C Journal of Carbon Research

MDPI

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The Complex Case of Carbon-Measuring Tools in Landscape Architecture

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Abstract: As the world takes a more strategic approach to the climate crisis, carbon in its various forms has become a key factor in ascertaining the sustainability of the landscape. Landscape has been recognised as a resource and mechanism for addressing the role of carbon in the environment, with literature focused on the landscape's carbon capacity as interconnected systems of land, soil, water and organic life. It has, however, largely neglected the crucial role of the cultural, social and historical aspects of the landscape, particularly at the level of design. This paper acknowledges and explores the complexity of landscape as a natural-cultural system with the consequent difficulties this poses in legislating, calculating and measuring carbon for global, national and local targets for low/zero carbon and carbon offsetting. The discussion takes place in the arena of landscape architecture at regional/city/local scales and the life-cycle of a project including its integration into its wider social, cultural and environmental setting. This paper develops the discourse in three major areas: first, by examining how the complexity of landscape is obscured in the context of carbon-measuring tools used in landscape architecture; secondly exploring one such tool in practice to demonstrate how site-specific design decisions can impact carbon levels; and third by proposing how an integrated understanding of landscape can be built into projects to embrace complexity and operationalise low carbon visions.

Keywords: carbon; landscape; carbon tools; landscape design; landscape architecture; climate crisis; mitigation; policy; cities; carbon interpretation; whole-life carbon

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Citation: Nikologianni, A.; Albans, A. The Complex Case of Carbon-Measuring Tools in Landscape Architecture. *C* **2023**, *9*, 69. https://doi.org/10.3390/c9030069

Academic Editors: Manuel Fernando Ribeiro Pereira and Sergey Mikhalovsky

Received: 31 March 2023
Revised: 28 June 2023
Accepted: 3 July 2023
Published: 12 July 2023

1. Introduction

Low/net zero carbon concepts are being embedded in spatial planning and landscape design as integral elements in the creation of sustainable cities [1–3]. To this end, when the landscape is significantly altered such as by urban design, infrastructure or landscape architectural intervention, embedded carbon, carbon emissions and/or sequestration and environmental impact can be calculated and monitored by a number of industry-specific tools (Section 4 below). The aim of this paper is to explore the complexity surrounding industry-specific carbon measurement tools in landscape architecture and call for their further development and refinement when accounting for place-based specificity. This necessitates challenging the current siloed way of measuring carbon levels as discreet construction projects divorced from their socio-cultural and natural systems, and the impact this has on the successful creation of sustainable cities. Carbon calculation/measurement tools for the construction industries are widely available, even if their uptake is slow [4] and measurements complex [5], but very few focus on landscape architecture and the challenges of carbon calculation in open spaces and landscape developments. Tools designed to observe carbon levels associated with the construction and implementation of landscape architecture projects serve a niche that expand on those available in other industries [6–8] but differ enough to warrant separate attention here.

Carbon calculation will be discussed together with the interpretation of carbon within landscape architecture and the importance of evaluating what this means for our landscapes and future cities. Within the landscape architecture industry, carbon is still often perceived in narrow terms, either abstractly as 'something that needs reducing' or else as a scientific element which exists in many forms, but without considering its relation to the landscape and the ways in which such an element can take shape in a landscape development.

This paper has taken steps to observe carbon calculation methods within the landscape architecture profession and associated industries, and seeks a wider debate regarding the role of landscape in the climate crisis (in relation to carbon and CO_2). Set within a wider debate regarding the disaggregation of landscape into component silos that position landscape not as the vast, integrated infrastructure upon which we depend, but as discrete entities such as hydrology, biomass, construction and emissions, this paper demonstrates how carbon monitoring tools have yet to fully accommodate the complexity of urban landscapes. Reference is also made to the role of policy and targets which underpin the application of these tools, and to the scarcity of literature relating to the same.

Fundamental to this enquiry is a lack of clarity or agreement [9,10] over what constitutes landscape in urban environments, and therefore what carbon means through a 'landscape lens'. Taking the European Landscape Convention [11,12] as a basis, the urban landscape is understood not as the 'green' parts of a city, but the city as a whole. An urban landscape is a complex matrix of form and function which makes it challenging for those utilizing carbon measurement tools to produce comprehensive and informed carbon accounts. Perpetuating this complexity, as Meng and Chen [13] explain, certain urban-landscape typologies (such as parks and gardens) have multiple functions such as releasing oxygen, fixing or reducing carbon emissions as well as dealing with the urban heat island effect and energy consumption.

The United Nations have already projected that 68% of the world population will live in urban areas by 2050, and although occupying only 3% of the earth's surface [14,15] they account for 70% of carbon dioxide emissions [16]. The landscape architecture profession is promoting environmentally sustainable urban development by demonstrating the importance of the landscape and its direct relation to the environment, place and people [11,17]. International and National Federations and Associations have taken steps to explore climate-positive design and better understand how landscape architecture can become more sustainable and with lower emissions. The International Federation of Landscape Architects (IFLA), the American Society of Landscape Architects (ASLA), the Australian Institute of Landscape Architects (AILA), the Landscape Institute UK (LI) have all published climate action plans [18–21] aiming to understand and evaluate how carbon can be tackled from a landscape point of view.

2. Methodology

The research underpinning this paper explores the importance and impact of carbon from a landscape architectural perspective and its associated industries including urban design, sustainable urban development and planning. Following an extended examination of the way carbon is addressed and impacts the landscape and planning disciplines, a significant gap has been identified in how carbon is understood and interpreted in the landscape. This gap is confirmed by a literature search of articles and books using the keywords 'carbon', 'landscape design', 'low carbon landscape', 'zero carbon landscape' and 'landscape architecture'. Although the terms carbon, low and zero carbon are trending in academic research and can be found in manuscripts, there is often no relevance to landscape architecture. For that reason we have specified that the search includes 'landscape' and 'carbon' in the titles of papers.

The ScienceDirect terms used to conduct the search are as follows:

- TITLE-ABS-KEY (carbon) AND TITLE-ABS-KEY (landscape) showing 220 results of which very few relevant to landscape architecture and design
- TITLE-ABS-KEY (low carbon) AND TITLE-ABS-KEY (landscape) showing 8 results
- TITLE-ABS-KEY (zero carbon) AND TITLE-ABS-KEY (landscape) showing 0 results

- TITLE-ABS-KEY (carbon) AND TITLE-ABS-KEY (landscape architecture) showing 0 results

The Google Scholar terms used to conduct the search are as follows:

- ALLINTITLE: (carbon) AND ALLINTITLE (landscape) showing 1650 results including citations of which few relevant to landscape architecture
- ALLINTITLE: (low carbon) AND ALLINTITLE (landscape) showing 92 results including citations
- ALLINTITLE: (zero carbon) AND ALLINTITLE (landscape) showing 8 results including citations
- ALLINTITLE: (carbon) AND ALLINTITLE (landscape architecture) showing 25 results including citations

Locating this discourse in context, the literature is discussed below with emphasis on the lack of clarity evident around the role and impact of carbon in the urban landscape and attempts to address the same through policy and guidance.

Acknowledging the wide availability of carbon calculation tools to suit specific industries or case-scenarios [22] (e.g., construction, buildings), this study narrows the focus to those tools designed for and widely used by landscape architects. However, the goal is to demonstrate the ability and importance of a landscape-led carbon calculation tool and not to provide a comparison of the tools themselves. Of the six key tools currently dealing with landscape or elements of landscape architecture (e.g., trees) the key characteristics are presented in a table below (Section 4). The two most recent tools are introduced by this paper, whilst the remaining four have been previously examined [23]. Following a brief industry-informed overview of the tools' effectiveness and applicability, the most comprehensive was selected to demonstrate its capabilities and limitations as a way of measuring carbon from the perspective of landscape architecture. The demonstration uses a real-life scenario of a small urban park in Greece, comparing the existing built form with a speculative alternative designed by Nikologianni for the purpose of this exercise. The case study is used to demonstrate how carbon can be integrated and interpreted in landscape architecture and the importance of acknowledging it in current and future schemes.

3. Landscape Complexity and Carbon

Rather than a collection of 'hard' and 'soft' materials that carbon-measuring tools are set to monitor, the authors understand landscape to be the vast, complex natural-cultural infrastructure within which life on earth operates [24]. Although landscape can be described in numerous ways, it is perhaps most succinctly defined by the Council of Europe as "an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors" [11]. This definition acknowledges the interconnection of the landscape with our cities and regions and covers natural, rural, urban and peri-urban areas. In making the case that the landscape does not stop at the edge of a town or city, it highlights the need to understand the interaction and impact of carbon across an incredibly complex milieu of land-use, typologies, systems and cultural interactions, which are not easily captured by extracting one site from the larger whole. It also hints at an understanding of landscape as relational, by which we mean that it is a material and a setting with which humanity interacts according to societal and cultural values and priorities. Humans have always interacted with the world around us: we've altered landform and ecologies for agriculture, habitation, infrastructure and as symbols of religion, power and wealth. The landscape around us is the physical outworking of our ideas about the land. In part therefore, the levels of carbon associated with the landscape can be understood as a manifestation of a society's relationship with the land because collectively, we have made decisions that variously release, embed or sequester carbon depending on what we choose to do with the land.

The limits inherent in assessing a specific section of a larger complex whole, combined with the focus on one aspect (carbon), can also perpetuate a reductive process that divides and disconnects landscape into a series of siloed concerns (biodiversity, economics, hydrology, culture, housing, health etc.) to be dealt with by distinct actors. The tools outlined below, by design, take account of static construction and vegetation materials, and are not currently able to monitor carbon as it flows in and out of a specific site (e.g., as sediment within hydrological systems), nor can they account for vegetation that is moved by fauna above and below ground. These natural systems do not start and end within the bounds of an individual site, but form part of a larger and more complex context. Socio-economic and cultural decisions also impact the landscape and its embedded carbon, such as planning laws which allow building over floodplains, the economics of exporting waste or importing food, and the observable landscape differences linked to those demonstrated by Indices of Multiple Deprivation [25,26].

For some, 'carbon' is quite a straightforward term relating to the chemical element, but within the realm of landscape architecture, the term can be variously interpretated. More than a decade ago, Selman [27] was stating that 'carbon neutrality' was a difficult and confusing term as it was mainly referring to fossil carbon reduction and Greenhouse Gas (GHG) emissions. In the past decade much progress has been made by scientists and industry professionals to understand fossil fuel emissions and how our cities and regions can reach net zero [28] In its latest report the IPCC [29] has stated that the total of net anthropogenic GHG emissions between 2010–2019 has unfortunately continued to rise and the average annual GHG emissions during that decade were higher than any previous. More positively, they also confirm that the rate of growth for GHG emissions was lower than in the previous decade (2000–2009). Following its previous report on global warming and the 1.5 °C target [30], the latest data show that the "global GHG emissions are projected to peak between 2020 and at the latest before 2025 in global modelled pathways that limit warming to 1.5 °C (>50%) [. . .] and in those that limit warming to 2 °C (>67%) and assume immediate action" [29].

As Ackerman et al. [31] suggest, designers, spatial planners and landscape architects are charged with the task of designing to mitigate all the environmental challenges we face, such as the temperature rise in cities, wildfires, flash flooding, the severe changes appearing in coastlines and more. It could be, as Moosavi et al. [32] state, that it is "often believed that green infrastructure assets are net carbon sinks and this may have contributed to the lack of consideration of embodied greenhouse gas emissions by landscape architects". Looking specifically into the built environment Ness and Xing [33] state that it is responsible for over 33% of GHG emissions, but with no more specific information differentiating emissions of different parts of the urban typology (housing, industry, parks, gardens, infrastructure etc.). In addition, these numbers are quite different from the figures given 15 years ago, where it was suggested that cities contributed about 75% of GHG emissions [34]. Could this be down to uncertainty of what we include as components of the built environment, or has the percentage actually dropped so quickly?

Although carbon can be measured accurately for emissions in energy, heating, buildings and more, when it comes to the landscape, there is still uncertainty about what a low carbon or carbon neutral landscape would require and what it would look like. Meng and Chen [13] make a significant point when stating that landscape designs are frequently high-carbon instead of low carbon or net zero variously due to ignorance of environmental context, natural systems or ecological value, and improper application of landscape materials. As a result, some landscape typologies such as parks or town-squares can become carbon sources, or embody more carbon than might be expected of a 'green space'. Even though landscape design is generally considered as a benefit to the environment, there are cases that its embodied carbon has the opposite effect.

Whilst challenging their definition of landscape, the authors do stand by Moosavi et al. [32] who argue that "the way we plan and design our landscapes (i.e., green and blue infrastructures, parks and urban open spaces) has to transform if we want to address global challenges such as climate change". Landscape designers, professionals, technicians and every spatially-concerned profession needs to understand and account for the net life-cycle of GHG emissions associated with design decisions and implementation. It is noted by this research that more recent attention on carbon by landscape professionals has highlighted the challenges associated with calculating carbon levels in landscape designs. Lin and Lin [35] explain that although embodied carbon research in construction is growing, it is still at an initial stage for the landscape profession. Existing literature on construction, also discusses embodied (EC) and operational (OC) carbon, but there is very limited information on how such terms connect to the landscape [36–38] and in most cases they are limited to construction materials [39]. In other cases, the classification examines built environment, but without revealing if landscape is considered a part of it or not in each study. Neighbourhood-scale is also believed to be a key step in environmental research for the built-environment [40], but it is also a scale that landscape architects very often operate.

Policy and Regulation Standards

IPCC makes it clear that policy plays a major role in addressing climate related issues, as it states that "without a strengthening in policies beyond those that are implemented by the end of 2020, GHG emissions are projected to rise beyond 2025, leading to a median global warming of 3.2 °C (2.2 to 3.5 °C) by 2100" [29]. Despite such warnings, most professional regulations relating to carbon in the urban environment come from the construction or building industries [17,27,41], with a notable lack of policy pertaining to landscape [23,42–44]. Lin and Lin make it clear that "there are currently no international calculation guidelines for carbon footprint exclusive to landscape, [and therefore] it is reasonable to assume that any landscaping LCA should follow EN15978" [35]. However, EN15978 consists of guidelines for EC calculations specific to the construction industry and therefore raises important questions about how much landscape architecture professionals have to compromise before landscape-specific regulations arise. Compounding this issue, landscape architects rely on 'Product, Construction Process, Use and End of Life' [35], regulations for life cycle assessment (LCA) based on ISO 14040 (1997) [45] and embodied carbon (EC) EN15978 [46] (replacing ISO 21931 (2010) [47]), all of which are designed for the construction industry, and miss key areas of landscape design and spatial planning.

With professional standards on carbon absent or ill-defined for landscape architects, the authors caution against a unified approach to achieving net zero landscapes at a global level, largely because landscape is entirely contextual and cannot be universally assessed. The methodologies and tools relating to embodied carbon are continuously developing, and need to take into consideration systems that "interact with the surrounding environment through energy exchange in the form of water, carbon, nutrients, organisms, materials" [48]. For a new-build landscape project, the carbon from five key stages is generally monitored:

a. strategic planning and policy,
b. design and documentation,
c. construction and emissions phase,
d. operational life of the landscape scheme,
e. demolition of the scheme (when this is projected).

It is important to note that even within this framework, the interpretation of what constitutes low or net zero carbon is left to landscape designers due to a lack of clear guidance.

Further research is urgently needed to develop and refine standards which balance the contextual sensitivity required for a landscape-led approach with robust-enough measures to avoid the misuse of necessarily flexible standards.

4. Carbon Assessment Tools in Landscape Architecture

In order to manage the complexity of a landscape system, the available tools isolate a new-build landscape from its context for the purpose of monitoring, which in and of itself is problematic because landscapes do not operate in isolation. Furthermore, in terms of measurement, current tools account for standardised carbon levels absorbed and released through the projected lifecycle of a new-build landscape (demolition, construction, maintenance etc.) and the vegetation planted therein. They do not or cannot—account for all other factors that play a role in the carbon within that landscape, such as the fauna existent in that place, that landscape's specific hydrological cycle, the varying climate and microclimatic factors, localised soil variation, or the biological, economic, political or social functions of human inhabitants and their various technologies.

As policy and regulations do not provide specific requirements and support for the landscape, it is inevitable that carbon calculation tools specifically designed for the landscape are limited. Until recently four tools focusing on carbon calculation with some spatial characteristics were available, but not all of them use a landscape-led approach [23]; one focuses on trees (i-Tree) and one being designed especially for landscape architects (Pathfinder). The Embodied Carbon in Construction Calculator (EC3) calculates carbon related to materials and construction and can be used in planning or procurement phase of a project. The Precinct Carbon Assessment (PCA) tool examines low-carbon development options, but focuses on buildings. However, two new tools have been developed recently with a focus on the landscape profession. Table 1 below, presents the 6 tools that have functions on spatial planning and carbon with three being very significant to landscape architecture and two mostly focusing on buildings. The i-tree tool is considered significant as it gives accurate information on trees, but it does not provide a holistic view for landscape designs.

Table 1. Selected tools and key elements.

Tools	Landscape Focus	Use/Applied to	Carbon Relevance	Previously Reviewed
Pathfinder	Very significant	Landscapes/Green Spaces	Calculates project sequestration	Existing
Landscape Carbon Calculator	Very significant	Landscape	Calculates carbon emissions and sequestration	New
Carbon Concience App	Very significant	Early Stage of planning and design	Calculates embodied, sequestered and stored carbon	New
i-Tree	Significant	Green Infrastructure (trees)	Calculates impact of trees	Existing
PCA	Less significant	Buildings	Calculates environmental elements of buildings	Existing
EC3	Less significant	Planning/Buildings	Calculates carbon related to materials and construction	Existing

The Pathfinder, i-Tree, PCA and EC3 tools above have been presented in previous research [23], but a short overview of the two new tools by this paper is considered necessary.

Developed by Elder Creek Landscapes, the Landscape Carbon Calculator (LCC) was selected by this study due to its landscape focus and offers 300 data inputs, tracks carbon footprint and sequestration. It uses the major landscape-industry categories such as grading, hardscape, drainage, irrigation, rain catchment, lighting, water features, plants, soils, mulch, transportation, deliveries and equipment. It also gives an indication of the sequestration for the design's planting areas. It is not clear if the tool has been tested outside the US, and therefore if the data used are relevant at a European or global scale, however its developers state that they have taken different metrics into consideration.

The Carbon Conscience App (CCA) focuses on the early stages of the design concept. It was designed to help with the preliminary planning decisions in order to improve the carbon footprint of a project. It has been developed by Sasaki and contrary to the other tools that focus on advanced designs, the CCA team explains that their focus has been the initial stages of a project, as these determine the impactful decisions for the environment. The interesting part of this tool is the holistic approach to carbon and its role in design. The tool does not limit itself to embodied carbon, but examines stored and sequestered carbon in living systems. This is also developed in the US and it is not confirmed if it has been tested outside the North American region.

Pathfinder Case Study

The scope of this research is not to compare the tools available, but to examine the importance of carbon in landscape architecture by presenting the tool's data and discussing how its interpretation will inform decision making in a project. The authors would like to make it clear that this is not a recommendation of one tool over another, but a case study using the most established tool to date. In this instance Climate Positive Design's Pathfinder tool has been selected for this demonstration because of its well-regarded software allowing for carbon calculation in landscape design. Described by its creators as a "back end calculation tool that computes greenhouse gas (GHC) emissions and sequestration associated with landscape projects" [49]. Pathfinder utilizes the following metrics (Figure 1) across an industry-standard project life cycle stage model using data from the Athena Impact Estimator and the Forest Service for sequestration data, with a verification of environmental consultants [50]. The tool's creators readily admit its limitations, stating that users needing a "more accurate inventory" should utilize itree, Athena, Tally, Gabi or SimaPro [51] suggesting a degree of inherent measurement ambiguity within the system. This is particularly concerning given the existing barriers to adopting measures to reduce emissions identified by Jackson and Kaesehage [4].

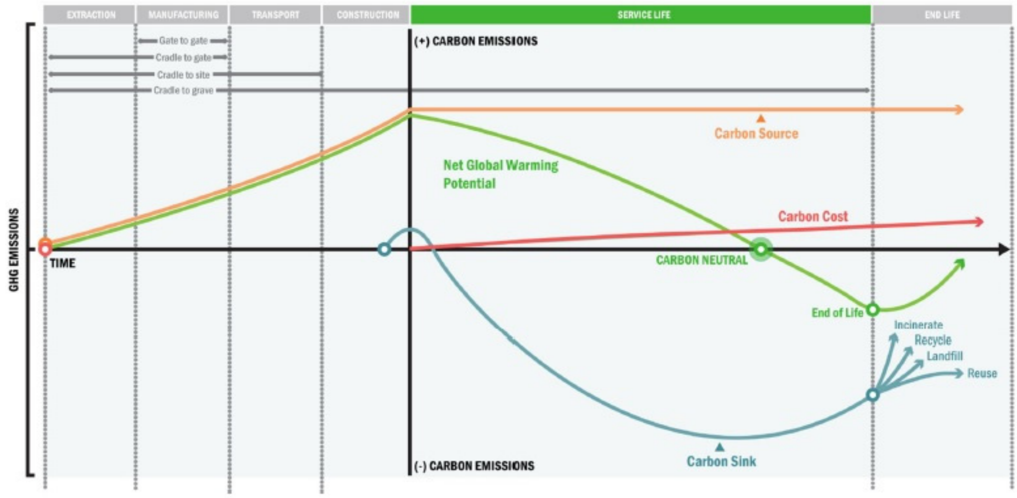

Figure 1. Calculations the Pathfinder tools uses to produce its metrics.

Pathfinder Tool Comparison Metrics as provided by the tool designers.

- Net Global Warming Potential (GWP) in Year X:
- Source + Cost Emissions—Sink Sequestration (cumulative up to Year X)

"The Net GWP metric represents how many cumulative metric tons of CO_2-equivalent have been emitted or sequestered by a given year. A negative value indicated that the project has sequestered more than it has emitted. Most projects would start as 'emitters' in Year 0 and have a positive Net GWP value. As vegetation sequesters CO_2 from the atmosphere, the Net GWP drops every year" [49].

- Years to Neutral (YTN): The year in which New GWP first equals zero, i.e.,
- Project Year in which cumulative Sink Seq. = (Source + Cost Emissions)

"This metric tells the user how long it will take the project sequester as much as it has emitted or become carbon neutral/'net zero carbon'. After this year, the project's net impact on the planet is climate positive, and it acts as an asset to reversing climate change. For many projects this year might be beyond 80 years, in which case the tool calculates the YTN by extrapolating a best-fit line for the Net GWP curve to a zero value. However, for this extrapolation, the tool does not account for embodied carbon associated with material replacement during that time" [49].

- Offset in Year X:
- Sink Seq/(Source + Cost Emissions)

"The Offset metric is a point-in-time cumulative metric similar to Net GWP, which tells the user the % of emissions that have been sequestered or 'offset' by a given year" [49].

The case study below is a design proposal for a park area in Attica, Greece using the Pathdfinder tool's outcomes to present how carbon is currently evaluated from a landscape perspective, and provide a specific case for its interpretation. Figure 2 shows the existing situation of the area, with a few trees, asphalt pavements and a few bench seats. The component parts of this landscape (e.g., m^2 asphalt, grass, concrete; number and species of trees etc.) are entered into the Pathfinder's dashboard to generate a scorecard (Figure 3) and a headline figure of 'years to positive'.

Figure 2. Existing situation of a park in Kantza, Attica Greece.

It has been a shocking realization that in its current state, according to the Pathfinder tool, this existing urban roadside park in Greece would need 435 years to reach a 'carbon positive' state (Figure 3). Not only is the timeline extraordinary but the fact that a space that has only a few pavements and benches can generate so much carbon. Acknowledging that the Pathfinder tool was originally designed for North America it has however reached 179 countries to date and its creators are confident that the results are close to reality. Unsurprisingly, Figure 3 shows that the paving is responsible for most of the emissions and armed with this knowledge, landscape architects can make informed decisions in collaboration with their clients to make design decisions and material selections that have less net impact.

Whilst incredibly useful as a crude measure, such tools by design do not allow for the site-specific subtleties of a landscape design. It was not possible, for example, to input data on the soil type or health, nor whether the soil was already in-situ or imported. Furthermore, the tool calculates a static environment because it cannot account for the way that parcel of land connects into wider hydrological or biological systems, let alone take into account the impact of human activity therein.

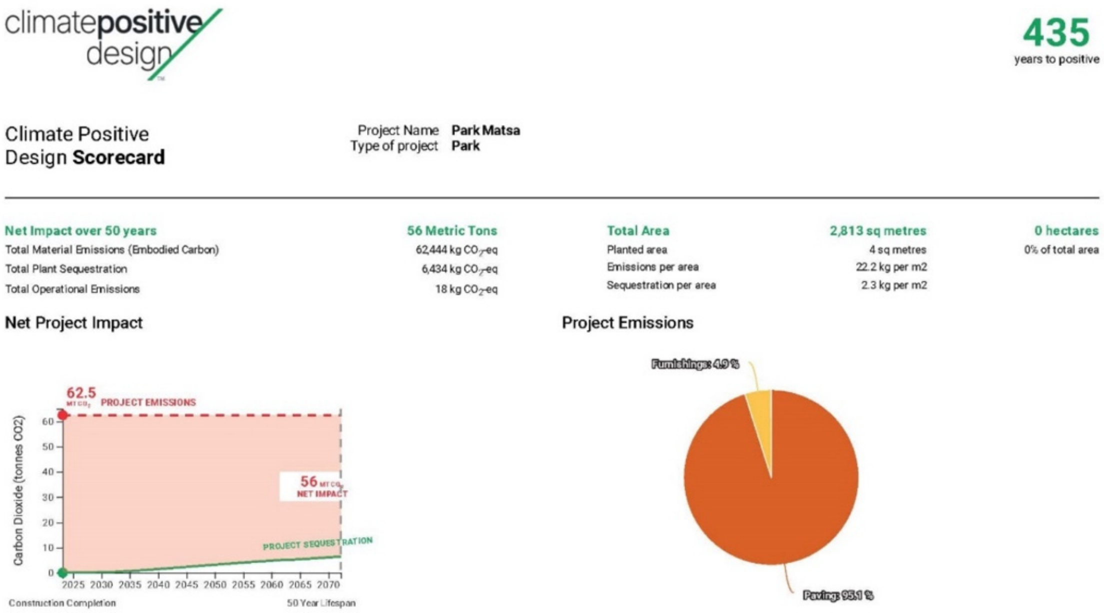

Figure 3. Pathfinder tool report for existing situation of the park.

To compare the effects of utilising more environmentally sensitive materials the authors have proposed an alternative version of the park changing only materials, without altering the existing layout (Figure 4). Stone replaced concrete for the pavements, shrubs and trees have been added and operations were kept to a minimum. Seemingly simple material substitutions have drastically reduced the 'years to positive' figure to 16 (Figure 5) with paving and furnishings still having the greatest impact. Despite this being a major improvement on the existing situation it is still more than three times longer than the 5 years suggested target such projects are advised to have by the tool creators (5 years for parks, residential, campus—20 years for streetscapes and plazas). This new design proposal is calculated to sequester 35 tonnes more carbon than it emits for its estimated lifespan and is expected to reach climate positive in 2039. This whole exercise does not aim to demonstrate just the importance of trees, but the real difference prudent decisions made at the initial stages of design have over the long term for our landscapes, communities and future cities.

Figure 4. Park proposal perspective realizations.

Designers of this and other carbon tools make generalized recommendations for landscape architects: Do not destroy ecosystems, be very careful with concrete and hardscapes, reduce the use of metals and plastics, especially non-recycled ones, use wood, add woodlands, wetlands and prairies [52]. Furthermore, focus on "more woody plants; warm season grasses; deciduous trees, which are denser; and nitrogen-fixing plants, which enable the productivity of the entire plant communities" and native plants, which have deeper roots, are "more productive and resilient" and will therefore store more carbon over time [53].

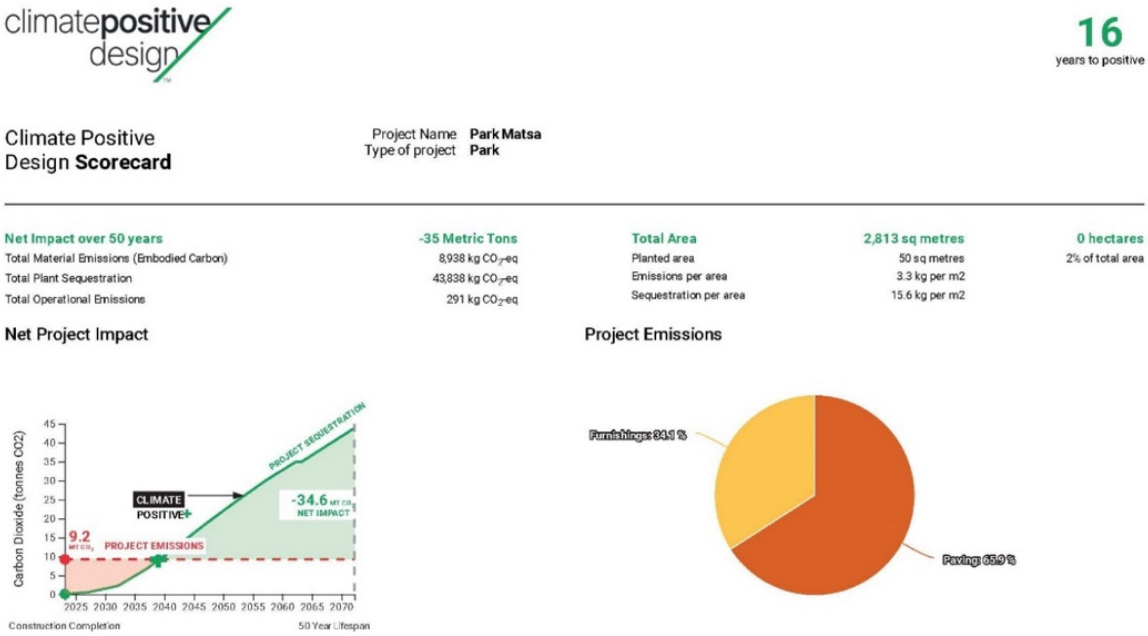

Figure 5. Research project design for the park area in Kantza, Attica Greece.

5. Landscape Complexity and Carbon

The abovementioned tools provide data on carbon sequestration, embodied carbon etc. and allow us to make decisions about which building materials and plants will release least or sequester most carbon, but they cannot help make design decisions on aesthetics, placemaking or cultural significance, nor can they currently account for the landscape-scale context within which a new-build will form a part. For this, the expertise and judgement of the professional is still necessary, and must take into account wider contextual data regarding the role and impact of carbon accounting from case-studies, best practice and scientific study to help make such decisions.

These tools are primarily used to examine new-build projects, however there is much benefit in evaluating the landscape as it currently exists (Figure 3) to ascertain its present environmental impact [54]. Whilst these tools cannot currently account for the vast complexity of a landscape-scale system, sectioning it into smaller work-parcels (sites) can build up a picture of present carbon levels in construction material and vegetation (typically referred to as 'hard' and 'soft' landscape materials). With a network of data for individual sites stitched together, it may be possible to generate a wide-scale low-resolution picture of site-specific carbon data. Future research could be conducted to ascertain whether one of the aforementioned tools, or a combination thereof would provide a more nuanced and helpful apparatus for the profession, and likewise, whether there is data loss in sectioning the landscape into smaller parcels. Data alone cannot tell the landscape architect what to design, but acting as a baseline, it is anticipated that measurements of existing built-environment landscapes could, for example, be used to decide the efficacy of wholescale redevelopment versus adaptation of a specific site, thereby setting certain design parameters [55,56]. For the example above (Figure 2) we might feasibly be able to ascertain whether more carbon is released in dismantling the existing concrete paving to replace it with natural materials, versus leaving it as is and focusing on adapting the existing design with more productive and resilient vegetation, better water-capture and drainage systems and a programme of social and cultural engagement to highlight natural systems for local residents. It is recognised that these tools are built for a very specific purpose, and that in this respect help professionals to make evidence-based decisions regarding the construction and operational life of a site-specific landscape design. The data from such tools can be interpreted and re-interpreted as policy and guidance responds to changing evidence, and adapted to fit local environmental conditions [57]. Data from such tools are a welcome addition to the professional's knowledge base as an aid to making informed decisions.

It requires landscape-scale thinking to address global issues such as climate emergencies, and whilst this often requires local implementation aided by tools such as those mentioned here, there is further work required to appreciate the complexity of landscape as an integrated natural-cultural system. As a system, it is impossible to separate economics, politics, science, society or culture from the landscape and as such the measurements provided by these tools are useful only insofar as they feed into a system which determines their usage and efficacy in addressing carbon levels. Whilst these tools are welcome, their scope is necessarily limited to very specific aspects of the landscape. This narrow focus maintains a view that landscape architecture is limited to the technological application of nature within urban settings, a "green veneer to be applied in a vain attempt to soften dysfunctional parts of the city" [55]. Likewise, guidelines, policies and targets addressing specific facets of our environment negates the understanding of landscape as an integrated natural-cultural system.

6. Conclusions and Recommendations

Within the context of calls for a zero-carbon future the authors welcome the use of carbon monitoring tools for the landscape industry. In doing so, it is acknowledged that their scope is generally limited to the (re)construction of the built environment and that this narrow focus needs to be balanced with a more expansive understanding of landscape complexity. With this complexity comes challenges in measuring and monitoring carbon, and so we recommend and anticipate future tools that can account for this complexity. It is hoped that as modelling progresses, a carbon calculation tool will be able to cover the life cycle for an entire landscape design project, and eventually also account for the wider system within which it sits.

We would like to see these tools being used (alone or in combination) to build a wide-scale picture of current carbon levels so that landscape architects and related disciplines can make informed choices about whether retrofitting or enhancing existing landscape would achieve 'climate positivity' more effectively than demolition and reconstruction. We would like to see the data produced using these tools made open-source for further research, development and decision making. In addition, to engage the wider public, simpler versions of these tools might be made available to the public as a way of measuring and monitoring the carbon levels of private gardens, public parks, schools and more.

Returning to the subject of complexity the authors conclude that in addition to the monitoring of carbon in all aspects of the landscape it will also be necessary to address the cultural, economic and political aspects of this interaction. In landscape architecture, data can help designers, planners, funders etc. to make informed decisions, but cannot be used as a proxy for design responsibility. Reducing the carbon levels of a place might be deemed successful in one sense, but that design could still function poorly, be disconnected from its context, culturally inappropriate or cause unintended consequences for all manner of ecological systems. To this end, tools to measure carbon must be combined with professional knowledge and expertise, social engagement, and impact indicators, such as the 'Principles for Harnessing the Landscape' adopted by United Nations Habitat Roadmap to Recovery [41] and set out here:

1. Making quality of life and environment the priority.
2. Environmentally and culturally productive and regenerative use and care of all land and water.
3. Engaging communities, especially the young, in the climate agenda focusing on transformative action.
4. Seeing the bigger picture by crossing and collaborating silos and boundaries.
5. Creating community resilience through land and water-based culture, identity, stewardship and replenishment.
6. Connecting policy and practice in finance and governance.

7. Learning from indigenous cultures.
8. Use of expertise to reimagine the landscape.
9. Shaping community pride, confidence and physical and mental health.

Set within this ambitious context, tools to monitor carbon are effective elements within the armory of landscape architects and associated professions.

Author Contributions: Conceptualisation, A.N. and A.A.; methodology, A.N. and A.A.; validation, A.N. and A.A.; formal analysis, A.N. and A.A; investigation, A.N. and A.A.; data curation, A.N.; writing—original draft preparation, A.N. and A.A; writing—review and editing, A.N. and A.A.; visualisation, A.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

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

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