continuous effort to expand RE in combination with the fact that low-impact sites for such projects are declining (Deshaies and Herrero-Luque, 2015; Kaldellis et al., 2012; Nitsch et al., 2004), will render the RE transition one of the most significant drivers of landscape change in the following decades. It is evident that the mitigation of impacts to landscapes will be a key goal for both investors and local communities that aim to protect their landscapes (Ioannidis and Koutsoyiannis, 2020), since the associated conflicts are detrimental to both groups, as it is especially manifested in countries with highly developed economies (Diógenes et al., 2020). Technological tools, such as the R-ZTV analysis, can aid towards this effort, by improving the quantitative data generated for RE planning while also maintaining potential for a synergetic relation with the participatory planning methods proposed by the ongoing research on public discourse and participation schemes (Picchi et al., 2019; Stober et al., 2021; Wolsink, 2018) and decision making policies (Frantál et al., 2018; Weinand et al., 2021; Wolsink, 2020a).

4 PROJECT-SITE SCALE: THE UTILITY AND POTENTIAL OF ARCHITECTURAL AND LANDSCAPE TREATMENT OF INFRASTRUCTURE

4.1 Introduction

4.1.1 The question of landscape design of major civil infrastructure

In Section 2.4, it was established the architectural and landscape design are essential tools in the effort to mitigate the landscape impacts of infrastructure works. However, the capability of infrastructure works to be treated architecturally is not a given; wind and solar energy works as well as overhead power transmission lines and other infrastructure seem to suffer significantly, from a landscape impact perspective, by the fact that their shape and form cannot be modified as part of architectural design studies. Works that are capable of receiving architectural treatment, such as dams (Koutsoyiannis and Ioannidis, 2017), bridges (Denn, 1995), irrigation channels, etc., seem to benefit significantly when such studies are applied, by enjoying a better integration with the natural, cultural and aesthetic characteristics of their surrounding landscapes.

The advancement of the architectural and landscape design of major civil infrastructure has also been identified as a crucial focus-point for the future research agenda of landscape architecture (Meijering et al., 2015; Nijhuis et al., 2015; van der Wal et al., 2021). The major role that the so called "landscape impacts" have had in the discussion over the sustainability of the renewable energy transition (Ioannidis and Koutsoyiannis, 2020; Jefferson, 2018; Pasqualetti, 2011) has certainly contributed to this regard.

However, so far and in most countries, architectural and landscape design studies are still not required for major projects of civil infrastructure such as dams, bridges and highways (Kara et al., 2017). When it comes to major infrastructure projects, the landscape design sector is generally considered to be underdeveloped both in practice (Fischer et al., 2000; Moosavi et al., 2016) and in academic research (Vicenzotti et al., 2016). The few cases worldwide in which landscape design has been consistently and widely implemented during the development of infrastructure are limited to some of the countries with highly developed economies[12], where landscape design requirements are included in institutional design standards, e.g. in countries in Europe and in the USA (Chugh, 2011; Thompson et al., 2006). It has to be noted though that in practice, even in those countries, the implementation of landscape design is in many instances limited to peripheral interventions such as slope restorations and planting trees, without intervening in the form and surface of infrastructure.

Hence, the primary research question of this Section is whether landscape design can have a more important role in the design process of infrastructure. To this aim, we focus on the following two issues that we perceive as most essential for decision makers in matters of design and planning policy: (a) the investigation of the utility of landscape design in works of civil infrastructure and (b) the investigation of the potential for its wider implementation with

[12] We use the term as it is defined in the UN classification (United Nations Department for Economic and Social Affairs, 2019)

emphasis on the examination of cost-associated or technical limitations. According to the results of these investigations the academic community could potentially argue for a more important role for landscape design of infrastructure, to technical and political authorities that shape relevant policy.

4.1.2 Dams as the focus of the investigation

The decision to focus on a particular type of infrastructure was made so that the investigation of the general research questions of this Section can be done in a predominantly practice-oriented context rather than in a theoretical one. This was considered necessary for addressing adequately and realistically the research questions of the Section regarding the utility and feasibility of landscape design in major civil infrastructure projects.

Dams are arguably some of the most crucial works of infrastructure (Koutsoyiannis, 2011; Nikolopoulos et al., 2018) and are multipurpose projects that are used for water supply, irrigation, energy generation, flood protection, recreation and other purposes (Dimas et al., 2017; Efstratiadis and Hadjibiros, 2011; Sargentis et al., 2020, 2019b). They were identified as a suitable focus for the investigation of landscape design practice in infrastructure for two reasons. Firstly, due to the fact that various cases can be found globally in which landscape design has been utilized and positively perceived landscape transformations have been generated[13] (Fleetwood, 2010; Frolova et al., 2015a; Ioannidis and Koutsoyiannis, 2017a; Kreuzer, 2011; Nynäs, 2013). Secondly, because on the contrary various cases in which no landscape or architectural treatment has been applied can also be observed in global practice. Thus, through the focus on landscape design practice in dams, interesting comparisons could be made between cases with or without implementation of architectural design and the general research questions of the Section could be partitioned into these more specific and quantifiable research questions: Has landscape and architectural design been implemented successfully in dams? At what cost? Can it be demonstrated that it has contributed to increasing the sustainability of the generated landscape changes (especially in comparison to cases in which it has not been applied)? And if that is the case, is the wider realization of landscape design in this type of projects technically and economically feasible?

In terms of the scale of the analysis, the investigation for the feasibility and typology of landscape practice in dams was carried out on a global scale, examining cases of landscape design implementations from more than 20 countries. On the contrary, the examination of projects' budgets was approached through a more targeted and detailed analysis of three projects. It is also noted in this regard, that so far the architectural potential of dams has largely been left untapped and landscape design has only been utilized sporadically (Ioannidis and Koutsoyiannis, 2017a). Therefore, the investigation of landscape-design practices in dam projects was carried out globally, so that a sufficient number of cases of dams could be collected and analysed. This challenge led on the one hand to the inclusion of dams from all around the globe in the study, while on the other hand, it further demonstrated how landscape design has been neglected in

[13] The definition for landscape that is followed in this thesis is the definition of the European Landscape Convention (https://www.coe.int/en/web/landscape/the-european-landscape-convention) that "landscape is part of the land, as perceived by local people or visitors, which evolves through time as a result of being acted upon by natural forces and human beings".

major civil infrastructure projects. Notably, given that dams have been recipients of criticism over various social and environmental impacts (Mamassis et al., 2021), it would be reasonable to expect the implementation of any available measure to mitigate them, including landscape design, would have been supported more.

4.1.3 Section structure

In Section 4.1, we described the scientific focus and the research questions of this Section (Section 4.1.1), the reasoning behind the selection of dams as the focus of the investigation that follows (Section 4.1.2) as well as the overall structure of the Section 4 (Section 4.1.3). In the methods Section, we initially we briefly describe the setup of dam projects and the basic components of dams, in Section 4.2.1. In Section 4.2.2, we analyse landscape-design practice in dams and formulate a typology of architectural and landscape design implementations. In Section 4.2.3, we investigate how the utilization of the designs of the typology of Section 4.2.2 has affected the perception of the public on transformed landscapes. This is carried out through the analysis of photograph uploads in the proximity of dams in geotagged photography databases in Greece (Section 4.2.3.1) and also globally through literature review (Section 4.2.3.2). In Section 4.2.4, we investigate the project-cost requirements for the implementation of landscape design studies through the analysis of the budgets of two realized projects as well as the budget of a theoretical case study specifically formulated for the purposes of this investigation. Finally, in Section 4.3 we discuss the results of the Section and in Section 4.4 we present the conclusions.

4.2 Methods

4.2.1 Dam projects' setup

References to dam design in this research will be limited to the basic setup of a dam's site and to its primary structural parts (Figure 16). The body of a dam is the main structure that blockades water and creates an artificial lake or reservoir. It has three main parts: the downstream face that is visible in Figure 16, the upstream face, which fronts onto the reservoir, and finally, the dam-crest. Reference will also be made to appurtenant structures and to the peripheral landscape of dams. With the term "peripheral landscape" we define the broader reservoir area including the natural terrain surrounding the structural parts of dams; this is the area that commonly requires restoration after the construction of dams. In relation to the appurtenant structures of dams, reference will be made to (i) spillways and outlet works that are used to channel or siphon, respectively, excess water downstream of the dam when the reservoir reaches its full capacity (Koskinas et al., 2019) (ii) powerhouses that are the buildings where energy generation and conversion equipment is installed, in the case of hydroelectric dams, and finally (iii) valve towers that provide access to valves for the control of outlet works.

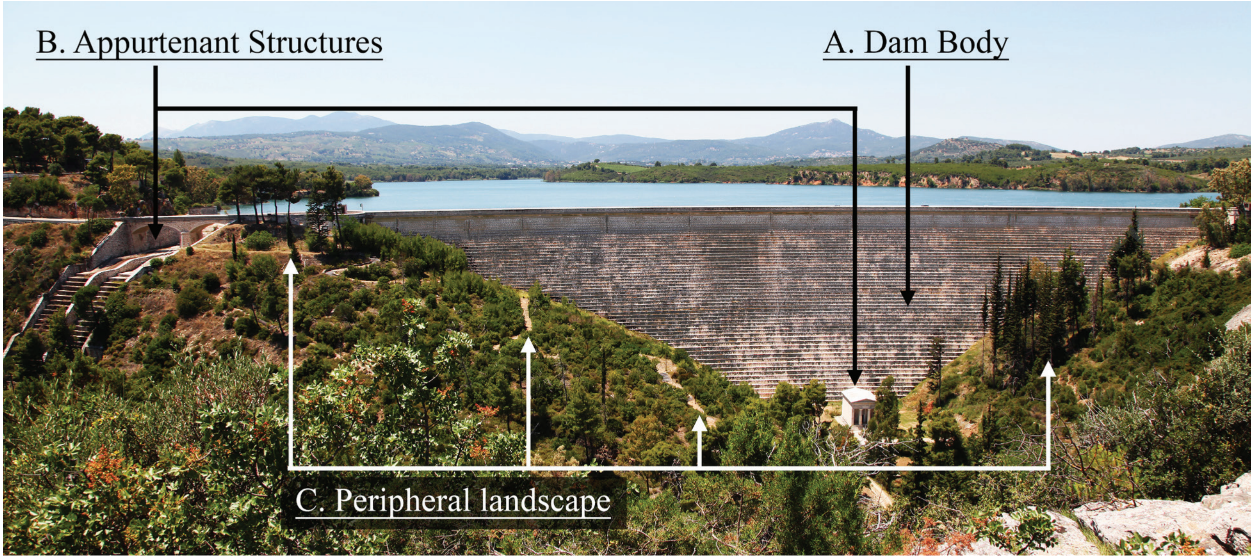


Figure 16. A dam's project-site: (A) Dam body, (B) Appurtenant structures (spillway, entrance to the interior of the dam and reservoir control facility in this case) and (C) Peripheral landscape (planted with trees and redesigned with walking trails in this case). The dam presented in this figure is the Marathon dam in Greece.

4.2.2 Practice of landscape design in dams

Dams, similarly to all works of engineering, have inherent aesthetic qualities regardless of whether they have had architectural treatment or not. The majority of dams globally are in fact formed solely as the result of their technical requirements, meaning that architectural and landscape concerns have no role in the design process. The focus of this investigation however is not on these cases of dams; we rather focus on the cases where additional design elements have been specifically implemented in order to better integrate the dam into landscapes or to enhance its aesthetics[14]. Thus, in this Section, we collected cases of dams that included architectural and landscape design features, from global practice, aiming (i) to investigate the feasibility of landscape and architectural design in dams, as demonstrated in realized projects, and (ii) to create a typology of designs that can be used later in the Section for the assessment of the contribution of landscape design to improving landscape quality perception.

4.2.2.1 Collection of data

For the collection of data from landscape-design practice in dams, searches were initially carried out in academic and institutional literature. However, since literature in this field was not very extensive and was either focused on individual case studies (Kreuzer, 2011) or on single countries (Fleetwood, 2010; Nynäs, 2013), data searches were also carried out in web search engines. The searches were directed to data from websites of institutions and organizations that are active on the fields of dam design, hydropower and cultural heritage. The keywords "dam landscape design in (country name)" and "dam architecture (country name)" were used followed by searches using the same keywords translated into the respective official languages of various countries using Google translate. The countries that were included in the searches were, firstly, the top 10

[14] The only exception to this is our reference to arch and buttress dams, because their highly perceived aesthetics have already been correlated to their inherent geometrical characteristics in literature, as explained in more detail in Section 4.2.2.2.

countries globally, ranked by number of dams[15], and secondly, various other countries that were identified by the authors as potentially relevant, based on their personal experience, such as: The United Kingdom, Norway, Switzerland, Greece, Australia, France, Egypt, Algeria, Germany, Italy, Turkey, New Zealand and others.

Other than the text of the examined literature and websites, dam-photographs included in these sources were also investigated. Since dams do not have publicly accessible interior spaces, architectural and landscape design features are by default visible on the exterior of dams and their appurtenant structures. Thus, landscape design features of dams were identified both from the examination of literature and from photographs of dams. For the latter, the experience of the authors on dam design was utilized in order to separate the additional landscape-design features from the standard structural parts of dams that are necessary from a technical standpoint, as defined by the universally standardized dam types (Chugh, 2011; Ioannidis and Koutsoyiannis, 2017a; Tanchev, 2014).

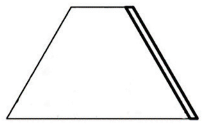
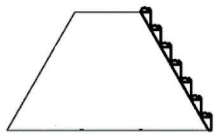
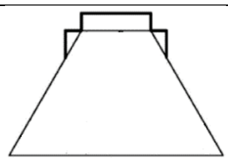
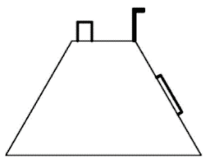
As a result of this investigation, more than 70 cases of architectural and landscape interventions in dams were found, originating from counties across all inhabited continents. The typologies of landscape design in dams were then formed, by grouping cases of implementation of landscape design techniques with similar characteristics.

4.2.2.2 Landscape design: dam body

The analysis of landscape-design practice in dams demonstrated that, even though landscape design is not implemented in the majority of dams globally, a great variety of distinctive implementations can also be found. Beginning with the dams' body, architectural interventions are mainly carried out in the downstream face, which is the largest visible part of the dam. In dams built from concrete or hardfill, various different types of coatings have been used in this area. In the compiled examples (Table 10), the technique that has been most regularly utilized is ashlar masonry with natural stones both in carved and semi-carved form, using marble, slate, limestone, basalt and granite. Alternative facing techniques also include brickwork and concrete moulds. In the case of the downstream face of dams that are built of earth or rock material (also called embankment dams), different techniques have been developed that mainly focus on the formation of the outer layer of the dam's material with rubble masonry. Downstream slopes have also been planted, primarily in embankment dams but also in some cases of concrete dams. In dams made from earth or rock material, the most common techniques include planting with grasses, shrubs or even trees, such as in the Aswan High dam in Egypt. In concrete dams, planting is commonly limited to planter boxes in the crest or sparsely scattered in the downstream face. However, in the La Breña II dam, completed in 2009 in Spain, it was demonstrated that full planting of the downstream slope is possible in gravity dams as well.

[15] https://www.icold-cigb.org/article/GB/world_register/general_synthesis/number-of-dams-by-country-members

Table 10. Typology of techniques used in the landscape design of the dam's body and examples of cases where they have been implemented.

Dam Section sketch	Type of design	Examples of dams
	Downstream slope facing	Howden (UK-England), Vyrnwy (UK-Wales), Marathon (Greece), Bornos (Spain), Cataract (Australia), Solbergofoss (Norway), Wachuset (USA), Minamiaiki (Japan), Kuriyama (Japan), Tirajana (Spain), Kurodani (Japan), Pinios (Greece)
	Planted downstream face or crest	Ladybower (UK-England), La Breña II (Spain), Bhandardara or Wilson (India), Arriaran (Spain), Charco Redondo (Spain), Sorpe (Germany), Jarrama (Spain), Aswan High (Egypt), Kalangur (China), Nangoumen (China)
	Dam crest features	Kawachi (Japan), Vyrnwy (UK-Wales), Cataract (Australia), Möhnetalsperre (Germany), Jandula (Spain), Grand Dixence (Switzerland)
	Information boards, decorative elements, lighting and art	Oddatjorns (Norway), Miharu (Japan), Arriaran (Spain), Sannokai (Japan), Hume (Australia),
	Arched-buttress dams' bodies form distinctiveness	Emosson or Barberine (Switzerland), Meishan (China), Roselend (France), Navatn (Norway), Plastiras (Greece)

The dam crest has also been the recipient of landscape and architectural interventions. Such interventions include the design of parapets, railings and other auxiliary structures on the crest of the dam. Examples of this type of structures are valve towers (Gandy, 2006), which can be included into the architectural design of dams as demonstrated in the cases of Cataract dam in Australia or Solbergfoss dam in Norway, or viewing towers, such as in the example of Möhnetalsperre dam in Germany. Other than major architectural interventions, smaller scale designs and artistic elements can also be found in several dams of all the various dam-types; e.g., in their parapets and railings, such us the minimalistic concrete parapet of the Grand Dixence dam in Switzerland or the stone parapet of the Oddatjorndammen in Norway. Artistic interventions include sculptures, wall-painting of parts of the dam (Pérez et al., 2013; Ramos and Alonso, 2003) and inscriptions in the downstream façade of dam, such as in Sannokai dam in Japan.

Finally, the investigation also demonstrated that certain types of dams are in some cases considered to be architecturally significant even solely due to their form or their historical significance, without requiring additional landscape-design interventions. Plasticity of forms, body form distinctiveness and the structural "honesty" (Bacon, 2015) of reinforced concrete, have been identified as elements of inherent architectural and aesthetic value in dams, by Le Corbusier and others (Kreuzer, 2011; Le Corbusier, 1925); the types of dams that usually combine these structural characteristics are arch dams and buttress dams. Masonry dams are also perceived positively, but mainly due to their historical significance (García Martín, 2012) as they were a popular dam throughout European history, beginning from Ancient Greece (Dounias, 2020; Mamassis and Koutsoyiannis, 2010) and Ancient Rome (Arenillas and Castillo, 2003). Arguably, most of these dams were not affected by the "split between architecture and engineering" (Berrocal Menárguez and Holgado, 2014) that took place in the post-industrial era and contributed to the emergence of issues of landscape industrialization.

Figure 17. Example of dam with architectural intervention in downstream slope facing – Vyrnwy dam (UK). Image source: https://lh5.googleusercontent.com/p/AF1QipOcDGIoGN27CJjyFFeTsU9F6vz 6lLeUja7CjzgO=h720

Figure 18. Example of dam with planted downstream face - La Breña II (Spain). Image source: https://lh5.googleusercontent.com/p/AF1QipM5InliGbtf4FyZqMJG1GdY73tAet1oodlPGB=h1440

Figure 19. Example of dam with architectural features it its crest – Kawachi dam (Japan). Image source: https://lh5.googleusercontent.com/p/AF1QipNeqJ6r00d6-plvffpFCWwi0Ym2YypsVwjFeqCe=h1440

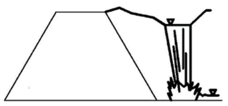
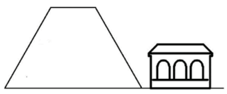
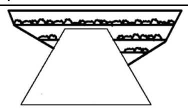
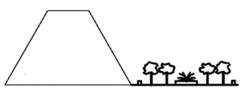
Figure 20. Example of dam with decorative elements and inscription in downstream face – Nangoumen dam (China). Image source: Google Earth screen capture.

Figure 21. Example of arched dam of architectural and landscape significance – Barnerine or Emosson dam (Switzerland): Image source: https://lh5.googleusercontent.com/p/AF1QipMuEgKJDDHwrsHSEFol 7iI51m zR2GAAL2-3fgxJ=h1440

4.2.2.3 Landscape design: appurtenant structures and peripheral landscape

The appurtenant structures and the peripheral landscape of dams have also been incorporated into landscape designs in several cases (Table 11). In general, spillways and outlet works of dams commonly follow standardized designs that are predetermined by technical requirements (Retsinis and Papanicolaou, 2020). However, in the examined cases, creative non-standard-practice designs have been used to improve landscape integration (Table 11). Examples include conveying water to lateral rocky abutments, either directly below (e.g. Bhandardara-Wilson dam) or downstream of the dam (e.g. La Pena Dam in Spain) (García Martín, 2012), so that the water is finally released to flow naturally over stones, similarly to natural waterfalls. Another alternative to mainstream standardized spillway-design, is the use of customized overflow channels to convey the excess flood water directly over the downstream face of dams; a technique primary utilized in dams built from masonry (Winter et al., 2010), concrete or hardfill.

Table 11. Typology of techniques used in the landscape design of dams' appurtenant structures and peripheral landscape and examples of cases where they have been implemented.

Dam Section sketch	Type of design	Examples of dams
Appurtenant structures		
	Non-standard landscape design of spillway and outlet works	Bhandardara/ Wilson (India), Jandula (Spain), La Pena (Spain), Tunhovd (Norway)
	Special cases of architectural design of spillways with overflow on dam body	Derwent (UK-England), Batanejo (Spain), Kuromata (Japan), Ovre Eggevatn (Norway), Malpaso del Calvillo (Mexico)
	Architectural design of facilities and appurtenant structures	Marathon (Greece), Bermejales (Spain), Rocky Reach (USA), Dalsfos (Norway), Pitlochry (UK-Scotland), Beni Haroun (Algeria)
Peripheral landscape		
	Restoration of excavated slopes	Fukashiro (Japan), Kitakawachi (Japan), Shimokubo (Japan), Haizuka (Japan)
	Public park in the dam area or the broader reservoir area	Asari (Japan), Haizuka (Japan), Kensico (USA), Lenexa (USA), Mettur (India), Sardar Saroar (India)

In addition to spillways and outlet works, other appurtenant structures of dams, such as water-intake towers, fish passes and power stations (in hydroelectric dams) have also been modified in efforts to improve the landscape integration of dams. Representative examples of architectural design of water-intake towers are the Marathon dam in Greece (Ioannidis and Koutsoyiannis, 2020) and the Vyrnwy Dam in Wales. Fish passes or fish ladders, as they are also called, have also been referenced in regard to their potential for successful integration into landscapes when particular landscape design techniques are followed (DVWK, 2002). Finally, power generation facilities (needed in the case of hydroelectric dams) have also been treated architecturally and various architectural design approaches have been used for their design, with references to cultural, natural and aesthetic attributes of the project's location (Table 11).

Other than the design of dam infrastructure and facilities, landscape design of dams also concerns the peripheral area of the dam. Indicative works include the rehabilitation of local landscape impacts from excavation works, landscaping the area surrounding the structural parts of the dam and construction of park infrastructure. Techniques for slope and excavation rehabilitation primarily include the use of gabions and planting. In addition to landscape rehabilitation, in various examples public parks have been constructed in the proximity of dams (Table 11). In such cases, the dam is commonly used as a central landmark of the park and the park itself is constructed close to it, usually right downstream of the dam or in its lateral abutments. Public parks in dams usually include benches, information signs for the dam, terraces, etc. In a larger scale, the construction of the dam might also include the creation of coastal trekking trails or biking paths in the periphery or the reservoir. Cases where trees were planted were also found, usually in the proximity of the dam and the reservoir area (Koutsoyiannis and Ioannidis, 2017) but also in more distant areas, as remedial measures; such us for example in Andevalo dam in Spain (Pérez et al., 2013).

Figure 22. Example of dam with non-standard landscape design of outlet works - Bhandardara or Wilson (India) with overflow of outlet water on rocky dam abutments. Image source: https://lh5.googleusercontent.com/p/AF1QipNviWUiYR_Yu0jWixBF5irk27i0beAhEJMH6VwN=h720

Figure 23. Example of dam with a special architectural design of its spillway with overflow over dam body – Derwent dam (UK). Image source: https://lh5.googleusercontent.com/p/AF1QipNV_vl6wBhjacD sGQLuWEC EL2h-UkFP7v_3Mc2E=w1280-h720-pd

Figure 24. Example of dam with landscape design of appurtenant structure, in this case of fish pass, - Rocky Reach dam (USA). Image source: https://lh5.googleusercontent.com/p/AF1QipP5I8DvzPQGWtKry b0t7UbOCAKI3UYkWI74 30_w=h1440

Figure 25. Example of dam with restored excavation slopes – Fukashiro dam (Japan). Image source: https://lh5.googleusercontent.com/p/AF1QipN8v9YgphblHlzA_A_S2kFEMImwiksyMkRv Ooq_=h720

Figure 26. Example of dam with public park in the dam area – Kensico dam (USA). Image source: https://lh5.googleusercontent.com/p/AF1QipNPTQRNJpEeLa1YGimGjmI9_trtamnTOlyLxZ8=h720

4.2.3 Contribution of landscape design to improving landscape quality perception

The typology of landscape-design techniques that was formed in Section 4.2.2 (Table 10 and Table 11) is used in this Section to evaluate the effect of landscape design to public perceptions of dams' landscapes. This evaluation is carried out using two separate methods: (a) the investigation of the impact of the use of designs from the typologies of Table 10 and Table 11 on the numbers of photograph uploads near dams in geotagged photography databases and (b) the investigation of literature on dams, looking for positive references to dams in which the techniques that are presented in the typologies of Table 10 and Table 11 have been used; positive references had to be relevant to improvement of landscape qualities or landscape-value perception.

4.2.3.1 Landscape-quality perception analysis using geotagged photography databases

The level of public activity in geotagged photography web applications or social media platforms has already been used in investigations of place attachment, landscape qualities or landscape value perception (Komossa et al., 2020; Oteros-Rozas et al., 2018; Pettorelli et al., 2016; Zhang and Zhou, 2018). Thus, online geotagged photography data bases were examined in the effort to identify potential correlations between the implementation of landscape design in dams and increased landscape-value perception. The analysis of this Section was limited to dams of Greece for two reasons: Firstly, because the personal experience of the authors in the dams of this country allowed for the qualitative oversight of the results. Secondly, because the required research procedures (count of photographs uploads, examination of photographs, etc.) were carried out manually therefore limiting the potential for a global analysis due to the significant work-load required.

The initial step of the analysis was the selection of a group of dams and the identification of any architectural and landscape design features (such as those presented in the typologies of Table 10 and Table 11) on them. For this, we used the data set of the 27 large-dams of Greece with height over 50 m, as listed in the inventory of large dams of the Greek Committee on Large dams (Greek Committee on Large Dams [GCOLD] and TEE Larissa, 2012). Out of the 27 examined dams, three dams included any of the features of the typologies of Table 10 and Table 11: Marathon dam (Figure 16), Tavropos (also referred to as Plastiras) dam and Pinios dam (both in Figure 28). In the Marathon dam, a broad set of landscape-design interventions has been carried out in order to integrate the dam with its natural and cultural environment; the design includes downstream slope and crest facing with marble, careful architectural treatment of appurtenant structures and a public park in the abutments of the dam. The Pinios dam is the only Greek dam with a freely planted downstream slope including grass, shrubs and trees, overall managing to resemble a natural hillside. In the Tavropos (Plastiras) dam, landscape design features include the methodical architectural design of the appurtenant structures of the dam, three viewing balconies in the middle and the edges of the dam, an open market and furthermore the dam also presents architectural value in itself due to the distinctiveness of its form, being the only arch dam in Greece

The second step of the analysis was the examination of the density of uploaded images in geotagged photography data bases in the proximity of all examined dams, followed by the comparison of the number of uploads between dams with and without architectural and landscape design interventions. All uploaded photographs in Panoramio and Google Earth platforms within a buffer zone of approximately 50 m surrounding all of the dams were examined. Out of those photographs, we counted those that met either of the following two criteria: (a) captured the dam or its appurtenant structures or (b) captured the reservoir of the dam; The reservoir was also included in the analysis since the reservoir is also a derivative of the dam and its landscape significance has been highlighted in literature (Ioannidis and Koutsoyiannis, 2020), as is the presence of water in landscapes in general (Yamashita, 2002). The resultant photograph counts for the 27 examined dams are presented in Figure 27.

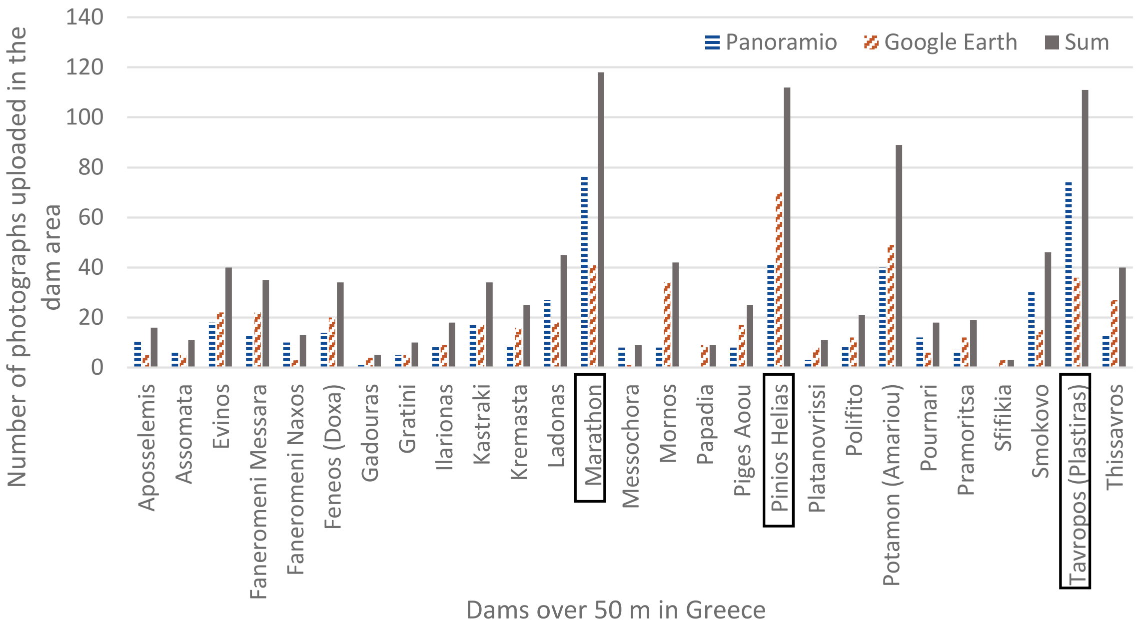


Figure 27. Count of photograph uploads in Panoramio and Google Earth geotagged-photography databases in the proximity of Greek dams with height over 50 m. The names of the dams that include landscape-design features are presented inside rectangles with black outline. Data from Panoramio were collected in March of 2016 and data from Google Earth in November of 2019.

The results demonstrate that the three Greek dams with the largest number of uploaded photographs are the Marathon, Tavropos (Plastiras) and Pinios dams, followed closely by Potamon (Amariou) dam. Interestingly, the top three dams in terms of photograph-upload count are actually those that include features of landscape and architectural design, such as those listed in Table 10 and Table 11. The fourth dam in the photograph count, the Potamon (Amariou) dam, does not include any notable features of landscape design (other than a plateau for parking and viewing the reservoir in the left abutment of the dam) but also presents a high number of photograph uploads in its vicinity. It is possible that the large number of uploads is associated with the influx of tourists in the region of Crete, which is where the dam if built. Nevertheless, it should be noted that it seems that high numbers of photograph uploads cannot be solely attributed to landscape design. Other parameters such us ease of access to the dam, proximity to highly populated cities, tourist load of the broader dam's area, etc. could also contribute to the larger number of photograph uploads. With that said, the strong correlation between the presence of architectural design features and the high density of photograph uploads indicates that landscape-design features probably contribute to the higher number of uploads, to some extent. Indicatively, the average photograph count in dams including architectural design features is 113.7 photographs/dam in comparison to 25.8 photographs/dam for the remaining dams.

Figure 28. Photographs of Pinios (left) and Plastiras/Tavropos dam (right)16.

4.2.3.2 Analysis of literature on landscape qualities

Dams and their reservoirs have in various instances been cited in positive regard in terms of their capacity to improve landscape quality perception. This has been observed both in academic (Ananiadou-Tzimopoulou and Nana, 2015; Berrocal Menárguez and Holgado, 2014; Callis, 2015; Frolova, 2010; Frolova et al., 2015a; Ioannidis and Koutsoyiannis, 2017a; Kreuzer, 2011) and in institutional literature (Douet, 2018; Fleetwood, 2010; Norges vassdrags- og energidirektorat., 2013; Pérez et al., 2013). Attributes of dams that are cited in this regard are usually cultural, natural or purely aesthetic.

In the academic literature, the architectural and landscape design of dams have been associated with the creation of scenic landscapes (Frolova et al., 2015a), enhancing built heritage (Callis, 2015) and creating tourist attractions (Ananiadou-Tzimopoulou and Nana, 2015). Even though dams of standardized technical design, i.e. without additional landscape-design features, have also been referenced for their positive landscape contribution, either due to their form (e.g. arch or buttress dams as described in Section 4.2.2.2) or due to the aesthetics of the natural scenery surrounding them (Sargentis et al., 2021b, 2005), positive contribution to landscapes is more commonly highlighted in cases where architectural and landscape design features are present (Ioannidis and Koutsoyiannis, 2017a). In Table 12, we compiled a list of dams that have been referenced positively regarding landscape qualities, built heritage or tourism and presented them alongside the

[16] Sources: https://lh5.googleusercontent.com/p/AF1QipNTM286rj_ceC2VKN0NpGU96Bmv3mOJSKSpolu=h1440 and https://lh5.googleusercontent.com/p/AF1QipPyOqUAmI4H_EAEgRPsdeZd6Wjc9jyRhOk3jPy3=w1440-h1440-pd

corresponding landscape design features from Table 10 and Table 11 that were found in each case.

Likewise, in institutional publications, references to positive landscape-changes induced by dams are commonly associated with the presence of features of architectural and landscape design. Institutions that have published relevant reports and studies include governmental agencies for the preservation and management of natural and cultural resources such as, e.g., in Norway (Nynäs, 2013), Scotland (Fleetwood, 2010) and Spain (Pérez et al., 2013), as well as international societies for the preservation of cultural heritage (Douet, 2018). The former institutions have examined dams at a national level while the latter have approached the topic from a global perspective. Dams are referenced mostly in relation to their contribution to built-heritage but also for promoting tourism and recreation in their respective areas. Dams that include architectural interventions have in many cases been designated as monuments of cultural heritage (Douet, 2018; Fleetwood, 2010; Norges vassdrags- og energidirektorat., 2013) or as places of Interest for the Community (e.g. the Bolarque dam in García Martín (2012)) and have been included in registers of Historic Places (e.g. the Wachusett dam in the USA, listed in National Park Service - Intermountain Region Museum Services Program (2016)).

Finally, the importance of the architectural and landscape features of dams and reservoirs has also been highlighted in the context of the discussion on the emerging renewable energy landscapes (Frolova et al., 2015c). In a systematic review of literature on the topic of landscape impacts of renewable energy, hydroelectric dams were highlighted for generating, on average, the least landscape impact in comparison with the other two major renewable energy technologies that are utilized globally, i.e. wind turbines and solar panels (Ioannidis and Koutsoyiannis, 2020). Among others, one of the origins of this differentiation is that dams do not have completely predefined forms like wind turbines and solar panels but can be modified and be integrated into local landscapes through architectural and landscape design (Koutsoyiannis and Ioannidis, 2017), thus generating more positively-perceived landscape change (Keilty et al., 2016; Matveev, 1988; Sargentis et al., 2019a; Sherren et al., 2016; Thaulow et al., 2009). We have to note though that all literature referenced in this Section is associated with landscape perception by individuals experiencing the finished projects and does not concern environmental impacts of dams on ecosystems or the displacement of communities; areas in which there have been important criticisms against dams.

Table 12. Dams with architectural and landscape design features and their corresponding positive references in literature, for contribution to landscape qualities, built heritage and tourism.

Type of design	References for positive contribution to landscape qualities, built heritage or tourism
Dam body	
Downstream slope facing	Jandula dam - Spain (Pérez et al., 2013), Vyrnwy dam - UK (Wales) (Douet, 2018; Roberts, 2006), Miharu dam – Japan (Japan Dam Foundation, 2011), Minamiaiki dam – Japan (Ioannidis and Koutsoyiannis, 2017a), Naramata, Minamiaiki and Sagae Dams – Japan (Japan Dam Foundation, 2021)

Planted downstream face	Charco Redondo dam – Spain (Ioannidis and Koutsoyiannis, 2017b), La Breña II dam, Spain (Pérez et al., 2013), Sorpe dam – Germany (Sorpesee LLC, 2021)
Dam crest features	Ringedalsvatn – Norway (Nynäs, 2013), Möhnetalsperre dam – Germany (Economics and Tourism LLC Möhnesee, 2021)
Information boards, decorative elements, lighting and art	Wachusett dam – USA (National Park Service - Intermountain Region Museum Services Program, 2016), Hoover dam – USA (Wilson, 1985)
Dam body form distinctiveness	(Sargentis et al., 2005) (Tavropos (Plastiras) - Greece, (Norges vassdrags- og energidirektorat., 2013) (Navatn - Norway), (Bacon, 2015) (Barberine dam - Switzerland)
Appurtenant structures	
Non-standard landscape design of spillway and outlet works	Bhandardara (Wilson) dam – India (Ioannidis and Koutsoyiannis, 2017a; Laskowski, 2017)
Architectural design of spillways with overflow on dam body	New Croton dam - USA (Laskowski, 2017)
Architectural design of facilities and appurtenant structures	Norris – USA (Bacon, 2015), Dalsfos, Vamma, Solbergfoss dams – Norway (Norges vassdrags- og energidirektorat., 2013), Pitlochry, Bonnington dams –UK (Scotland)) (Fleetwood, 2010)
Peripheral landscape	
Restoration of excavated slopes	Fukashiro dam – Japan (Ioannidis and Koutsoyiannis, 2017a), Osatogawa Dam – Japan (Japan Dam Foundation, 2003)
Public park in dam area	Miramar Reservoir and Poway lake – USA (Koutsoyiannis and Ioannidis, 2017)

4.2.4 Analysis of project-costs for landscape design

In this Section, we investigate landscape design of dams from a project-cost standpoint, through the analysis of three case studies, aiming to gain insights on whether landscape design of infrastructure projects is necessarily associated with high additional costs or if there are cases of low-cost yet efficient landscape design.

4.2.4.1 Case studies: completed projects

Additional project costs for the implementation of landscape design studies in dams are expected to differ depending on type and scale of the proposed interventions. For example, the cost for the downstream face of Marathon dam in Greece, which is coated with high-quality marble, is expected to be significantly higher than the cost for the downstream face of Charco Redondo dam in Spain, which is planted with grass. Given this variability of costs for the implementation of landscape design, we investigated whether landscape design of infrastructure is necessarily associated with high additional project costs or if low-cost designs are also a possibility. In this vein, we initially found and compared the budgets of two cost-wise antithetical cases: La Breña II dam in Spain and Kensico dam in the USA. The two dams share common characteristics in terms of size and dam-type, as they are both gravity-type dams with heights of the same scale, 119 m for La Breña II and 94 m for Kensico dam. However, the costs for the implementation of landscape design differ significantly between the two cases.

In the case of La Breña II dam, the cost for the implementation of the selected landscape design technique on the dam was calculated at €0.67 million, i.e., 0.56% of the total project's cost, analysing the official project-cost data from ACUAES (A. Sandoval, personal communication, 2015) (more details in supplementary material). On the other hand, in the case of Kensico dam, the original dam budget could not be accessed but the budget for a rehabilitation project that largely concerned reconstruction and maintenance of the landscape design works of the dam was found and it amounted to US$31.4 million (NYC Department of Environmental Protection Public Affairs, 2005). Such a high cost for maintenance demonstrates that probably the cost for the initial construction was even higher. The significant difference in project costs between these two cases is attributed to the fact that the landscape design of Kensico dam includes highly detailed masonry, colonnades and paved terraces, all of which have significant construction and maintenance costs. On the other hand, in the La Breña II dam the project costs were kept relatively low as the primary landscape intervention carried out was the planting of the downstream slope of the dam using a low-cost innovative technique.

4.2.4.2 Case study: architectural re-design proposition

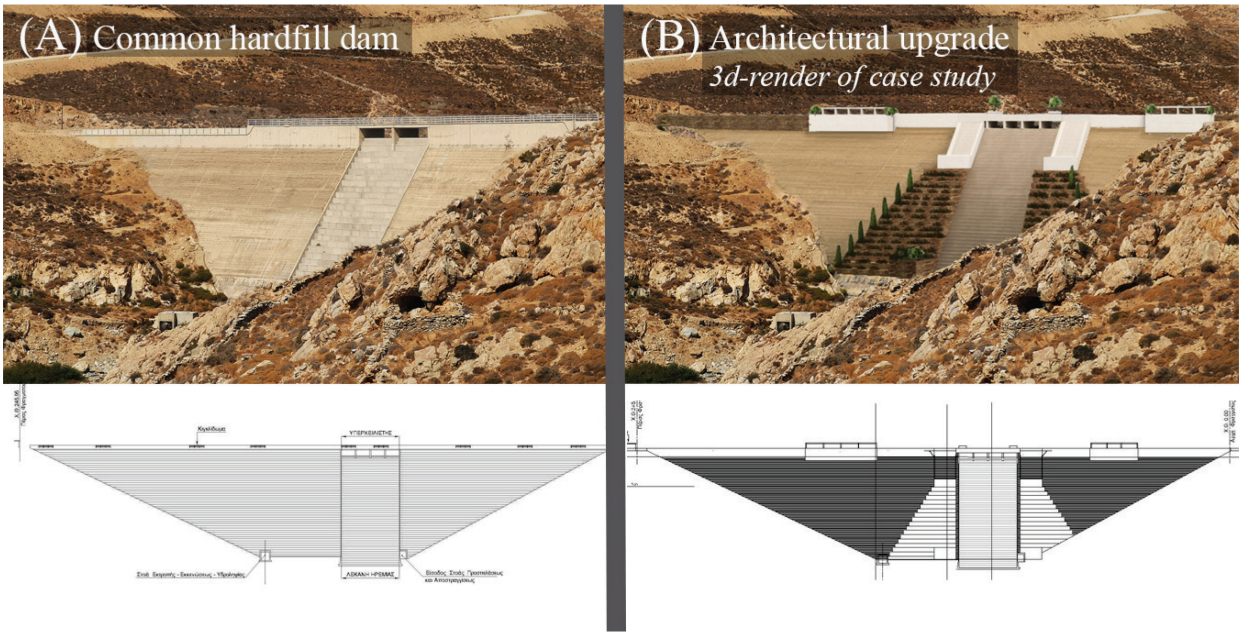


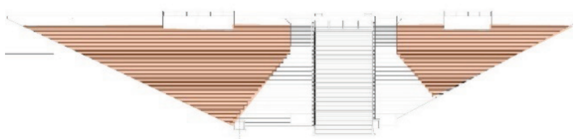
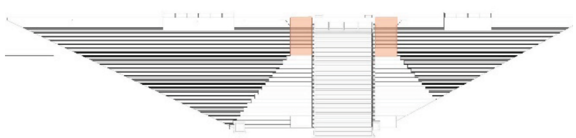
Figure 29. (A) left side: photograph of a hardfill dam (in Steno - Serifos, Greece) and common front view of a hardfill dam. (B) right side (case study): 3d render of the architectural design proposition and front view of the dam after the architectural upgrades.

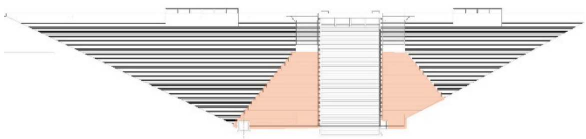
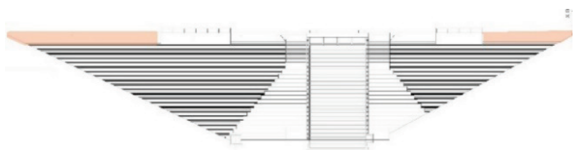
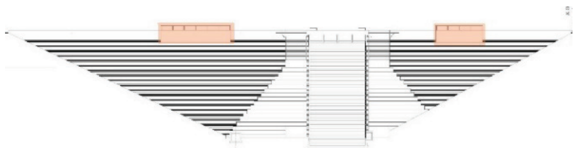
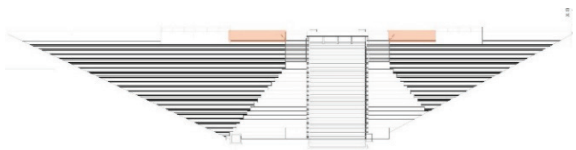
For a deeper insight into the costs for the implementation of landscape design in dams, we formulated a landscape-design upgrade proposition for an existing dam, so that we can analyse the cost of landscape design in dams in more detail. For the generation of the upgraded design, the typology of Table 10 was utilized as reference, taking inspiration from best-practices for potentially low-cost landscape designs. The original budget of the dam was then compared to the new increased budget, which included the additional architectural features, loosely following the research to design process of the "experiential model", as described by Milburn and Brown (2003).

In detail, the case study was carried out through the following steps: (a) The original technical plans of Filiatrinos Dam, in Greece, were collected and analysed. (b) Landscape design upgrades were designed and integrated in the original technical plans, aiming for improved landscape integration of the dam and utilizing the typology of landscape-designs of dams presented in Table 10 as a source of ideas and techniques; a basic overview of the end result of the landscape design upgrade proposition is presented in Figure 29, as designed with 3d-software (Figure 29-(B)), alongside a photo of a typical hardfill dam in Greece (Figure 29-(A)). (c) The budget for the landscape-design upgrade of the dam was calculated, following the official procedure for public-work costing in Greece, including quantity measurement and costing with the use of standard tariffs; the procedure followed was the same with the one used for the calculation of the original budget of Filiatrinos dam. (d) The original budget and the updated budget for the re-design proposition were compared.

The selection of a simplistic design with the utilization of earth material, planting and limited amounts of additional concrete and hardfill material led to relatively small increase to Filiatrinos dam budget, equal to €0.50 million, i.e., 1.41% of the total project's budget. The detailed budget of the updated architectural design is provided on the supplementary material. In Table 13 we also present the individual sub-budgets for the landscape-design upgrade of each dam part along with a summary of the budgeted tasks in each case.

Table 13. Budget and summary of budgeted tasks for the landscape-design upgrade case study (More details on the supplementary material).

Dam zone	Budgeted tasks summary	Budget as percentage of total project budget (%)
Zone 1 - Downstream Slope hardfill moulding		
	Downstream face hardfill moulding	0.10%
Zone 2 - Downstream Slope balconies		
	Precast concrete units, concrete construction, coating and colouring	0.44%
Zone 3 - Downstream Slope planted spaces		

	Gabion assemblage and installation, preparation of green areas, planting, Irrigation system	0.48%
Zone 4 - Crest gabion facade		
	Gabion assemblage and installation	0.07%
Zone 5 - Crest balconies		
	Concrete and hardfill construction, coating and colouring	0.27%
Zone 6 - Crest concrete finish		
	Concrete coating and colouring	0.01%
Additional works (Upstream slope crest, lighting)		
Concrete coating and colouring, lighting fixtures		0.04%
Sum		
1.41%		

4.3 Results - Discussion

The key findings from the analysis of landscape-design practice in dams are the following:

Technical feasibility: The compiled list of 53 dam projects in which landscape design has been applied in various different scales and styles, demonstrated that there are no insurmountable technical issues to the implementation of landscape design in dams (Table 10 and Table 11).

Perceived quality of infrastructures' landscapes: In the online geotagged photography databases of Google Earth and Panoramio, a significantly higher density of uploaded content was observed in the proximity of dams that included features of landscape and architectural design. In particular, in the largest 27 Greek dams (over 50 m in height), the average number of uploaded photographs in the proximity of the dams that included features of landscape design was 113.7 photographs per dam, in contrast to 25.8 photographs per dam in dams that did not include such features. Furthermore, in institutional and academic literature, dams that include architectural and landscape-design features have been praised for their contribution to built cultural heritage, to touristic development and to the creation of scenic landscapes. Thus, it can overall be argued that the implementation of landscape design in dam projects has contributed to improved landscape-value perceptions and landscape qualities in local landscapes.

Cost: Additional project-costs for the large-scale integration of landscape-design features in dams can be kept at the order of 1% of projects' budgets. This is supported both by the case study of La Breña II dam, constructed in Spain in 2009, and also by the calculation of additional project costs for a theoretical complete architectural re-design proposition for Filiatrinos dam, constructed in 2017 in Greece; a case study that was specifically formulated for the purposes of this research.

In regard to the limitations of our research in Section 4, a significant point to be made is that the above-mentioned results originate from the analysis of landscape design practices in dams, in particular, out of all types of major civil infrastructure. It has to be noted though, that many of the results also apply to other major civil infrastructure as well. Indicatively, the typologies of landscape design in dams (Table 10 and Table 11) include various types of landscape-design techniques that are also commonly implemented in many other types of infrastructure as well, such as highways, bridges, water supply infrastructure, etc.; e.g. the restoration of excavated slopes, the architectural design of facilities and appurtenant structures, the integration of public parks in the areas of the projects, the inclusion of information boards, green infrastructure, decorative elements associated with local cultural background and architectural preferences, lighting and art installations and finally treatment of the facades of generated structural slopes. Nevertheless, more targeted research on the technical and cost-associated feasibility of landscape-design in other types of infrastructure would certainly generate valuable insights for the advancement of this field of landscape design.

It also has to be noted that in most cases presented in the landscape-design typology of Table 10 and Table 11 it is not clear whether the compiled designs are the result of targeted landscape and architectural studies or the results of individual initiatives of participating architects or engineers. Unfortunately, literature and publicly available information on the dam projects compiled did not include details on whether architects actually participated in the projects, in most cases. It can be assumed that in most large-scale implementations of architectural interventions architects have indeed participated. However, this is not certain for all cases, especially for less extensive interventions. For example, the participation of architects is confirmed in various projects in Norway, e.g. Bredo Greve in Solbergfoss dam and Thorvald Astrup in Nomeland dam (Norges vassdrags- og energidirektorat., 2013)or in the Möhnetalsperre dam in Germany, designed by Franz Brantzky[17]. However, in the La Breña II dam, for example, it is known that the planted downstream slope was designed by the dam engineers of Dragados S. A. as a

[17] https://www.reisefuehrer-moehnesee.de/sehenswuerdigkeiten/moehnetalsperre/

measure for limiting the visual impact of the dam (A. Sandoval, personal communication, October 14, 2015).

4.4 Inferences for the architectural and landscape design of major civil infrastructure

Beginning from the global observation that landscape design is usually not implemented in major civil infrastructure projects, in this Section we investigated whether this shortcoming is justified by practical or utility-related limitations or if the role of landscape-design in infrastructure projects should be reinforced. Landscape-design practice in dam projects was selected as the focus of the investigation, due to the fact that landscape-design interventions in dams present a wide spectrum of approaches, ranging from minor beatification efforts or full architectural studies to complete lack thereof. Hence, through the analysis of the various implementations of landscape design in dams the utility as well as the technical and economic feasibility of landscape design could be evaluated, using data from real projects and forming revealing comparisons.

The results demonstrated that landscape design of infrastructure projects is beneficial for landscape quality perception, cultural heritage and touristic development and that, with proper design, these benefits can even be achieved with low costs and without remarkable technical challenge. Thus, the primary policy implication of the study is that the role of landscape design in major civil infrastructure projects should be bolstered and could be supported more by policy and design guidelines or guidances. In this regard, the utilization of knowledge from global best-practice as reference and inspiration for new designs can facilitate the minimization of the technical and economic requirements for the wider integration of landscape design into infrastructure projects.

On a final note, it should be acknowledged that the results of this Section are more relevant to countries with developed economies that can allocate more resources to the sustainable design of projects and that are already ahead in terms of landscape design and landscape planning policy. However, this is not to say that countries with developing economies have no capacity to integrate of landscape design in infrastructure projects, as several of the cases of dams that were presented in this study attest to the opposite.

5 CONCLUSIONS

5.1 Landscape impacts of infrastructure – Do they differ between different types of works and how?

The first level of the analysis, was targeted on the investigation of whether generic levels of landscape -impact severity can be attributed to different types of major infrastructure. This analysis was carried out in Section 2 and in a generic-global scale, investigating data and literature from on landscape impacts of RE works from global sources.

The aim of the analysis was to improve our understanding of landscape impacts of infrastructure, quantify and compare those impacts and eventually build the empirical and theoretical background that would lead to the formation of improved measures for the mitigation of landscape impacts in Sections 3 and 4. Other than its utility as the foundation for the next levels of the research, the analysis of Section 2 was also considered important due to the fact that landscape impacts are often subject to dispute, due to being considered unquantifiable and thus subjective by stakeholders in infrastructure development. The identification of the distinct characteristics of those impacts was hence seen as a way to overcome this uncertainty and to proceed to planning and design improvements to how infrastructure is integrated into landscapes.

Three specific metrics were identified as illustrative and descriptive of landscape impacts of infrastructure: (a) land use, (b) visibility and (c) public perception. Through the investigation of these metrics both the quantitative-spatial and the qualitative-perceptual aspects of landscape impacts of infrastructure works could be addressed. Additionally, the metrics were also already established in relevant literature regarding wind, solar and hydroelectric energy works. Therefore, additional emphasis was given on utilizing the largest possible global data sets from realized projects but also on maintaining an independence from potential biases of data due to terrain differences between origin countries as well as from design-quality standards differentiations.

The results of the investigation, are presented in detail in Section 2 (or in this Section, condensed in the graphical abstract of Figure 30) and the primary conclusions are the following:

- Wind energy works were identified as the most impactful to landscapes, on average, both spatially and perceptually, followed by solar and hydroelectric energy works, respectively.
- The quantitative (spatial) aspect of landscape impact was found to be directly correlated to the qualitative (perceptual) one. In other words, infrastructure works that introduce negatively perceived elements into larger landscape areas and produce the most extensive visual impacts are also the ones that are perceived most negatively by the public. In the examination of landscape impacts of RE works this was demonstrated by the fact that the types of infrastructure that cause the most extensive impacts from a spatial perspective are also the ones that are perceived more negatively.
- The above-mentioned conclusions offer enlightening insights for the scientific debate over the emotionality or rationality of landscape-impact induced opposition and its relation with the NIMBY phenomenon. In particular, the results demonstrate that public perception is more negative for types of infrastructure works that are actually linked to

increased landscape impacts, through the examined metrics. In that logic, it is reasonable to argue that uncritical attribution of landscape-impact opposition to underlying NIMBY predispositions should be avoided. Instead, research should be focused on the investigation, assessment and eventually, on the mitigation of landscape impacts from the various types of infrastructure.

- Two characteristics of infrastructure works were identified as crucial for the type of public perception that their transformations to landscapes receive:
  1) Perception of industrialization is the major determinant for negative perception of infrastructure in terms of its landscape impacts. This perception is particularly incited by types of infrastructure whose form is completely predefined by industrial-technical specifications. In the case of large-scale renewable energy works, these problems are met with wind and solar energy projects, since wind turbines and solar panels have fixed forms and shapes that cannot be modified to fit into local landscapes, architectural traditions and preferences etc. Similar critique has been observed for other types of infrastructure works, with similar characteristics, such as overhead electric power transmission lines or for stacks and cooling towers of fossil fuel power generation complexes. We named these types of major infrastructure "non-architecture-friendly" infrastructure.
  2) Infrastructure works that are capable of receiving architectural treatment enjoy more positive perception, particularly so if architectural and landscape design designs studies are implemented. In our investigation this observation was initially made for hydroelectric dams, for which positive perceptions over their landscape transformations were found to be predominant. Other infrastructure works such as bridges, ports and airports also enjoy the same benefits, as they are also receptive of architectural treatment, to varying extents. We named these types of major infrastructure "architecture-friendly" infrastructure.

Overall, we conclude that landscape impacts are indeed different among different types of infrastructure and should be dealt with according to the extents of their spatial impacts and the public perception over those impacts. Effective policy for the mitigation of landscape impacts of infrastructure should combine both measures for the mitigation of the negative visual impacts of the so called "non-architecture-friendly" infrastructure and measures for the exploitation of the positive aspects of the so called "architecture-friendly infrastructure". So far, policy has mainly focused on the former, primarily in the form of project-oriented visual impact analyses, which are analysed and expanded in Section 3. A more holistic approach should include both approaches, thus dealing with landscape impact of infrastructure as cumulative problem and utilizing all available means to reduce it from all possible directions. A more comprehensive framework of designing and planning infrastructure for landscape integration can reduce their impacts and consequently the public opposition incited by them; overall, contributing to increasing the sustainability of infrastructure and the facilitation its development.

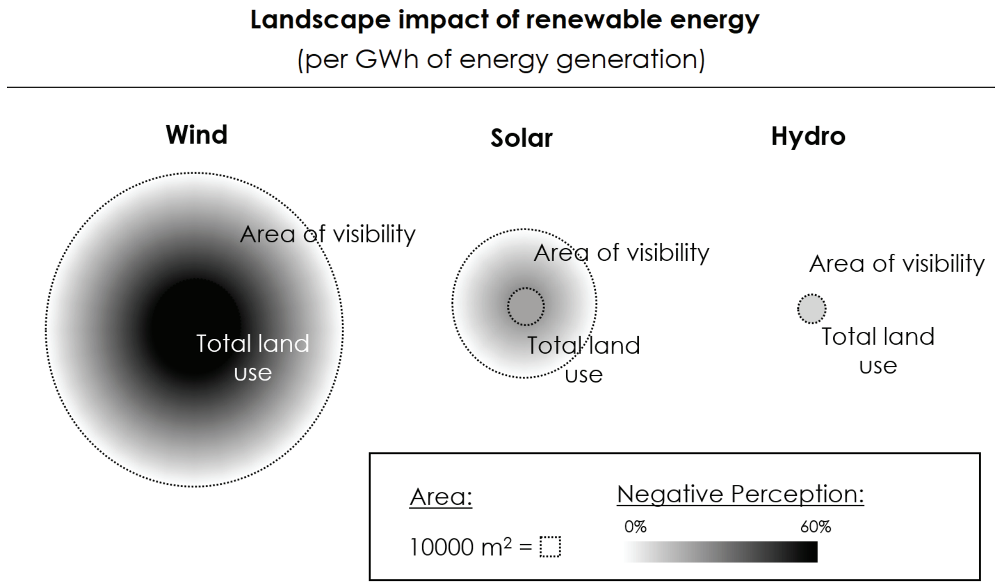


Figure 30. Graphical abstract of the results of Section 2.

5.2 Upgrading spatial planning for the mitigation of landscape impacts by reversing visibility analyses

Visibility analysis has been established as the primary method for the anticipation and assessment of landscape impacts of infrastructure. Its importance has increased along with the increase of the spatial requirements of infrastructure during the last two decades, primarily due to the expansion of wind and solar energy works. These works affect larger areas of land than other civil infrastructure, can alter the visual scenery of countries in double digit percentages and are often perceived as elements of landscape industrialization. The mitigation of the landscape impacts of such types of infrastructure, can only be approached by targeted planning and siting so that their visibility from within areas of high landscape value is reduced. Architectural or landscape treatment is not a potentiality for utility scale developments of wind turbines or solar panels, since their shape and form cannot be modified and such works were included in the category "non-architecture-friendly" infrastructure, along with overhead power transmission lines and other similar works.

Visibility analysis has therefore already been used extensively to assess landscape impacts of RE projects. However, conventional visibility analyses have been restricted by important limitations as a planning tool. In particular, the predominant viewshed-type visibility analyses cannot be implemented in the early strategic planning of infrastructure, as they require the finalized locations of projects as input. Thus, landscape impacts of proposed projects can only be assessed after the locations of the examined projects have largely been partially or fully finalized, therefore usually, after the licensing of projects in underway. This has hindered the timely projection of landscape impacts, as evidenced especially in the case of wind energy development, and has impeded their mitigation, arguably contributing to the contemporary issues of significant public opposition that is largely prompted by landscape impacts. It is thus overall argued that even though visibility analysis has so far been implemented *a posteriori* and in a project-site spatial scale it would be more useful as a planning tool if it was implemented *a priori* and at the regional or national scale, which however is impossible in its conventional format.

In this research, in Section 3, the implementation of a methodological shift in visibility analyses is proposed as a solution to the above-mentioned shortcomings. Specifically, we propose shifting the focus of visibility analysis from the infrastructures that cause visual impacts to the landscape elements that should be protected from such impacts. With this modification, reverse visibility analyses can be implemented precautionary from the perspective of important landscape elements and therefore can be already ready for use in early stages of investigation of the siting of projects, much before their design studies and before the steps of licensing and EIA.

Reverse visibility analyses, in the format of R-ZTVs (Reverse Zones of Theoretical Visibility) or in similar configurations, benefit from the following advantages, as demonstrated through the theoretical and practical investigations of Section 3 (also summarized in Figure 31):

1) The reversal of visibility analyses enables their use into the early planning stages of infrastructure, which has been impractical so far. Since important landscape features (historical-archaeological sites, cultural monuments, touristic areas, etc.) are in fixed and known locations, visibility analysis can be instead carried out from their perspective in the form of reverse viewshed, using their locations as input. The combination of the computed reverse viewsheds in R-ZTV-type maps formulates a novel type of map that projects potential visual impacts to the examined landscape elements. This map can be used as early as in the conception phase or can be integrated into multi-criteria strategic planning studies, along with other technical, economic and environmental criteria, thus allowing for the early anticipation of potential landscape impacts.
2) After a single calculation, R-ZTV maps of protected landscape elements can then be used for the assessment of landscape impacts of any potential project in their proximity. Hence, in terms of policy implications, R-ZTV maps can potentially render the requirement for individual visibility analyses for each new project obsolete, thus accelerating the relevant stages of EIA. Since protected landscape sites are static, the reverse viewshed computation of every site is only required once, and would not need to be re-calculated for each new project, as is the case with common visibility analyses. A new implementation will only be required if basic geometrical features of examined projects, such as wind turbine or solar photovoltaic panel heights, are modified significantly.
3) The proposed R-ZTV analysis, can have a more synergetic relation with participatory planning, design and decision-making processes. These processes have been identified as pivotal for the mitigation of landscape impacts of infrastructure and of the associated public opposition. In particular, R-ZTV maps can be co-produced with local communities and landscape protection institutions, by allowing their involvement in the selection of the landscape features to be included in the R-ZTV analysis. Thus, from the perspective of these communities, R-ZTV maps can facilitate their direct involvement in planning processes and also ease the communication and public discourse over projected landscape impacts.
4) Finally, R-ZTV maps can be used independently by stakeholders in infrastructure development from the early planning phases of projects, when siting is still under

consideration, allowing for better-informed siting decisions. From the perspective of investors of RE or example, R-ZTV maps can be used for the selection of project locations with low anticipated landscape impacts, from preliminary stages of development such as early planning or conception, in order to reduce investment risks.

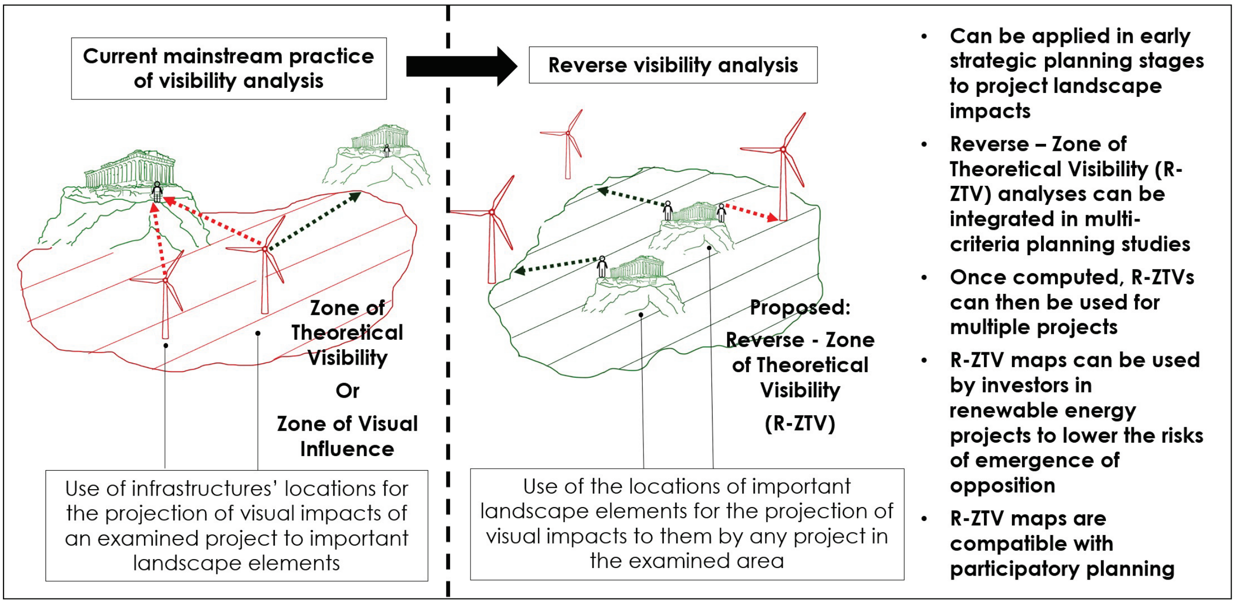


Figure 31. Graphical abstract of the concept of reverse visibility analysis and its benefits

5.3 The role and potential of architectural and landscape design in major infrastructure

In Sections 2.4.2 and 4.2.3, architectural adaptability potential was identified as a significant parameter that can facilitate the positive public perception of landscape transformations by infrastructure works that enjoy it. Therefore, we grouped infrastructure works that can be treated through architectural and landscape studies: e.g., dams, bridges, water and wastewater treatment plants, airports etc. under the term "architecture-friendly" infrastructure. This term is used to differentiate between these types of infrastructure with the "non-architecture-friendly" infrastructure, such as wind and solar energy works and overhead power transmission lines.

Nevertheless, albeit being recognized for its importance, architectural design is usually not implemented in major civil infrastructure projects, or it is limited to landscape works in the periphery of infrastructure without intervening in its surface and functionalities. In Section 4, we investigated whether this lack of implementation of architectural and landscape design is justified by its technical or cost-related limitations or if the role of landscape-design in infrastructure projects should be reinforced. Landscape-design practice in dam projects was selected as the focus of this analysis, due to the fact that landscape-design interventions in dams present a wide spectrum of approaches, ranging from minor beatification efforts to full architectural studies or complete lack thereof. Thus, through the analysis of the various different implementations of landscape design in dams the technical and economic feasibility of landscape design could be evaluated, using data from real projects and forming revealing comparisons. Furthermore, the sporadic application of architectural studies in dams also allowed us to investigate the effect of architectural design to the public perception of infrastructure. We did this by comparing public perception in dams that have been treated architecturally to those that have not been, through the analysis of literature and photograph uploads in geotagged photography data bases.

The results demonstrated that landscape design of infrastructure works is beneficial for landscape quality perception, cultural heritage and touristic development and that, with proper design, these benefits can even be achieved with low costs and without remarkable technical challenge. Thus, the primary policy implication of this investigation is that the role of landscape design in major civil infrastructure projects should be bolstered and could be supported more, through targeted policy and design guidelines or guidances. In this regard, the utilization of knowledge from global best-practice as reference and inspiration for new designs can facilitate the minimization of the technical and economic requirements for the wider integration of landscape design into infrastructure projects.

On a final note, it should be acknowledged that the results of this part of the research are more relevant to countries with developed economies that can allocate more resources to the sustainable design of projects and that have already developed landscape design and landscape planning policy. However, this is not to say that countries with developing economies have no capacity to integrate landscape design in infrastructure projects, as several of the cases of dams that were presented in this thesis attest to the opposite.

5.4 Strategic inferences for policy of landscape integration for major civil infrastructure - synthesis of the conclusions

Through the synthesis of the conclusions, we propose a set of inferences for policy regarding the mitigation of landscape impacts of infrastructure. These inferences are grouped into a generic strategy for assessing, planning and designing major infrastructure with the aim of landscape integration. The strategy consists of three successive levels, in decreasing spatial scales. Particular emphasis is given on the first level that largely defines the proposed actions in the following ones. In more detail the strategy proposes the following levels of analysis for any examined type of major infrastructure:

(Level A) Generic theoretical investigation in global scale:

Investigation of the generic landscape impacts of the examined type of infrastructure work utilizing academic literature and realized data from global sources. Assessment of the generic severity of landscape impacts of the examined type of infrastructure both quantitatively-spatially and qualitatively-perceptually.

In more detail, based on the investigation of Section 2, the following two questions should be answered:

(i) Are the landscape impacts of this type of infrastructure generally identified as intrusive in literature in terms of land use, visibility and public perception? How do their impacts in this regard compare with other types of infrastructure with similar purpose?

(ii) Is the examined type of infrastructure capable of receiving architectural treatment or is its form rigidly defined by industrial or technical specifications? According to the answer to this question the examined type of infrastructure can be labelled as architecture-friendly or non-architecture friendly.

(Level B1) National and regional level spatial planning:

If from the answer of question (i) it is concluded that the examined infrastructure type is perceived as highly impactful and also has high demands in terms of land use and/or generates extensive visual impacts then particular emphasis should be placed in its spatial planning, no matter what the answer to question (ii) is. For types of infrastructure works that are identified as highly impactful to landscapes both perceptually and spatially the mitigation of their visual impacts to important landscape elements or areas should be prioritized.

In this regard, the implementation of reverse visibility analyses and their use in their national-regional scale spatial planning is seen as an upgrade to current practices of conventional visibility analyses, which are carried out in the project-site scale. Reverse visibility analyses, such as the R-ZTV methodology developed in Section 3, can be utilized to facilitate the *a priori* and accelerated anticipation of visual impacts. Potential project locations with high anticipated impacts can be dismissed earlier that with conventional visibility analyses and thus potential conflicts and project delays can be averted. The R-ZTV methodology is also compatible with participatory planning processes, which have been recognized as essential in efforts to mitigate landscape impacts and increase the public acceptance of projects.

(Level B2) Architectural and landscape design in the project site scale:

If the answer to question (ii) is affirmative, this means that the implementation of architectural studies is possible in the examined type of infrastructure.

For these types of infrastructure works, the implementation of architectural and landscape design studies is proposed. From the investigation of Section 4, it was demonstrated that the implementation of architectural and landscape studies can be carried out while only demanding an increase in the order of 1% of the projects' budgets and without posing any significant technical challenges. Furthermore, it was demonstrated that architectural and landscape studies can have measurable positive impacts to the public perception of the works they are implemented in.

In more detail, two different options can be identified for the implementation of architectural studies in infrastructure works that belongs in the "architecture-friendly" group, in the context of policy: (B2i) the imposition for a universal requirement for the implementation of architectural and landscape design studies (B2ii) the identification of particular cases or projects in which the application of architectural studies should be required, depending on the anticipated severity of their landscape impacts and on the perceived quality of the landscape in which they will be built. Reverse visibility analyses could be used to this regard, in order to identify which proposed projects are projected to cause visual impacts to areas of high landscape significance and therefore enforce the implementation of architectural studies in such projects only.

The decision over the preference of universal or selective architectural treatment will probably also depend on the economic-developmental status of the country/region that implements such a policy as well as on the public perception regarding the landscape impacts of the examined type of infrastructure that was assessed in question (i).

The strategic inferences of this Subsection of the Conclusions, primarily refer to those responsible for the development of legislation, licencing procedures and guidances for the planning and design of infrastructure in the national or regional level. In addition however, they can also be useful to stakeholders in the protection of landscapes and the mitigation of landscape impacts of infrastructure and practitioners in the fields of landscape planning, spatial planning and renewable energy planning and stakeholders in the development of infrastructure projects.

5.5 Directions for future research

In regard to future research, we mostly focus on the direction of the further improvement of the planning and design methodologies that we proposed for the improvement of the integration of infrastructure into landscapes. Initially, further steps for the evaluation and utilization of reverse visibility analysis for the planning of infrastructure would include: (i) its implementation across even larger spatial scales, e.g., in the scale of a whole country and (ii) the incorporation of R-ZTV-type maps in large-spatial multi-criteria studies for the investigation of the locations of projects, along with the other common criteria that are used in such analyses. Another, interesting area for relevant future research would be the investigation of how R-ZTV-type maps can be introduced in policy and in licencing procedures of infrastructure. This could be potentially combined with the formations of concepts and schemes for the participatory formation of those maps, by the inclusion of bodies and organizations involved in the management and protection of landscapes in the selection of landscape sites to be protected. Furthermore, qualitative analysis of the efficacy of reverse visibility analysis in assessing potential landscape impacts, e.g., by means of photomontage and questionaries for visitors of important landscape sites, would also be useful. Finally, further research should also be carried out in the direction of architectural and landscape design of major infrastructure projects. Following the identification of architectural treatment potentiality as an important attribute of some infrastructure projects and the eventual split of infrastructure between the classification of "non-architecture-friendly" or "architecture-friendly" infrastructure, we believe that further research is required in regard to the latter. In particular, we propose that studies following the format of our investigation on the utility, costs and technical requirements of the architectural design of dams should be expanded to other "architecture-friendly" infrastructure works. For example, to bridges, water and wastewater treatment plants, water supply works, airports, etc. Additionally, the formation of best-practices guidelines for the architectural treatment of infrastructure works would also be very useful and could contribute to reducing the cost, technical and maintenance requirements of such applications in the future.

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6 FIGURE AND TABLE LISTS

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8 APPENDICES AND SUPPLEMENTARY MATERIAL

Summary of content:

Appendix A: Additional considerations over the data screening and the selection of metrics and technologies that were analysed in Section 2.2.2.2 on hydroelectric energy land use.

Appendix B: On-depth analysis of older estimates of hydroelectric land use, following the identification of some relevant data infelicities.

Appendix C: Detailed methodology and results of the perception analysis of Section 2.2.4.

Appendix D: Link to the excel tables of the perception analysis of Section 2.2.4.

Appendix E: Table of La Brena II dam landscape detailed design costs.

Appendix F: Table of the detailed costs for the case study of the Greek dam in Section 4.2.4.2.

Appendix G: Summary of the thesis in Greek language.

Appendix H: Complete list of publications of R. Ioannidis associated with this thesis.

Appendix A – Details over data screening and selection of metrics and technologies

Other metrics and technologies

Other quantifiable aspects of landscape impact from RE that are acknowledged but were not reviewed are listed below, along with a brief description on why they were not included:

a) Full life-cycle landscape impact: For a comprehensive understanding of the overall impact of RE on landscapes a full life-cycle impact analysis is necessary (Fthenakis and Kim, 2009; Voorspools et al., 2000). However, the analysis of impacts from facilities and processes of manufacturing and decommissioning RE machinery and infrastructure components is a complex task that requires specialized research, and unfortunately relevant studies are scarce (Fthenakis and Kim, 2009; Lagaros et al., 2015). Additionally, it exceeds the boundaries of national and regional planning and sitting practices, which are in focus in this analysis, since life-cycle impacts do not concern a single region or country but are spread across several countries (Smoucha et al., 2016). For example, the materials required for manufacturing wind turbines include steel, carbon fibre, cast iron, fiberglass and aluminium (Martínez et al., 2009; Psomopoulos et al., 2019), most of which are imported to the countries that manufacture RE technology.

b) Duration of impact: Duration of impact (Koellner and Scholz, 2008; Pasqualetti and Stremke, 2018) was not examined in this analysis. Since renewable energy is designed to be a permanent replacement for fossil fuel, RE developments are expected to provide continuously to the new fossil fuel- free energy world until new technologies can replace them. The type and extents of landscape impacts remaining after a large scale decommission would differ for each technology (Psomopoulos et al., 2019), but were overall considered a distant problem.

c) Short-term construction related landscape impact: Short-term construction related landscape impact was not examined. Emphasis was put on large scale and long-term impacts and therefore impacts during the life span of the project were prioritized.

In regard to RE technologies that were not included in the analysis, the most developed were small hydroelectric dams, amounting to approximately 11% of the total installed capacity of hydropower globally (148 GW in 2016) (Couto and Olden, 2018), and offshore wind energy, with 18,8 GW of installed capacity globally (Global Wind Energy Council [GWEC], 2017). In comparison, the global installed capacity of solar energy, which is the least utilized out of the three technologies that were examined, was 222 GW (World Energy Council [WEC], 2016c). It is pointed out that both small hydroelectric dams (Kelly-Richards et al., 2017) and offshore wind turbines have distinct characteristics and should be analysed independently regarding their landscape impact.

Primary study screening

Study screening was more complex in the review of land use and visibility, which are quantitative (spatial) metrics, due to the fact that their estimates are greatly dependent on parameters such as terrain, energy efficiency, scale of data sets used etc. These additional parameters were thus addressed through the secondary study screening. In the review of public perception, on the other hand, which is an exclusively qualitative (perceptual) metric, the collection of studies from academic databases was adequate for the statistical analysis of literature and further screening was not required.

Secondary study screening

This Section is dedicated to additional clarifications over the secondary screening methods for the literature review on land-use and visibility:

Scale of data sets: The scale of datasets used in the estimates that were distinguished for generic applicability, depended on data quality and availability. Limiting factors to the exclusive use of global data were their scarcity and the difficulty in maintaining an overview of their reliability, which was at times questionable for estimates based on the largest available datasets (as described in Appendix B for hydroelectric land use). As a result, for example, in the review of land-use studies based on national datasets were finally utilized (Denholm et al., 2009; Ong et al., 2013; Trainor et al., 2016) and in the review of visibility studies based on regional data were also included (Degórski et al., 2012; Díaz Cuevas et al., 2016; Möller, 2010; Tsilimigkas et al., 2018), since national-scale visibility analyses (Rodrigues et al., 2010; Scottish Natural Heritage [SNH], 2014; Statistics Netherlands [CBS] et al., 2014) were scarce and global scale visibility analyses were not found.

Terrain: As an example of the utilization of the ruggedness index of Nunn and Puga in our study we present the examples of Switzerland (CHE), which is an exceptionally mountainous country and has a ruggedness index of 4.76, and Brazil (BRA), which is an exceptionally flat country with a ruggedness index of 0.24. Based on their ruggedness index, countries with similar characteristics were excluded from the generic estimation of average hydroelectric reservoir size (Dones and Gantner, 1996; Fearnside, 1995; Gagnon and van de Vate, 1997), as their results were not considered of generic value.

Energy generation efficiency: Since data where not always available in the desired format, conversions of installed capacity to expected average energy generation were made, using the capacity factors (CF) of the technologies examined (Table 11). The cases in which such conversions were carried out are reported in the text.

Realized data vs. theoretical estimates: Even though theoretical estimates were also useful, especially when data from built projects had not been collected (as was the case with visibility analyses for solar energy (Rodrigues et al., 2010)), they have also been found to differ from reality, in some instances. Such a case, for example, is the discrepancy of theoretical from realized CF of wind energy, described by Boccard (2009), which was one of the examples that acted as alerts for prioritizing realized data over theoretical estimates, when possible.

Appendix B – Analysis of older estimates of hydroelectric land use

In this Appendix, further details on the older studies with estimates of hydroelectric land use are provided, with emphasis on the characteristics that hindered their generic applicability.

Gagnon and van de Vate (Gagnon and van de Vate, 1997) thoroughly researched the subject of hydroelectric land use in the context of estimating the greenhouse gas emissions produced by reservoirs. The data analysed by Gagnon and van de Vate are extensive, and produce a weighted average of 91 448 m^2/GWh. However, the national-scale studies they cite, which analyse data from China (Ziqiang et al., 1996), Switzerland (Dones and Gantner, 1996) and Finland (Väisänen et al., 1996) could not be found and accessed for a more in depth-analysis of the datasets used. The study of Dones and Gantner, even though it is apparently based on a large percentage of Switzerland's installed capacity, would be unsuitable for the discussion on generic hydroelectric land use, since Switzerland has exceptionally mountainous topography. Similarly, the study of Väisänen et al. would again be unsuitable, this time due to flat topography, since Finland is slightly outside the ruggedness limits set for this analysis in Figure 2. On the other hand, the study of Ziqiang et al. would be useful if more information on data sets used could be found, since it is referenced that it includes data from a significant percentage of the installed capacity of China, at the time (1996) and China has a ruggedness index close to the global average.

Ledec et al. (Ledec and Quintero, 2003) conclude on 600 000 m^2/MW as a global average land use of large hydroelectric dams, based on personal communication with J. Goldemberg. Other than this personal communication, the report includes data from 49 hydroelectric reservoirs whose weighted average, in terms of installed capacity, is 546 958 m^2/MW, that is, in line with their global estimate. However, based on their selection of data the estimate of Ledec et al. should be more accurately described as an estimate of land use of reservoirs with extreme environmental and social impacts from developing countries, rather than an estimate of global average hydroelectric land use. Even though the projects included in the analysis originate from various countries globally, it is noticed that 47 out of the 49 projects were from developing countries and least-developed countries, according to the United Nations categorization (United Nations Department for Economic and Social Affairs, 2019). No further justification is provided on why these particular projects can be used to reach conclusions on a global average. Secondly, even though most data refer to hydroelectric projects with installed capacities over 100 MW, the only projects included whose capacities are smaller than 150 MW have some of the largest ratios of inundated land to installed capacity found in literature. In particular, these are five small projects from countries with developing economies with installed capacities of 34, 30, 30, 29 and 16 MW. These projects average 16 527 300 m^2/MW or 53 568 400 m^2/GWh for reservoir land-use, which is even larger than the most pessimistic estimates of average hydroelectric land use by two orders of magnitude. Additionally, as stated in the report, it "includes a few multipurpose projects for which hydroelectric power was less important than other objectives", which certainly contributes to overestimating the reservoir area. Furthermore, some of the projects were listed with erroneous installed capacities or have since been upgraded with larger installed capacities, such the Pak Mun and Akosombo dams.

The study of Goodland on the environmental sustainability of hydro projects (Goodland, 1995) has been cited in several occasions, when discussing hydroelectric land use (Gagnon and van de

Vate, 1997; Ledec and Quintero, 2003; Williams and Porter, 2006). Many of the projects presented in this study are common with those of the dataset used by Ledec et al. (Ledec and Quintero, 2003), with the difference that the few small projects with extreme land use that Ledec et al. have included in their data are not included in the study of Goodland. Similar to Ledec et al., land use data originate mainly from developing and least-developed countries (69 out of the 73 projects). Goodland himself however, makes no claim that the data set he compiled in his study is representative of the global average of hydroelectric land use and comments that "corrections or additions... would be most welcome". He also comments on the purposes of the reservoirs presented that the "most are hydropower, rather than irrigation or flood control reservoirs", but evidently not all, incorporating additional bias to the use of his estimations as a generic estimate of hydroelectric land use.

Appendix C – Detailed methodology and results of the perception analysis of Section 2.2.4

The exact algorithmic procedure followed to label publications over their perception on landscape impact of RE technologies comprised of the following steps:

1. The abstract and keywords were read to determine if landscape impact of RE was the main point of focus or one of the main points of focus of the article. If it was not the article was labelled "Irrelevant" and did not proceed to the next steps[18].
2. The introduction, conclusions and discussion of the article were read.
3. If at least one sentence was found, by the authors or by reference to others, in which it was evident that landscape impact was considered a problem of the RE technology examined, the article was marked for having at least one negative reference.
4. If at least one sentence was found, by the authors or by reference to others, in which it was evident that the RE mentioned was considered to have a positive contribution to the landscape the article was marked for having at least one positive reference.
5. If either a positive or negative or both types of references had not already been found, the whole article was then searched for the words: landscape, visual, aesthetic and tourism. Sentences containing any of these words were read to ensure that no relevant parts of the text had been omitted.
6. Based on the sentences found and analysed in this second search the article was marked accordingly, as having at least one positive or negative reference.
7. If only one of the two types of references had not yet been found, the article was searched with some additional keywords to ensure that the other type of reference did not exist in the text.
8. If only a positive reference had been found, the article was searched for the words: negative, problem and impact.
9. If only a negative reference had been found the article was searched for the words: improve, enhance and heritage.
10. According to the sentences found and analysed in this third search the article was marked as having at least one positive or negative reference.
11. If the article was marked for having both one negative and one positive reference after all of the previous steps, then the article was labelled as being of "Mixed" perception.

[18] Articles labelled irrelevant are those that included the keywords searched but in context irrelevant to landscape impact analysis; In addition, articles that did not specifically address landscape impact of renewable energy but just included relevant comments by the authors, without sufficient justification, were classified in this category too.

Otherwise, if the article was marked for having exclusively negative of positive references, it would be labelled accordingly as being of "Negative" or "Positive" perception.

The results of these analyses are presented in Table 14 and the sentences used to label the articles are recorded in the supplementary material.

Table 14. Publications that were analysed in the perception analysis of literature grouped by perception label. Publications labelled as "Irrelevant" are not cited in this table but are referenced in the supplementary material and their percentage is reported alongside the general statistics of the analysis in Figure 6.

Publisher	Type of RE	Positive	Negative	Mixed
ELSEVIER	Hydro	(Keilty et al., 2016) (Sherren et al., 2016)	(Jefferson, 2018)	(Pagnussatt et al., 2018) (Ferrario and Castiglioni, 2017)
	Wind		(Sklenicka and Zouhar, 2018) (Scherhaufer et al., 2017) (Nadaï and Labussière, 2017) (Jefferson, 2018) (Grima Murcia et al., 2017)	(Weiss, 2017) (Pasqualetti and Stremke, 2018) (Delicado et al., 2016) (Nordman and Mutinda, 2016) (van Grieken, 2017) (Llewellyn et al., 2017) (Maehr et al., 2015) (Ribe et al., 2018)
	Solar		(Pasqualetti and Stremke, 2018) (Jefferson, 2018) (Delicado et al., 2016) (Walz and Stein, 2018)	(Weiss, 2017)
WILEY	Hydro	(Thaulow et al., 2009)	(Berchin et al., 2015)	
	Wind		(Petrova, 2013) (Phadke, 2011) (Berry et al., 2011) (Horbaty et al., 2012) (Lee, 2017) (Burton et al., 2001) (Nordman et al., 2015)	(Devine-Wright, 2005) (Fast et al., 2015)
	Solar			(Pasqualetti, 2011)
SPRINGER	Hydro	(Matveev, 1988)	(Tikhomirova and Novozhenin, 2004) (Harris, 2011) (Sternberg, 1985)	(Frolova et al., 2015a) (Davasse et al., 2015) (Pavlickova et al., 2014)
	Wind		(Labussière and Nadaï, 2015) (Brahimi et al., 2018)	(Betakova et al., 2016) (Mathew and Energy, 2006) (Wolsink, 2012)

	(Hajto et al., 2017) (Díaz-Cuevas and Domínguez-Bravo, 2015) (Petri and Lombardo, 2008) (Pavlickova et al., 2014) (Huber et al., 2017) (Deshaies and Herrero-Luque, 2015) (Steele, 1991) (Frolova et al., 2015b)	(Baraja-Rodríguez et al., 2015)
Solar	(de Andrés-Ruiz et al., 2015) (Huber et al., 2017) (Frolova et al., 2015b) (Pavlickova et al., 2014) (Franco, 2017)	(Mérida-Rodríguez et al., 2015a) (Mérida-Rodríguez et al., 2015b)

Appendix D - Excel tables of perception analysis - Supplementary material

The supplementary data in regard to the data used in the public perception analysis through literature review can be found online at https://doi.org/10.1016/j.apenergy.2020.115367.

Appendix E - La Brena II dam landscape design costs

Table 15. La Brena II dam landscape design costs.

No.	Work*	Unit	Cost (€)	Quantity	Budget (€)
1	Planting soil placed on downstream slope	m^3	28,01	12.614,400	353.329,34
2	Hydroseeding of herbaceous plants	m^2	2,67	15.974,784	42.652,67
3	Hydroseeding of herbaceous and shrubs	m^2	2,88	3.993,696	11.501,84
4	Tree supply	pc.	19,07	440,000	8.390,80
5	Tree supply	pc.	16,71	860,000	14.370,60
6	Tree planting	pc.	119,94	440,000	52.773,60
7	Shrub planting	pc.	95,14	860,000	81.820,40
8	Tree planting	pc.	2,90	440,000	1.276,00
9	Shrub planting	pc.	1,70	860,000	1.462,00
10	Pumping system from the river to the regulating tank	pc.	66.944,29	1,000	66.944,29
11	Pumping system to the distribution centre	pc.	61.637,98	1,000	61.637,98
12	Installation of drip irrigation system in Section 1	pc.	8.605,50	1,000	8.605,50
13	Installation of drip irrigation system in Section 2	pc.	10.076,62	1,000	10.076,62
14	Installation of drip irrigation system in Section 3	pc.	7.931,87	1,000	7.931,87
15	Installation of drip irrigation system in Section 4	pc.	8.190,46	1,000	8.190,46
16	Installation of drip irrigation system in Section 5	pc.	8.705,46	1,000	8.705,46

17	Installation of drip irrigation system in Section 6	pc.	8.826,73	1,000	8.826,73
18	Installation of drip irrigation system in Section 7	pc.	7.334,30	1,000	7.334,30
19	Formation of downstream face access road	m	8,67	2.700,000	23.409,00
Total budget					**779.239,46**
Contractor Discount Rate				0,6999	
Final budget					**545.389,70**

No.	Work	Unit	Cost (€)	Quantity	Budget (€)
20	Complete installation of galvanized steel staircase of 1.20 m width	pc.	560,00	118,000	66.080,00
21	Braided galvanized steel wire 6Φ, anchored with screws every 5 m, including pretensioners, rings and assembly	m	3,8	22.240,000	84.512,00
Total budget					**150.592,00**
Contractor Discount Rate				0,828309498	
Final budget					**124.736,78**

*The original language of the budget provided to us by Antonio S. Zabal, manager engineer of La Brena II dam, was Spanish. Thus, all terms that are presented in this file have been translated by the authors to English.

Appendix F - Greek dam case study landscape design costs

Table 16. Greek dam case study landscape design costs.

Π.Τ	Α.Τ	Work*	Unit	Revision name	Cost (€)	Quantity	Budget (€)
Section 1- Downstream slope hardfill moulding							
ΦΡΓ	9.01	Metal or wood formwork for flat surfaces	m^2	ΥΔΡ 6301	4.50	4688.64	21098.88
Section 2 - Downstream slope balconies							
	N/A	Precast concrete units C16/20[1]	pc.	ΥΔΡ 6329	450.00	96.00	43200.00
ΥΔΡ	9.10.04&01	Concrete construction with C16/20	m^3	ΥΔΡ 6328	82.50	11.49	948.02
ΦΡΓ	8.06.01	Concrete construction with C20/25	m^3	ΥΔΡ 6329	88.00	63.94	5626.51
ΦΡΓ	9.01	Metal or wood formwork for flat surfaces	m^2	ΥΔΡ 6301	4.50	229.94	1034.73
ΦΡΓ	8.05	Supply and installation of concrete reinforcement	kg	ΥΔΡ 6311	0.90	7542.88	6788.59
ΦΡΓ	9.06	Additional cost for forming detailed concrete surface finishes	m^2	ΥΔΡ 6304	5.40	404.10	2182.14
ΦΡΓ	8.05	Supply and installation of concrete reinforcement	kg	ΥΔΡ 6311	0.90	29387.76	26448.98
	N/A	Dam hardfill[2]	m^3	ΥΔΡ 6323	22.50	36.12	812.59
ΟΙΚ	71.46	Rubbed coating on meshes with	m^2	ΟΙΚ 7146	11.00	491.28	5404.08

		lime mortar using plastering trowel					
ΟΙΚ	77.01	Lime water-colouring of new surfaces	m^2	ΟΙΚ 7701	1.50	491.28	736.92
Section 3- Downstream slope planted space							
Concrete steps							
ΥΔΡ	8.01.03	Assemblage of wires of gabions of galvanized wire mesh from alloy of zinc and aluminium	kg	ΥΔΡ 6151	2.50	17293.83	43234.56
ΥΔΡ	8.02.01	Filling of gabions with crushed material of quarry origin	m^3	ΥΔΡ 6154	16.00	1010.45	16167.28
ΦΡΓ	9.01	Metal or wood formwork for flat surfaces	m^2	ΥΔΡ 6301	4.50	1155.09	5197.91
ΦΡΓ	4.24	Supply and installation of mesh support anchors	pc.	ΥΔΡ 7025	9.00	895.42	8058.77
Preparation of green areas							
ΠΡΣ	Δ7	Supply of gardening soil	m^3	ΠΡΣ 1710	8.50	157.75	1340.84
ΠΡΣ	Δ8	Supply of topsoil	m^3	ΠΡΣ 1620	5.00	591.55	2957.74
ΠΡΣ	Δ9	Supply of manure	m^3	ΠΡΣ 5340	24.60	39.44	970.14
ΟΙΚ	10.01.02	Loading and unloading by mechanical means	m^3	ΟΙΚ–1104	1.50	788.73	1183.10
ΠΡΣ	Γ1	General soil surface formation for planting plants	acre	ΠΡΣ 1140	100.00	0.61	60.77
Plant material							

ΠΡΣ	Δ4.2	Slope plants of category S2 (cypress)	pc.	ΠΡΣ-394.2	1.50	14.00	21.00
ΠΡΣ	Δ2.2	Shrubs category Θ2 (olive)	pc.	ΠΡΣ-392.2	3.50	12.00	42.00
ΠΡΣ	Δ6.1	Herbaceous - perennial plants category P1 (thyme)	pc.	ΠΡΣ-396.2	0.75	405.00	303.75
Planting							
ΠΡΣ	Ε1.1	Digging pits with dimension: 0.30 X 0.30 X 0.30 m	pc.	ΠΡΣ 5130	0.60	800.73	480.44
ΠΡΣ	Ε9.3	Planting plants with balled roots of volume up to 1.50 litres	pc.	ΠΡΣ 5210	0.80	788.73	630.98
ΠΡΣ	Ε9.3	Planting plants with balled roots of volume up to 4 litres	pc.	ΠΡΣ 5210	1.00	591.55	591.55
ΠΡΣ	ΣΤ 2.1.5	Irrigation of plants with ground irrigation system, automated	pc.	ΠΡΣ 5321	0.01	1905.87	19.06
Irrigation system							
Primary irrigation network							
ΠΡΣ	Η9.1.1	Irrigation control solenoid valves (solenoid valves), PN 10 atm, plastic Φ 2 1/2΄΄	pc.	ΗΛΜ 8	140.00	4.00	560.00
ΠΡΣ		Other equipment for irrigation control systems [4]					15000.00
ΠΡΣ	Η3.1	Pipeline made of galvanized iron pipe with heavy type seam Φ 2 1/2΄ [3]	m	ΗΛΜ 5	17.10	64.00	1094.40

ΠΡΣ	H5.12.2	Pressure reducer PN 16 atm Φ 3/4''	pc.	ΗΛΜ 11	28.70	4.00	114.80
ΥΔΡ	13.03.01.03	Drawer vales with flange diameter of 100 mm and nominal pressure of 10 atm.	pc.	ΥΔΡ 6651.1	200.00	4.00	800.00
ΠΡΣ	H7.2.8	Water filter, mesh or disc, plastic, nominal pressure 10 atm Φ 3"	pc.	ΗΛΜ 8	400.00	2.00	800.00
Secondary irrigation network							
ΠΡΣ	H5.12.2	Pressure reducer PN 16 atm Φ 3/4''	pc.	ΗΛΜ 11	28.70	4.00	114.80
ΠΡΣ	H2.3.5	Pipeline from PVC pipe 10 atm Φ 110	pc.	ΗΛΜ 8	9.90	55.00	544.50
ΠΡΣ	H8.1.1	Self-regulating dripper, accessible	pc.	ΗΛΜ 8	0.21	862.00	181.02
ΠΡΣ	H8.2.9	Driper carrier Φ20 mm from PE with self-regulating drippers and root repellent for underground installation.	pc.	ΗΛΜ 8	0.94	646.50	607.71
ΠΡΣ	H5.3.2	Drawer valves, brass, threaded Φ 3/4''[5]	pc.	ΗΛΜ 11	3.70	68.00	251.60
ΠΡΣ	ΣΤ2.1.6	Irrigation of plants with ground irrigation system, automated	pc.	ΠΡΣ 5321	0.01	800.73	8.01
Section 1 - Crest gabion facade							
ΥΔΡ	8.01.03	Assemblage of wires of gabions of galvanized wire mesh from alloy of zinc and aluminium	kg	ΥΔΡ 6151	2.50	5329.50	13323.75

ΥΔΡ	8.02.01	Filling of gabions with crushed material of quarry origin	m^3	ΥΔΡ 6154	16.00	106.59	1705.44
Section 2 - Crest balconies							
ΟΙΚ	71.46	Rubbed coating on meshes with lime mortar using plastering trowel	m^2	ΟΙΚ 7146	11.00	489.80	5387.80
ΟΙΚ	77.01	Lime water-colouring of new surfaces	m^2	ΟΙΚ 7701	1.50	489.80	734.70
ΦΡΓ	9.06	Additional cost for forming detailed concrete surface finishes	m^2	ΥΔΡ 6304	5.40	195.80	1057.32
ΦΡΓ	8.06.01	Concrete construction with C20/25	m^3	ΥΔΡ 6329	88.00	228.29	20089.47
ΦΡΓ	9.01	Metal or wood formwork for flat surfaces	m^2	ΥΔΡ 6301	4.50	830.00	3735.00
ΦΡΓ	8.05	Supply and installation of concrete reinforcement	kg	ΥΔΡ 6311	0.90	22828.94	20546.05
	N.T	Dam hardfill	m^3	ΥΔΡ 6323	22.50	213.07	4793.96
Section 3 - Crest concrete finish							
ΟΙΚ	71.46	Rubbed coating on meshes with lime mortar using plastering trowel	m^2	ΟΙΚ 7146	11.00	247.80	2725.80
ΟΙΚ	77.01	Lime water-colouring of new surfaces	m^2	ΟΙΚ 7701	1.50	247.80	371.70
Additional works							
Upstream slope crest							

OIK	71.46	Rubbed coating on meshes with lime mortar using plastering trowel	m^2	OIK 7146	11.00	486.60	5352.60
OIK	77.01	Lime water-colouring of new surfaces	m^2	OIK 7701	1.50	486.60	729.90
Lighting fixture modification							
ΟΔ	Z-3.2.3	Lighting fixture with arm and lamp Na of 400 W power	pc.	ΗΛΜ-103	340.00	6.00	2040.00
				Sum (€)			298211.65

Appendix G – Summary in Greek

(Εκτεταμένη Περίληψη)

ΣΥΝΟΨΗ

Η περίπτωση των έργων Ανανεώσιμων Πηγών Ενέργειας (ΑΠΕ) κατέδειξε ότι η ένταξη των έργων υποδομής στα τοπία μπορεί να αποτελέσει σημαντική πρόκληση. Συγκεκριμένα, η παραμέληση των επιπτώσεων των έργων στα φυσικά και πολιτιστικά χαρακτηριστικά των τοπίων και η περιθωριοποίηση των κοινοτήτων που επηρεάζονται από αυτές τις επιπτώσεις, φαίνεται να οδηγεί σε έναν φαύλο κύκλο αναπτυξιακής αβεβαιότητας και δημόσιας αναταραχής. Στην παρούσα εργασία, αρχικά διερευνάται το πώς τα έργα υποδομής τροποποιούν τα τοπία, τόσο από χωρική-ποσοτική άποψη όσο και αντιληπτικά-ποιοτικά. Στη συνέχεια, αξιοποιώντας τα αποτελέσματα αυτής της διερεύνησης προτείνονται βελτιώσεις στον χωρικό και αρχιτεκτονικό σχεδιασμό των έργων υποδομής, με στόχο την καλύτερη ένταξή τους στα τοπία. Η μελέτη εμβαθύνει στη μελέτη έργων αιολικής, ηλιακής, υδροηλεκτρικής ενέργειας και φραγμάτων, αλλά τα συμπεράσματα που εξάγονται αφορούν όλα τα μεγάλα έργα υποδομής. Η ανάλυση δομείται σε τρία ιεραρχικά επίπεδα σε βαθμιαία φθίνουσες χωρικές κλίμακες:

(A) Παγκόσμια κλίμακα – Συγκριτική αξιολόγηση των τυπικών επιπτώσεων των διαφόρων τύπων έργων υποδομής στο τοπίο:

Οι φορείς που συμμετέχουν στον σχεδιασμό, την αδειότηση και τις επενδύσεις σε έργα υποδομής συχνά αμφιβάλλουν για το κατά πόσο οι αποκαλούμενες "επιπτώσεις στο τοπίο" είναι ένα αντικειμενικό ζήτημα ή εάν είναι μια ακόμα έκφραση μιας προκατειλημμένης αρνητικής στάσης των τοπικών κοινωνιών απέναντι σε νέα έργα. Η αβεβαιότητα αυτή όμως δυσχεραίνει την ανάπτυξη μεθόδων σχεδιασμού για τον μετριασμό αυτών των επιπτώσεων. Για το λόγο αυτό, η ανάλυσή ξεκινά διερευνώντας το κατά πόσον η χωρική έκταση και η σοβαρότητα των επιπτώσεων των διαφορετικών τύπων υποδομής στο τοπίο μπορεί να ποσοτικοποιηθεί και να συγκριθεί με αντικειμενικό και καθολικό τρόπο. Τα έργα ΑΠΕ αναλύθηκαν λεπτομερώς από αυτή τη σκοπιά, μελετώντας την επιστημονική βιβλιογραφία και δεδομένα από υλοποιημένα έργα, από παγκόσμιες πηγές. Τρεις δείκτες των επιπτώσεων των έργων στο τοπίο επιλέχθηκαν ως οι πιο χαρακτηριστικοί και αναλύθηκαν σε βάθος: η χρήση γης, η ορατότητα και η κοινή γνώμη για την επίπτωση των έργων στο τοπίο. Τα αποτελέσματα από τη διερεύνηση αυτών των δεικτών έδειξαν ότι τα έργα αιολικής ενέργειας είναι μέχρι σήμερα, κατά μέσο όρο, τα πιο επιδραστικά στα τοπία, ανά μονάδα παραγωγής ενέργειας, ακολουθούμενα από τα ηλιακά φωτοβολταϊκά έργα και τα υδροηλεκτρικά φράγματα, κατά σειρά. Γενικότερα, συνάγεται το συμπέρασμα ότι διαφορετικοί τύποι έργων υποδομής έχουν όντως διαφορετικών τύπων επιπτώσεις στο τοπίο και επομένως σε κάθε περίπτωση χρειάζονται στοχευμένες προσεγγίσεις για τον μετριασμό τους. Οι προσεγγίσεις αυτές φαίνεται να απαιτούν διαφοροποίηση ανάλογα με: (i) το εάν ο εξεταζόμενος τύπος έργου γίνεται αντιληπτός αρνητικά από την κοινή γνώμη, στο πλαίσιο του τοπίου, (ii) τη χωρική έκταση των επιπτώσεων του στο τοπίο είτε από άποψη χρήσης γης είτε οπτικά και (iii) τη επιδεκτικότητά ή όχι σε αρχιτεκτονική επεξεργασία.

(B) Εθνική κλίμακα & κλίμακα Διοικητικής Περιφέρειας- Βελτίωση του χωρικού σχεδιασμού για την ένταξη των έργων υποδομής στο τοπίο:

Σε αυτή την κλίμακα, δίνεται έμφαση στα έργα υποδομής τα οποία δέχονται έντονη κριτική για τις οπτικές τους επιπτώσεις στα τοπία. Μέχρι σήμερα, η λεγόμενη ανάλυση ορατότητας έχει καθιερωθεί ως το βασικό εργαλείο χωροθέτησης αυτών των έργων, ούτως ώστε να μειώνεται η ορατότητά τους από περιοχές υψηλής τοπιακής αξίας. Ωστόσο, οι συμβατικές αναλύσεις ορατότητας έχουν περιορισμένη χρησιμότητα ως εργαλείο πρόβλεψης και αποφυγής των επιπτώσεων, καθώς μπορούν να εφαρμοστούν μόνο στα τελευταία στάδια του σχεδιασμού. Αυτό οφείλεται στο γεγονός ότι για να υλοποιηθούν οι αναλύσεις αυτές απαιτείται οι τοποθεσίες των εξεταζόμενων έργων να έχουν ήδη καθοριστεί. Για την βελτίωση λοιπόν του χωρικού σχεδιασμού των έργων προτείνεται η αντιστροφή των αναλύσεων ορατότητας, ώστε οι αναλύσεις να μπορούν να υλοποιηθούν νωρίτερα, από τη σκοπιά των τοποθεσιών των προστατευόμενων στοιχείων του τοπίου, έναντι των τοποθεσιών των έργων. Αυτή η μεθοδολογική αλλαγή επιτρέπει τη δημιουργία σταθερών χαρτών προστασίας τοπίου που περιβάλλουν τα σημαντικά στοιχεία των τοπίων, οι οποίοι έχουν τα εξής πλεονεκτήματα: (i) μπορούν να χρησιμοποιηθούν για την πρόβλεψη των επιπτώσεων στο τοπίο από πρώιμα στάδια σχεδιασμού, πριν οριστικοποιηθούν οι τοποθεσίες των έργων, (ii) μπορούν να εξοικονομήσουν χρόνο, καθώς χρειάζεται να εφαρμοστούν μόνο μία φορά σε μια περιοχή ή χώρα, υποκαθιστώντας την ανάγκη για μεμονωμένη ανάλυση ορατότητας για κάθε νέο έργο και (iii) έχουν καλύτερη συμβατότητα με τις διαδικασίες συμμετοχικού σχεδιασμού. Η αντίστροφη ανάλυση ορατότητας εφαρμόστηκε διερευνητικά στην περιφέρεια της Θεσσαλίας, για την οποία διαμορφώθηκαν χάρτες Αντιστρόφων Ζωνών Θεωρητικής Ορατότητας (Α-ΖΘΟ) οι οποίοι στη συνέχεια χρησιμοποιήθηκαν για την πρόβλεψη των οπτικών επιπτώσεων από προγραμματισμένα έργα αιολικής ενέργειας σε προστατευόμενα στοιχεία του τοπίου.

(Γ) Κλίμακα τοποθεσίας του έργου – Η χρησιμότητα και οι δυνατότητες επέκτασης του αρχιτεκτονικού σχεδιασμού των έργων:

Σε αυτή την κλίμακα, διερευνήθηκε η χρησιμότητα της αρχιτεκτονικής επεξεργασίας των έργων υποδομής, στο πλαίσιο του μετριασμού των επιπτώσεών τους στο τοπίο. Για το σκοπό αυτό, αναλύθηκαν οι διεθνείς πρακτικές αρχιτεκτονικού σχεδιασμού και σχεδιασμού τοπίου στα φράγματα και συστάθηκε μια τυπολογία παρεμβάσεων οι οποίες και διερευνήθηκαν από άποψη κόστους-οφέλους. Τα αποτελέσματα έδειξαν ότι εφαρμογή μελετών αρχιτεκτονικής και αρχιτεκτονικής τοπίου (i) μπορεί να βελτιώσει μετρήσιμα την κοινή γνώμη για τα έργα υποδομής και (ii) ότι δεν υπάρχουν ανυπέρβλητοι τεχνικοί ή οικονομικοί περιορισμοί στην ευρύτερη εφαρμογή τέτοιων μελετών. Επομένως, συμπεραίνεται συνολικά ότι η αρχιτεκτονική επεξεργασία των έργων υποδομής έχει αντίκρισμα και ότι υπάρχουν προοπτικές για την επέκταση της εφαρμογής αρχιτεκτονικών μελετών σε όποια από τα έργα υποδομής υπάρχει αυτή η δυνατότητα.

ΘΕΩΡΗΤΙΚΟ ΚΑΙ ΠΡΑΚΤΙΚΟ ΠΛΑΙΣΙΟ

Το θέμα της ένταξης των έργων υποδομής στο τοπίο, έχει αναδειχθεί περισσότερο από ποτέ τις τελευταίες δεκαετίες, μέσω των σχετικών προβλημάτων που παρατηρήθηκαν κατά τη ανάπτυξη των έργων Ανανεώσιμων Πηγών Ενέργειας (ΑΠΕ). Η εμπειρία από την ανάπτυξη των έργων ΑΠΕ κατέδειξε συγκεκριμένα ότι η παραμέληση των επιπτώσεων των έργων στα φυσικά και πολιτιστικά χαρακτηριστικά των τοπίων και η περιθωριοποίηση των κοινοτήτων που επηρεάζονται από αυτές τις επιπτώσεις, μπορεί να οδηγήσει σε έναν φαύλο κύκλο δημόσιας αναταραχής και αναπτυξιακής αβεβαιότητας.

Η ομαλή ένταξη των έργων υποδομής στο τοπίο, συνεχίζει όμως ακόμα και σήμερα να αποτελεί μια σημαντική πρόκληση. Ενδεικτικά, παρουσιάζονται αρχικά κάποιες από τις περιπτώσεις Αιολικών έργων στην Ελλάδα, σε διάφορα στάδια εξέλιξης, για οποία εντοπίζονταν αντιδράσεις διαφόρων τύπων κατά την περίοδο 2017 και 2018 (Πίνακας 1) από τις τοπικές κοινωνίες. Οι αντιδράσεις απέναντι στα έργα δεν αποδίδονται φυσικά μόνο στην επίπτωση τους στο τοπίο. Αναφέρεται, περαιτέρω, ότι στις δικαστικές διαμάχες που προκύπτουν από τις αντιδράσεις των τοπικών κοινωνιών η αναφορά στην επίπτωση στο τοπίο συνήθως δεν προτιμάται καθώς αναζητούνται πιο ποσοτικοί δείκτες για τα νομικά επιχειρήματα (Lee, 2017). Συχνά λοιπόν οι αντιδράσεις στρέφονται σε άλλες κατευθύνσεις αν και εντοπίζονται και αρκετές περιπτώσεις στις οποίες το τοπίο εμφανίζεται και αυτό στις σχετικές δικογραφίες (Council of State and Administrative Justice, 2015, 2013a, 2013b, 2012a, 2012b, 2011). Σε κάθε περίπτωση όμως, καθίσταται εμφανές ότι το τοπίο αποτελεί έναν από τους κυριότερους, αν όχι τον κυριότερο, λόγο αντίταξης στα αιολικά έργα και τα έργα ΑΠΕ γενικότερα. Αυτό παρατηρείται τόσο από την βιβλιογραφική έρευνα όσο και από την έρευνα στις δράσεις δημοσιότητας των κοινωνικών ομάδων που αντιδρούν. Περαιτέρω, η αντίδραση έναντι στα έργα ΑΠΕ με επιχείρημα τις επιπτώσεις τους στο τοπίο δεν αφορά μόνο την Ελλάδα αλλά είναι ένα διεθνές φαινόμενο.

Ως ενδεικτικά των διεθνών διαστάσεων των θεμάτων της ένταξης των έργων ΑΠΕ στο τοπίο παρουσιάζονται παραδείγματα σχετικής βιβλιογραφίας από διάφορες χώρες της Ευρώπης και από τις ΗΠΑ. Συγκεκριμένα, σχετικά προβλήματα έχουν παρουσιαστεί τις τελευταίες δεκαετίες στην Ευρώπη, σε χώρες όπως η Γαλλία, ή Ολλανδία, η Ισπανία, η Σκωτίας και πολλές άλλες (Nadaï and Labussière, 2017; Pasqualetti, 2011; Uyterlinde et al., 2017; Wolsink, 2000). Αντίστοιχα, στις ΗΠΑ, οι νομικές αγωγές με επιχειρήματα σχετικά με το τοπίο, την ορατότητα και την αισθητική όχληση από τα έργα ΑΠΕ είναι συνηθισμένες, τόσο κατά των αιολικών όσο και, σε μικρότερο βαθμό, και κατά τον φωτοβολταϊκών έργων (Brown and Escobar, 2007; Butler, 2009; Elkind et al., 2018; Lewis, 2014; Pasqualetti and Stremke, 2018; Phadke, 2009). Οι αντιδράσεις έναντι στα έργα προκαλούν φυσικά καθυστερήσεις και ακυρώσεις και έχουν μάλιστα συσχετιστεί από ερευνητές με σημαντικές οικονομικές επιπτώσεις. Στις ΗΠΑ για παράδειγμα, τα έργα ΑΠΕ αποτελούν ένα σημαντικό ποσοστό των έργων για τα οποία εμφανίζονται δικαστικές διαμάχες για περιβαλλοντικούς λόγους, με αναφορά στη σχετική νομοθεσία (National Environmental Protection Act, federal Environmental Quality Acts και Environmental Protection Acts) (Pociask and Fuhr Jr, 2011; Schneider and Takahashi, 2011).

Πίνακας 1. Παραδείγματα αιολικών έργων έναντι των οποίων εμφανίζονταν αντιδράσεις κατά την περίοδο 2017 and 2018.

Τοποθεσία	Ισχύς (MW)	Αριθμός ανεμογεννητριών	Τύπος αντίδρασης

Πάρος, Νάξος, Τήνος και Άνδρος	218.5	95	Νομικές ενέργειες από την τοπική αυτοδιοίκηση
Σαμοθράκη	110.7	39	Ψηφίσματα από ομάδες πολιτών και συλλόγους
Βέρμιο	465	174	Αρνητική απόφαση από την τοπική αυτοδιοίκηση
Άγραφα	86	40	Νομικές ενέργειες από πολίτες
Σητεία	81	27	Αρνητική απόφαση από την τοπική αυτοδιοίκηση
Κάρυστος	167.9	73	Νομικές ενέργειες από την τοπική αυτοδιοίκηση
Μάνη	103.2	48	Νομικές ενέργειες από πολίτες και συλλόγους
Μονεμβασιά	5.4	5	Νομικές ενέργειες από την τοπική αυτοδιοίκηση

Τα δεδομένα συλλέχθηκαν από ειδησεογραφικά άρθρα σε εθνικά μέσα μαζικής ενημέρωσης (οι σύνδεσμοι παρουσιάζονται κατά τη σειρά αναφοράς των αντίστοιχων δεδομένων στον πίνακα): http://www.kathimerini.gr; https://www.ert.gr/; http://www.alterthess.gr/; https://www.efsyn.gr/; https://www.efsyn.gr/; https://www.alfavita.gr/; http://www.kathimerini.gr; https://www.rizospastis.gr/.

Περαιτέρω σημαντικό ενδιαφέρον παρουσιάζουν και οι οικονομικές και αναπτυξιακές επιπτώσεις των διαμαχών που αφορούν την ένταξη των έργων υποδομής στο τοπίο. Για παράδειγμά, σε σχέση με την Ελλάδα, η συνολική προβλεπόμενή εγκατεστημένη ισχύς των έργων που παρουσιάζονται στον Πίνακα 1 αθροίζεται σε 1237.7 MW. Γίνεται αντιληπτική λοιπόν ή έκταση των αναπτυξιακών επιπτώσεων αυτών των αντιδράσεων, ιδιαίτερα δε αν ληφθεί υπόψη ότι ο στόχος της Ελλάδας για την επέκταση των έργων αιολικής ενέργειας μέχρι το 2020 ήταν τα 7500 MW (Ministry of Environment, Energy & Climate Change, 2009), από τα οποία όμως μόνο 4114 MW είχαν πράγματι εγκατασταθεί μέχρι τότε. Σε σχέση με τα αντίστοιχα φαινόμενα στις ΗΠΑ, ως ενδεικτική του οικονομικού αντικτύπου των σχετικών δικαστικών υποθέσεων, παρουσιάζουμε τη μελέτη του 2010 από το Εμπορικό Επιμελητήριο των ΗΠΑ, στην οποία συγκεντρωθήκαν και αναλύθηκαν 351 αμφισβητούμενα και υπό-καθυστέρηση έργα. Σε αυτή τη μελέτη, υπολογίστηκε ότι η οικονομία των ΗΠΑ στερήθηκε βραχυπρόθεσμη οικονομική ανάπτυξη 1,1 τρισεκατομμυρίων δολαρίων και 1,9 εκατομμύρια θέσεις εργασίας ετησίως, λόγω των νομικών κωλυμάτων των έργων. Βέβαια η μελέτη αυτή δεν αφορούσε αποκλειστικά τα έργα ΑΠΕ (το 45% από αυτά ήταν έργα ΑΠΕ) και δεν διαχωρίστηκε κάποιο συγκεκριμένο ποσοστό των αντιδράσεων που να αφορούσε συγκεκριμένα τη χρήση νομικών επιχειρημάτων σχετικά με οπτικές επιπτώσεις και επιπτώσεις στο τοπίο. Παρόλα αυτά, οι αριθμοί που παρουσιάζονται είναι ενδεικτικοί του εύρους των οικονομικών επιπτώσεων από προβλήματα που προκύπτουν από την ακύρωση ή την καθυστέρηση μεγάλων ενεργειακών έργων.

Ωστόσο, οι προκλήσεις της ένταξης των έργων υποδομής στο τοπίο δεν θα πρέπει να αντιμετωπίζονται αποκλειστικά υπό το πρίσμα των οικονομικών και αναπτυξιακών τους επιπτώσεων. Αντιθέτως είναι εμφανές ότι τα έργα υποδομής προκαλούν και θα συνεχίσουν να προκαλούν σημαντικές και εκτεταμένες αλλαγές στα τοπία, με τα έργα ΑΠΕ να φαίνεται να πρωτοστατούν σε αυτή την κατεύθυνση. Ως προς τα έργα ΑΠΕ, είναι η πρώτη φορά στην ανθρώπινη ιστορία που η παραγωγή ενέργειας έχει τόσο υψηλές απαιτήσεις σε χρήση γης (Apostol et al., 2016; Stremke and van den Dobbelsteen, 2012; Trainor et al., 2016; van Zalk and Behrens, 2018) και που τα απαιτούμενα έργα δημιουργούν τόσο εκτενείς οπτικές επιπτώσεις (Degórski et al., 2012; Möller, 2010; Scottish Natural Heritage [SNH], 2014). Η πραγματική κλίμακα των οπτικών και κατ' επέκταση τοπιακών επιπτώσεων των έργων ΑΠΕ, αναδεικνύεται από τους υπολογισμούς των λεγόμενων Ζωνών Θεωρητικής Ορατότητας (ΖΘΟ), οι οποίοι αφορούν κυρίως τα έργα αιολικής ενέργειας. Συγκεκριμένα, τα αποτελέσματα από μεγάλης κλίμακας αναλύσεις ΖΘΟ από τη διεθνή βιβλιογραφία, έδειξαν ότι ανεμογεννήτριες ήταν πλέον ορατές από περίπου το 17% της χερσαίας έκτασης της Ισπανίας[19] (Rodrigues et al., 2010), 21% της Ολλανδίας (Statistics Netherlands [CBS] et al., 2014), 46% της Σκωτίας (Scottish Natural Heritage [SNH], 2014) και 96% της Περιφέρειας της Βόρειας Γιουτλάνδης, στη Δανία (Möller, 2010). Επιπλέον, η παγκόσμια προσπάθεια για αύξηση της παραγωγής ενέργειας από ΑΠΕ, αναπόφευκτα θα οδηγήσει στην διατήρηση της προβληματικής σχέσης μεταξύ παραγωγής ενέργειας και της διαφύλαξης της ποιότητας των τοπίων. Στην Ευρώπη, για παράδειγμα, το μερίδιο των ΑΠΕ στην κατανάλωση ενέργειας, που το 2018 ήταν 18%, σχεδιάζεται να αυξηθεί στο 27%, έως το 2030 (European Council, General Secretariat of the Council, 2014). Επομένως, είναι λογικό να υποθέσουμε ότι η μετάβαση προς τις ΑΠΕ θα συνεχίσει να είναι μία από τις μεγαλύτερες δυνάμεις μετασχηματισμού των ευρωπαϊκών τοπίων τις επόμενες δεκαετίες. Επιπλέον, η μετάβαση από το 18% στο 27% αναμένεται να είναι ακόμα πιο δύσκολη, καθώς τα έργα ΑΠΕ θα πρέπει σταδιακά να τοποθετούνται πιο κοντά σε ευαίσθητες-τοπιακά τοποθεσίες, καθώς οι διαθέσιμες τοποθεσίες για έργα έχουν ήδη μειωθεί αισθητά από την τρέχουσα επέκταση των ΑΠΕ (Deshaies and Herrero-Luque, 2015; Kaldellis et al., 2012; Nitsch et al., 2004).

ΣΤΟΧΟΙ ΚΑΙ ΒΑΣΙΚΗ ΔΟΜΗ

Στην παρούσα διατριβή, αρχικά διερευνάται το πώς τα έργα υποδομής τροποποιούν τα τοπία, τόσο ποσοτικά-χωρικά όσο και ποιοτικά-αντιληπτικά. Με βάση την Ευρωπαϊκή επιτροπή το τοπίο ορίζεται ακόλουθα: «Τοπίο σημαίνει μια περιοχή, όπως αυτή γίνεται αντιληπτή από τον λαό, της οποίας ο χαρακτήρας είναι αποτέλεσμα της αλληλεπίδρασης φυσικών ή/και ανθρώπινων παραγόντων». Συνεπώς, δεν αρκεί η χωρική μόνο ανάλυση των επιπτώσεων των έργων υποδομής στο τοπίο αλλά απαιτείται και διερεύνηση του πως οι χωρικές τροποποιήσεις του τοπίου από τα έργα υποδομής γίνονται αντιληπτές από τον άνθρωπο και την κοινωνία. Αξιοποιώντας λοιπόν τα αποτελέσματα αυτής της συνδυαστικής διερεύνησης, στη συνέχεια της

[19] Από την εξέταση ενός υποθετικού σεναρίου αξιοποίησης της αιολικής ενέργειας στην Ισπανία, που αναφέρεται σε εθνική εγκατεστημένη ισχύ σχεδόν ίση με την τρέχουσα εγκατεστημένη ισχύ αιολικής ενέργειας στην Ισπανία.

διατριβής διαμορφώνονται προτάσεις αναβαθμίσεων του χωρικού και του αρχιτεκτονικού σχεδιασμού των έργων υποδομής, με στόχο τη βελτιωμένη ένταξη τους στα τοπία. Εντός της εργασίας δίνεται περισσότερη έμφαση στην μελέτη των έργων αιολικής, ηλιακής και υδροηλεκτρικής ενέργειας και των φραγμάτων, αλλά τα συνολικά συμπεράσματα που εξάγονται αναφέρονται σε όλα τα μεγάλα έργα υποδομής.

Στόχος της έρευνας είναι η βελτίωση των μεθόδων σχεδιασμού των έργων για τον μετριασμό των αρνητικών επιπτώσεων τους στα τοπία. Η προσπάθεια αυτή κρίνεται χρήσιμη τόσο (α) για την ελαχιστοποίηση των επιπτώσεων στην ποιότητα ζωής των τοπικών κοινωνιών στην εγγύτητα μεγάλων έργων υποδομής όσο και (β) για την αποτροπή συγκρούσεων των τοπικών κοινωνιών και φορέων με τους δημόσιους ή ιδιωτικούς φορείς που αναλαμβάνουν την υλοποίηση αυτών των έργων, και συνεπώς και για την επιτάχυνση της απρόσκοπτης ανάπτυξης των έργων υποδομής. Όταν δεν λαμβάνονται μέτρα για την ένταξη των έργων στο τοπίο, οι συγκρούσεις που προκαλούνται καταλήγουν συχνά να έχουν αμοιβαία αρνητικές επιπτώσεις. Στην περίπτωση των έργων ΑΠΕ για παράδειγμα, από τη μια πλευρά δημιουργούνται αναπτυξιακά και οικονομικά προβλήματα λόγω αντιδράσεων που οφείλονται στον φόβο για τις επιπτώσεις των έργων στο τοπίο, και από την άλλη, τα τοπία πράγματι επηρεάζονται πολλές φορές σημαντικά λόγω ελλιπούς σχεδιασμού. Διαιωνίζεται έτσι ένας κύκλος συγκρούσεων, αναταραχών, αναπτυξιακών προβλημάτων αλλά και αρνητικών επιπτώσεων για την ποιότητα ζωής των τοπικών κοινωνιών. Είναι επομένως εύλογο να υποστηριχθεί ότι, συνολικά, τα αποτελεσματικά μέτρα για τον μετριασμό των επιπτώσεων στο τοπίο μπορούν να συμβάλλουν τόσο στη διασφάλιση της ποιότητας ζωής των κοινοτήτων που επηρεάζονται από τα έργα όσο και στην μείωση των εμποδίων στην ανάπτυξη των έργων υποδομής.

Η διατριβή δομείται σε τρία ιεραρχικά επίπεδα ανάλυσης σε βαθμιαία φθίνουσες χωρικές κλίμακες. Το πρώτο μέρος της εργασίας παρουσιάζεται αναλυτικά στην Ενότητα 2 και αφορά την συγκριτική αξιολόγηση των τυπικών επιπτώσεων των διαφόρων τύπων έργων υποδομής στο τοπίο. Η ανάλυση αυτή πραγματοποιείται σε παγκόσμια κλίμακα αξιοποιώντας την σχετική διεθνή επιστημονική βιβλιογραφία καθώς και δεδομένα από είδη ολοκληρωμένα έργα, τα οποία συγκεντρώθηκαν από παγκόσμιους και εθνικούς επιστημονικούς οργανισμούς κα φορείς. Το δεύτερο επίπεδο παρουσιάζεται αναλυτικά στην Ενότητα 3 και αφορά την βελτίωση των διαδικασιών χωρικού σχεδιασμού για την ένταξη των έργων υποδομής στο τοπίο. Έμφαση δίνεται στην επιτάχυνση και αναβάθμιση των αναλύσεων ορατότητας που γίνονται σε Συστήματα Γεωγραφικών Πληροφοριών (ΣΓΠ). Η διερεύνηση αυτή αναφέρεται κυρίως στην εθνική κλίμακα ή την χωρική κλίμακα της διοικητικής περιφέρειας, κλίμακες στις οποίες γίνονται συνήθως οι πολυκριτιριακές αναλύσεις για την χωροθέτηση μεγάλων έργων υποδομής. Τέλος το τρίτο και τελευταίο επίπεδο της έρευνας, που παρουσιάζεται αναλυτικά στην Ενότητα 4, αφορά (α) τη διερεύνηση της συνεισφοράς του αρχιτεκτονικού σχεδιασμού και του σχεδιασμού τοπίου στην βελτίωση της κοινωνικής αποδοχής των έργων υποδομής αλλά και (β) στην διερεύνηση των δυνατοτήτων επέκτασης της εφαρμογής τέτοιου τύπου μελετών, εξετάζοντας τους πιθανούς οικονομικούς ή τεχνικούς περιορισμούς. Η ανάλυση αυτή αφορά την χωρική κλίμακα της περιοχής κατασκευής του έργου, την οποία και αφορούν οι αρχιτεκτονικές μελέτες ή μελέτες αρχιτεκτονικής τοπίου.

ΣΥΝΟΨΗ ΜΕΡΟΥΣ Ι

Διερεύνηση σε παγκόσμια κλίμακα

Συγκριτική αξιολόγηση των τυπικών-χαρακτηριστικών επιπτώσεων στο τοπίο των διαφορετικών τύπων έργων υποδομής:

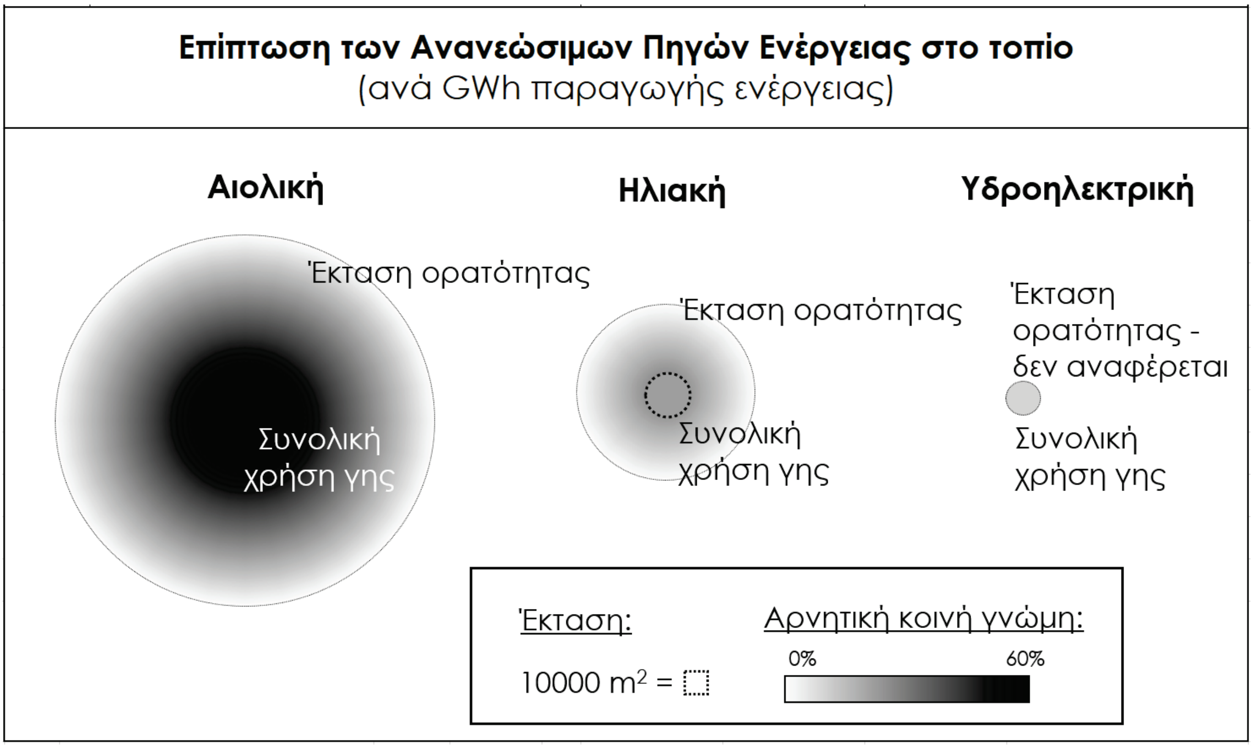
Οι φορείς που συμμετέχουν στον σχεδιασμό, την αδειότηση και τις επενδύσεις σε έργα υποδομής συχνά αμφιβάλλουν για το κατά πόσο οι αποκαλούμενες "επιπτώσεις στο τοπίο" είναι ένα αντικειμενικό ζήτημα ή εάν αποτελούν απλά μια πρόφαση των τοπικών κοινωνιών για να αντιταχθούν σε προτεινόμενα έργα. Συχνά λοιπόν, οι αντιδράσεις που επικαλούνται τις επιπτώσεις των έργων στο τοπίο αποδίδονται στην προκατειλημμένη αρνητική στάση των τοπικών κοινωνιών απέναντι σε έργα υποδομής. Η συμπεριφορά αυτή αποδίδεται και στην διεθνή επιστημονική βιβλιογραφία με τον όρο NIMBY (not in my back yard - όχι στην πίσω αυλή μου). Συνολικά όμως, η άκριτη αμφισβήτηση της αντικειμενικότητας των επιπτώσεων των έργων στο τοπίο, που δεν προκύπτει μετά από κάποια σχετική ανάλυση. συντελεί στην παραμέληση τους τους και δυσχεραίνει την ανάπτυξη βέλτιστων μεθόδων σχεδιασμού για τον μετριασμό τους. Για το λόγο αυτό, η πρώτη θεματική ενότητα της διατριβής αφιερώνεται στη διερεύνηση του κατά πόσον η έκταση και η σοβαρότητα των επιπτώσεων των διαφόρων έργων υποδομής στο τοπίο μπορεί να ποσοτικοποιηθεί αντικειμενικά και συνεπώς στο κατά πόσο μπορούν να συγκριθούν τα διαφορετικά έργα ή τύποι έργων ως προς την δριμύτητα των επιπτώσεων τους στο τοπίο.

Για τη διερεύνηση αυτή επιλέχθηκε να αναλυθούν συγκεκριμένα τα έργα ΑΠΕ ως προς τις επιπτώσεις τους στο τοπίο. Η απόφαση αυτή λήφθηκε για δυο λόγους. Αφενός, λόγω του ότι στην σύγχρονη εποχή τα έργα αυτά αποδέχονται την πιο έντονη κριτική σε θέματα σχετικά με την αλλοίωση των τοπίων. Αφετέρου, λόγω του ότι έχει υπάρξει ήδη αρκετό επιστημονικό ενδιαφέρον προς αυτή την κατεύθυνση οπότε και υπάρχουν διαθέσιμες πολλές σχετικές επιστημονικές εργασίες και πολλά σχετικά δεδομένα από υλοποιημένα έργα, για να αναλυθούν. Περαιτέρω, κάτι που αναδείχθηκε ως ιδιαίτερα σημαντικό κατά τη συνέχεια της εργασίας, είναι ότι τα βασικά έργα ΑΠΕ, δηλαδή τα υδροηλεκτρικά, τα αιολικά και τα φωτοβολταϊκά έργα, περιλαμβάνουν και μια σημαντική ποικιλομορφία διαφορετικών τύπων έργων. Η ποικιλομορφία αυτή, εξασφαλίζει την δυνατότητα επέκτασης των συμπερασμάτων από την ανάλυση των έργων ΑΠΕ και σε άλλα έργα υποδομής. Συγκεκριμένα, η ποικιλομορφία αυτή συνίσταται στο ότι τα έργα ΑΠΕ περιλαμβάνουν τόσο έργα υποδομής τα οποία χαρακτηρίσαμε στη συνέχεια ως «φιλικά προς την αρχιτεκτονική επεξεργασία», όπως είναι τα υδροηλεκτρικά φράγματα (η γενικότερα έργα όπως οι γέφυρες, οι εγκαταστάσεις επεξεργασίες νερού ή λυμάτων) και έργα «μη-φιλικά προς την αρχιτεκτονική επεξεργασία» όπως είναι οι ανεμογεννήτριες και τα φωτοβολταϊκά πάνελ (ή γενικότερα οι πυλώνες μεταφοράς ενέργειας, κάποια έργα οδοποιίας, κλπ.). Στην πρώτη κατηγορία εντάσσουμε τα έργα στα οποία μπορούν να εφαρμοστούν αρχιτεκτονικές μελέτες ενώ στη δεύτερη αυτά στα οποία αυτό δεν είναι δυνατό λόγω της τυποποιημένης και δεσμευμένης από πρακτικούς περιορισμούς μορφής τους

Για την ποσοτικοποίηση των επιπτώσεων των έργων ΑΠΕ στο τοπίο επιλέχθηκε εν τέλει η διερεύνηση τριών διαφορετικών δεικτών των επιπτώσεων τους στο τοπίο, οι οποίοι έχουν ήδη αναφερθεί εκτενώς στη διεθνή βιβλιογραφία. Αυτοί είναι (i) η χρήση γης των έργων, (ii) η περιοχή από την οποία γίνονται ορατά και (iii) η κοινή γνώμη για τις επιπτώσεις τους στο τοπίο. Οι δείκτες αυτοί ναι μεν έχουν αναλυθεί ήδη εκτενώς αλλά οι αναλύσεις αυτές είναι κυρίως μεμονωμένες και αποσπασματικές και δεν έχουν ως στόχο της δημιουργία μιας συνολικής εικόνας για τις επιπτώσεις των έργων στο τοπίο. Από τη διερεύνηση των δεικτών, αποδείχθηκε ότι τα έργα αιολικής ενέργειας έχουν προκαλέσει μέχρι σήμερα κατά μέσο όρο, τις πιο έντονες επιπτώσεις στα τοπία, ανά μονάδα παραγωγής ενέργειας, ακολουθούμενα από τα ηλιακά φωτοβολταϊκά έργα και τα υδροηλεκτρικά φράγματα, κατά σειρά. Τα αποτελέσματα που οδήγησαν σε αυτό το συμπέρασμα παρουσιάζονται συνοπτικά στον Πίνακα 2 και την Εικόνα 1.

Πίνακας 2. Εκτιμήσεις της χρήσης γης, της περιοχής ορατότητας και της κοινής γνώμης σε σχέση με τις επιπτώσεις των έργων ΑΠΕ στο τοπίο.

Τύπος τεχνολογίας ΑΠΕ	Συνολική χρήση γης (m^2/GWh)	Περιοχή ορατότητας (m^2/GWh)	Δείκτης αρνητικής κοινής γνώμης από τη διεθνή βιβλιογραφία (%)
Αιολική (χερσαία έργα)	176 000	2 014 800	60%
Ηλιακή (φωτοβολταϊκά έργα μεγάλης κλίμακας)	28 000	451 500	22%
Υδροηλεκτρική	16 900	N/A	15%



Εικόνα 1. Γραφική απεικόνιση - οπτικοποίηση των αποτελεσμάτων του Πίνακα 2. (α) Η χρήση γης παρουσιάζεται με συνεχές χρώμα. (β) Η έκταση της ορατότητας απεικονίζεται με χρώμα που φθίνει βαθμιδωτά όσο απομακρυνόμαστε από τον κύκλο που αφορά τη χρήση γης. Αυτή η απεικόνιση εκφράζει το γεγονός ότι η οπτική επίπτωση των έργων μειώνεται ανάλογα με την απόσταση. (γ) Το χρώμα που έχει επιλεχθεί σε κάθε περίπτωση είναι ανάλογο του ποσοστού αρνητικής κοινής γνώμης για τις επιπτώσεις του εν λόγω έργου στο τοπίο, με βάση τον δείκτη που υπολογίστηκε από τη επιστημονική βιβλιογραφία.

Συνολικά, συνάγεται το συμπέρασμα ότι οι διάφοροι τύποι έργων υποδομής έχουν όντως επιπτώσεις στο τοπίο οι οποίες διαφοροποιούνται ως προς τα τυπικά τους χαρακτηριστικά και επομένως απαιτούν και ειδικές στοχευμένες προσεγγίσεις μετριασμού σε κάθε περίπτωση. Η δριμύτητα των επιπτώσεων των έργων υποδομής στο τοπίο εξαρτάται σε μεγάλο βαθμό από (i) το εάν ο εξεταζόμενος τύπος έργου γίνεται αντιληπτός αρνητικά από την κοινή γνώμη ως προς την επίπτωση του στα φυσικά, πολιτισμικά και αισθητικά χαρακτηριστικά του τοπίου από (ii) την έκταση των χωρικών απαιτήσεων του έργου τόσο σε όρους χρήσης γης όσο και σε όρους περιοχής που επηρεάζεται οπτικά και (iii) το εάν το έργο επιδέχεται η όχι αρχιτεκτονικής επεξεργασίας.

ΣΥΝΟΨΗ ΜΕΡΟΥΣ ΙΙ

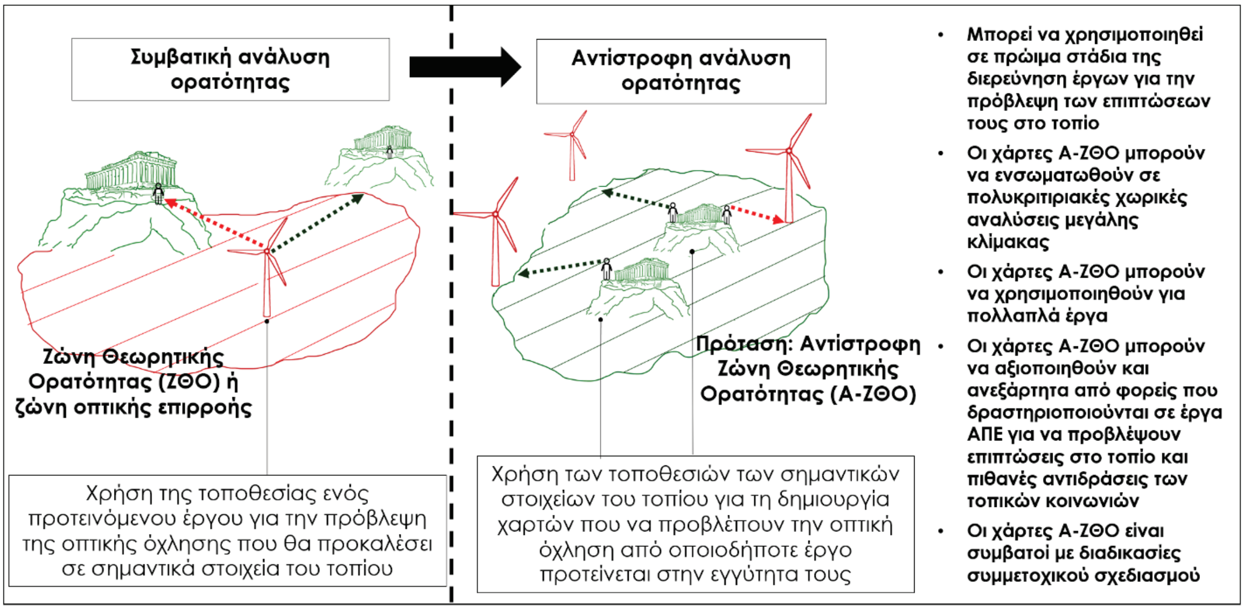
Διερεύνηση στην εθνική-περιφερειακή κλίμακα

Βελτίωση του χωρικού σχεδιασμού για την ένταξη των έργων υποδομής στο τοπίο

Με βάση τα συμπεράσματα του Μέρους Ι, στο Μέρος ΙΙ διερευνάται η αντιμετώπιση των επιπτώσεων των έργων εκείνων τα οποία κρίνονται ως ιδιαίτερα επιδραστικά στα τοπία, τόσο χωρικά όσο σε σχέση με αντίληψη της κοινής γνώμης για αυτά. Για τέτοιου τύπου έργα η ορατότητα τους εντός ενός τοπίου γίνεται αντιληπτή ως αρνητική επίπτωση, από σημαντικά ποσοστά του πληθυσμού. Το πιο χαρακτηριστικό παράδειγμα τέτοιου τύπου έργου είναι στην σημερινή εποχή τα αιολικά έργα, για τα οποία και η οπτική όχλησή αναφέρεται ως βασικό κίνητρο των αντιδράσεων των τοπικών κοινωνιών. Η έντονη κριτική για την οπτική επιρροή των αιολικών έργων στα τοπία φαίνεται να προκύπτει από ένα συνδυασμό παραμέτρων με βασικούς άξονες (i) ότι τα έργα αυτά έχουν σημαντικές χωρικές απαιτήσεις και επηρεάζουν μετρήσιμα την εικόνα των τοπίων εντός μιας χώρας, φτάνοντας εύκολα στο να γίνονται ορατά ακόμα και από διψήφια ποσοστά της έκτασης μιας χώρας, της τάξης του 20% με 45% ,(ii) ότι είναι έργα «μη-φιλικά στην αρχιτεκτονική επεξεργασία» από την άποψη ότι η μορφή τους δεν μπορεί να τροποποιηθεί ούτως ώστε να προσαρμοστεί στα φυσικά και πολιτισμικά χαρακτηριστικά του τοπίου στο οποίο τοποθετούνται, όπως μπορεί να γίνει για παράδειγμα σε έργα όπως γέφυρες, φράγματα και άλλα έργα υποδομής.

Για την αντιμετώπιση των επιπτώσεων των έργων που προκαλούν οπτική όχληση στο τοπίο, μέχρι σήμερα δίνεται έμφαση στον χωρικό τους σχεδιασμό και συγκεκριμένα στη χρήση των λεγόμενων «αναλύσεων ορατότητας». Οι αναλύσεις αυτές υλοποιούνται με τη χρήση Συστημάτων Γεωγραφικών Πληροφοριών (ΣΓΠ) και χρησιμοποιούνται για την χαρτογράφηση των περιοχών οπτικής επιρροής των έργων και τον εντοπισμό της πιθανής τους οπτικής επίπτωσης σε σημεία και περιοχές υψηλής τοπιακής αξίας. Ωστόσο, οι συμβατικές αναλύσεις ορατότητας έχουν αρκετά μειονεκτήματα ως εργαλείο σχεδιασμού, καθώς μπορούν να εφαρμοστούν μόνο στα τελευταία στάδια του σχεδιασμού όταν ουσιαστικά η χωροθέτηση του έργου έχει ολοκληρωθεί και η τοποθεσία του έχει οριστικοποιηθεί. Σε αυτό το στάδιο όμως, η ανάλυση ορατότητας μπορεί ουσιαστικά μόνο να εγκρίνει η να απορρίψει το έργο με βάση τις οπτικές του επιπτώσεις αλλά όχι να προτείνει κάποια καλύτερη χωροθέτηση, ειδικά σε έργα όπως τα αιολικά που γίνονται ορατά από μεγάλες αποστάσεις.

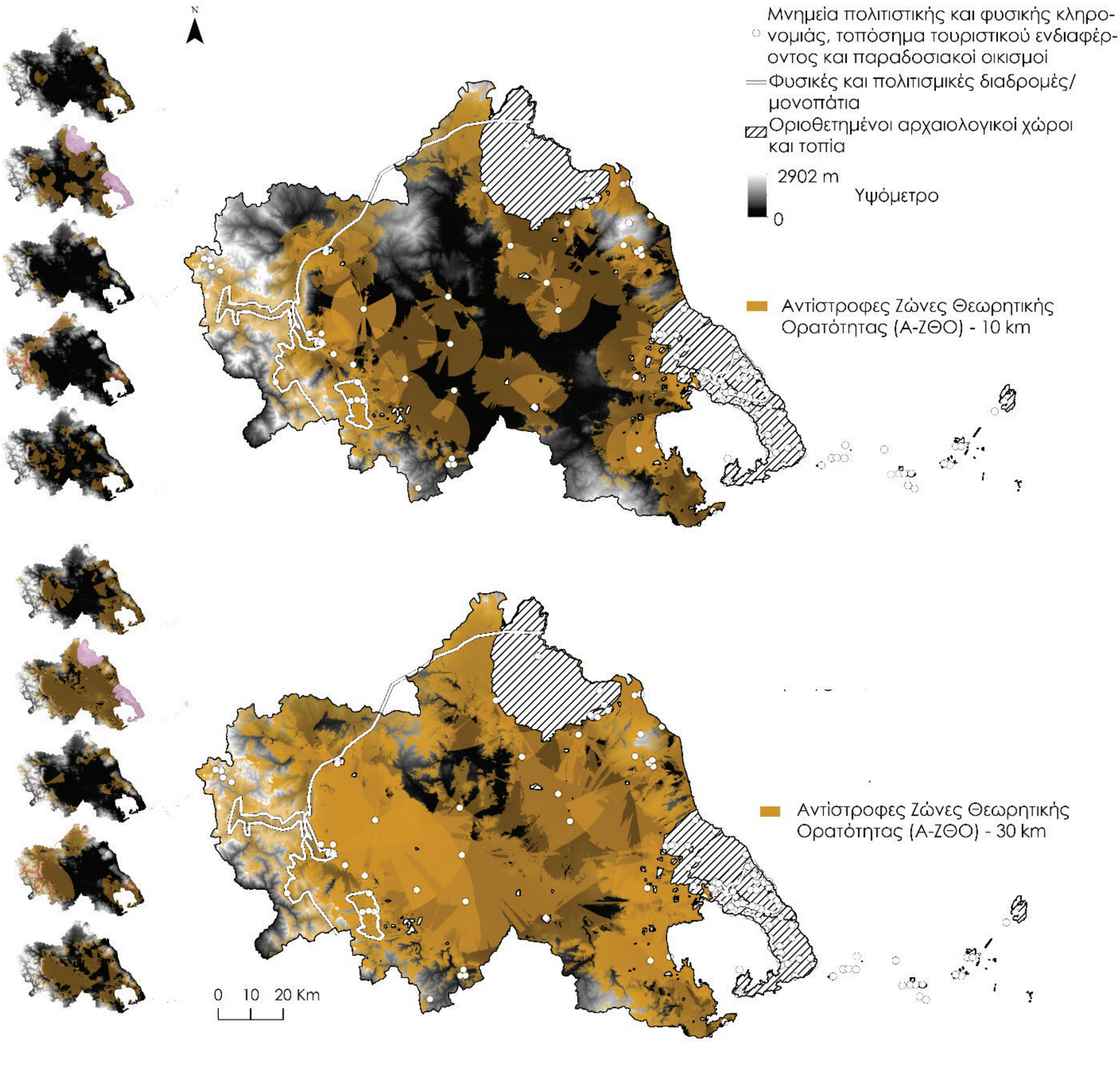
Για την αντιμετώπιση των παραπάνω αδυναμιών των αναλύσεων ορατότητας προτείνεται σαν λύση η αντιστροφή τους. Δηλαδή, η υλοποίηση τους με σημείο αναφοράς όχι τις τοποθεσίες των ανεμογεννητριών αλλά τις τοποθεσίες των περιοχών που επιδιώκεται να προστατευτούν από την οπτική όχληση. Εάν οι αναλύσεις πραγματοποιούνται από τη σκοπιά των ανεμογεννητριών τότε πρέπει να ολοκληρωθεί η χωροθέτηση τους ούτως ώστε να εισαχθούν οι τοποθεσίες των ανεμογεννητριών σε ΣΓΠ όπου θα γίνουν στη συνέχεια οι υπολογισμοί ορατότητας. Εάν όμως οι αναλύσεις γίνονται από τη σκοπιά των προστατευόμενων περιοχών τότε οι υπολογισμοί μπορούν να γίνουν σε οποιαδήποτε χρονική στιγμή, αφού οι προστατευόμενες περιοχές είναι στατικές και σε συγκεκριμένες-γνωστές θέσεις. Έτσι, η αντίστροφη ανάλυση ορατότητας μπορεί να υλοποιηθεί μαζικά για το σύνολο των προστατευόμενων περιοχών μιας ολόκληρης περιφέρειας ή κράτους και να δημιουργήσει σταθερούς χάρτες για την οπτική προστασία των εν λόγω περιοχών από μελλοντικά έργα.



Εικόνα 2. Γραφική απεικόνιση των διαφορών των συμβατικών αναλύσεων ορατότητας με τις αντίστροφες αναλύσεις ορατότητας στο πλαίσιο της χωροθέτησης έργων υποδομής και παρουσίαση των βασικών πλεονεκτημάτων των αντιστρόφων αναλύσεων ορατότητας.

Η μεθοδολογική αλλαγή από την συμβατική στην αντίστροφη ανάλυση ορατότητας, επιτρέπει λοιπόν τη δημιουργία σταθερών χαρτών προστασίας του τοπίου που θα περιβάλλουν τα επιλεγμένα σημαντικά στοιχεία του τοπίου (βλ. Εικόνα 2). Κάποια από τα πλεονεκτήματα αυτών των χαρτών είναι τα ακόλουθα: (i) επιτρέπουν την νωρίτερη πρόβλεψη των επιπτώσεων των προτεινόμενων έργων στο τοπίο, καθώς μπορούν να χρησιμοποιηθούν από πολύ αρχικά στάδια διερεύνησης ή σχεδιασμού των έργων, κάτι που δεν ήταν δυνατό με τις συμβατικές αναλύσεις ορατότητας (ii) μπορούν να οδηγήσουν σε σημαντική εξοικονόμηση χρόνου και προσπάθειας, καθώς οι αντίστροφες αναλύσεις ορατότητας χρειάζεται να υπολογιστούν μόνο μία φορά σε μια περιοχή, περιφέρεια ή χώρα, άρα μπορούν να αντικαταστήσουν την μέχρι-τώρα απαίτηση για μεμονωμένη ανάλυση ορατότητας για κάθε νέο έργο, (iii) έχουν καλύτερη συμβατότητα με τις διαδικασίες συμμετοχικού σχεδιασμού, καθώς μπορούν να επιτρέψουν την συμμετοχή των τοπικών κοινοτήτων στον καθορισμό των σημείων και περιοχών του τοπίου οι οποίες θα συμπεριληφθούν στους χάρτες (iv) οι χάρτες που προκύπτουν από αντίστροφες αναλύσεις ορατότητας αφορούν ακόμα και μεγάλες χωρικές κλίμακες (πχ. εθνική κλίμακα ή κλίμακα διοικητικής περιφέρειας) και άρα μπορούν να χρησιμοποιηθούν σε πολυκριτιριακές αναλύσεις που διερευνούν πιθανές τοποθεσίες για νέα έργα συνήθως σε τέτοιες κλίμακες. Κάτι τέτοιο είναι δυνατό στις συμβατικές αναλύσεις ορατότητας οι οποίες επικεντρώνονται αναγκαστικά σε κάποιο συγκεκριμένο έργο.

Στο πλαίσιο της διατριβής, η μέθοδος της αντίστροφης ανάλυσης ορατότητας εφαρμόστηκε ενδεικτικά για την Περιφέρεια της Θεσσαλίας, στην Ελλάδα. Συγκεκριμένα διαμορφώθηκαν χάρτες Αντίστροφων Ζωνών Θεωρητικής Ορατότητας (Α-ΖΘΟ) (βλ. Εικόνα 3) οι οποίοι στη συνέχεια χρησιμοποιήθηκαν για την πρόβλεψη των οπτικών επιπτώσεων σε προστατευόμενα τοπία της περιφέρειας από προτεινόμενα έργα αιολικής ενέργειας.

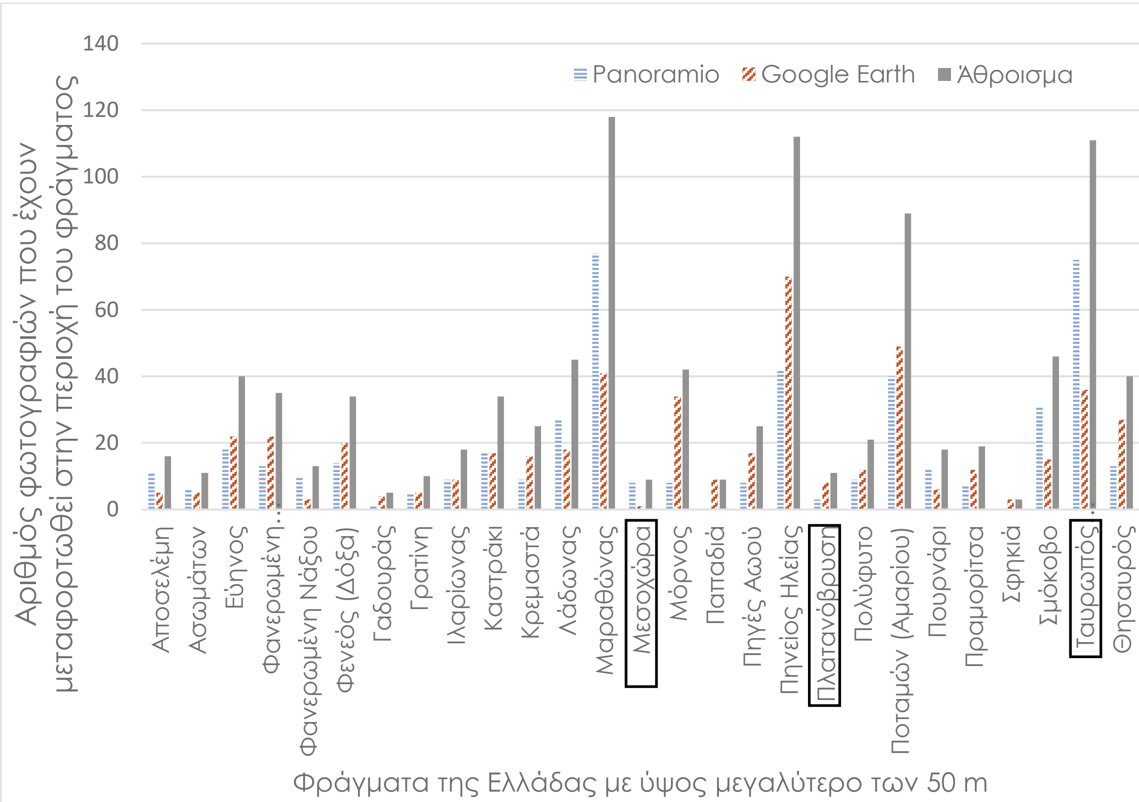


Εικόνα 3. Χάρτες Αντιστρόφων Ζωνών Θεωρητικής Ορατότητας (Α-ΖΘΟ) για την προστασία σημείων και περιοχών σημαντικών για το τοπίο της Περιφέρειας Θεσσαλίας από την οπτική όχληση από αιολικά έργα. Οι επιμέρους αναλύσεις για τους διαφορετικούς τύπους σημείων και περιοχών παρουσιάζονται αριστερά και οι τελικοί συγκεντρωτικοί χάρτες Α-ΖΘΟ δεξιά. Ο άνω χάρτης αναφέρεται σε ανάλυση που έγινε με όριο θεωρητικής ορατότητας των παρατηρητών ίσο με 10 km ενώ ο κάτω χάρτης για όριο 30 km.

ΣΥΝΟΨΗ ΜΕΡΟΥΣ III

Διερεύνηση της συνεισφοράς και των δυνατοτήτων επέκτασης της εφαρμογής αρχιτεκτονικών μελετών

Αναφερόμενοι πλέον στην κλίμακα της περιοχής κατασκευής του έργου, στο μέρος III διερευνήσαμε τη συνεισφορά των αρχιτεκτονικών μελετών των έργων υποδομής στην βελτίωση της κοινής γνώμης που λαμβάνουν, και κατ' επέκταση δηλαδή στο μετριασμό των επιπτώσεών τους στο τοπίο. Για το σκοπό αυτό, επικεντρωθήκαμε στα φράγματα, ως παραδειγματική διερεύνηση. Τα φράγματα παρουσιάζουν διεθνώς μια πληθώρα παραδειγμάτων εφαρμογής αρχιτεκτονικών μελετών κα μελετών τοπίου διαφορετικού τύπου και έκτασης. Διαμορφώσαμε λοιπόν μια παγκόσμια τυπολογία πρακτικών αρχιτεκτονικού σχεδιασμού σε φράγματα, συγκεντρώνοντας μια λίστα από 53 φράγματα από όλες τις κατοικημένες ήπειρούς. Στη συνέχεια, διερευνήσαμε τις εφαρμογές αυτής της τυπολογίας από άποψη κόστους-οφέλους, δίνοντας έμφαση αφενός στην συνεισφορά των μελετών στην βελτίωση της κοινής γνώμης για τα έργα και αφετέρου στο κόστος και τις τεχνικές απαιτήσεις για την εφαρμογή τέτοιων μελετών.



Εικόνα 4. Αριθμός μεταφορτωμένων φωτογραφιών στην εγγύτητα φραγμάτων, όπως μετρήθηκε από τις βάσεις δεδομένων γεωαναφερμένων φωτογραφιών Panoramio (δεδομένα 2016) και Google Earth (δεδομένα 2019). Τα ονόματα των φραγμάτων τα οποία βρέθηκαν να περιλαμβάνουν στοιχεία αρχιτεκτονικού ή τοπιακού σχεδιασμού παρουσιάζονται μέσα σε μαύρο περίγραμμα και σχολιάζεται ότι σε αυτά είναι και τα έργα για τα οποία εντοπίστηκε και ο μεγαλύτερος αριθμός μεταφορτωμένων φωτογραφιών.

Η έρευνα έδειξε ότι εφαρμογή αρχιτεκτονικών μελετών και μελετών αρχιτεκτονική τοπίου:

(i) Μπορεί να βελτιώσει μετρήσιμα την κοινή γνώμη της κοινωνίας για τα έργα υποδομής στα οποία εφαρμόζονται αυτές οι μελέτες. Αυτό παρατηρήθηκε τόσο μέσω της ανάλυσης της διεθνούς βιβλιογραφίας και τον εντοπισμό δεκάδων θετικών αναφορών σε φράγματα στο οποία είχαν εφαρμοστεί αρχιτεκτονικές μελέτες όσο και μέσω μιας επιπλέον στοχευμένης σύγκρισης που πραγματοποιήθηκε για τα ελληνικά φράγματα (βλ. Εικόνα 4)

(ii) Δεν υφίστανται ανυπέρβλητοι τεχνικοί ή οικονομικοί περιορισμοί στην ευρύτερη εφαρμογή αρχιτεκτονικών μελετών και μελετών αρχιτεκτονικής τοπίου στα έργα υποδομής. Συγκεκριμένα, παρατηρήθηκε ότι το κόστος της εφαρμογής τέτοιου τύπου μελετών κυμαίνεται σημαντικά ανάλογα με τις σχεδιαστικές επιλογές, αλλά παράλληλα υπάρχουν αρκετά παραδείγματα εφαρμογών με χαμηλό κόστος που μπορούν να αποτελέσουν υπόδειγμα για αντίστοιχες μελλοντικές μελέτες. Περαιτέρω η πληθώρα περιπτώσεων αρχιτεκτονικής επεξεργασίας φραγμάτων η οποία εξετάστηκε δεν κατέδειξε κάποια σημαντική τεχνική δυσκολία στην εφαρμογή αρχιτεκτονικών μελετών.

Υποστηρίζεται λοιπόν συνολικά, ότι οι αρχιτεκτονικές μελέτες μπορούν και πρέπει να εφαρμοστούν περισσότερο στα έργα υποδομής, στα οποία αυτό είναι δυνατό.

ΣΥΜΠΕΡΑΣΜΑΤΑ ΚΑΙ ΠΡΩΤΟΤΥΠΑ ΣΗΜΕΙΑ

Τα βασικά συμπεράσματα και σημεία πρωτοτυπίας της εργασίας είναι τα ακόλουθα:

Μέρος I

Η ύπαρξη αβεβαιότητας σε σχέση με την αντικειμενικότητα και την χωρική διάσταση των λεγόμενων «επιπτώσεων των έργων υποδομής στο τοπίο», δυσχεραίνει την αποτελεσματική αντιμετώπιση τους και συμβάλλει στη διαιώνιση ενός φαύλου κύκλου κοινωνικών συγκρούσεων και αναπτυξιακής διαταραχής. Ένα αρχικό σημείο πρωτοτυπίας της παρούσας διατριβής, είναι η αξιολόγηση των επιπτώσεων των έργων υποδομής στο τοπίο ολιστικά, αναλύοντας τα διαθέσιμα παγκόσμια δεδομένα και τη διεθνή βιβλιογραφία και συνδυάζοντας τόσο χωρικούς-ποσοτικούς δείκτες όσο και αντιληπτικούς-ποιοτικούς δείκτες. Με αυτό τον τρόπο καλύπτεται όλο το εύρος των εν λόγω επιπτώσεων και αξιοποιούνται πραγματικά δεδομένα έναντι θεωρητικών εκτιμήσεων. Συγκεκριμένα, η συγκριτική αξιολόγηση των διαφορετικών τύπων έργων υποδομής ως προς τις επιπτώσεις του στο τοπίο υλοποιήθηκε μέσω του εντοπισμού και της ανάλυσης τριών δεικτών οι οποίοι αξιολογήθηκαν ως χαρακτηριστικοί αυτών επιπτώσεων: Τη χρήση γης των έργων, την περιοχή-έκταση της ορατότητάς τους και την κοινή γνώμη της κοινωνίας για τις επιπτώσεις των έργων στο τοπίο. Αναλύοντας παγκόσμια δεδομένα και τη διεθνή βιβλιογραφία σε σχέση με αυτούς τους δείκτες κατέστη δυνατό να ποσοτικοποιηθούν και να συγκριθούν οι τυπικές επιπτώσεις των βασικών έργων ΑΠΕ στο τοπίο, δηλαδή των υδροηλεκτρικών φραγμάτων, των έργων αιολικής ενέργειας και των έργων ηλιακής ενέργειας. Αναδείχθηκαν λοιπόν γενικότερα οι βασικοί άξονες που διαμορφώνουν την επίπτωση των έργων στο τοπίο και ειδικότερα οι λόγοι για τους οποίους τα αιολικά έργα δημιουργούν τις πιο έντονες τροποποιήσεις στα τοπία, ακολουθούμενα από τα φωτοβολταϊκά και τα υδροηλεκτρικά έργα, κατά σειρά. Τα συμπεράσματα του Μέρους I της έρευνας παρουσιάζονται και πιο αναλυτικά στην Ενότητα 5.1 των Συμπερασμάτων της διατριβής.

Μέρος II

Σε σχέση με τον χωρικό σχεδιασμό για την ένταξη των έργων υποδομής στο τοπίο η διατριβή παρουσιάζει πρωτοτυπία ως προς τον εντοπισμό βασικών περιορισμών που βαραίνουν τις πρακτικές που εφαρμόζονται μέχρι σήμερα και την πρόταση λύσεων για την υπέρβαση τους. Συγκεκριμένα, η αντιστροφή των συμβατικών αναλύσεων ορατότητας προτάθηκε και αναλύθηκε ως μια σημαντική μεθοδολογική τροποποίηση η οποία μπορεί να οδηγήσει στην επίλυση των μέχρι τώρα θεμάτων αυτών των αναλύσεων. Συγκεκριμένα, παρόλο που οι αναλύσεις ορατότητας αποτελούν μέχρι σήμερα το βασικότερο εργαλείο χωρικού σχεδιασμού για την μετρίαση των επιπτώσεων των έργων υποδομής, βαρύνονται από σημαντικούς περιορισμούς ως προς τη ικανότητα ουσιαστικής πρόβλεψης των επιπτώσεων των έργων και του φόρτου εργασίας που απαιτούν. Συγκεκριμένα, η έρευνα απέδειξε τόσο μέσα από θεωρητικές προσεγγίσεις όσο και από πρακτική εφαρμογή της προτεινόμενης μεθοδολογικής βελτίωσης ότι η αντιστροφή των αναλύσεων ορατότητας (i) επιτρέπει την πρόβλεψη των επιπτώσεων των έργων στο τοπίο από πρώιμα στάδια σχεδιασμού ή διερεύνησης τους, κάτι το οποίο μέχρι σήμερα δεν ήταν δυνατό, (ii) μπορεί να οδηγήσει στην κατάργηση της απαίτησης για μεμονωμένη ανάλυση ορατότητας σε κάθε έργο ΑΠΕ, έναντι μια συνολικής επιταχυμένης τέτοιες ανάλυσης στην κλίμακα μιας ολόκληρης περιφέρειας ή κράτους (iii) αυξάνει τη συμβατότητα των αναλύσεων ορατότητας με συμμετοχικές διαδικασίες σχεδιασμού, οι οποίες προτείνονται στην διεθνή βιβλιογραφία ως ιδιαίτερα σημαντικές στο πλαίσιο της προσπάθειας κατευνασμού των αντιδράσεων των τοπικών κοινωνιών απέναντι σε έργα υποδομής, και (iv) δημιουργούν χάρτες οι οποίοι μπορούν να αξιοποιηθούν στο πλαίσιο πολυκριτηριακών αναλύσεων είτε και ανεξάρτητα, από οποιαδήποτε ενδιαφερόμενα μέρη στην ανάπτυξη των έργων υποδομής, βοηθώντας στην διερεύνηση πιθανών θέσεων νέων έργων. Τα πλεονεκτήματα αυτά αναλύονται και σε μεγαλύτερη λεπτομέρεια στην Ενότητα 5.2 των Συμπερασμάτων της διατριβής.

Μέρος ΙΙΙ

Ένα ακόμα σημείο πρωτοτυπίας της εργασίας είναι η αξιολόγηση της χρησιμότητας της εφαρμογής μελετών αρχιτεκτονικού σχεδιασμού σε έργα υποδομής και η κριτική διερεύνηση της πιθανής μελλοντικής επεκτασιμότητας τους, στη βάση ανάλυσης οφέλους-κόστους. Η διερεύνηση αυτής της πτυχής του σχεδιασμού των έργων υποδομής κρίθηκε σημαντική, καθώς, μέχρι σήμερα, σπάνια υλοποιούνται αρχιτεκτονικές μελέτες για έργα υποδομής. Περαιτέρω, ακόμα και στην επιστημονική κοινότητα τα οφέλη αυτών των μελετών αλλά και οι τεχνικές και οικονομικές απαιτήσεις της εφαρμογής τους δεν έχουν αναλυθεί εκτεταμένα. Για το λόγο αυτό, πραγματοποιήθηκε στο πλαίσιο της εργασίας μια στοχευμένη διερεύνηση της εφαρμογής αρχιτεκτονικού σχεδιασμού σε έργα υποδομής, αξιοποιώντας διεθνή δεδομένα από την εφαρμογή τέτοιων μελετών σε φράγματα. Η ανάλυση αυτή επικεντρώθηκε τόσο στην ικανότητα της αρχιτεκτονικής να βελτιώσει την κοινή γνώμη για τα έργα υποδομής όσο και στις δυνατότητες επέκτασής της εφαρμογής αρχιτεκτονικών μελετών στα έργα υποδομής μεγάλης κλίμακας. Ιδιαίτερη έμφαση δόθηκε στη διερεύνηση του κόστους και των τεχνικών προκλήσεων μια τέτοιας προσπάθειας. Όπως παρουσιάζεται λεπτομερώς στην Ενότητα 5.3 των Συμπερασμάτων της διατριβής, συμπεραίνεται ότι η εφαρμογή αρχιτεκτονικών μελετών και μελετών αρχιτεκτονικής τοπίου βελτιώνει μετρήσιμα την κοινή γνώμη για τα έργα υποδομής και ότι οι μελέτες αυτές δεν σχετίζονται απαραίτητα με σημαντικές απαιτήσεις πόρων και απαιτητικές επιπρόσθετες τεχνικές αναλύσεις.

Συνολικά

Τέλος, η πρωτοτυπία της εργασίας αφορά και το ερευνητικό αντικείμενο αυτό καθαυτό καθώς και την καταληκτική σύνθεση των επιμέρους συμπερασμάτων της διατριβής. Μέχρι σήμερα, παρόλο που η ένταξη των έργων υποδομής στο τοπίο έχει διερευνηθεί σε επιστημονικές εργασίες, η διερεύνηση αυτή είναι συνήθως αποσπασματική. Εξειδικεύεται δηλαδή σε μεμονωμένα έργα και συγκεκριμένα ειδικά ζητήματα χωρίς όμως να έχει προταθεί μέχρι σήμερα μια συγκεντρωτική μεθοδολογία – στρατηγική, που να συνδυάζει (α) ποικίλες χωρικές κλίμακες, (β) πολλαπλούς επιστημονικούς κλάδους και (γ) την δυνατότητα εφαρμογής σε διάφορους τύπους έργων υποδομής. Στην παρούσα έρευνα, προτείνεται μια ολιστική στρατηγική για την ένταξη των έργων υποδομής στο τοπίο, η οποία συνδυάζει όλα τα παραπάνω (α έως γ). Συγκεκριμένα, περιλαμβάνει την ανάλυση των διαθέσιμων δεδομένων και της επιστημονικής βιβλιογραφίας σε παγκόσμια κλίμακα, τον χωρικό σχεδιασμό των έργων, σε περιφερειακή ή εθνική κλίμακα και, τέλος, τον αρχιτεκτονικό σχεδιασμό, στην κλίμακα της περιοχής έργου. Με αυτόν τον τρόπο καλύπτεται το πλήρες φάσμα των διαδικασιών ανάλυσης και σχεδιασμού για την ένταξη των έργων υποδομής στο τοπίο οι οποίες και ενοποιούνται σε μια δομημένη στρατηγική. Η στρατηγική αυτή μπορεί να χρησιμοποιηθεί για τη βελτίωση της ένταξης οποιουδήποτε τύπου έργου υποδομής στο τοπίο, αξιολογώντας αρχικά την δριμύτητα των τυπικών επιπτώσεων του εν λόγω έργου και κατευθύνοντας στη συνέχεια τις προσπάθειες μετρίασης των επιπτώσεων του σε εξειδικευμένα μέτρα χωρικού ή αρχιτεκτονικού σχεδιασμού ή συνδυασμού και των δυο (βλ. Ενότητα 5.4 των Συμπερασμάτων της διατριβής).

Appendix H – Complete list of publications carried out during the PhD research

The list below contains all the publications of the author carried out during his PhD research.

Publications in Scientific Journals

Ioannidis, R., Koutsoyiannis, D., & Sargentis, G.-F. (2022). Landscape design in infrastructure projects-is it an extravagance? A cost-benefit investigation of practices in dams. Landscape Research. https://doi.org/10.1080/01426397.2022.2039109

Ioannidis, R., Mamassis, N., Efstratiadis, A., & Koutsoyiannis, D. (2022). Reversing visibility analysis: Towards an accelerated a priori assessment of landscape impacts of renewable energy projects. Renewable and Sustainable Energy Reviews, 161, 112389. https://doi.org/10.1016/j.rser.2022.112389

Ioannidis, R., & Koutsoyiannis, D. (2020). A review of land use, visibility and public perception of renewable energy in the context of landscape impact. Applied Energy, 276, 115367. https://doi.org/10.1016/j.apenergy.2020.115367

Ioannidis, R., Iliopoulou, T., Iliopoulou, C., Katikas, L., Petsou, A., Merakou, M.-E., Asimomiti, M.-E., Pelekanos, N., Koudouris, G., Dimitriadis, P., Plati, C., Vlahogianni, E.I., Kepaptsoglou, K., Mamassis, N., Koutsoyannis, D., 2019. Solar-powered bus route: introducing renewable energy into a university campus transport system. Adv. Geosci. 49, 215–224. https://doi.org/10.5194/adgeo-49-215-2019

Sargentis, G.-F., **Ioannidis, R.**, Bairaktaris, I., Frangedaki, E., Dimitriadis, P., Iliopoulou, T., Koutsoyiannis, D., & Lagaros, N. D. (2022). Wildfires vs. Sustainable Forest Partitioning. Conservation, 2(1), 195–218. https://doi.org/10.3390/conservation2010013

Sargentis, G.-F., **Ioannidis, R.**, Iliopoulou, T., Dimitriadis, P., & Koutsoyiannis, D. (2021). Landscape Planning of Infrastructure through Focus Points' Clustering Analysis. Case Study: Plastiras Artificial Lake (Greece). Infrastructures, 6(1), 12. https://doi.org/10.3390/infrastructures6010012

Sargentis, G.-F., **Ioannidis, R.**, Karakatsanis, G., Sigourou, S., Lagaros, N.D., Koutsoyiannis, D., 2019b. The Development of the Athens Water Supply System and Inferences for Optimizing the Scale of Water Infrastructures. Sustainability 11, 2657. https://doi.org/10.3390/su11092657

Sargentis, G.-F., Dimitriadis, P., **Ioannidis, R.**, Iliopoulou, T., Koutsoyiannis, D., 2019a. Stochastic evaluation of landscapes transformed by renewable energy installations and civil works. Energies 12. https://doi.org/10.3390/en12142817

Sargentis, G.-F., Dimitriadis, P., **Ioannidis, R.**, Iliopoulou, T., Frangedaki, E., Koutsoyiannis, D., 2020a. Optimal utilization of water resources for local communities in mainland Greece (case study of Karyes, Peloponnese). Procedia Manufacturing, The 1st International Conference on

Optimization-Driven Architectural Design (OPTARCH 2019) 44, 253–260. https://doi.org/10.1016/j.promfg.2020.02.229

Klousakou, E., Chalakatevaki, M., Dimitriadis, P., Iliopoulou, T., **Ioannidis, R.**, Karakatsanis, G., Efstratiadis, A., Mamasis, N., Tomani, R., Chardavellas, E., & Koutsoyiannis, D. (2018). A preliminary stochastic analysis of the uncertainty of natural processes related to renewable energy resources. Advances in Geosciences, 45, 193–199. https://doi.org/10.5194/adgeo-45-193-2018

Book Chapters

Sargentis, G.-F., **Ioannidis, R.**, Chiotinis, M., Dimitriadis, P., Koutsoyiannis, D., 2021. Aesthetical Issues with Stochastic Evaluation, in: Belhi, A., Bouras, A., Al-Ali, A.K., Sadka, A.H. (Eds.), Data Analytics for Cultural Heritage: Current Trends and Concepts. Springer International Publishing, Cham, pp. 173–193. https://doi.org/10.1007/978-3-030-66777-1_8

Mamassis, N., Efstratiadis, A., Dimitriadis, P., Iliopoulou, T., **Ioannidis, R.**, Water and Energy, Handbook of Water Resources Management: Discourses, Concepts and Examples, edited by Bogardi, J.J., Tingsanchali, T., Nandalal, K.D.W., Gupta, J., Salamé, L., van Nooijen, R.R.P., Kolechkina, A.G., Kumar, N., and Bhaduri, A., Chapter 20, 617–655, doi:10.1007/978-3-030-60147-8_20, Springer Nature, Switzerland, 2021, (in press).

Fully evaluated conference publications

Ioannidis. R., Mamassis, N., Moraitis, K., & Koutsoyiannis, D. (2022). Προτάσεις χωρικού και αρχιτεκτονικού σχεδιασμού για τη βιώσιμη ένταξη των έργων ανανεώσιμης ενέργειας στο ελληνικό τοπίο. [Spatial planning and architectural design proposals for the sustainable integration of renewable energy works into the Greek landscape] Research and Action for the Regeneration of Mountainous and Isolated Areas. 10th Conference of MIRC (Metsovion Interdisciplinary Research Center) - NTUA, Metsovo.

Ioannidis, R., Iliopoulou, C., Iliopoulou, T., Katikas, L., Dimitriadis, P., Plati, C., Vlahogianni, E.I., Kepaptsoglou, K., Mamassis, N., Koutsoyannis, D., 2020b. Solar-electric buses for a university campus transport system, in: Advances in Geosciences. Presented at the Transportation Research Board (TRB) 99th Annual Meeting, Washington, D.C.

Ioannidis, R., Koutsoyiannis, D., 2017. Η αρχιτεκτονική και τοπιακή αξία των φραγμάτων: Από τα διεθνή παραδείγματα στις προτάσεις για την Ελλάδα [The architectural and landscape value of dams: From international examples to proposals for Greece], in: Proceedings of 3rd Hellenic Conference on Dams and Reservoirs. Presented at the 3rd Hellenic Conference on Dams and Reservoirs, Hellenic Commission on Large Dams, Zappeion, Athens.

Conference publications and presentations with evaluation of abstract

Ioannidis, R., Koutsoyiannis, D., 2017. Evaluating the landscape impact of renewable energy

plants, in: Geophysical Research Abstracts. Presented at the EGU General Assembly 2017, Vienna.

Ioannidis, R., Koutsoyiannis, D., 2017. Η αρχιτεκτονική και τοπιακή αξία των φραγμάτων: Από τα διεθνή παραδείγματα στις προτάσεις για την Ελλάδα [The architectural and landscape value of dams: From international examples to proposals for Greece], in: Proceedings of 3rd Hellenic Conference on Dams and Reservoirs. Presented at the 3rd Hellenic Conference on Dams and Reservoirs, Hellenic Commission on Large Dams, Zappeion, Athens.

Ioannidis, R., Dimitriadis, P., Meletopoulos, I.T., Sargentis, G.F., Koutsoyiannis, D., 2020a. Investigating the spatial characteristics of GIS visibility analyses and their correlation to visual impact perception with stochastic tools, in: Geophysical Research Abstracts, Vol. 22. Presented at the EGU General Assembly 2020, European Geosciences Union, Vienna. https://doi.org/10.5194/egusphere-egu2020-18212

Ioannidis, R., Dimitriadis, P., Sargentis, G.-F., Frangedaki, E., Iliopoulou, T., Koutsoyiannis, D., 2019. Stochastic similarities between natural processes and art: Application in the analysis and optimization of landscape aesthetics of renewable energy and civil works, in: European Geosciences Union General Assembly 2019. EGU.

Manta, E., **Ioannidis, R.**, Sargentis, G.-F., Efstratiadis, A., 2020. Aesthetic evaluation of wind turbines in stochastic setting: Case study of Tinos island, Greece, in: European Geosciences Union General Assembly 2020. https://doi.org/10.5194/egusphere-egu2020-5484

Sargentis, G.-F., **Ioannidis, R.**, Meletopoulos, I.T., Dimitriadis, P., Koutsoyiannis, D., 2020b. Aesthetical issues with stochastic evaluation., in: Geophysical Research Abstracts, Vol. 22. Presented at the European Geosciences Union General Assemply 2020, European Geosciences Union, VIenna. https://doi.org/10.5194/egusphere-egu2020-19832

Sargentis, G.-F., **Ioannidis, R.**, Karakatsanis, G., Koutsoyiannis, D., 2018b. The scale of infrastructures as a social decision. Case study: dams in Greece, in: European Geosciences Union General Assembly 2018. EGU.

Sako, M., Tsoli, E., **Ioannidis, R.**, Frangedaki, E., Sargentis, G.-F., Koutsoyiannis, D., 2019. Optimizing the size of Hilarion dam with technical, economical and environmental parameters, in: Geophysical Research Abstracts. Presented at the European Geosciences Union General Assembly 2019, European Geosciences Union, Vienna.

Sargentis, G.-F., Dimitriadis, P., Iliopoulou, T., **Ioannidis, R.**, Koutsoyiannis, D., 2018a. Stochastic investigation of the Hurst-Kolmogorov behaviour in arts, in: European Geosciences Union General Assembly 2018. EGU.

Karataraki, M., Thanasko, A., Printziou, K., Koudouris, G., **Ioannidis, R.**, Iliopoulou, T., Dimitriadis, P., Plati, C., Koutsoyiannis, D., 2019. Campus solar roads: a feasibility analysis, in: European Geosciences Union General Assembly 2019. EGU.

Petsou, A., Merakou, M.-E., Iliopoulou, T., Iliopoulou, C., Dimitriadis, P., **Ioannidis, R.**, Kepaptsoglou, K., Koutsoyiannis, D., 2019. Campus solar roads: Optimization of solar panel and electric charging station location for university bus route, in: European Geosciences Union General Assembly 2019. EGU.

Sigourou, S., Dimitriadis, P., Iliopoulou, T., **Ioannidis, R**., Skopeliti, A., Sakellari, K., Karakatsanis, G., Tsoulos, L., Koutsoyiannis, D., 2018a. Comparison of climate change vs. urbanization, in: European Geosciences Union General Assembly 2018. EGU.

Sigourou, S., Dimitriadis, P., Iliopoulou, T., **Ioannidis, R.**, Skopeliti, A., Sakellari, K., Karakatsanis, G., Tsoulos, L., Koutsoyiannis, D., 2018b. Statistical and stochastic comparison of climate change vs. urbanization, in: European Geosciences Union General Assembly 2018. EGU.

Klousakou, Elli, Chalakatevaki, M., Dimitriadis, P., Iliopoulou, T., **Ioannidis, R.**, Karakatsanis, G., Efstratiadis, A., Mamasis, N., Tomani, R., Chardavellas, E., Koutsoyiannis, D., 2018. A preliminary stochastic analysis of the uncertainty of natural processes related to renewable energy resources, in: Advances in Geosciences. Presented at the European Geosciences Union General Assembly 2018, EGU Division Energy, Resources & Environment (ERE) - EGU General Assembly 2018, Vienna, Austria, 8–13 April 2018, Copernicus GmbH, pp. 193–199. https://doi.org/10.5194/adgeo-45-193-2018

Klousakou, E., Chalakatevaki, M., Tomani, R., Dimitriadis, P., Efstratiadis, A., Iliopoulou, T., **Ioannidis, R.**, Mamassis, N., Koutsoyiannis, D., 2018. Stochastic investigation of the uncertainty of atmospheric processes related to renewable energy resources, in: European Geosciences Union General Assembly 2018. EGU.

Invited conference and seminar talks

Koutsoyiannis, D., **Ioannidis, R.**, 2017. Η ενεργειακή, περιβαλλοντική και αισθητική υπεροχή των μεγάλων υδροηλεκτρικών έργων έναντι των άλλων έργων ανανεώσιμης ενέργειας [The energetic, environmental and aesthetic superiority of large hydropower projects over other renewable energy projects], in: Proceedings of 3rd Hellenic Conference on Dams and Reservoirs. Presented at the 3rd Hellenic Conference on Dams and Reservoirs, Hellenic Commission on Large Dams, Zappeion, Athens.

Ioannidis, R., 2018. Ο αρχιτεκτονικός και τοπιακός σχεδιασμός των φραγμάτων: Από τα διεθνή παραδείγματα στις προτάσεις για την Ελλάδα [Architectural and landscape design of dams: From international examples to proposals for Greece], Invited lecture in the course "History and theory of landscape: Schematization through landscape interpretation" of the post-graduate program of the School of Architecture NTUA, School of Architecture NTUA, Athens.

Ioannidis, R., 2018. Ο αρχιτεκτονικός και τοπιακός σχεδιασμός των φραγμάτων: Από τα διεθνή παραδείγματα στις προτάσεις για την Ελλάδα [Architectural and landscape design of dams: From international examples to proposals for Greece], Invited lecture in the course "Architectural design V-VIIα" of the under-graduate program of the Department of Architecture of the University of Thessaly, University of Thessaly, Volos (http://www.arch.uth.gr/el/activities/1913)