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Article

Optimal Electricity Distribution Framework for Public Space: Assessing Renewable Energy Proposals for Freshkills Park, New York City

Kaan Ozgun *, Ian Weir and Debra Cushing

Creative Industries, School of Design, Department of Landscape Architecture, Queensland University of Technology, Gardens Point, 2 George St, GPO Box 2434, Brisbane, QLD 4001 Australia; E-Mails: ian.weir@qut.edu.au (I.W.); debra.cushing@qut.edu.au (D.C.)

* Author to whom correspondence should be addressed; E-Mail: k.ozgun@qut.edu.au; Tel.: +61-424-470-731; Fax: +61-731-381-528.

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Abstract: Integrating renewable energy into public space is becoming more common as a climate change solution. However, this approach is often guided by the environmental pillar of sustainability, with less focus on the economic and social pillars. The purpose of this paper is to examine this issue in the speculative renewable energy propositions for Freshkills Park in New York City submitted for the 2012 Land Art Generator Initiative (LAGI) competition. This paper first proposes an optimal electricity distribution (OED) framework in and around public spaces based on relevant ecology and energy theory (Odum's fourth and fifth law of thermodynamics). This framework addresses social engagement related to public interaction, and economic engagement related to the estimated quantity of electricity produced, in conjunction with environmental engagement related to the embodied energy required to construct the renewable energy infrastructure. Next, the study uses the OED framework to analyse the top twenty-five projects submitted for the LAGI 2012 competition. The findings reveal an electricity distribution imbalance and suggest a lack of in-depth understanding about sustainable electricity distribution within public space design. The paper concludes with suggestions for future research.

Keywords: renewable energy distribution; public space; sustainability; LAGI; Freshkills Park; New York City; triple bottom line (TBL)

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1. Introduction

A growing body of research suggests energy potential mapping to design more sustainable cities based on local energy potentials at multiple scales [1]. Moreover, the application of renewable energy infrastructure within urban environments is growing rapidly, yet it is still commonly conceived of as an add-on feature, rather than as an integral characteristic of urban space. This underestimation of the potential for renewable energy systems is demonstrated in both the urban design profession and their counterpart policy makers, where the focus is on increasing the environmental sustainability of cities by retrofitting spaces and buildings with so-called "techno-fixes" [2] (p. 24) [3], such as green walls and photovoltaic arrays. Commentators have identified a now common trait, where designers make "crafty attempts to get on the 'eco' bandwagon without linking the project to the messy and unpredictable dynamics of nature" [4] (p. 178). In these cases, the primary design objective is often one of superficial display, rather than genuine and in-depth knowledge of sustainability. Although individual buildings are designed with green infrastructures at ever-increasing rates, landscape architects and urban designers need to investigate the integration of renewable energy within urban open spaces where the contextual issues are more multi-layered than in private domains.

First, a new conception of public space is essential, one that addresses the ever increasing complexity of urban environments. For example, swarm planning theory deals with the increasing complexity and uncertain futures of cities, focusing predominantly on the planning process within a regional scale [5] (pp. 606–609). The theory explains the transformation of spatial land use over time and enables new self-sufficient and resilient developments. Therefore, rather than perpetuating the idea of public space as a static artefact, or end product, the new conception of public space must embrace a more dynamic definition, one that is concerned with connectivity, network flow and multi-functional participatory space [6] (p. 234).

Second, this paper argues that renewable energy can no longer be considered a techno-fix or a mere cosmetic intervention in public space. Instead, designers need to consider renewable energy as an important 'ecological infrastructure' similar to the management of water resources, waste cycling, food production and mass mobility [7] (p. 348). Renewable energy infrastructures can also be fully recognized as complete localized electricity production, consumption and distribution systems when integrated in public spaces. For example, Byrne *et al*. [8,9] argue for locating "energy-ecology-society relations in a 'commons' space […]," focusing on techniques and social arrangements that can serve the aims of sustainability and equity. Public space can be a showground for implementing a renewable energy commons approach [10,11]. It can be seen as a bridge that connects mainstream energy with the emerging alternative decentralized energy movements. This approach must complement the rapidly changing renewable energy technologies and their increasing energy generation capacity. Such an approach also exposes social, environmental and economic relationships of renewable energy usage, which brings the accepted triple bottom line (TBL) framework to the foreground. Originated in the 1990s as a medium to integrate sustainability into the business world, the TBL framework operationalizes and implements sustainability into practice [12–14] (p. 252). The balance between these three accepted pillars of the TBL becomes a critical aspect to achieve sustainable production, consumption and distribution. Renewable energy-embedded public space designs that encourage direct and indirect consumption and production of electricity can help to increase public engagement, while also educating the public about renewable energy.

In an effort to engage more people with energy in public spaces, the Land Art Generator Initiative (LAGI) is an international enterprise that hosts regular design competitions dealing with renewable energy within urban environments. In comparison to engineering solutions, which often satisfy quantitative metrics of electricity capture, storage and distribution, LAGI exemplifies a qualitative conception of renewable energy within public spaces and uses design competitions to promote its motto, "renewable energy can be beautiful." LAGI's philosophy and innovative approach demonstrates an awareness of the societal issues surrounding the production of energy within public spaces and was honoured as a top sustainable solution at the United Nations Rio+20 conference and published in "Sustainia100" [15].

In 2010, LAGI announced its first international competition to design and construct public art installations for three different locations in the United Arab Emirates. In 2012, LAGI organized a second competition for Freshkills Park (Former Freshkills landfill) in New York City. Most recently, in May, 2014, LAGI held a third design competition for a shipyard site in Copenhagen, Denmark. All competitions advance the same strategic objective to integrate art into the interdisciplinary creative process and re-imagine sustainable design solutions in public domains. Over four years of competitions, LAGI has increasingly sought to address what it means to embed renewable energy into daily public life. The competition recognizes that practitioners of urban design and public art can have agency over the diversity, richness, quality and types of interactions between the user and energy in public spaces. When successful, designs can effectively communicate new information to the community.

This study focuses on the distribution of produced electricity from renewable sources within a public space context. It introduces an optimal [16] electricity distribution (OED) framework for public space design that organizes potential relationships of local electricity production, consumption and distribution by adapting ecologist Howard T. Odum's theories about energy flow and hierarchy in nature. It then uses the OED framework to assess the top 25 LAGI 2012 proposals. The paper concludes with a discussion of the results and implications of using the OED framework to assess and design new conceptions of energy-embedded public space. Areas of future research are also explored.

2. Linking Public Space and Renewable Energy: The Optimal Electricity Distribution Framework

"Environmental sustainability", a concept stemming from sustainable development, is defined as social and economic development that is also environmentally responsible [17] (p. 6). Renewable energy has since become associated with sustainable development, enabling projects to have less environmental impact and much greater energy capacity compared to fossil fuels and nuclear energy, while being self-sufficient, locally based and less dependent on national energy networks [18] (p. 172). This conception of renewable energy acknowledges its agency over the economic and social dimensions of sustainable development, including, but not limited to, new jobs, by producing ones' own power facilities, avoiding infrastructure costs (transmission, transport, distribution), promoting decentralized new economic relationships, increasing productivity by having fewer conversion steps and spreading ownership [19] (pp. 75–76). Of particular interest to designers and policy makers, the social aspect of renewable energy needs to be emphasized within the context of well-designed and well-used public space.

To enable this shift, this study developed the OED framework to effectively distribute on-site-produced electricity into public space. The framework requires an understanding of the economic-social-environmental TBL relationships of the produced electricity within a public space context. The European commission's report on sustainable cities argues that the environmental function is achievable if only the economic and social components are also in line [20] (p. 2). That is, a balance between all three is required for a truly sustainable distribution of produced electricity in public spaces.

Similarly, the renowned ecologist Howard T. Odum made significant contributions to ecosystems ecology and incorporated thermodynamics law into ecology. One of his provisional ideas [21,22], "Tripartite Altruism," is useful to landscape and environmental design because it identifies an energy/nature equation. For example, this self-regulatory feedback system is applied in permaculture, a holistic gardening practice that works with nature, not against it [23] (p. 15). Rabbits exemplify the "Tripartite Altruism" theory. "They eat grass to live, grow and reproduce. Their manure fertilizes the grass that feed[s] them, and they 'sacrifice' weak rabbits to predators to help keep the population fit and in balance" [24] (p. 73). According to "Tripartite Altruism", approximately one-third of the energy in an organism or a mature complex system [25] is used for self-maintenance and/or energy storage, one-third is for lower order operations and one-third is contributed upward to higher-order system controllers [23]. The following diagram (Figure 1) conceptualizes an optimal distribution of produced electricity from renewable resources embedded in public open spaces, representing the optimum balance between TBL components.

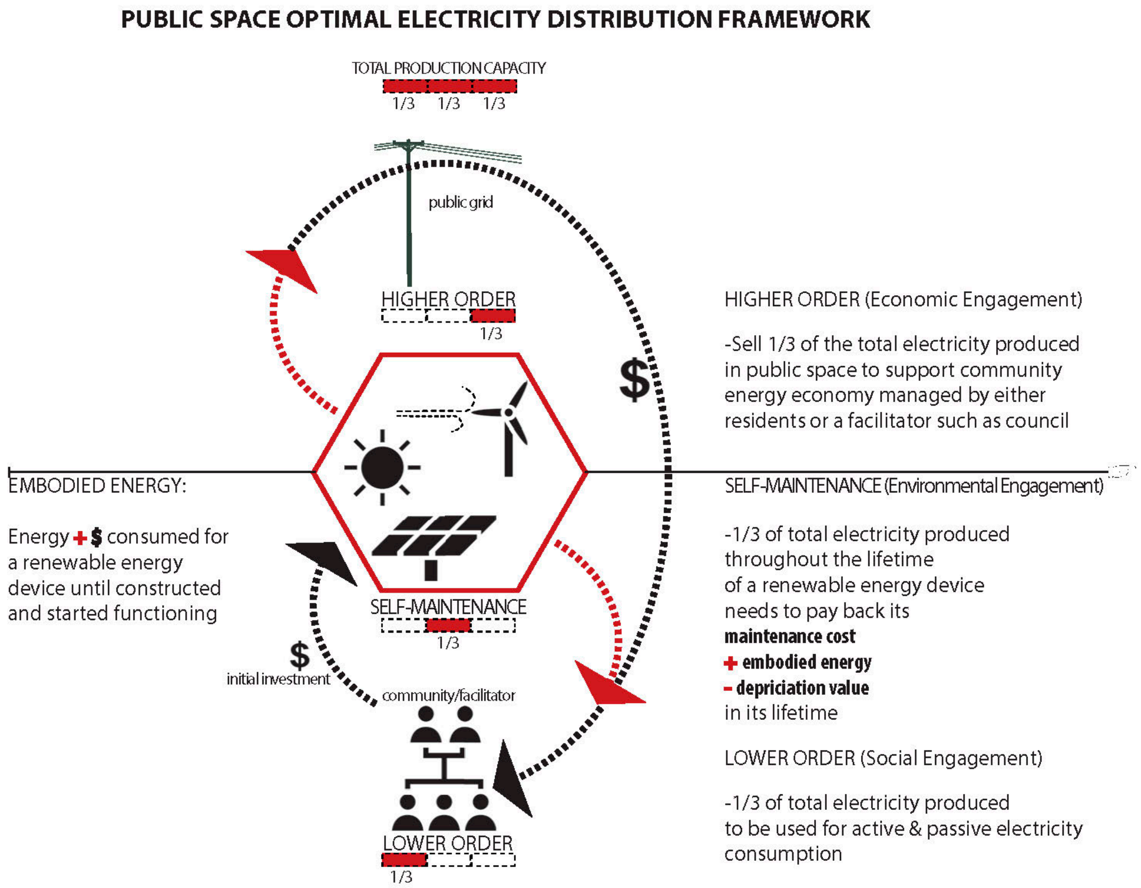

Figure 1. Public Space Optimal Electricity Distribution Framework. This figure was initially published in the Journal of Landscape Architecture, Taylor & Francis Ltd. [26].

The OED framework illustrated in the diagram simplifies Odum's provisional energy/nature equation, designating one-third of the on-site-produced electricity to be used for active and passive engagement, representing "social engagement." One-third of the on-site-produced electricity can be sold to the public grid to create a local energy economy, representing "economic engagement." The remaining one-third of the on-site-produced electricity can be used for self-maintenance, representing "environmental engagement."

2.1. The OED Framework Lower Order: Social Engagement with Renewable Energy in a Public Space

Generating social engagement by on-site-produced electricity from renewable sources is rooted in the innate nature of public space. Public space is a social place where people communicate, interact and engage with their surroundings. For example, Miller [27] (p. 204) argues that "Public spaces do not exist as static physical entities but are constellations of ideas, actions, and environments." The social aspect of public spaces can best be described by Amidon [4] (p. 178), who states that "New public space designs need to arouse desire in the public to participate, to cultivate and to advocate." Unlike embedding renewable energy into a building, designers need to complement the evolutionary and dynamic nature of a public space when embedding renewable energy. Accordingly, North [28] (p. 15) argues, "While a building begins to erode once built, a landscape continuously evolves." Lefebvre contends that the spaces of the modern city have to provide not only consumable material goods for its dwellers, but also evoke the need for creative activity and information [29] (p. 18). Similarly, Gehl states that public spaces provide a source of information about the social world outside, as well as a source of inspiration for action [30] (p. 21). Public space can, therefore, be seen as an education and information agent, through which renewable energy can be introduced to a community.

Odum particularly focused on useful information as concentrated energy and as one possible product of the energy cycle in self-organized systems. "Concentrated energy" has an important role in the energy hierarchy, because it monitors, controls and provides feedback to higher and lower orders constantly. In this instance, an ecologically well-designed public space can play a similar role by interacting with its users, as well as its immediate vicinity and the city's greater energy grid. Similarly, Abel describes useful information as [31] (p. 85), "[f]undamentally a product of the self-organization of systems, wherein its function is to remember successful configurations of cells, organisms, ecosystems, and […] human adaptations."

This paper stresses public spaces as an education and information agent to encourage a sustainable lifestyle and increase general environmental awareness in an effort to maximize energy efficiency in the broader community. A growing body of literature indicates urban environments as complex systems [5,32]. When conceptualized as a self-organized system, public space can be considered a platform to create useful information for a community, which can thus promote greater uptake of sustainable energy across multiple domains in society. This claim is grounded in the "maximum power principle", which is considered the fourth law of thermodynamics [33,34]. According to this law, in the self-organizational process, systems develop parts, processes and interactions that maximize efficiency and production [35] (p. 71) [36].

For the purpose of this paper, interactions with renewable energy are identified as active and passive. Active social interaction with on-site-produced electricity includes activities that promote direct consumption of electricity, including educational, performance or recreational based activities, such as electric car charging points, personal device charging utilities and wireless services. Active interaction also refers to direct electricity production from users' movements, such as capturing energy from the downforce of footsteps via piezoelectric generators.

Passive social interaction with renewable energy refers to activities that have an indirect relationship with electricity consumption. Passive modes are characterized by activities involving artful play and the interpretation of renewable energy systems, including information centres, interactive energy toys, interpretive energy screens and media displays. Simply put, the on-site produced electricity needs to be consumed internally without any external output. For example, a public space user consumes the on-site-produced electricity for way-finding through the site using the embedded interpretive energy screen.

Active and passive interactions are imperative for the generation of shared knowledge, because they directly connect users with their environment and economics [37–39] in the public space, both literally and symbolically. For optimal electricity distribution, active and passive social engagement with renewable energy must achieve a combined total of one-third of the electricity production capacity. This comprises the 'lower order usage' in the devised OED framework. The two interaction modes demonstrate the necessity for an integrated approach to renewable energy and public space, to not only achieve meaningful and measureable sustainability, but to also communicate the reciprocal relationship between society and energy. To achieve this, designs must employ best practice principles of interpretation and sense of place into the design.

This paper argues that such enhancements in our interactions with energy correlate with the observed tendencies of self-organized mature ecosystems. For example, the fifth law of thermodynamics states that, 'system processes maximize power by interacting abundant energy forms with ones of small quantity, but a larger amplification ability' [40] (p. 122). Therefore, the more ecologically-sustainable public space is one that responds to the fifth law by engaging with renewable energy, through both active and passive interactions. The greater the number of active and passive interactions that exist between renewable energy and public space users, the greater the likelihood that the public space will influence society's sustainable energy lifestyle.

2.2. The OED Framework Higher Order: Economic Engagement with Renewable Energy in a Public Space

In Odum's "Tripartite Altruism", another one-third is assigned to "economic engagement", where electricity distribution contributes to the local energy economy. Applied to the context of public space, produced electricity could be sold to the utility grid and used to support the community renewable energy economy managed by either local residents or a facilitator, such as a local council. The initial investment cost to accomplish this can be subsidized by the community or the facilitator. There is an expanding body of literature about sustainable energy transition that points to a shift from centralized autocratic energy economies, towards decentralized modes of electricity production that bring new socio-economic relationships to cities [41–44].

To understand the potential for a decentralized energy economy based on public spaces, it is useful to refer to 'system size' in ecology, which is the spatial extent or physical boundary of a system. The system size measurement of the energy capacity of conventional public spaces would include an assessment of the total energy demand supplied from the main energy grid. A public space also contains, but is not limited to: users; hard landscapes, such as paved floors, stairs, ramps and street furniture; soft landscapes, such as grass and other plant material; infrastructure; the continuous information and matter flow; and the built structures within and around it. Thus, an energy system in a public space has many components, not unlike ecosystems composed of a community of organisms and chemical cycles [45] (p. 523).

The concept of system size simply frames the energy demand and supply relationship. When a conventional system requires more energy to sustain its demand, an external energy supply feeds the system. System size becomes more significant because of energy availability that is dependent on the produced electricity from renewables. Both the quantity and quality of available energy in the system determines the optimum system size [46]. As current research [1] on potential energy mapping underpins the importance of the local energy potentials for sustainable city design and planning, environmental designers also have to consider the optimum system size of each energy resource [47] (pp. 33–34). A public space as an optimum system may be achievable by considering both the quality and quantity of on-site-produced electricity. Energy quality refers to the emergy concept, which is discussed in the next section.

2.3. The OED Framework Self-Maintenance: Environmental Engagement with Renewable Energy in a Public Space

To complete Odum's "Altruistic Tripartite", the final one-third of the produced on-site energy is designated for environmental engagement. This engagement refers to the electricity utilized for "self-maintenance" of the public space and to recoup its maintenance cost and embodied energy of the renewable energy devices [48–50]. Embodied energy is also directly related to the 'emergy' concept. Emergy represents energy memory emphasized by the prefix (em) in emergy and defined as the history, the time and the processes involved up to the present state of a system [51] (p. 33). Odum quantifies 'energy quality' in an urban environment and defines it via the emergy concept [52,53]. This parallels the fifth law of thermodynamics, which states that information generally has the highest energy quality and the densest form of the emergy/energy ratio, as highlighted in Table 1 [39] (p. 88).

Table 1. Exemplars show the emergy/energy ratio; a higher number means a higher quality of work [36] (p. 69).

ITEM	Solar Emcalories per calorie *
Sunlight energy	1
Wind energy	1500
Organic matter, wood, soil	4400
Potential of elevated rainwater	10,000
Chemical energy of rainwater	18,000
Mechanical energy	20,000
Large river energy	40,000
Fossil fuels	50,000

Table 1. *Cont.*

ITEM	Solar Emcalories per calorie *
Food	100,000
Electric Power	170,000
Protein foods	1,000,000
Human services	100,000,000
Information	1×10^{11}
Species formation	1×10^{15}

* calories of solar energy previously transformed directly and indirectly to produce one calorie of energy of the type listed. Source: Odum 1996 [35].

The depreciation value of a renewable energy device in its lifetime can be calculated based on existing data from energy payback time (EPT) and embodied energy values, subtracted from the production value. Applied to the public space context, this would include the basic energy demands, such as lighting. This type of electricity consumption is similar to that which occurs in a normal household, including the energy need of appliances. By grouping consumption modes, we can monitor, control and create better sustainable outcomes.

According to Odum, it is beneficial to have a large amount of electricity production, as long as enough storage is available for the lower and higher order interactions to exist in the system. Odum states, 'With increasing scale of available energy (the production capacity of renewable energy in public space), storages increase, depreciation decreases and pulses are stronger but less frequent' [39] (p. 63). This definition depicts the behaviour of mature complex ecosystems [39] (p. 54). From a public space point of view, a larger amount of electricity produced from renewables means that more interaction and storage will be required to use the produced electricity sustainably.

The application of Odum's "Tripartite Altruism" to the urban space context establishes the OED framework, through which speculative and built projects can be assessed. The next section describes how this study used the OED framework to assess competition entries for the LAGI 2012 competition, set in Freshkills Park, NYC.

3. Methods: Using the OED Framework for Assessment

Out of the 250 entries submitted in LAGI's 2012 competition, 65 projects were selected and published in the book, *Regenerative Infrastructures of Freshkills Park, NYC* [54]. To better understand current design thinking about renewable energy embedded into public space, the study used the first 25 entries, including four place-winning and twenty-one shortlisted schemes, for content analysis. These schemes were selected for LAGI 2012 by experts from a multidisciplinary jury and a selection committee [54] (p.29).

For the purposes of the study, the authors overlaid the OED framework with LAGI's judging criteria. Three out of the seven judging criteria directly aligned with the framework:

- The annual electricity production capacity (economic engagement);
- How the proposal engages with the public (social engagement); and
- The embodied energy required to construct the renewable energy infrastructure (environmental engagement) [54] (p. 30).

The other four judging criteria are not directly related to renewable energy usage and were, therefore, excluded. The authors determined how the projects responded to the three judging criteria using thematic content analysis of images and text in the *Regenerative Infrastructures* [54,55] book and also LAGI's official website [56]. Thematic content analysis focuses on the occurrence and meanings of keywords and concepts in texts to generate themes, employing either a predefined analytical structure or an interactive structure [57] (p. 83). The authors employed NVivo software to thematically code the collected data based on the three criteria.

Competition submissions, active on the official LAGI website at the time of data collection, communicate their designs through A4 pages with project descriptions, as well as four A1 panels with graphics and text. The published content in the book is a refined version of the original A1 panel submitted through the website. The amount of information published differs, depending on the jury's selection order and editing. While the four place-winning projects have six pages of content published, shortlisted projects have four pages.

This assessment addresses the social, environmental and economic engagement with on-site-produced electricity identified in the devised OED framework. To quantify this, we created a quality impact assessment scoring scale from one to three to align with the OED framework. The analysis aims to quantify the quality of each project's energy interventions: a score of one for no/low quality, a score of two for medium quality and a score of three for high quality. Entries obtaining higher scores were perceived as more responsive to renewable energy distribution.

First, the study assessed the social engagement (lower order) aspects of an entry and determined the extent of public engagement that it was likely to generate by using on-site-produced electricity from renewable sources. For example, if an entry does not consider any engagement, or the assessment outcome is unknown, the entry scores a one. If an entry considers either active or passive engagement, it scores a two. If an entry considers both active and passive engagement, it scores a three.

Next, the study investigated the economic engagement of renewable energy (higher order usage). For example, if an entry designates none of its on-site electricity production to be sold to the local grid or if this is unknown, it scores a one. If an entry considers all on-site-produced electricity from renewables to be sold to the local grid, without any maintained for self-maintenance described below, it scores a two. If the on-site-produced electricity is to be partially sold to the local grid, an entry scores a three.

Finally, the study assessed the environmental engagement (self-maintenance) aspects of the entries, including embodied energy, using a portion of the produced electricity for maintaining the renewable energy installation, energy storage, general public space maintenance and other primary electricity needs of services within the space. If an entry does not appear to respond to any of these aspects or the situation is unknown, it scores a one. An entry that partially considers these factors scores a two. If an entry considers most or all of these, it scores a three.

In summary, the content data were analysed against the framework and the three LAGI judging criteria relevant to renewable energy usage. The next section discusses the findings from this assessment.

4. Findings

The following table (Table 2) illustrates the quality impact level (scores from one to three) of each competition entry, displaying their individual, average and total scores using the OED framework. The order of projects in the table follows the same order in the competition book, *Regenerative Infrastructures of Freshkills Park, NYC*. Although not explicitly clarified by LAGI organizers, the order of shortlisted projects in the publication somewhat indicated the LAGI jury's order of preference. The embedded text under Table 2 is a brief summary of the methods in Section 3.

Table 2. Distribution assessment for the LAGI 2012 renewable energy proposals.

Distribution Assessment for the Lagi 2012 Renewable Energy Proposals					
Quality Impact Level	**Annual Capacity**	**Social**	**Environmental**	**Economic**	
1 2 3	MWh	Lower Order	Self-Maintenance	Higher Order	
Four winning entries					Total
Entry 1-scene-sensor	5500	3	2	3	8
Entry 2-fresh hills	238	1	2	3	6
Entry 3-pivot	1200	1	1	2	4
Entry 4-99 red balloons	14,000	3	2	3	8
(4 entries) Total		8	7	11	26
(4 entries) Average		2	1.75	2.75	6.50
Twenty-one shortlisted entries					
Entry 5-solar loop	10,000	1	2	3	6
Entry 6-power play	100	2	1	2	5
Entry 7-in between scapes of light	4800	2	1	3	6
Entry 8-inefficiency can be beautiful	672	2	1	3	6
Entry 9-field of energy	13,000	2	2	3	7
Entry 10-flightaic	1,000	1	2	3	6
Entry 11-biofuel armature	60,000	1	1	2	4
Entry 12-robo zoo	10	2	1	1	4
Entry 13-flirt	72,000	3	2	3	8
Entry 14-solar cairn	1000	1	2	1	4
Entry 15-electric meadow	unknown	1	3	1	5
Entry 16-art-wind-energy unit	145	1	3	3	7
Entry 17-blossommings	520	3	3	3	9
Entry 18-heliofield	15,000	2	2	3	7
Entry 19-beauty of recycling	3600	2	2	3	7
Entry 20-cloudfield	5910	2	2	3	7
Entry 21-fresh clouds	65,000	2	2	3	7
Entry 22-solar bloom	35,500	3	3	3	9
Entry 23-tree	1700	2	2	3	7
Entry 24-nawt balloons	30,500	1	2	3	6
Entry 25-currents	28,470	2	2	3	7
(25 entries) Total		46	48	66	160
(25 entries) Average		1.84	1.92	2.64	6.40

Table 2. *Cont.*

Distribution Assessment for the Lagi 2012 Renewable Energy Proposals
Economic Engagement (Higher Order)
(1) None/Unknown of the electricity produced to be sold to the local grid
(2) All on-site electricity produced to be sold to the local grid
(3) On-site produced electricity to be partially sold to the local grid
Environmental Engagement (Self Maintenance) *
(1) None/Unknown
(2) Only considers partially
(3) Considers majority/all
Social Engagement (Lower Order) ***
(1) None/Unknown **
(2) Active or passive engagement through direct electricity consumption or production ****
(3) Active and passive engagement through direct electricity consumption or production †

* Electricity demand of permanent functions such as lighting, heating, energy storage and other primary electricity needs of services of public spaces Energy demand of maintaining the energy device/installation Embodied energy consideration; ** No engagement through direct electricity consumption/production; *** Educational, informative, event and recreational use; **** For example Piezoelectric generator used to generate power from people movement. † Personal device, event, electric car recharge in the car park, wireless.

The content analysis of the four place-winning entries (labelled Entries 1–4 in Figure 2) revealed that the designs focused on economic engagement first (higher order), with social engagement (lower order) and environmental engagement (self-maintenance) considered as secondary (Figure 2). Similarly, the shortlisted entries scored higher for economic engagement (higher order), with environmental engagement and social engagement secondary (Figure 3).

Figure 2 shows the assessment quality impact level (scores from one to three) of four place-winning design entries based on social (orange), environmental (green) and economic (blue) engagement. The results showed that the four place-winning design entries did not score overwhelmingly higher than the shortlisted projects, indicating that they do not necessarily promote the most ideal electricity distribution for a public space context according to the OED framework. Instead, the average score for the place-winning entries was 6.50 out of nine, which is slightly higher than the average score for the shortlisted entries of 6.40 out of nine.

For example, one of the top scoring projects was Entry 22, Solar bloom*,* which scored nine out of nine. The project addressed the OED framework criteria fully. Entry 22 integrated a sterling-based solar dish engine into a sculptural installation. The installation generates 35,500 MWh of electricity annually and can power 3087 houses every day. While visitors can directly engage with the produced electricity through charging outlets as active engagement, they can also engage indirectly through LED lighting that demonstrates the systems efficacy through visual means and refers to passive engagement with produced electricity. Thus, the project scored a three, addressing economic and social engagement. Lastly, the project is also responsive to environmental engagement because the dish engine is made of an eco-friendly resin that is 40 percent recycled content and 100 percent recyclable. The installation is modular and complies with the LEED (Leadership in Energy and Environmental Design) green building practice to reduce its environmental impact. The project also includes energy storage units. Thus, the project considered the majority of environmental criteria and scored a three for environmental engagement.

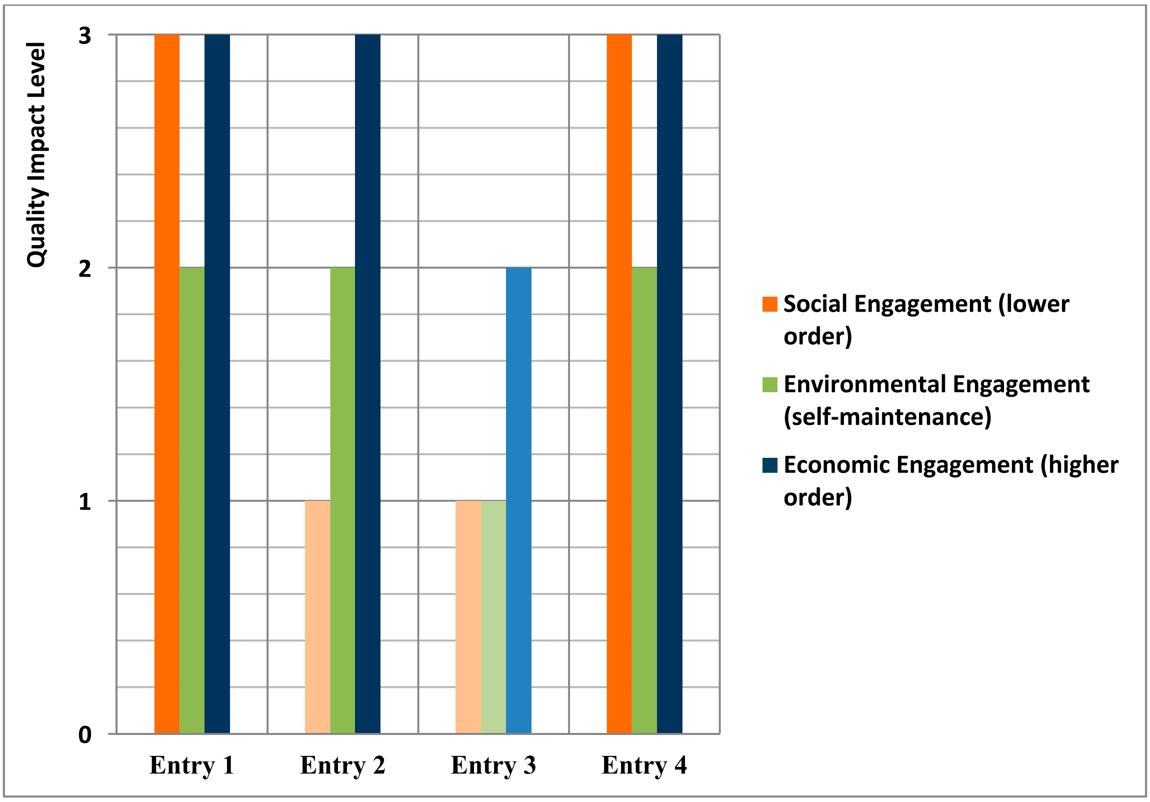

Figure 2. Optimal electricity distribution assessment of the four LAGI place-winning entries.

Entry 1, Scene-sensor, scored eight out of nine, using piezoelectric generators for electricity production through people movements and wind power. According to the OED framework, Entry 1 addressed active social engagement through direct electricity production from footsteps, whereas no data were provided concerning the direct on-site electricity consumption. Entry 1 also addressed the passive engagement with the produced electricity through wind mapping and LED lighting performance integrated into the installation. Therefore, Entry 1 scored a three by addressing active and passive engagement through direct electricity consumption or production. From an environmental engagement perspective, only minor data were found with regards to lighting. This enabled Entry 1 to score a two; since other factors underpinned in the OED framework, including embodied energy, energy storage, and other primary electricity needs, were not stated anywhere in the project description. Lastly, at an economic engagement level, Entry 1 produced electricity (5500 MWh annually) for 1200 households while using part of the electricity for LED lighting performance, therefore scoring a three.

One of the lower scoring projects according to the OED framework was Entry 12, Robozoo. This entry produced 10 MWh of electricity annually through solar ivy, a novel solar energy generating system inspired by ivy leaves. However, no data were found in the project submission content about selling the on-site-produced electricity to the city grid. The project proposed a mechanical ecosystem with electricity producers (flora) and electricity consumers (fauna). The visitors can engage with this ecosystem by harvesting the batteries from electricity producers and integrating them into the mechanical creatures. This refers to passive engagement with electricity, and no data were found concerning active engagement with electricity. Therefore, Entry 12 scored a two out of three for social engagement. The project also scored a one from environmental engagement, since no data were identified.

High annual clean electricity production capacity requires more environmental engagement (self-maintenance) and social engagement (lower order) to create an optimal distribution, according to the OED framework. Out of twenty-five entries assessed, ten entries produced over 10,000 MWh of electricity annually.

The findings showed that the total assessment scores for these entries were also higher than the entries producing less than 10,000 MWh (Table 3). The table displays the annual energy capacity of twenty-four entries [58]. While ten out of twenty-four have more than a 10,000-MWh annual capacity, the other fourteen have less than 10,000 MWh. This result aligns with the theory reasoning that high production capacity entries not only produce more electricity, but also sell energy to the public grid, generating more income.

Table 3. Distribution assessment of LAGI winning entries with their annual electricity production capacity.

Annual Capacity		**Social**	**Environmental**	**Economic**	**Total**
10 entries	>10,000 MWh	2	2	2.90	6.90
14 entries	<10,000 MWh	1.78	1.78	2.57	6.13

However, it is important to note that entries with the highest production capacity did not necessarily score highest using the proposed framework. For example, Entries 20 and 25 were compared, and both scored seven out of nine (Figure 3). Entry 20 produced 5910 MWh of electricity, and Entry 25 produced 28,470 MWh of electricity, nearly six-times more. Therefore, Entry 25 required innovations with a greater intended social and environmental engagement impact, in order to balance the higher electricity production. Entry 20 promoted passive engagement through direct electricity consumption for music and theatre events, but did not promote active engagement; whereas, Entry 25 promoted only active engagement and provided electric car plug-ins from electricity produced on-site. Thus, both entries scored a two out of three under the social engagement criterion. However, since Entry 20 provided these interactions with less electricity production capacity, it is actually more energy responsive and sustainable according to the OED framework.

The findings from this study demonstrate a discrepancy between sophisticated designs as chosen by the LAGI jury and their approach to sustainable distribution of on-site-produced electricity (indicated by their resulting OED assessment in Figure 3).

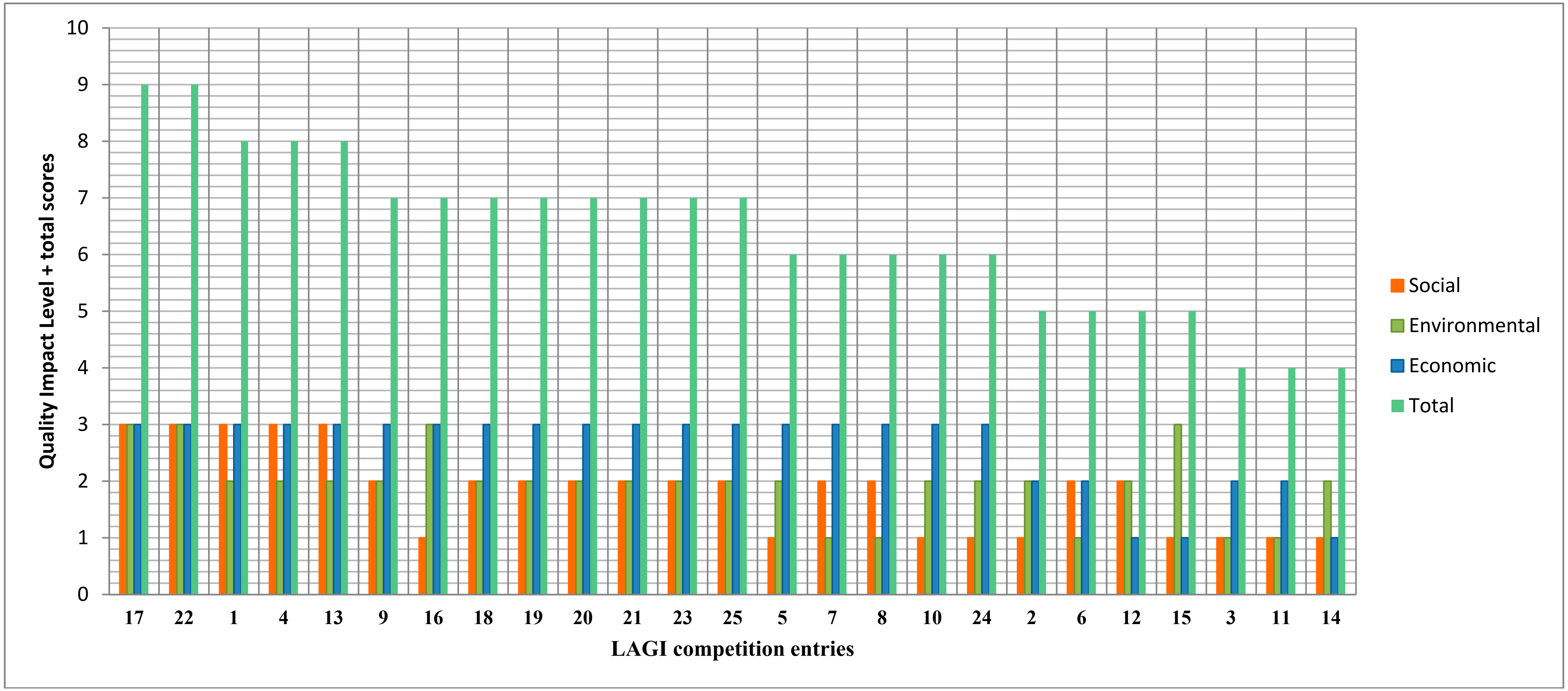

Figure 3. The graph shows entries ranked according to the optimal electricity distribution (OED) framework assessment from highest to lowest score. Entry numbers in bold black represent LAGI competition ranking order. For example, Entry 1 refers to LAGI's first place winner project, and Entry 25 is the very last shortlisted project.

The next section, therefore, discusses the implications of these findings and the significance of the proposed OED framework from the perspective of current design thinking about renewable energy-embedded public spaces.

5. Discussion

This study set out with the aim of assessing cutting-edge design propositions that integrate clean electricity production into public space. The assessment of twenty-five LAGI 2012 competition entries using the proposed OED framework described in this paper revealed that the primary focus was on economic engagement with on-site clean electricity production. A secondary focus was on environmental and social engagement.

In addition, the four winning LAGI entries did not score highest in the OED assessment. This suggests a lack of association between cutting edge design propositions and the science of sustainability, with respect to the optimal distribution of produced electricity from renewable sources. The findings also show that although predefined themes relevant to renewable energy usage were included in the judging criteria list, competition entries did not address them specifically. Likewise, LAGI's assessment criteria are perhaps not precise enough to reveal the relationship between sophisticated designs and their genuine sustainability. This could be attributed to LAGI's highly artistic and conceptual emphasis, which prompts designers and artists to focus heavily on the aesthetic attributes of their entries, rather than sustainable energy production and distribution.

A further reason might be the lack of a well-defined design framework that effectively addresses renewable energy usage within the public space context. LAGI's judging criteria includes three types of engagement; however, the criteria are not specific and, therefore, remain secondary. Instead of embedding the three types of engagement (economic, environmental and social) into the criteria, the LAGI enterprise could potentially provide this information to designers as foundational public space sustainability knowledge with respect to electricity distribution.

In addition, ecologically-sophisticated public space designs need to address energy more deliberately. Initiatives similar to LAGI are imperative to advancing the uptake of these concepts in the broader society. While LAGI is primarily an art initiative and, therefore, focuses on the aesthetics of renewable energy, our developed OED framework seeks to expand the relationships and interactions between public space users and renewable energy. This includes the production of electricity from on-site renewable sources and its effective and optimal distribution with respect to three different types of public space-specific engagement: environmental, social and economic. This could be beneficial to LAGI for the continued evolution of their art/science/urban design framework and to leverage LAGI's artistic approach to advance sustainable energy transition. Considering the current conjecture about sustainable energy transition, LAGI's role in promoting renewable energy is indispensable.

The next section concludes with the implications of using the devised OED framework as a method of assessing and designing energy-embedded public spaces, the limitations of this study and recommendations for future research.

6. Conclusions

Both the findings and the developed OED framework contribute to the sustainable design and assessment of public spaces. The framework, when used as a design tool, enables designers to engage with sustainability throughout the design phases, rather than after the project has been completed, which is what commonly happens. Rather than perceiving renewable energy as a 'techno-fix' addendum to the existing public space designs, this paper introduced a novel path to treat renewable energy-embedded public space as micro-scale ecological infrastructure. This infrastructure would potentially establish new social, cultural, economic and environmental relationships between the city environment and its dwellers, complementing the sustainable energy transition and the increasing number of urban production activities. Likewise, when conceived of as a method of assessment, the devised OED framework can potentially be integrated into the existing public space sustainability assessment tools [59,60], which only assess renewable energy as an indicator of environmental sustainability and often downplay the social and economic aspects of local electricity production. Thus, the method employed in this study will serve as a starting point for future research to advance an effective assessment tool.

6.1. Limitations

The OED framework specifically focuses on clean electricity distribution in public spaces in relation to the economic, social and environmental dimensions of engagement. Therefore, one limitation is the lack of recognition of the aesthetic dimension of design. Each public space design contains site- and designer-specific features, such as site characteristics, aesthetic sensibilities, historically- and culturally-significant features, the financial context and budget and universal access. Yet, the LAGI 2012 competition entrants are speculative, without real-life political, financial and logistical constraints. Although the proposed OED framework accepts and works with this diversity and assumes designers will accommodate these opportunities and constraints as necessary, further research is needed to apply the OED framework to built projects.

An additional limitation includes the limited detail available for each LAGI 2012 entry. LAGI's entries are conceptual, and therefore, the energy-relevant data are limited. For example, the available data for each entry do not provide an exact quantity of energy designated for social, environmental and economic engagement. Therefore, for the purposes of this study, entries were only analysed to understand if their energy interventions aligned with the devised OED framework.

6.2. Future Research

The theories contributing to the OED framework of this study provide several implications for future research. From a landscape architecture and environmental design perspective, the extant research focuses on energy-conscious planning and design within a regional scale, often neglecting the micro-scale. The devised OED framework for renewable energy-embedded public space fills this gap.

Scholars of energy-conscious design and planning focus predominately on the first and second law of thermodynamics [61,62], yet this study integrates the fourth and fifth law into energy-conscious design. This expanded theoretical framework has the potential to connect society, energy and information at a micro-urban scale, specifically in public space. Despite the criticisms of Odum's approach to information by conventional ecologists and information theorists, systems ecologists and emergy scholars have started to integrate emergy research into cultural and societal studies [31,63]. Additional research possibilities exist to apply emergy analysis to public spaces.

Sustainable energy transition can only be achieved with the right policies and tools. This transition can occur when renewable energy in public spaces is regarded as an embedded and context-specific feature of public space, rather than as an add-on or techno-fix to conventional spaces. Such rethinking presents opportunities for new urban perspectives regarding planning policies, new levels and modes of community participation and engagement, place-making strategies, entrepreneurship and management of clean electricity-producing public spaces. With the increasing number of production activities in cities, public spaces offer great opportunities to share renewable energy knowledge and to educate the public in order to facilitate a quicker transition to sustainability. Any policy or framework that identifies the relationships between renewable energy and urban environments, considering the social, economic and environmental perspective simultaneously, supports this transition. This research clearly demonstrates the need for further discussion on the aesthetics of renewable energy technology when electricity production and its emerging TBL relationships come into focus.

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Author Contributions

Kaan Ozgun conceived of and designed the OED framework as part of his Ph.D. research project. Kaan Ozgun collected and analysed the data, and wrote the first draft. Ian Weir revised the initial version and co-wrote the second draft. Debra Cushing helped to develop the study and revised the paper. All three authors read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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