Diagnoses for Potential Enaction of Water–Energy Nexus in Green Building Rating Systems: Case Study of the Pearl Rating System of United Arab Emirates

Reshna Raveendran, Ahmed Hassan and Kheira Anissa Tabet Aoul *

Architectural Engineering Department, College of Engineering, United Arab Emirates University, Al Ain P.O. Box 15551, UAE; Reshna.R@uaeu.ac.ae (R.R.); Ahmed.Hassan@uaeu.ac.ae (A.H.)
* Correspondence: kheira.anissa@uaeu.ac.ae

Received: 26 August 2020; Accepted: 3 October 2020; Published: 12 October 2020

Abstract: The green building rating system within the sustainability framework of the United Arab Emirates (UAE), the Pearl Rating System (PRS), similar to most international rating systems such as LEED, considers several strategies, regulations, and policies to improve the energy and water performance in buildings. However, the applicability of considering water as part of energy or the fact that the utilization of energy mandates the usage of water seems unexplored and is not yet included in any of the existing building rating systems. A unified approach of water and energy resources is thus vital for future considerations in energy policy, planning, and the inclusion of the same in the sustainability rating systems. This paper investigated, as a case study, the prospects of water–energy nexus in the prevailing UAE green building rating system—PRS—to uncover whether any water conservation strategy has an adverse effect on energy and vice versa. The review revealed that the major shortcomings of the PRS in terms of water–energy nexus strategy are the usage of reference codes that are not suitable for the UAE’s climate and geographical conditions, inexistent synergy between some credit categories, the oversight of rebound effects, and a need for credit reassessment. The paper also recommends that any proposed strategy to realign credit categories in terms of the water–energy nexus with the potential risk to also have a hidden negative rebound effect that researchers and practitioners should identify lest the water–energy tradeoff brings unprecedented repercussions. The theoretical analysis establishes that the bifurcating management of water and energy in the sustainability rating system and energy policy needs to be revisited in order to reap more sustainable and optimum results that are environmentally, ecologically, and financially consistent.

Keywords: water–energy nexus; green buildings rating systems; Pearl Rating System; Estidama; sustainability; built environment; United Arab Emirates

1. Introduction

The United Arab Emirates (UAE), similar to many fast-growing economies, has been indexed as one of the countries producing the highest carbon footprints in the world [1,2]. Researchers have revealed that electricity consumption has doubled in the last ten years, and the main contributing factor to this surge is attributed to rapid urbanization, population, and economic growth in the country [3]. Energy consumption has been increasing at an annual rate of 4% and has reached 5% in 2020. Statistics have also revealed that the country’s domestic electricity consumption is in the range of 141 terawatt-hours in 2020 [4]. Similarly, the water demand of the UAE is around 550 L/day, which is thrice the water demand in Europe and US [5] and twice that of neighboring desert regions of Saudi Arabia, Lebanon, and Egypt [6].

Conversely, the UAE, whose climate conditions are harsher than other desert regions in the world, has an insignificant amount of fresh water—97% of its water needs are produced through desalination,
requiring a considerable amount of energy to extract, desalinate, and transport [5]. In Abu Dhabi, the largest emirate in the UAE, the majority of electricity and water demand is produced by thermal cogeneration plants, of which 84.6% and 92.2%, respectively, are consumed for building use [7]. Hence, from generation to consumption, water and energy resources are interlinked by supply, transmission, treatment, and utilization [8].

Water and energy, two primary resources that are both managed at multiple scales and domains, from the regional scale to administrative management, are deeply interdependent and interconnected [9–12]. A constraint on one of these resources has both direct and indirect influence on the other, while the requirements of future usage and development of resource management are subjected to the vulnerability of factors such as population and urbanization growth, states of the economy, and local climate change [13,14].

Most research carried out regarding the water–energy nexus is concentrated around energy production and water treatment facilities. However, the building sector consumes nearly 80% of the UAE’s energy, and the water–energy nexus’s applicability has not yet been considered in the built environment [15]. Green building rating systems such as Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM), and the Pearl Rating System all aim to conserve energy and water by incorporating several strategies [16–18]. However, it can be argued that water–energy nexus approach strategies are not addressed in these rating systems or in any current policy applicable to the built environment. The water–energy nexus concept was introduced because many strategies that aimed to save one resource in isolation often caused a strain on the other, sometimes to the extent of creating negative rebound effects. This problem can potentially become volatile in the UAE, because, although energy and water are produced in thermal co-generation plants, strategies to conserve them are conditioned to be implemented in isolation with no regard to the rebound effects that the resources could impinge on each other. Therefore, it is essential to explore whether any strategies implemented in the built environment related to water or energy domains without synergy consideration are producing a negative rebound effect. The identification of these possible relationships may serve in the considered case study and beyond.

2. Review Methodology

This paper aimed to diagnose, as a case study, the prospects of applying the water–energy nexus within the local green building rating system, which is referred to as the Pearl Rating System (PRS) [19], under the sustainability framework in Abu Dhabi, which is referred to as Estidama (the Arabic word for sustainability), against the current approach of categorizing and implementing suitable strategies of water and energy credits in isolation. The peer-reviewed research technique of meta-synthesis was primarily used for the case study as a qualitative research paper to carry out the diagnosis of the local green building rating system. The study sought to diagnose by juxtaposing the two main categories, ‘water’ and ‘energy,’ of the PRS by analyzing any rebound effect present by evaluating the mentioned strategies, along with any other synergy aspects from other credit categories—mostly through theoretical triangulation. The current shortcomings for nexus implementation in the PRS have been identified, and potential technical possibilities have been recommended to reap optimal benefits. While dissecting the categories, this paper also examined how the integrated approach of the nexus in the PRS can serve its purpose to align with the global need for energy conservation, the mitigation of climate change, and the reduction of CO₂ emissions. Though the study was conducted in regard to the UAE’s local green building rating system and its climatic and geographical conditions, the same methodology can be applied to other rating systems such as LEED and BREEAM to eliminate the problems arising from these vital resources when reviewed in a traditional differentiated approach. The identification of the hidden problems of not juxtaposing of these resources in the rating system can potentially lead to the formulation of policies that can truly, strategically serve the resources that conservation targets.
3. Water–Energy Nexus: Conceptualization

The water–energy nexus has been attracting global attention in the last decade, although the concept was conceived in the middle of the 20th century where the formal address of water-energy nexus was initiated by the US federal government enacting it in the Energy Policy Act 2005 under section 979 [20]. Since then, the interrelation between water and energy has been debated and discussed at various international conferences [21]. However, the lack of data availability including robust research in this area has blurred the accurate understanding of this phenomenon [22–25].

Some of the highlights from research studies related to the tradeoff in the water–energy nexus are summarized below. Scott et al. (2011) improvised various methods in which water–energy coupling can be done at multi-scale domains [10]. Bartos and Chester (2014) addressed the potential advantages of several conservation strategies of the nexus and developed a spatially explicit model for assessing it during different periods of use and reuse [26]. A GIS (Geographic Information System) model was used to demonstrate both current and future water demands at power plants in Illinois [27]. Similarly, a bottom–up approach was conducted to interlink energy and water resources of China, as well as to predict water demand and its impact on energy production [28]. Many researchers have analyzed the water–energy nexus in varying climatic conditions by correlating it with greenhouse emission (GHG) reductions [29,30].

The water footprint of energy has been relatively less studied compared to the energy footprint of water [31]. Often, consideration of water as a form of energy is overlooked, but its extraction and processing require an indispensable quantity of water similar to secondary energy generation, e.g., electricity [32]. Similarly, 75% of water distribution and wastewater treatment costs are associated with electricity consumption, infamous the energy cost [33]. Renewable energy generally broadcasts an image of green energy and conserving the environment against the exploitation of fuel extraction and processing found in the conventional energy generation systems, but in contrast to this popular belief, it has been found that some of these renewable energy systems are more water-intensive than conventional ones [24,32], including the carbon capture and sequestration systems by thermoelectric power plants [34].

Only few research works have examined the feasibility of integrating the water–energy nexus into sustainability requirements, with the research of Frankel and Carbonnier (2017) [35] standing prominently. Their study quantified water savings through the reduction of energy use in buildings and compared those savings to the savings gained through site water reduction strategies. Their calculation methodology involved the identification of the water usage of thermoelectric power generation based on fuel types. Their finding was that water savings made through a 20% reduction of energy use equaled or exceeded the site-based water savings, thus proving potential benefits through their pilot studies. However, the energy savings made through water reduction use in the building was not considered because its calculation tool has not yet been developed [35].

Only one study related to the water–energy nexus in the Estidama PRS has been done. In their 2014 study, Asaf and Nour [36] analyzed three types of buildings in a business-as-usual scenario. They found out by applying PRS regulations to these buildings, energy and water consumption savings of 31–38% and 22–36%, respectively, could be achieved. Moreover, an estimated equivalent amount of CO₂ of 31.4 million tons could be reduced. However, their simulation-based study did not take the water–energy nexus inclusion into the rating system into consideration, which may have impacted the accuracy of results.

4. Status of Water and Energy Consumption of UAE

Water and energy resources are critically needed in various sectors of the UAE’s economy such as power generation, oil extraction, wastewater treatment, and domestic consumption. Water and energy use in buildings is substantially much larger compared to other sectors, primarily because of climate conditions, rapid urbanization, and economic growth [37]. The extreme hot climate of the UAE translates into demanding more than 50% of energy consumption for cooling loads, as shown
in Figure 1 below [7]. To counteract this issue and to implement sustainability in the building sector, the UAE Pearl Rating System, which gives maximum emphasis to the installation of energy-efficient systems to reduce operational energy expenditures along with water-saving strategies, was developed in 2010.

Figure 1. Water and electricity use per sector in Abu Dhabi, UAE (Data adapted from [38]).

On average, the UAE’s energy consumption per capita is nine times higher than the world and is expected to rise due to the rapid rate of urbanization and population growth [39]. Figure 2 illustrates the increase in electricity production and consumption from 25,000 TWh in 2005 to 67,000 TWh in 2016. The UAE is also one of the world’s highest consumers of water, with a daily average of 90 gallons per capita and the production of around 12.5% of the world’s total desalinated water [40].

Figure 2. Electricity production and consumption [35].

Fath et al. (2011) mentioned in his study that the UAE has 70 desalination plants that produce fresh water and electricity from cogeneration thermal plants, while some only produce fresh water by implementing reverse osmosis technology [41]. Moreover, more than two-thirds of water produced from these cogeneration thermal plants are fossil-fuel-based [42]. It is also imperative to mention that the water-to-power ratio for the sole Emirate of Abu Dhabi plants is approximately 320–1170 m$^3$/day per MW of the cogeneration capacity of the plant. In Abu Dhabi, a large quantity of water is required for power generation, depending on the type of turbines used, e.g., steam and gas turbines. Since fresh water is not available, seawater provides the stable water demand for cooling in power generation systems [7]. However, the water, which is ejected back into the sea at a high temperature, causes imbalances in marine life [43].
Data regarding the energy required for wastewater treatment in the UAE is unavailable. According to some international estimates, the energy intensity of primary treatment is 0.1–0.3 kWh/m³, and for secondary treatment, the energy range is between 0.275 and 0.59 kWh/m³ [44]. It is imperative to note that since water and energy are mostly produced in co-generation plants, as in many desert regions, proactively considering this fact of the nexus in the sustainability rating systems would also facilitate financial and economical savings.

5. Case Study: Pearl Rating System of Estidama

5.1. General Overview of Pearl Rating System

The first and most widely used rating system, the PRS of Estidama, is a design methodology that was developed as a key product of “Abu Dhabi Vision 2030” to drive the construction industry of Abu Dhabi to green building standards. The PRS is an evaluation framework that evaluates the building in the design, construction, and operation phase under the four social, economic, environment, and cultural pillars [19] of the PRS was mandated by the Executive Council of Abu Dhabi and came into effect starting September 2010. The government of Abu Dhabi further strengthened this initiative by publishing a mandatory requirement that all government buildings in Abu Dhabi must have a minimum 2 Pearl rating and non-government buildings must have at least a 1 Pearl rating. The rating system applies to all building types such as schools, residences, villas, and hospitals in the Emirate of Abu Dhabi, UAE.

Additionally, there are four more rating systems implemented in the UAE—Al Safat (Emirate of Dubai), Barjeel (Emirate of Ras Al Khaimah), LEED, and BREEAM, the last two being international sustainability rating systems. Al Safat and Barjeel are relatively new and in their initial stage of implementation, whereas the PRS is well-established. The theoretical analysis conducted for the PRS is also valid for all aforementioned rating systems including the international ones, as the two resources are extremely vital in their importance. Figure 3 illustrates the different credit categories of the PRS.

![Credit Categories](image_url)

**Figure 3.** Credit categories of Pearl Rating System.

5.2. Case Study Description

This case study aimed to analyze the energy and water credit categories of the PRS from the water-energy nexus point of view to understand and abridge the potential benefits of synergizing the two resources through theoretical triangulation. Theoretical triangulation combined with the meta-synthesis research process was used to dissect the rating system. Though the two resources can be constraints to each other, an integrated approach in energy policy guidelines and building rating
systems was deemed necessary to understand and validate the benefits of water and energy savings. The assessment that was carried out for water and energy credit categories also tried to determine the concordance with other credit categories that utilize energy or water in a holistic manner. The technical possibilities for nexus implementation with the identified drawbacks were also briefly described.

5.3. Assessment of Energy Credits of Pearl Rating System

The energy section in the PRS aims to reduce the consumption of energy per capita in the country because it is feared that the demand for energy will surpass its supply if the current trend remains. Buildings consume a tremendous amount of energy and release CO\textsubscript{2}. Hence, the PRS believes that the use of proper techniques and strategies during building design and construction will bring significant results to curb energy demand during the operational stage [19].

The following section briefly conduct the diagnosis of the ‘Resourceful Energy’ category of PRS in regard to water-energy nexus enactment and also analysis of credits from other categories for concordance with these vital resources. Specific categories are discussed below that seem to undermine optimal energy utilization or strategies that tend to over-exploit the energy usage instead of conserving it. The majority of credit points from ‘Resourceful Energy (RE)’ category have been dissected for nexus enactment. Few credit points from other categories that are found to use extensive energy or have a direct synergy with energy are also discussed. They include subcategories from ‘Stewarding materials (SM)’ and ‘Livable Buildings (LB)’ and ‘Integrated Development Process (IDP)’. Table 1 provides the credit subcategories of “Resourceful Energy (RE)” of PRS.

Table 1. Different credit categories under the “Resourceful Energy” (RE) category of the Pearl Rating System.

| Credit Code | Credit Title | General Building Credits |
|-------------|--------------|--------------------------|
| RE-R1       | Minimum Energy Performance | Mandatory Requirement |
| RE-R2       | Energy Monitoring and Reporting | Mandatory Requirement |
| RE-R3       | Ozone Impacts of Refrigerants and Fire suppression systems | Mandatory Requirement |
| RE-1        | Improved Energy Performance | 15 |
| RE-2        | Cool Building Strategies | 6 |
| RE-3        | Energy Efficient Appliances | 3 |
| RE-4        | Vertical Transportation | 3 |
| RE-5        | Peak Load Reduction | 4 |
| RE-6        | Renewable Energy | 9 |
| RE-7        | Global Warming Impacts of Refrigerants and Fire suppression systems | 4 |

Under the ‘Resourceful Energy’ category of PRS RE-2 (‘Cool Building Strategies’), the usage of very high Solar Reflective Roofing materials (SRI > 78) is specified because it is predicted to reduce external heat gain, as well as to have a positive impact on the local climate. Similarly, in the ‘Livable Building’, LBo-R3 (‘Outdoor Thermal Comfort Strategy’) and LBo-1 categories (‘Improved Outdoor Thermal Comfort’), the usage of highly reflective materials and high-albedo surfaces is advised. However, reflecting all the heat from the building ejects more heat into the atmosphere. In particular, in dense urban areas, high rise buildings can develop a canyon of trapped heat that get swirled in and around the buildings due to improper wind flow and the obstructions caused by massive structures [45]. Researchers (2008) have pointed out that the ejection of heat from the buildings can also strike multiple surfaces and amplify the external heat that is eventually transmitted back to the atmosphere, thereby further increasing air temperature [46]. Though it has been well-argued and
documented that light-colored and reflective surfaces reduce heat built up for a single building or small area, research conducted to evaluate the net global warming has informed us that these surfaces set off chain reactions that intensify the overall sunrays a place is receiving whilst decreasing the vertical transport of moisture [47]. Thus, instead of reducing the heat inside a building, this process ultimately raises the cooling demand of nearby buildings, which, in turn, disturbs the local microclimate.

Additionally, in the RE-2 (‘Cool Building Strategies’) category, it is recommended to use vegetated roof gardens if the building size is small. This option is predicted to have a very positive impact on overall heating. In contrast, if the building size is massive, then a vegetated roof will require an extra expenditure of water and energy resources, even in the case of native or adapted plant species.

RE-6 (‘Renewable Energy’) suggests that a credit point of ‘1’ is awarded for offsite renewable energy; however, for a company or bearer to obtain a Renewable Energy Certificate (REC), it must provide renewable energy to the grid, an act that has not yet materialized in the Emirate of Abu Dhabi. In 2017, Dubai Electricity and Water Authority’s (DEWA) solar park became the first organization in the Arabian Gulf to receive a REC [48], but the credit category was developed in 2010. Furthermore, in the same Renewable Energy category (RE-6), the PRS proposes to accept projects using other renewable energy forms such as deep geothermal systems, landfill gas systems, and organic/agricultural energy. Currently, none of the aforementioned systems are used in the region, and the claims of these systems to be completely clean and green must be reassessed. Additionally, there have been reports that state the repercussions from implementing these alternative renewable systems, e.g., geothermal systems have been reported caused to have earthquake tremors in Germany [49]. Apart from these challenges, there are also some other potential hazards such as thermal pollution, groundwater contamination, and the release of toxic gases from these same systems [49].

The PRS has prime concerns about waste diversion, recycling, and incineration plants that encourage the reduction of waste (Stewarding Materials (SM) credit categories). Dubai and Sharjah are on a joint project to build the world’s best incineration plant and to produce nearly 60% of their electricity demand from converting solid waste to energy [50]. While the benefits of an incineration plant include their ability to help offset the environmental damage produced by methane from the decomposition of solid landfill waste and to create energy from waste [51], overlooking the fact that these plants emit more CO₂ than coal plants (14 times higher) or require a high water supply [52], as well as needing a constant source of waste for its operation and Capital Expenditures (CapEx), may not yield the expected results [53]. For example, the incineration plant in Torino, Japan, uses around 421,000 tons/yr, and most of the water used, around 735,000m³/yr, is evaporated in the cooling towers [54]. This reinforces the notion that if proper planning and analysis are not conducted for incineration facilities, significant monetary and energy losses can occur [49].

The PRS provides a maximum of four credit points for Life Cycle Cost (LCC) analysis in the Integrated Development Process (IDP) section. However, if LCC analysis is linked to energy costs or consumption [55], known as LCC-E (LCC and Energy taken together), it would yield better results because energy costs, including operational costs, are generally high in the UAE. Several researchers have pointed out that LCC-E is a better strategy because, most of the time, energy costs are overlooked [56]. Similarly, the use of other credit categories such as the SM section, which has many credit sub categories (‘SM-10 Recycled Materials,’ ‘SM-9 Regional Materials,’ and ‘SM-12 Reused/Certified Timber’) and suggests a high energy consumption, could result in better and transparent outcomes that also urge technical teams to consider them. More importantly, the SM section is oriented in such a way that a lot of importance and weightage is given to waste diversion from sites, both during the construction and operation phases of the building to landfills, incineration plants, or recycling plants (SM-13, 14, and 15, respectively). However, this raises few concerns. Though there are significant credits assigned to these categories, there are neither any incineration plants in the UAE nor any significant waste flow to recycling plants [57]. Additionally, most construction and demolition waste is generally discarded into landfills and account for around 70% of the total solid waste, thus causing discernible damage to local ecology [58].
LBo-7 (‘Bicycle Facilities’) requires the provision parking spaces for cycles with safety lockers for securing a cycle, and an extra point is even awarded if a reasonable number of showerheads per gender (max. of 10) with changing rooms are provided. If sought, this credit would require additional water and energy supplies because the cooler winter season lasts for about three-to-four months in Abu Dhabi; hence, for nearly 8 months, the facility cannot be used. This credit point is mostly suitable for colder regions in the world where there are better transitional climatic conditions. Table 2 below summarizes the analysis of the energy category of the PRS from the nexus standpoint.
| Category Code | ‘Resource Energy’ Category | PRS Requirements | Identified Pitfalls | Technical Possibilities |
|---------------|-----------------------------|------------------|---------------------|-------------------------|
| RE-R1         | Minimum energy performance  | ●The PRS focusses on performance improvements related to reduction in energy consumption ignoring energy costs. ●Use of code ASHRAE 90.2 for energy calculations. | May provide incomprehensive methodological analysis in relation to efficiency calculations in the PRS. | Modifications to reference codes reflecting the actual energy issues of the country. |
| RE-2, LBo-R3, LBo-1 | Cool building strategies, outdoor thermal comfort strategy, and improved outdoor thermal comfort | ●Recommends the use of high SRI roofing materials to reduce heat gain to the building, and the PRS argues this strategy will provide positive impact of local microclimate. ●Recommended to use vegetated roof gardens for cooling roofs. | ●Reflection of one building will affect the daylighting views and the energy requirements of adjacent buildings [47]. ●Increases urban heat island effect [46]. | ●IR reflective coatings for facades and roofs for hot climatic regions [59]. ●Reflective cool roofs and facades that generally have a lower temperature than ordinary or even vegetated roofs [60]. |
| RE-6          | Renewable energy             | ●To provide renewable energy to grid and the bearer to be sufficed with renewable energy certificates (RECs). ●Credit awards for deep geothermal systems and landfill gas systems claiming these systems to be eco-friendly. ●Production of energy from waste diversion plants. | ●RECs have been provided in the UAE through I-REC since 2016 [61], even though the PRS was created in 2009. ●These systems have negative impacts like earthquakes and risks including release of toxic gases in case of waste incineration plants [49]. ●Most of the above systems are not currently established in the UAE [62]. Hence, it would be best if these credits are modified to only include what is currently possible in the country. | ●BIPV (Building-Integrated Photovoltaics) [63] as it suits the UAE’s climate. ●BIWT (Building-Integrated Wind Turbine), especially for tall buildings [64]. |
| IDP-LCC       | Life cycle cost             | ●Usage of non-local codes for LCC calculation methodology such as British standards without providing specifications suit the UAE’s need. | ●LCC not linked to energy costs/efficiency as the UAE has strong concerns about electricity consumption [65]. | ●LCC-E savings would prove benefits [56], especially based on the UAE’s climatic, energy, and water conditions. ●Modifications in the reference codes to suit local needs will produce better solutions. |
| SM-9 to13     | Stewarding materials       | SM category emphasize huge importance on incineration plants. | No incineration plants yet established in the UAE [57]. | Requires reassessment for this credit as it is important to include in the rating system, which can provide an actual credit score. |
| LBo-7         | Bicycle facilities         | ● Provision of a max of 10 showerheads with safety lockers and changing rooms. | Due to intense and harsh weather conditions, people use bicycles only for 3–4 months/year, making these extra facilities redundant. | Need the credit to be reassessed in concordance with the UAE’s climatic conditions. |
5.4. Assessment of Water Credits of Pearl Rating System

The water credit category of the PRS totals 45 points (Table 3), which is more than other prominent rating systems around the world and is justifiable when considering the acute shortage of freshwater in the desert regions. However, when water saving is linked to the energy required to produce or consume it, or when synergy between several assessment credit points is critically reviewed, some of these strategies seem to echo their inherent potential loopholes, as described in the section below. Unlike for energy, water usage is easy to identify at the consumption stage, and resolution strategies can be quickly identified. The following evaluation also sought to assess the suitability of the technical team to implement the strategies.

| Credit Code | Credit Title                                      | General Building Credits |
|-------------|--------------------------------------------------|--------------------------|
| PW-R1       | Minimum Interior Water Use Reduction             | Mandatory Requirement    |
| PW-R2       | Exterior Water Monitoring                        | Mandatory Requirement    |
| PW-1        | Improved Interior Water Use Reduction            | 15                       |
| PW-2.1      | Exterior Water Use Reduction: Landscaping        | 8                        |
| PW-2.2      | Exterior Water Use Reduction: Heat Rejection     | 8                        |
| PW-2.3      | Exterior Water Use Reduction: Water Features     | 4                        |
| PW-3        | Water Monitoring and Leak Detection              | 4                        |
| PW-4        | Stormwater Management                            | 4                        |

In ‘Exterior Water Use Reduction’ (PW-2.1), ‘landscaping’ refers to efficient strategies to improve irrigation practices including proper plant selection, which requires a predefined level of water per day, thus encouraging the use of recycled water for landscaping while awarding points for the same. A synergy exists between NS-3 (‘Ecological Enhancement’) under the ‘Natural System (NS)’ category, which requires 50–70% of plants to be comprised of native species for credit accreditation, and NS-4 (‘Habitat Creation and Restoration’), which also requires native plant species to enhance habitat restoration. Thus, essentially, all these three credit point sections are strongly interconnected, and the point award criteria could have added synergy amongst them because they are all optional credit points. Such a synergy reassessment could facilitate a client’s monetary savings while also responding to the promotion of native plant species and the associated benefits, including that of embodied energy.

In PW 2.2 (“Exterior Water Use Reduction: Heat Rejection Category”), eight credit points are awarded if a heat rejection system is non-water-based, and two-to-five points are awarded for a water-based heat rejection system depending on the percentage of water requirements that could be served when using the exterior water allowance. Though it can be argued that a non-water-based heat rejection system is more water conservative, it may not increase the overall energy demand of a system because air-cooled chillers require more life cycle costs after factoring in operational cost and energy [66]. Research has also pointed out that none of the current air-based systems are as efficient as their counterparts, leading to more wastage of resources; hence, larger buildings cannot replace these water-based heat rejection systems because they will become more cost and energy ineffective. Thus, a potential solution is to reassess the optimal point at which the efficiency of different heat rejection systems varies for different building sizes, with points awarded accordingly.

In PW-4: SM (‘Stormwater Management’), there are four designated credits that endorse quality control, operation and maintenance plan of stormwater management. The credit requires the project to install systems to collect and treat at least 90% of stormwater, along with the contaminants present in it. The Operation and Maintenance Plan (OMP) also requires the project team to allocate money for the active lifetime maintenance of their stormwater treatment system. On the contrary, the UAE is a place with little precipitation; hence, most of the year, the system is kept idle while these systems consume
operational and maintenance energy along with their associated costs. Many project teams may seek to gain the four credit points, particularly the ones that aim for a high Pearl rating, by installing these highly expensive purification stormwater treatment plants without considering the actual use behind them or the energy inefficiency caused by a stormwater management system. Moreover, one of the reference guideline mentioned by the PRS is Commonwealth Scientific and Industrial Research Organisation (CSIRO), which is an Australian code for the environmental management of urban stormwater. However, these guidelines are hardly suited or adaptable in this country, revealing a specific need for more explicit and upgraded guidelines regarding the justification of this credit point distribution in the PRS. Table 4 summarizes the water category of the PRS from the nexus standpoint.

**Table 4. Summary of the “Precious Water” (PW) category of the Pearl Rating System with identified problems from the nexus perspective.**

| Category Code | ‘Precious Water’ Category | PRS Requirements | Identified Problems | Technical Possibilities |
|---------------|--------------------------|------------------|---------------------|-------------------------|
| PW-2.1        | Exterior water use reduction | Credit points like PW-2.1, NS-3, and NS-4 all encourage the use of native plant species. | Not considered synergy amongst the credit categories that may cause the client not to consider them altogether. | Need to consider all credit points encompassing the usage of native plant species to be grouped together; hence, the water requirement will be lesser and help in the credit accumulation savings for client. |
| PW-2.2        | Exterior water use reduction | 8 credit points are for non-water-based heat rejection system, and only 2–5 are awarded for water-based ones. | Research shows water-based ones are more efficient, and, hence, larger buildings can only use them instead of the air-based one [66]. | Need for the reassessment of distribution of credits points based on performance. |
| PW-4          | Stormwater management      | Install appropriate systems and treat 90% of stormwater. Reference guide is Commonwealth Scientific and Industrial Research Organisation (CSIRO). | The UAE has little precipitation and hence does not justify the expensive installation of equipment that require additional energy for operation and maintenance. | •The guideline mentioned not suited for the UAE’s hot desert climate; hence, it is recommended to be changed.  
•Since precipitation is negligible, credit points could be reduced. |

**6. Results Comparison of Water and Energy Codes and Discussion about the Identified Pitfalls of Pearl Rating System**

Theoretical analysis revealed four major shortcomings within the Pearl Rating System. They can be generally categorized as the usage of reference codes that are non-compliant with the UAE’s geography and climate conditions, non-synergy between few categories, oversight of certain rebound effects, and, the need for credit reassessment. The analysis ascertained that even though the water–energy nexus can bring more effective energy savings, rebound effects must be considered when finalizing the optimal solution because even a solution viable from the nexus point of view may have other unforeseen ecological or economic problems. Figure 4 illustrates all the identified shortcomings with respect to the water–energy nexus along with the credit categories.
7. Recommendations to Implement Water–Energy Nexus in Pearl Rating System

After the identification of the shortcomings of the PRS from the nexus perspective, a few recommendations are proposed that could help in the smooth facilitation of credit reorganization. They are the linkage of the nexus in the energy model simulation, the consideration of rebound effects from the strategies, and the reassessment of credit point distribution.

7.1. Linking of Nexus in Energy Model Simulation

Currently, the PRS uses water building calculator tools and dynamic energy simulations like Equest and Integrated Environmental Solutions or in short IES for energy simulation and reduction. A few independent researchers have modified the simulation methodology to isolate the result of energy savings by water reduction and link it to savings of fuel types necessary to produce that electricity. However, these experiments are, still in the research and developmental phase [35]. Similarly if proper simulation tools can be developed to accommodate and take water quantification and hidden energy consumed by water in buildings into consideration based on the UAE’s climatic and regional requirements, the use of the water–energy nexus in buildings would be pioneered. Designers and other stakeholders will also be able to see the simulated results and to predict actual saving and usage of water and energy. The idea that buildings are the investments of the future for business investors further emphasizes the usage of energy models for forecasting the costs and benefits of implementing various energy systems, their operations and maintenance, return on investment for onsite renewable systems, the purchase of RECs, and other high performance outcomes.
7.2. Rebound Effect of Renewable Energy Systems

The low carbon emission, clean energy production using renewable energy systems may seem like the optimal solution to the fossil fuel depletion problem, but there are numerous rebound effects linked to renewable energy systems that are often ignored by policy-makers and jurisdiction alike [67]. For example, solar- and wind-based renewable energy systems are the two most important ones, but the notion that 50% or 100% of energy requirements can be fulfilled by these types of systems is simply ludicrous because their efficiency is considered to be too dilute. Henceforth, to concentrate on this dilute energy would require a lot of additional energy and heavy wiring, and, moreover, these plants are mostly located far away from the urban areas that require tremendous energy and monetary expenditure to properly distribute to [68].

Nevertheless, with the depletion of conventional fossil fuels, it is important to focus and build viable renewable energy systems. However, in doing so, besides studying the benefits of such systems, it is vital to understand their compound influence on the energy and water requirements along with their impacts on the environment. Moreover, this implantation will be successful only if an optimal point is ascertained while considering all constraints associated with the installation of renewable energy systems, especially from the water–energy nexus standpoint for the PRS.

7.3. Reassessment of Credit Points Distribution

There are credit points that are apportioned for certain facilities or features that are not yet implemented in Abu Dhabi like incineration facilities (SM-14), metro or rail stations (LBo-6 public transport—given three credit points), or even RECs that are not currently provided by the UAE. This can cause problems with the technical team seeking overall points for rating credits when they are not even made available in Abu Dhabi. Similarly, several codes or regulations that are American or Australian-based will not be completely adoptable in the UAE because its climatic and geographical conditions are significantly different. Hence, there is a need for more rigorous research both from academicians and industry professionals in the built environment so that these issues can be rectified and ameliorated in the newer versions of the PRS.

8. Further Research Direction

Since the concept of the water–energy nexus is still in the nascent form, it can be well-integrated in the Pearl Rating System because these two resources are co-generated. However, strategic and reformative considerations might be necessary for energy policymakers to allow for the facilitation of a smooth and transitioned change that substantially allocates both responsibilities and opportunities associated with these two vital resources. A pious solution would be needed to plan for short- and long-term goals, along with considerations of the rebound effects that might potentially emerge. This advertently formulates the rationale for the revision of the PRS and for the plausible consideration of water and energy strategies to be carried out in concordance rather than in isolation and that are also secure, affordable, and environmentally sustainable. If suitable policies, programs, and a revised PRS are implemented alongside the water–energy nexus philosophy, the benefits will be aligned with the UAE’s strategic goals in terms of the energy mix and reduction of CO₂ emissions.

9. Conclusions

The evaluation of a green building rating system, in this case the UAE’s Pearl Rating System, from the water–energy nexus revealed potential flaws when water efficiency strategies were considered separately from that of energy efficiency. From the theoretical analysis carried in this paper, it was clear that besides water savings imposing a rebound effect on energy savings that is eventually reciprocated, the interaction between these resources seems to reflect complex connections with other credit point categories, thus implying the need for its potential synergy inclusion while assessing it from the nexus perspective. This case study paper identified four major shortcomings of the PRS, namely the usage of
reference codes that are non-compliant with the UAE’s geography and climate, non-synergy, rebound effects, and a need for credit reassessment. It was established that policies and legislations aimed to reduce the consumption of one resource have unprecedented negative effects on the other. Though the two resources can be constraints to each other, an integrated approach in energy policy guidelines and building rating systems was deemed necessary to understand and validate the benefits of water and energy savings. The key to achieving green and building energy efficiency lies in a smooth and transitioned leap that considers and assesses the benefits and rebounds of any energy solutions that are undertaken, as well as its impact on water resources and vice-versa rather than an abrupt one. The identified relationships in the local case study should serve to assess the same in the exiting green building system in general.

**Author Contributions:** Conceptualization, A.H.; methodology, R.R. and K.A.T.A.; writing—original draft preparation, R.R.; writing—review and editing, K.A.T.A.; A.H. visualization, R.R. and K.A.T.A.; funding acquisition, K.A.T.A. All authors have read and agreed to the published version of the manuscript.

**Funding:** The authors gratefully acknowledge financial support from the United Arab Emirates University through the Emirates Centre for Energy and Environment Research funded research project (31R102).

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

**References**

1. Kazim, A. Strategy for a sustainable development in the UAE through hydrogen energy. *Renew. Energy* 2010, 35, 2257–2269. [CrossRef]
2. Saxena, R.P.; Kumar, B.R. Greening for sustainability: Green UAE—A classic example. *Interdiscip. Environ. Rev.* 2020, 20, 118. [CrossRef]
3. Al-Badi, A.; Almubarak, I. Growing energy demand in the GCC countries. *Arab. J. Basic Appl. Sci.* 2019, 26, 488–496. [CrossRef]
4. United Arab Emirates—Countries & Regions—IEA. Available online: https://www.iea.org/countries/united-arab-emirates (accessed on 12 September 2020).
5. Mohsen, M.S.; Akash, B.; Abu Abdo, A.M.; Akash, O. Energy Options for Water Desalination in UAE. *Procedia Comput. Sci.* 2016, 83, 894–901. [CrossRef]
6. Paleologos, E.K.; Farouk, S.; Al Nahyan, M.T. Water resource management towards a sustainable water budget in the United Arab Emirates. *IOP Conf. Ser. Earth Environ. Sci.* 2018, 191, 012007. [CrossRef]
7. Assaf, S.; Nour, M. Potential of energy and water efficiency improvement in Abu Dhabi’s building sector—Analysis of Estidama pearl rating system. *Renew. Energy* 2015, 82, 100–107. [CrossRef]
8. Yoon, H. A Review on Water-Energy Nexus and Directions for Future Studies: From Supply to Demand End. *Doc. d’Analisi Geografica* 2018, 64, 365–395. [CrossRef]
9. Kenway, S.K.; Lant, P.A.; Priestley, A.; Daniels, P. The connection between water and energy in cities: A review. *Water Sci. Technol.* 2011, 63, 1983–1990. [CrossRef]
10. Scott, C.A.; Pierce, S.A.; Pasqualetti, M.J.; Jones, A.L.; Montz, B.E.; Hoover, J.H. Policy and institutional dimensions of the water–energy nexus. *Energy Policy* 2011, 39, 6622–6630. [CrossRef]
11. Villamayor-Tomas, S. The Water–Energy Nexus in Europe and Spain: An Institutional Analysis from the Perspective of the Spanish Irrigation Sector. In *Competition for Water Resources*; Elsevier: Amsterdam, The Netherlands, 2017; pp. 105–122.
12. Voinov, A.; Cardwell, H. The Energy-Water Nexus: Why Should We Care? *J. Contemp. Water Res. Educ.* 2009, 143, 17–29. [CrossRef]
13. Gerbens-Leenes, W.; Hoekstra, A.Y.; Van Der Meer, T.H. The water footprint of bioenergy. *Proc. Natl. Acad. Sci. USA* 2009, 106, 10219–10223. [CrossRef] [PubMed]
14. Griffiths-Sattenspiel, B.; Wilson, W. *The Carbon Footprint of Water*; River Network, Energy Foundation: Colorado, OR, USA, 2009.
15. Dubey, K.; Krarti, M. *Economic and Environmental Benefits of Improving UAE Building Stock Energy Efficiency*; KAPSARC: Riyadh, Saudi Arabia, 2017.
16. Lee, E. Indoor environmental quality (IEQ) of LEED-certified home: Importance-performance analysis (IPA). *Build. Environ.* 2019, 149, 571–581. [CrossRef]
17. Wu, P.; Song, Y.; Shou, W.; Chi, H.; Chong, H.-Y.; Sutrisna, M. A comprehensive analysis of the credits obtained by LEED 2009 certified green buildings. Renew. Sustain. Energy Rev. 2017, 68, 370–379. [CrossRef]
18. Suzer, O. Analyzing the compliance and correlation of LEED and BREEAM by conducting a criteria-based comparative analysis and evaluating dual-certified projects. Build. Environ. 2019, 147, 158–170. [CrossRef]
19. Department of Urban Planning and Municipalities—Estidama Services. Available online: https://www.upc.gov.ae/en/upc-services-and-tools/services/estidama-services (accessed on 25 January 2020).
20. Marsh, D.M.; Sharma, D. Energy-water nexus: An integrated modeling approach. Int. Energy J. 2007, 8, 235–242.
21. Head, B.; Cammerman, N. The Water-Energy Nexus: A Challenge for Knowledge and Policy Urban Water Security Research Alliance Technical Report No. 39; University of Queensland: Queensland, Australia, 2010.
22. Hardberger, A.; Stillwell, A.S.; King, C.W.; Webber, M.; Duncan, I.J. Energy-Water Nexus in Texas; The University of Texas: Austin, TX, USA, 2009.
23. Kumar, M.D. Impact of electricity prices and volumetric water allocation on energy and groundwater demand management: Analysis from Western India. Energy Policy 2005, 33, 39–51. [CrossRef]
24. Macknick, J.; Newmark, R.; Heath, G.; Hallett, K.C. A Review of Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies; NREL US Department of Energy: Colorado, CO, USA, 2011.
25. Retamal, M.L.; Abeyesuriya, K.; Turner, A.J.; White, S. Water Energy Nexus Literature Review; Institute for Sustainable Features, University of Sydney: Sydney, Australia, 2009.
26. Bartos, M.; Chester, M.V. The Conservation Nexus: Valuing Interdependent Water and Energy Savings in Arizona. Environ. Sci. Technol. 2014, 48, 2139–2149. [CrossRef]
27. DeNooyer, T.A.; Peschel, J.M.; Zhang, Z.; Stillwell, A.S. Integrating water resources and power generation: The energy–water nexus in Illinois. Appl. Energy 2016, 162, 363–371. [CrossRef]
28. Huang, W.; Ma, D.; Chen, W. Connecting water and energy: Assessing the impacts of carbon and water constraints on China’s power sector. Appl. Energy 2017, 185, 1497–1505. [CrossRef]
29. Scanlon, B.R.; Duncan, I.; Reedy, R.C. Drought and the water–energy nexus in Texas. Environ. Res. Lett. 2013, 8, 045033. [CrossRef]
30. Conway, D.; Van Garderen, E.A.; Deryng, D.; Dorling, S.; Krueger, T.; Landman, W.A.; Lankford, B.; Lebek, K.; Osborn, T.; Ringler, C.; et al. Climate and southern Africa’s water–energy–food nexus. Nat. Clim. Chang. 2015, 5, 837–846. [CrossRef]
31. Schuck, E.; Green, G.P. Supply-based water pricing in a conjunctive use system: Implications for resource and energy use. Resour. Energy Econ. 2002, 24, 175–192. [CrossRef]
32. Mielke, E.; Anadon, L.D.; Narayananmurti, V. Water Consumption of Energy Resource Extraction, Processing, and Conversion—Energy Technology Innovation Policy Discussion Paper Series; Energy Technology Innovation Policy Project, Belfer Center: Cambridge, MA, USA, 2010.
33. Glassman, D.; Wucker, M.; Isaacman, T.; Champilou, C. The Water-Energy Nexus: Adding Water to the Energy Agenda; World Policy Institute: New York, NY, USA, 2011; p. 35.
34. U.S. Department of Energy. Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements; National Energy Technology Laboratory: Albany, OR, USA, 2011; p. 83.
35. Frankel, M.; Carbonnier, K. Quantifying the Water-Energy Nexus at the Building Project Scale; New Buildings Institute: Portland, OR, USA, 2017.
36. Assaf, S.; Nour, M. Overview of Water Energy Nexus of Abu Dhabi’s Power Sector-Energy Water Analysis of End Use Segment. In ICREGA’14-Renewable Energy: Generation and Applications; Springer: Cham, Switzerland, 2014; pp. 315–328.
37. Avtar, R.; Tripathi, S.; Aggarwal, A.K.; Kumar, P. Population–Urbanization–Energy Nexus: A Review. Resources 2019, 8, 136. [CrossRef]
38. Energy and Water Statistics. Report of Abu Dhabi; Energy and Water Statistics: Abu Dhabi, UAE, 2017; pp. 1–19.
39. Al-Mulali, U.; Sab, C.N.B.C. Energy consumption, CO2 emissions, and development in the UAE. Energy Sources Part B Econ. Plan. Policy 2018, 13, 1–6. [CrossRef]
40. Kazim, A. Assessments of primary energy consumption and its environmental consequences in the United Arab Emirates. Renew. Sustain. Energy Rev. 2007, 11, 426–446. [CrossRef]
41. Mezher, T.; Fath, H.; Abbas, Z.; Khaled, A. Techno-economic assessment and environmental impacts of desalination technologies. Desalination 2011, 266, 263–273. [CrossRef]
42. Sgouridisc, S.; Griffiths, S.W.; Kennedy, S.; Khalid, A.; Zurita, N. A sustainable energy transition strategy for the United Arab Emirates: Evaluation of options using an Integrated Energy Model. *Energy Strat. Rev.* 2013, 2, 8–18. [CrossRef]
43. Lattemann, S.; Höpner, T. Environmental impact and impact assessment of seawater desalination. *Desalination* 2008, 220, 1–15. [CrossRef]
44. Siddiqi, A.; Anadon, L.D. The water–energy nexus in Middle East and North Africa. *Energy Policy* 2011, 39, 4529–4540. [CrossRef]
45. Danks, R.; Good, J.; Sinclair, R. Assessing reflected sunlight from building façades: A literature review and proposed criteria. *Build. Environ.* 2016, 103, 193–202. [CrossRef]
46. Priyadarshini, R.; Hien, W.N.; David, C.K.W. Microclimatic modeling of the urban thermal environment of Singapore to mitigate urban heat island. *Sol. Energy* 2008, 82, 727–745. [CrossRef]
47. Sayed, M.A.E.D.A.; Fikry, M.A. Impact of glass facades on internal environment of buildings in hot arid zone. *Alex. Eng. J.* 2019, 58, 1063–1075. [CrossRef]
48. Dewa Earns Region’s First Renewable Certificate Recognition, Gulf News. 2017. Available online: https://gulfnews.com/going-out/society/dewa-earns-regions-first-renewable-certificate- recognition-12065530 (accessed on 12 July 2019).
49. Zhu, K.; Fang, L.; Diao, N.; Fang, Z. Potential underground environmental risk caused by GSHP systems. *Procedia Eng.* 2017, 205, 1477–1483. [CrossRef]
50. Waste-to-Energy—The Official Portal of the UAE Government. Available online: https://u.ae/en/information-and-services/environment-and-energy/water-and-energy/types-of-energy-sources/waste-to-energy- (accessed on 12 September 2020).
51. Bozorgirad, M.A.; Zhang, H.; Haapala, K.R.; Murthy, G.S. Environmental impact and cost assessment of incineration and ethanol production as municipal solid waste management strategies. *Int. J. Life Cycle Assess.* 2013, 18, 1502–1512. [CrossRef]
52. Rahman, H.A. Incinerator In Malaysia: Really Needs? *Int. J. Chem. Environ. Biol. Sci.* 2013, 1, 678–681.
53. Kuo, J.-H.; Lin, C.-L.; Chen, J.-C.; Tseng, H.-H.; Wey, M.-Y. Emission of carbon dioxide in municipal solid waste incineration in Taiwan: A comparison with thermal power plants. *Int. J. Greenh. Gas Control.* 2011, 5, 889–898. [CrossRef]
54. Castri’, A.; Conti, R.; Fino, D.; Conti, E.; Di Bartolo, G. *The Use of Water in the Incineration Plant of Torino; Environmental Science, IWWG: Venice, Italy, 2007.*
55. Lucchi, E.; Tabak, M.; Troi, A. The “Cost Optimality” Approach for the Internal Insulation of Historic Buildings. *Energy Procedia* 2013, 17, 412–423. [CrossRef]
56. Wang, J.; Pan, W. Influencing parameters of the life cycle cost-energy relationship of buildings. *J. Green Build.* 2018, 13, 103–121. [CrossRef]
57. Waste Management—The Official Portal of the UAE Government. Available online: https://u.ae/en/information-and-services/environment-and-energy/waste-management (accessed on 25 September 2020).
58. Mawed, M. Construction and demolition waste management in the uae: Application and obstacles. *Int. J. GEOMATE* 2020, 18. [CrossRef]
59. Becherini, F.; Lucchi, E.; Gandini, A.; Barrasa, M.C.; Troi, A.; Roberti, F.; Sachini, M.; Di Tuccio, M.C.; Garmendia, L.; Pockelè, L.; et al. Characterization and thermal performance evaluation of infrared reflective coatings compatible with historic buildings. *Build. Environ.* 2018, 134, 35–46. [CrossRef]
60. Macintyre, H.L.; Heaviside, C. Potential benefits of cool roofs in reducing heat-related mortality during heatwaves in a European city. *Environ. Int.* 2019, 127, 430–441. [CrossRef] [PubMed]
61. GCC Renewable Energy Certificates. Available online: https://gcc.re/ (accessed on 25 September 2020).
62. Atwany, H.; Hamdan, M.O.; Abu-Nabah, B.A.; Alami, A.H.; Attom, M. Experimental evaluation of ground heat exchanger in UAE. *Renew. Energy* 2020, 159, 538–546. [CrossRef]
63. Berawi, M.A.; Miraj, P.; Sayuti, M.S.; Berawi, A.R.B. Improving building performance using smart building concept: Benefit cost ratio comparison. *AIP Conf. Proc.* 2017, 1903. [CrossRef]
64. Li, Q.; Shu, Z.; Chen, F. Performance assessment of tall building-integrated wind turbines for power generation. *Appl. Energy* 2016, 165, 777–788. [CrossRef]
65. Paltsev, S.; Reilly, J.; Jacoby, H.; Tay, K.H. How (and why) do climate policy costs differ among countries. In *Human-Induced Climate Change: An Interdisciplinary Assessment;* Cambridge University Press: Cambridge, UK, 2007; pp. 282–293.
66. Hawit, O.; Jaffe, T. Water–Energy Nexus: Heat Rejection Systems. *ASHRAE J.* 2017, 59, 28–39.

67. Al-Mulali, U.; Solarin, S.A.; Sheau-Ting, L.; Ozturk, I. Does moving towards renewable energy cause water and land inefficiency? An empirical investigation. *Energy Policy* 2016, 93, 303–314. [CrossRef]

68. Johnson, E.P. *Measuring the Productive Inefficiency in Renewable Electricity Generation*; IRENA: Abu Dhabi, UAE, 2014; pp. 1–30.

© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).