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Systematic Review

Waste Management in Qatar: A Systematic Literature Review and Recommendations for System Strengthening

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Abstract: Billions of tons of waste are generated annually, with the amount of waste rapidly increasing and its management expected to worsen. Qatar is a small and wealthy country in the Arabian Peninsula that is undergoing enormous economic and urban development. This study presents the results of a systematic literature review on waste management in Qatar and offers recommendations for system strengthening based on an analysis of the available evidence. The PRISMA guidelines were followed to review literature from the ProQuest and SCOPUS platforms, from which 82 unique publications were analyzed according to ten themes. The results draw upon diverse disciplinary and research focus areas related to waste management, ranging from the generation of value-added products from wastes to the role of religion in waste management awareness. The main recommendations emerging from the available evidence include the need for a holistic approach to address increasing waste generation, which must include diverse stakeholders such as government entities, researchers, and broad community representation for decision making as well as raising awareness for behavior change. Additionally, the main waste types, including construction, food, plastic, and electronic wastes, require specific attention since the cause of generation and type of management varies accordingly. The rise of interest in improving waste management, in particular to work toward meeting the targets of the Qatar National Vision and the National Development Strategy should bring about positive outcomes for strengthening waste management systems.

Keywords: Qatar; waste; waste management; systematic review; system strengthening

Citation: Mariyam, S.; Cochrane, L.; Zuhara, S.; McKay, G. Waste Management in Qatar: A Systematic Literature Review and Recommendations for System Strengthening. *Sustainability* **2022**, *14*, 8991. https://doi.org/10.3390/su14158991

Academic Editors: Elena Cristina Rada and Daniela Baldantoni

Received: 29 May 2022
Accepted: 4 July 2022
Published: 22 July 2022

1. Introduction

Billions of tons of waste are generated annually, with the amount of waste rapidly increasing and its management expected to worsen [1,2]. The World Bank expects global urban waste to increase 70% from 2016 levels by 2050 (from 2.01 billion tons of solid waste to 3.4 billion tons) [3]. Improperly managed waste is not only economically inefficient, but it has also negative impacts on health and wellbeing, causes environmental and marine damage and contamination (soils, waterways, groundwater, etc.), and negatively contributes to climate change via greenhouse gas emissions [1,4]. The benefits of improved waste management is a reduction in these harms, but also the enabling of positive outcomes via shifts toward circular resource flows [5–7]. Waste management is under-researched, resulting in limited available data for evidence-based decision making [1]. However, available evidence needs to be utilized to strengthen existing waste management systems and to guide future research needs. This article presents the results of a systematic literature review of one country, the State of Qatar, the analysis of which enables recommendations for system strengthening. This country case study is important as it provides evidence for a unique sociopolitical and economic context, ensuring that while recommendations learn from best practices, they are tailored and appropriate for implementation. This country case study is relevant for other rapidly developing economies, from which lessons can be drawn.

High-income countries in the Middle East, including Saudi Arabia, Bahrain, Qatar, and the United Arab Emirates—all member states of the Gulf Cooperation Council (GCC)—are amongst the world's largest waste contributors on a per capita basis. In 2015, Bahrain produced the highest per capita municipal solid wastes (MSW)(2.7 kg per day), followed by Saudi Arabia, Qatar (1.8 kg per day respectively), and UAE (1.7 kg per day) [8]. MSW are the most common types of wastes, which includes trash or garbage from households and businesses. High standards of living combined with growing populations continually increase the total amount of MSW, and upon these trends waste production is expected to increase in the aggregate. The recycling sector in the region is underdeveloped, with only 10 to 15% of the waste being recycled [8]. Globally, waste management is a challenging problem, with limited management diversification and recovery of resources such as fuel, heat, power, and others. Inefficient waste management practices contribute to additional greenhouse gas emissions, compounding other global challenges [8].

In the Middle East, the majority of the produced waste is organic with much of the rest being recyclable materials such as glass, paper, and metals. Organic waste is generally dumped in a nonsanitary landfill, using large areas of land with little consideration to the environment [8]. Not only does the landfill contribute to harmful greenhouse emissions, but it is also known to pollute surrounding water bodies and soil, the latter of which also has the potential to contaminate underground water resources, collectively damaging ecosystems and creating health hazards for people living in the vicinity. Furthermore, some of the countries in the region lack sufficient land area and therefore find it difficult to place new landfills due to the abovementioned spatial issues, in addition to the environmental and human health-related risks [8]. Recently, these problems have led to a surge in diversifying waste management to recycling and research into value-added options for waste, as the majority of the produced waste is either decomposable or recyclable. Since there is an expected 3% median annual increase in MSW produced in the GCC [9], there needs to be further development of the infrastructure related to waste management to handle this annual increase [10]. Increasing recycling in the region comes with a significant reduction in the required land volume for waste disposal [11]. For example, recycling could save 2,631,650 USD/year from land volume for the 187, 975 tonnes of solids generated per year. However, the low cost of landfilling and lack of national or regional targets and policies related to recycling creates challenges the region for a transformation of the waste management system [11].

2. Country Context

The State of Qatar is one of the countries located in the Arabian Peninsula and is a member state of the GCC. The country is geographically small, with a land area of about 11,500 square kilometers. In recent decades the country has rapidly developed and now has one of the world's highest GDP per capita, enabled by immense hydrocarbon reserves, particularly natural gas [12]. The relatively small population has risen rapidly, from around 600,000 people in 2000 to 2.8 million in 2020, which is almost entirely urban [13]. Of the population, citizens are a minority, resulting in a diverse population home to different nationalities [12]. Qatar is the most religiously varied country in the Middle East, more diverse than Germany, India, or the USA [14].

In Qatar, the municipalities are responsible for waste collection, either through their own logistics or aided by the private sector [8]. The collected waste is taken by truck to one of three landfills: Umm Al-Afai (mainly for bulky and domestic waste), Rawda Rashed (for construction and demolition waste), or A-Krana (for sewage sludge). Sixty percent of the waste is organic, and the rest is mostly recyclables [8]; however, only a minimal amount (<15%) is recycled [8]. Qatar is trying to develop and implement alternate waste management techniques based on the waste hierarchy including prevention, the 3Rs (reduce, reuse, recycle), and energy recovery, and only resort to landfilling as the last option [8]. Qatar is the first country in the Middle East to implement a waste-to-energy

program, converting waste to energy in their Domestic Solid Waste Management Center (DSWMC) in Mesaieed [8].

The country aims to transition to a knowledge-based economy while staying committed to its cultural and traditional background [15]. This transition is supported by the R&D expenditure of the country, about 0.5% of its GDP, ranking second among the GCC countries, which, for example, resulted in a 50% increase in the R&D-related personnel between 2012 and 2015 [15]. This transformation is being led by the Qatar National Vision (QNV) 2030, a plan that was framed in the year 2008 to support economic transformation and human development while preserving the physical, natural, and cultural environment [15], framed around four pillars of human, social, economic, and environmental development [16]. The detailed operational ideas and targets are outlined in the Qatar National Development Strategy (QNDS), with two strategies being developed to date (the first in 2011 and the second in 2018, for the years 2011–2018, 2018–2022, respectively). The first QNDS articulates a multifaceted approach to waste management to include reducing, recycling, and increasing the efficient use of waste [17].

Furthermore, there is an emphasis on incentivizing waste reduction, promoting waste separation at the source, and shifting the tariff structure to promote mindful waste generation. The main targets included establishing a solid waste management plan, focusing on recycling—increasing the rate to 38%—which will reduce the amount of landfilled waste and avoid increasing waste generation, keeping the target rate at 1.6 kg/capita/day [17]. Figure 1 shows the historic and predicted waste generated and population growth in the country as presented in the second QNDS. The total solid wastes are linked to population, economic development, industrialization, urbanization, and local culture. A decline in population predicts a decrease in waste after 2020. Additionally, a waste hierarchy classification, following the definition by United Nations Environment Program to avoid, reduce, reuse, recycle, recover, treat, and dispose, has been adopted to ensure maximum minimization of waste streams to landfills (refer Figure 2 to see the version agreed on by parties at the Basel Convention) [18].

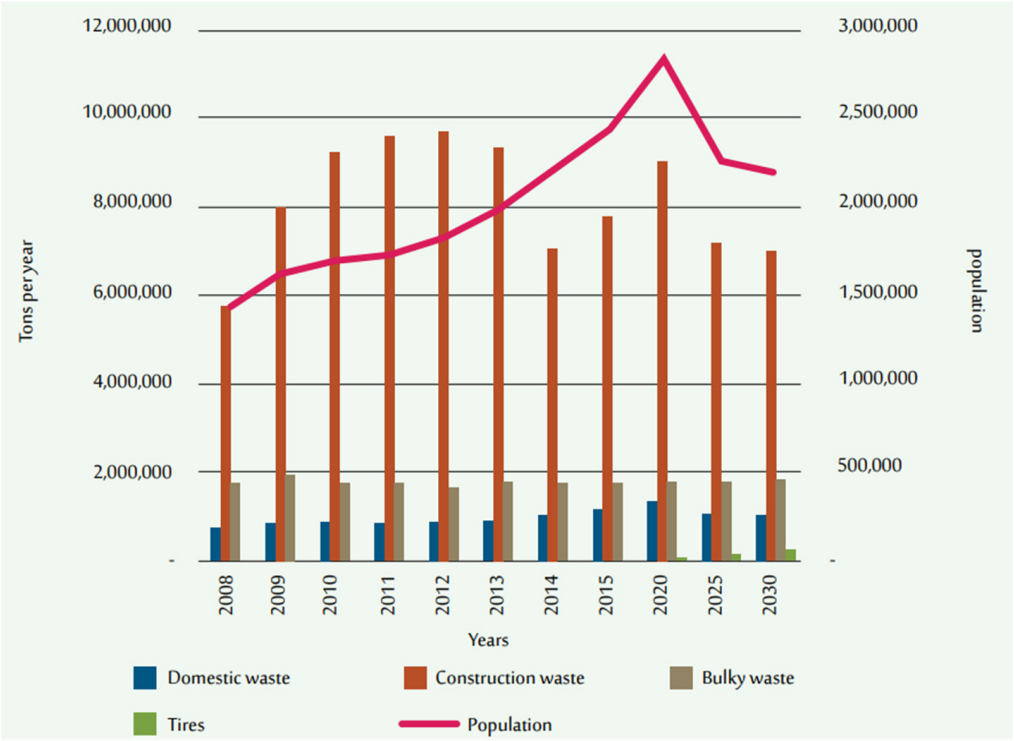

Figure 1. Historic and projected waste production from 2008 to 2030, from the Planning and Statistics Authority [19].

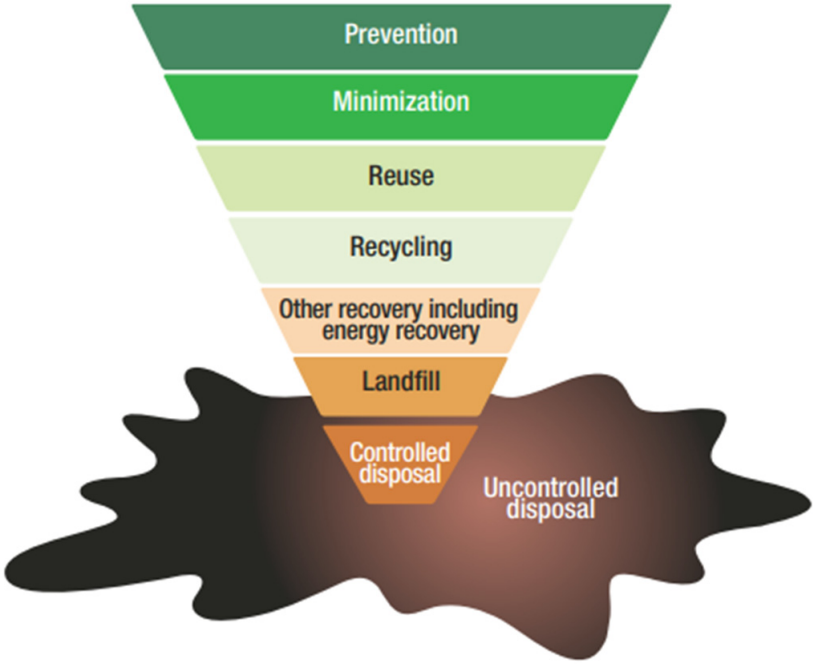

Figure 2. Waste management hierarchy as agreed on by the Basel Convention, United Nations Environment Programme (UNEP) [2].

The second strategy expanded waste considerations and targets, especially from the construction and building sector, and it was noted that 20% of all materials used for construction must be recycled, as seen in Figure 1 [19]. Commendably, the World Cup Stadium 974 was built using 95% recycled materials, which is one example of putting these ambitious targets into practice [20]. Alongside these targets, Qatar has committed to host the first carbon-neutral FIFA World Cup in 2022. Latest newspaper reports shared the approved draft decision of the Ministry of Municipality on banning single-use plastics in the country by prohibition in packaging, products, and merchandise, and replacing with multiuse bags. The country's initiatives toward improving waste management and sustainability in the past decade have been remarkable; however, there is room for significant improvement, particularly with the support of people living in the country for the implementation of changes and institutional shifts, all supported by the R&D sector's efforts.

This study—to the best of the authors' knowledge for the first time—conducts a systematic review of the literature on the Qatar waste management. The results of this study will interest researchers, policy makers, and stakeholders in Qatar, and by extension, the GCC region, as it analyzes the trends in waste management and hence helps focus initiatives and research to enhance waste management. The systematic review is essential to understand the research gaps that exist to achieve sustainable solid waste management in Qatar. Findings from this paper could aid in analyzing the outcomes of the Qatar National Research Strategy in waste management thus far and could be utilized by the countries in the region to research and develop appropriate solutions. The main objectives of this study are achieved by (i) collection of journal articles on waste management related to Qatar from two academic databases, (ii) bibliographic analysis of the identified publications, (iii) identify and examine emergent themes, and (iv) discuss the significance, research gaps, and future prospects of waste management system strengthening in Qatar.

3. Methodology

Systematic reviews provide a structure for assessing available evidence regarding a proposed research question by identifying, researching, and analyzing relevant research published in defined bibliographic databases with set search parameters [21]. In such an approach, the search strategies are communicated accurately, which this section aims

to do. The systematic literature review conducted for this paper seeks to identify and synthesize the available evidence on waste in Qatar and what the waste management strategies are within the country. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Protocols (2015) (PRISMA) guidelines were followed, as much as possible, considering this is a social science review article rather than a health review (PRISMA was first developed for health reviews). We conducted a systematic search on the academic databases of ProQuest and SCOPUS to achieve the research objectives. Every database has strengths and limitations. SCOPUS has become a widely used database since its launch in 2004, being comprehensive in comparison to other databases, such as Web of Science, due to data quality, source availability, and coverage [22]. We also utilized ProQuest, to expand and complement the study, as SCOPUS does not list all materials and offers unique search features [23]. We could have utilized other platforms, such as Google Scholar, which is arguably the most comprehensive as it includes evidence provided by governmental, intergovernmental, and nongovernmental sources that tend not to be indexed on academic databases. However, because Google Scholar is not limiting search results to peer-reviewed publications, challenges of data quality emerge from that platform.

The systematic review search was conducted on 20 February 2022 using keywords Qatar AND waste AND management in the search bars from 2011 to 2022. Using "AND" ensured (to some extent) that only articles with all the three keywords appeared in the results of the search. Based on the keywords and temporal parameters, 2230 articles were downloaded in RIS format and uploaded to Rayyan (a free web tool designed to help researchers manage articles when conducting systematic reviews). The tool helped screen articles quickly since all the uploaded articles with their titles and abstracts can be efficiently screened by multiple authors simultaneously, on one platform. Figure 3 summarizes the systematic search and review processes in this study.

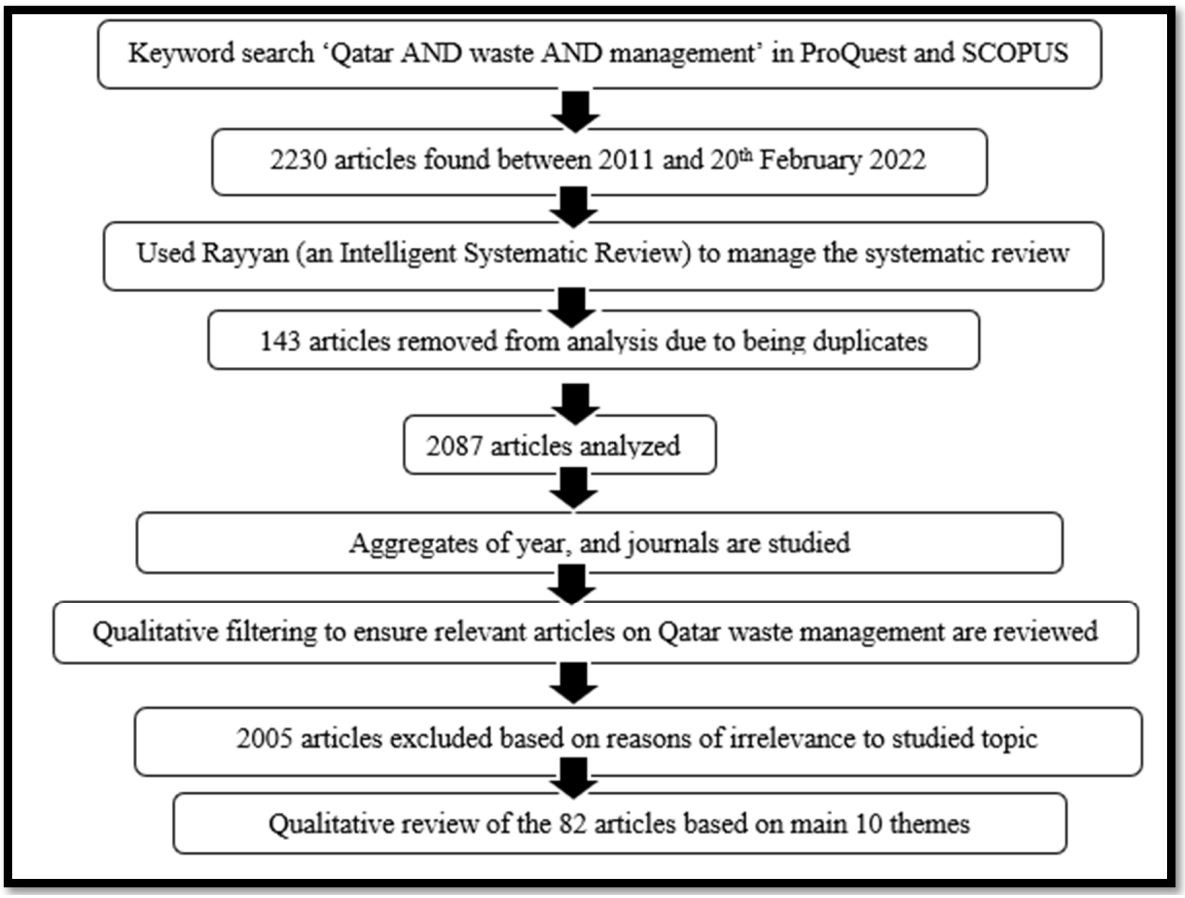

Figure 3. Systemic review process for the study.

The Rayyan tool also helped autodetect duplicates and suggested possible duplicates (which were verified by manual screening) [24]. The total number of autoduplicates and screened duplicates from the possible duplicates amounted to 82 and 61 articles, respectively; they were removed from further analysis. Out of the 2087 articles analyzed, a qualitative screening was conducted of titles and abstracts to assess if the publication was focused on the country case study and matched the subject (removing for false positives in the results). Review articles that included Qatar were included in this study.

Following these processes, only 82 articles met the inclusion criteria. Out of the 82 articles studied, 78 and 4 were peer-reviewed journal and newspaper articles, respectively. The type of articles ranged from reviews, experimental, surveys, and comparative studies, which reduced methodological bias. The 82 articles were then thematically coded based on the subject of study related to Qatar waste management. Figure 4 shows the distribution of articles according to the themes: out of the 10 themes identified, the main themes were waste to value, management, and food. The 10 themes with decreasing number of articles are the following: (1) waste to value, (2) management, (3) food (4) construction (5) sustainability and environment, (6) sports, (7) plastic, (8) economics, (9) supply chain, and (10) religion. The economics, sports, and supply-chain themes each have four articles. The waste-to-value section included three subsections based on applications: energy, agriculture, and waste treatment. The synthesis of literature sought to identify the key evidence emerging from the respective studies. This process enabled the development of recommendations together with the identification of gaps. Section 4 analyzed for the trends in literature and the commonly published journals. Section 5 discusses the themes individually (Sections 5.1–5.10) and Section 6 discusses the findings and recommendations, and includes a table (Table 1) that discusses the significance and gaps in the selected themes.

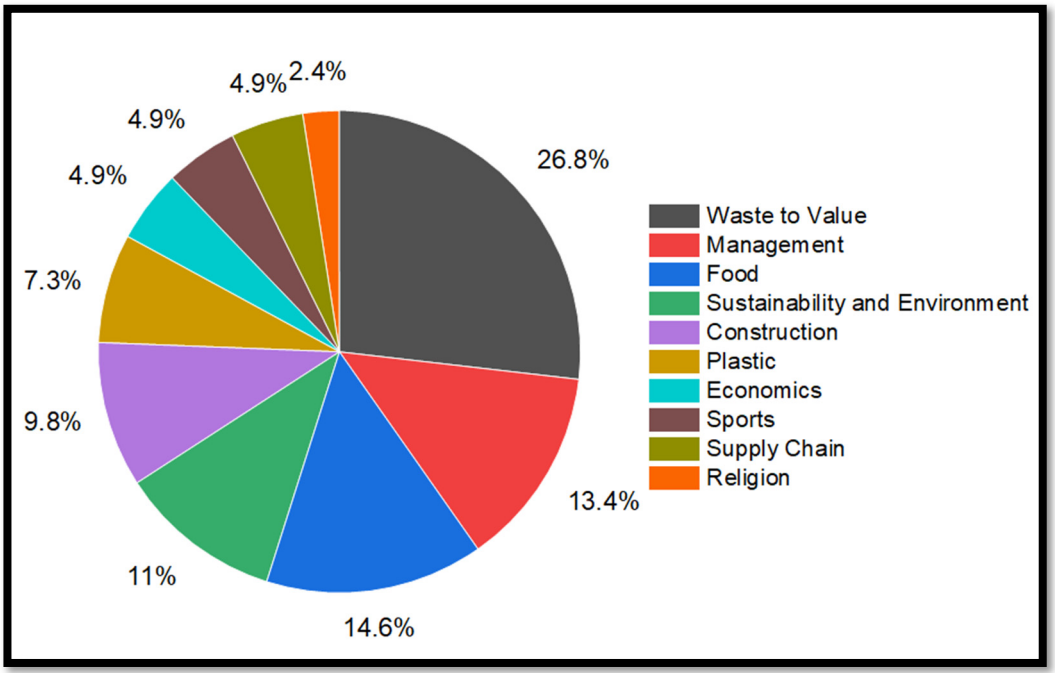

Figure 4. The main ten themes from this systematic literature review on Qatar waste management.

4. Trends in Literature

Based on the search results trends, the number of articles on waste management in Qatar have increased significantly over the years (refer to Figure 5). The increase signifies the interest in the field and funding to conduct such research in the country. The greatest number of papers was published in 2021 (21), while the lowest was in 2015, 2013, 2012 and 2011 (with one each). Furthermore, most of the studies (about 42%) were published by institutions within Qatar (Figure 6), followed by the UK, USA, India, and China. Within

Qatar, the main institutions were Qatar University (23) and Hamad Bin Khalifa University (7). Totally, 22 different countries (17 of which had less than or equal to 2) published on Qatar's waste management, either as comparative analyses or as focused country-specific studies. The journals with the most published articles (equal to or more than 2) were as follows (refer to Figure 7): *Sustainability* (9), *PLoS One* (4), *ChemEngineering* (2). The majority of the articles (55) were the only ones published in a journal on the topic (not shown in Figure 7). However, the variety in journals reflects the different themes, and the broad publishability of the topic.

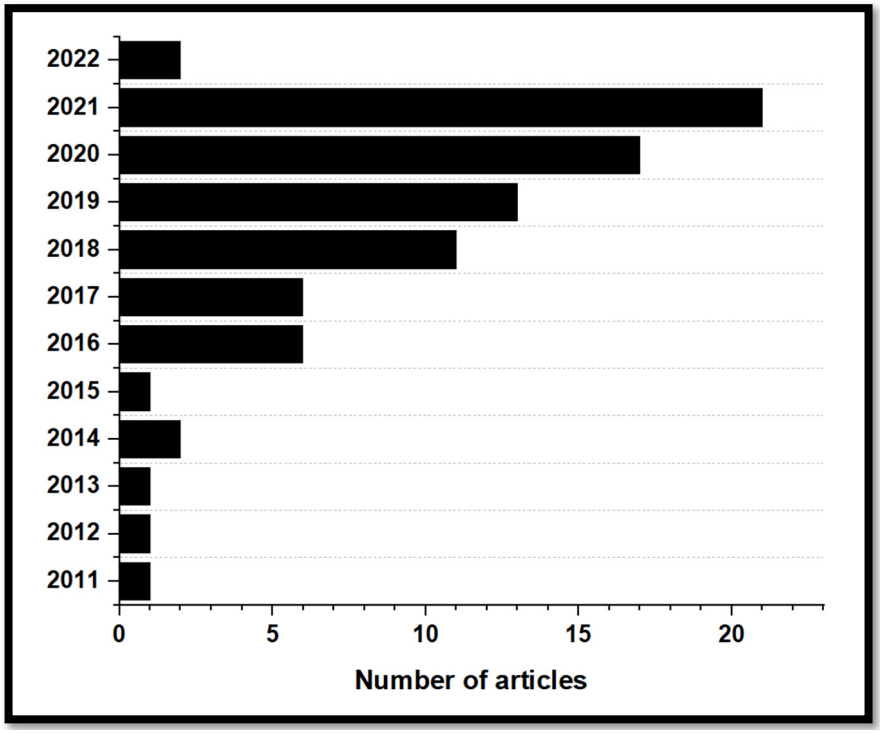

Figure 5. Yearly trends in Qatar waste management publications from 2011 to 20 February 2022.

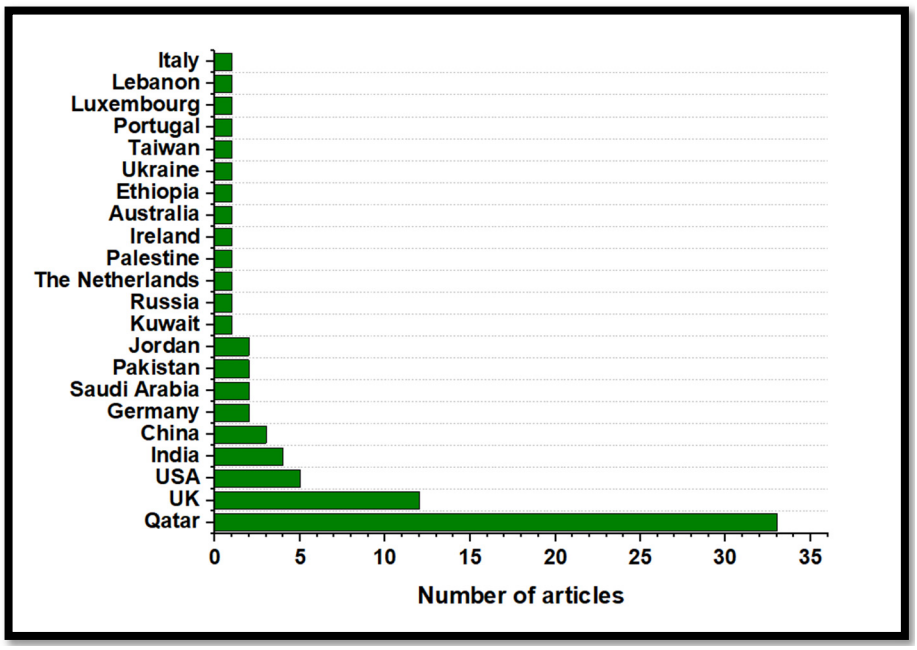

Figure 6. The country affiliation of the first authors in Qatar waste management articles published between 2011 and February 2022.

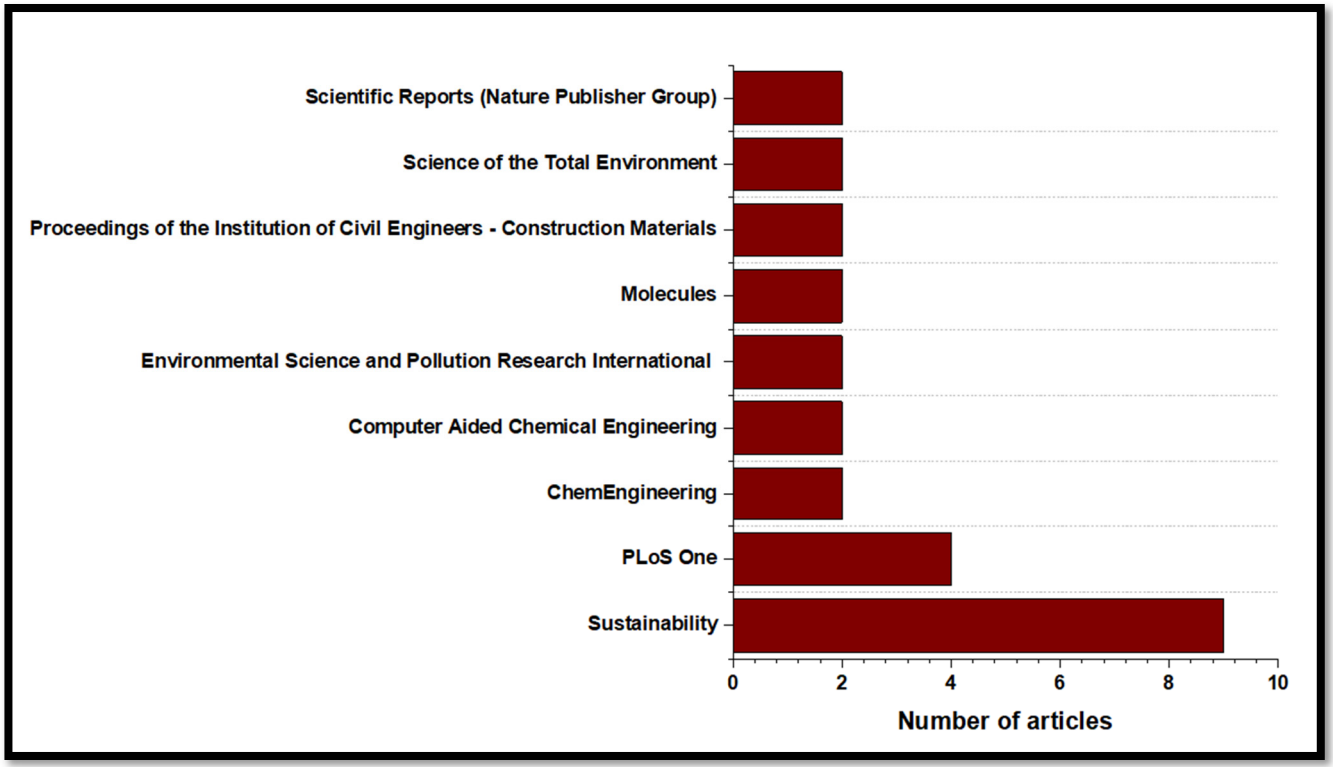

Figure 7. The top 9 journals with Qatar waste management articles published between 2011 and February 2022.

5. Thematic Discussion

The thematic areas identified above are analyzed in detail in the following subsections, in order of decreasing number of publications. Waste to value (the highest number of publications) mainly deals with the conversion of waste to value by having applications for energy production, water treatment, and agriculture. Such applications are often considered waste recycling, although in different forms. In Qatar, using waste for such applications is still in its early (experimental) stages, but extensive work has been conducted in recent years, due to increased grants and research projects in the field. The management theme is based on various articles discussing the best way to manage the increasing waste generation. For the sustainability and environment and supply-chain themes, the literature discusses the relationship between waste and SDGs, and manufacturing without wastes, respectively. For the themes of food, plastic, and construction, available literature discusses the main issues arising from the three waste types and offers suggestions for their management. The possible influence of religion and increasing sporting events on resource consumption and waste generation is also discussed in the religion and sports themes, respectively. The sections are presented in the following order: (i) waste to value, (ii) construction, (iii) management, (iv) sustainability and environment, (v) food, (6) plastic, (7) sports, (8) economics, (9) supply chain, and (10) religion.

5.1. Waste to Value

5.1.1. Energy

The generation of electricity from waste is a common endeavor in many parts of the world. Qatar is the only GCC country to have integrated bioenergy into its energy portfolio, although the literature on waste-to-energy utilization is limited [25]. Amongst many developed countries, such as Ireland, New Zealand, and Spain, Qatar sends more than 50% of municipal solid waste to landfills [26]. Installed renewable capacity in Qatar only amounts to 0.4%, which is mostly composed of biomass and wastes (38%) and solar PV (5%) [27]. Therefore, managing waste for electricity markets is still in primitive stages in the

country. As of 2015, 25 MW of the electricity generated arose from municipal solid wastes, while the total solid waste generated amounted to 485 kg/per capita/year in 2014 [28]. The electricity generation is higher than some other countries such as Indonesia (7 MW), Lithuania (10 MW), Slovakia (11 MW), and Luxembourg (17 MW), but still lower than other countries such as the USA (2254 MW), Germany (1888 MW), and Japan (1501 MW). It should be noted that this publication does not consider the population of the countries when making the comparison; thus, an accurate depiction of electricity generation in relation to quantified wastes is required. Additionally, although Qatar exceeds many other countries, there still is ample improvement to be made if it needs to use wastes for electricity.

Some research suggests that controlling wastage from a consumer perspective is more feasible than relying on a theoretical or pending innovative solutions to eliminate the expected increase in municipal solid waste [26]. On the other hand, other researchers suggest recycling MSW to recover energy and other useful materials to divert the wastes from ending in landfills is feasible and should be prioritized [29]. Thermal treatment processes, such as pyrolysis and gasification, converts wastes to various value-added products such as chars, liquids, and syngas, which could be used for fuel generation, power generation, and soil bioremediation [29]. Preliminary laboratory-scale studies on understanding the thermal decomposition behavior of plastic and nonrecyclable waste have been undertaken with promising results for upscaling technologies [29]. Subsequently, the lifecycle assessment of solid-recovered-fuels gasification in Qatar has shown immense promise due to reduced environmental impacts and dependence on natural gas for electricity generation, which is in line with Qatar's National Vision 2030 [30]. On the other hand, research points to the fact that these interventions need to be part of a broader energy systems transformation, such as improving energy-efficient buildings (which are necessary for Qatar due to rising energy demand). Wastes have the potential to create positive synergies in this transition; for example, one study showed that nanomaterials based on date pits—a common food waste in the region—have a promising future in thermal insulation applications [31]. The study showed the potential of this form of insulation in building air conditioning systems (a house area of 570 m^2) to reduce energy consumption by 4494 kWh and carbon dioxide emissions by 1.8 tonnes every year.

5.1.2. Agriculture

Several wastes are converted to value-added products for agricultural applications. Wastewater sludge or biosolids—a byproduct from wastewater-treatment processes—is a considerable component of the waste produced and is used in many countries (for example, Sweden, Netherlands, and Denmark) for applications ranging from recovered energy to organic fertilizers. A study in Qatar investigated biosolids as fertilizers for tomato production [32]. However, the main challenge for using biosolids for edible food products is the high amount of trace heavy metals, which requires significant advancements in removal processes before agricultural application. Another study found that using 5–7 kg/m^2 of biosolids is efficient and safe to enrich Qatar soils, with insignificant effects on the groundwater in Qatar from soil leachates [33]. The biosolids studied in this study (and not in the former) are class A biosolids that have undergone thermal treatment following US EPA specifications to make them suitable for organic fertilizers, hence serving as a great potential for Qatar to expand its use in agriculture.

Laboratory-scale studies have found potential for the utilization of waste nitrogen fertilizer from Qatar Fertilizer Company (QAFCO) for marine microalgae growth, which could further be used as animal feed [34]. The waste nitrogen fertilizers could also improve microalgae production's cost and environmental burdens. This is a perfect example of waste to value that creates positive synergies. Pyrolysis—a thermal waste treatment method—is increasingly being researched in the country. A modeling-based study found recycling food wastes in Qatar to produce chars using pyrolysis has the potential for water-treatment applications, soil amendments, and carbon sequestration [35]. Another study examined the technology as a sustainable waste management strategy while producing crops and se-

questering carbon [36]. Integrating carbon-capturing technologies with biomass-integrated gasification using an energy–food–water (EFW) nexus tool would help secure food security and self-sufficiency (40%) for Qatar [37]. The carbon-capture technology and PV could reduce the global warming potential by 98% [38]. Thermochemical methods such as pyrolysis and gasification show immense promise as waste treatment technologies due to their agricultural applications, carbon-capturing potential, and overall enhancement for improving self-sufficiency for the country.

5.1.3. Water Treatment

Various studies have focused on using wastes for water-treatment applications. Wastes such as bottom ash and fly ash from the incineration of municipal solid wastes could be utilized for such applications. A study showed great potential for using geopolymers using the ashes for the removal of methylene blue from water [39]. Another study also investigated the two residues for 21 different metal extractions, finding a sustainable and cost-effective utilization of MSW. Additionally, food wastes are studied for water treatment [40]. For example, raw and thermally treated tea waste reflect adsorbent properties for removing methylene blue from contaminated waters [41]. Similarly, raw and thermally treated pineapple leaves were found to remove rose Bengal dye from water samples by adsorption [42]. Furthermore, potato peels were optimized to remove cadmium ions by adsorption [43]. Alternatively, chars from olive stones acted as sorbents that removed rifampicin and tigecycline from wastewater [44]. Date pits have been used to remove lithium [45] and mercury [46] from seawater. These studies confirm the variety in application using wastes for specific water-treatment purposes.

5.2. Management

MSW management is one of the most important concerns in the GCC, particularly concerning negative impacts on health and the environment [47]. Although solid waste is increasing considerably in the GCC member states, a study published in 2015 identified minimal research activity about solid waste in the region, especially using a multidisciplinary approach [48]. As of 2015, about 6% of the total articles published on solid waste in the Arab world (21 countries, including the GCC) were from Qatar. Although 80% of the wastes in Qatar are degradable, putrescible, and recyclable, the major waste disposal is landfilling and composting, which are known to emit greenhouse gases contribute to climate change [49]. Notably, there is a difference in the amount of waste generated in the large cities and rural areas: about 2.5 and 0.6 kg of waste is generated per day in the former and latter, respectively [50]. The different approaches of waste management in the future should move from existing generation and management trends. Studies from other countries have utilized ashes and dusts from MSW incineration plants for backfilling technologies in underground mining [51,52]. For Qatar, the focus is urban given that almost the entire population is urban, therefore, applications specific to the country are essential.

Within MSW in Qatar, 13–14% comprises plastics [46]—Section 5.6 discusses more about plastic waste management in Qatar. Analyzing the situation in Qatar, and MSW composition, researchers have reiterated the need for a recycling philosophy integration with urban development and waste management, including: (i) laws to govern wastes, including positive and negative reinforcement for manufacturers and consumers; (ii) government follow "society pay principle", which shows the recycling fee payment (by the consumers) utilized for efficient solid waste management process and increased subsidies; and (iii) responsible units (RU) delegation at the municipality level or a unit within the government to enhance the administrative arrangements of solid waste management and encourage communities to recycle [53]. Keppel Seghers—a Singaporean company that runs the Domestic Solid Waste Management Center—estimated in 2014 that for every 500 tonnes of waste increase, about 800 million Qatar riyals (220 million USD) need to be spent for expanding the facilities [54].

Recent reports reflect a clear waste-recycling strategy by the Ministry of Municipality and Environment, based on legislative decisions and recent studies, and aims to support recycling companies and reduce materials for burning or burying [55]. The Global Sustainability Assessment System (GSAS), developed by the Gulf Organization for Research and Development in Qatar, has a Construction Management Certification (GSAS–CM) that optimizes construction management in all aspects, including waste segregation, disposal, and recycling and reuse of materials [56] These trends highlight positive developments, albeit there is much room for efficiency improvement. Incentives encouraging facilities management to focus on long-term solutions leading to savings in the long term is essential [57].

Furthermore, specific waste types have been raised for specialized waste management, such as food, medical, and electronic waste. One study analyzed food waste generated on a university campus in Qatar and found that most of the waste generated was avoidable due to overproduction (due to display purposes) and not necessarily consumer wastage [58]. Around two-thirds of the 329.5 kg/day wastes generated should be avoided, especially if the food-service providers were trained. In terms of medical waste, most of the nurses have been found to be well aware of waste segregation practices [59]. However, the excessive production of waste and unavoidable exposure were the main barriers to proper medical-waste management, which requires detailed waste-specific evaluation and control strategies [59]. Alternatively, around 40 kilotonnes of electronic waste, worth 36 million EUR, was generated in Qatar in 2018 alone [60]. The total economic worth of electronic waste generated in GCC member states amounted to 1.028 billion EUR, which highlights the immense potential in recovering value from electronic waste in the region. Minimizing the root cause of waste generation and maximizing value generation from specific wastes offer significant efficiency and value-creation opportunities.

5.3. Food

Food security is an important issue of concern in Qatar, as an arid country that imports much of its food supply [61]. However, there is limited research on the topic. A systematic review on food wastage in the GCC revealed a mere 32 articles published concerning GCC countries, out of which 8 are from Qatar [62]. Particularly, since the 2017 blockade of the country, there has been a reorientation of the approach to assure food security, including increasing domestic production and changing behaviors that lead to food waste. A nexus approach is essential in understanding Qatar's food security and wastage issues, and the interconnections with energy, water, and waste.

Although food waste happens at every stage in the supply chain, consumers wasting food poses a significant value-added loss to waste. An extensive literature review and empirical study conducted during Ramadan (a month when Muslims fast from sunrise to sunset) confirmed a significant relationship between food waste and motives due to leftover food, financial outlook, social relationships, planning habits, and Ramadan [63]. Although low-carbon lifestyles are not included in the national climate policies of Qatar [64], it is one of the only countries in the world whose dietary guidelines include sustainability messaging [65]. Qatar is one of the four countries in the world—including Brazil, Germany, and Sweden—to have indicators of sustainability included in their dietary guidelines. The indicators focus on food waste, since inputs such as pesticides, irrigation water, land, and plastics are wastes due to consumption behaviors [65,66]. Additionally, reducing leftovers and waste is part of dietary guidelines, another example of sustainability being integrated into the dietary guidelines [67,68].

The COVID-19 pandemic resulted a drop in food waste, according to a survey that found a 44.81% reduction due to the absence of panic buying and food stockpiling, and lack of outside eating scenarios [69]. Both attitude and behavioral change have significant potential to reduce food waste [70]. Irani et al. suggests creating a single food authority that would collaborate with local charities, food authorities, and supply-chain stakeholders [71]. For food waste that cannot be reduced, recent research looks at improving management,

such as a study that compared windrow composting, anaerobic digestion, and combining both for food-waste management in Qatar [72]. It concluded that an integrated approach presents a lower environmental burden than composting alone. However, emissions (global warming potential) pertained to transportation (60%) and composting itself (40%). The environmental impact for the acidification impact category is the highest for composting. Such comparative studies, which includes environmental burden studies, are useful in strategic management, and need to be integrated into decision-making processes.

5.4. Sustainability and Environment

Moving from a hydrocarbon economy to a knowledge-based economy requires international competitiveness, including environmental awareness and advancing zero-waste concepts [73]. Qatar is placed among the countries with significant room to improve environmental efficiencies, along with UAE, Philippines, Indonesia, South Korea, Saudi Arabia, China, Pakistan, and Vietnam [74]. Qatar and neighboring Abu Dhabi and Dubai have focused on addressing the problem of large carbon footprints via sustainable urbanization policies. While Dubai has many small free economic zones and academic institutions, Abu Dhabi and Qatar have fewer but larger ones. These undertakings, however, have minor effects on the overall ecological footprint. For example, Lusail—a city in Qatar—was developed with ecofriendly alternatives for transportation and sustainable infrastructures for waste collection [75]. A smart pipe network collects waste and transports it to recycling plants far from the city [76]. Such cities are not many in number and are recent undertakings; therefore, the impact on national ecological footprints has been minimal to-date.

The inclusive sustainable transformation (IST) index reflects "how a country has developed a modern economy that protects the environment and is gender inclusive" [77]. The index includes indicators related to manufacturing, trade, innovation, employment, gender inclusiveness, pollution, and energy resource management. Qatar's inclusive sustainable transformation (IST) index increased from 0.429 in 2000 to 0.520 in 2015; however, the specific reasons for the increase were not mentioned in the study [77]. These transitions are good for business. Subsequent to analyzing green initiatives and performance of 500 companies in the world—one of which is in Qatar—environmental protection in terms of waste and carbon reduction positively impact financial performances [78]. Alternatively, using ICT indicators, the readiness of countries to implement sustainable development goals (SDGs) places Qatar at a ranking of 80 amongst the 212 countries studied, with its score of 52.91 [79]. Another study found Qatar amongst the better SDG performers across the Arab countries out of 21 countries. Indicators of success within that study found the best performers reflect greatly on electronic waste and production of SO_2, but poor on treated wastewater [80]. A number of factors need to be considered if a country needs to be high on the sustainability index or indicators, including efficient waste management and the number of studies utilizing quantitative data.

5.5. Construction

As of 2018, about 60 industrial cities were planned to be built in the Middle East [81]. Countries such as Qatar, Syria, Saudi Arabia, Bahrain, and Jordan have state-level management in charge of industrial cities planning and construction. More often than not, circular economy and waste management are part of the industrial plans [81]. because of the FIFA World Cup 2022, additional infrastructure requires much construction activity, but according to a literature review, only a few studies have reported on the construction and demolition waste management processes [82]. More broadly, almost 20 million tonnes of construction waste are being generated annually due to the construction boom [83]. Estimates also show that almost 75% of the solid waste in Qatar is from construction activities, most of which is put into landfills [84]. The QNDS aimed to recycle 38% of its solid waste by 2016, which required a collaborative approach involving various stakeholders, yet the recycling of wastes is still a challenge. Recycling of construction waste involves using wastes as aggregates for applications, such as concrete. One study analyzed using

reclaimed asphalt pavement for constructing road bases. However, the results showed poor performance compared to Qatar's Construction Specification. Few studies analyze recycled construction wastes for construction activities. Cyclopean concrete used excavated boulders [85], and tunnel boring machines muck from the Gold Line of the Doha Metro Project [86] studied concrete mixes, which found a 32% reduction in GHG emissions, proving to be a low-cost and environmentally better material from waste products in Qatar. The former study analyzed the muck, mostly stockpiled in waste disposal, and proved it to have potential utilization as coarse aggregate in concrete mixes. Despite the number of studies, the main challenge of good quality aggregates remains, requiring an update of the Qatar Construction Specification [87]. An interesting study found that a fraction of the natural aggregate could be replaced by recycled polyethylene (a type of plastic). However, further studies are required to improve the strengths of such mixtures [88].

5.6. Sports

The Qatar 2022 FIFA World Cup 2022 and the sustainable positive legacy that it wants to leave has posed challenges, opportunities, and progress, especially in upholding the Qatar National Vision 2030 [89]. The first carbon-neutral megasports event entails the need for efficient waste management using technological advances and needs to ensure that the waste management policies address the value chains to mainly reuse and reduce wastes rather than recycle [90]. Overcoming the many challenges could showcase Qatar on a world platform as making a positive contribution to sustainable world cups in the long run. Subsequently, the responsibility placed on the host country for the long-term consequences of organizing a megasports event makes a sustainable and green economy legacy challenging. The bid for FIFA specifically requested measurable objectives of six topics: waste, water, energy, procurement, transportation, and climate change, reflected in a comprehensive sustainability strategy [91,92]. An exciting outcome of the FIFA World Cup in Qatar—besides being a carbon neutral event—is the design of the Ras Abu Aboud Stadium that is built with steel and other recyclable and dismountable parts, which considerably reduces waste [90]. Other outcomes based on sustainable waste management are still not reported in the literature.

5.7. Plastic

Plastic plays an essential role in human lives; however, plastic pollution is a global concern. Waste management practices for plastic wastes vary worldwide. The Qatar National Vision 2030 maintains the need to harmonize economic growth, social development, and environmental management. Furthermore, waste generation and plastic trajectory accounts for approximately 13–14% of the total municipal solid waste generated and is expected to reach 20,000 tonnes by 2025 [93]. Plankton nets have detected microplastics on the surface waters of Qatar's Exclusive Economic Zone, reiterating the need for better plastic management practices [94]. On this basis, researchers [93] suggests the need for new plastic recovery facilities to improve plastic recycling rates. Mixed wastes, including plastics, are handled on-site in Qatar (with few pilot exceptions, such as Education City), while other countries presort plastics. Although a lifecycle assessment was conducted by Al-Madeed et al., the process's start, intermediate, and end products are not reported due to plastics being mixed with others and associated differences in scope compared to other LCA studies reviewed in [95]. Although small initiatives such as the biodegradable and edible alternative to plastic bags were developed by a Qatar-based nonresident Indian, Aswath Hedge [96], tackling plastic pollution requires a collaborative approach on a bigger scale. For instance, there exists a summary of the main provisions associated with plastic waste management in the nationally determined contributions (NDCs) in various countries, including Qatar [97]. Waste separation and collection, wastewater, and/or sanitation; reducing, reusing and recycling; and energy/power from waste are the four areas of solid waste management addressed by Qatar and could affect plastic waste management. Alternatively, a legal instrument bringing Qatar, Bahrain, Kuwait, Saudi Arabia, Oman,

UAE, Iran, and Iraq together to coordinate activities to protect the marine environment by establishing protected areas and conserving biological diversity has been placed [98]. Such legal instruments, uniting GCC countries and including protection of the environment from detrimental effects of plastic pollution, are essential.

5.8. Economics

Since Qatar has experienced significant economic and social transitions in the last three decades, large volumes of resources have been consumed and much pressure has been placed on the environment. A study employing the environmental Kuznets curve hypothesis uses the ecological footprint to quantify resources consumed and waste generated in Qatar between 1980 and 2011 [99]. Qatar's average ecological footprint per person is the highest globally, which should be reduced by improving resource efficiency, consumer behavior, and intense resource production. Moreover, after studying developing countries, eliminating activities that provide no value improves productivity in manufacturing industries, which makes effective lean production (LP) [100]. LP in industries aims to remove waste and improve organizational productivity, thereby creating awareness about lean manufacturing and encouraging efficient tools. Using the environmental, social, and governance criteria (ESG) of insurance companies in 26 countries worldwide, including Qatar, it was found that the second maximum value of ESG risk was observed in one of the companies in Qatar [101]. The study found that countries that contribute to the SDGs have favorable conditions for sustainable development for markets, including insurance companies. Considering the small number of studies on this theme, more studies considering the impact of waste generation on the economic indictors of the country are essential.

5.9. Supply Chain

The green logistics performance of 19 developed economies, including Qatar, was studied and reiterated the need for renewable energy resources, energy demand, and economic sustainability to ensure green supply chains [102]. Green logistics include waste recycling, disposals other than landfilling, and energy recovery. Another study on various countries, including Qatar, found several barriers to reducing emissions, energy consumption, environmental risk, and waste production in companies. Suggestions included companies' voluntary practices for waste reduction, communicating the environmental effects of the products, and technology to create profitable and innovative products [103]. Additionally, managers who incorporate companies in the MENA region are expected to consider the logistics delivery mode for efficient waste and cost reduction [104]. A study conducted in six GCC countries, including Qatar, found that LP practices for supply-chain management practices could be developed to be effective. Additionally, it does not have significant negative effects on financial performance [105]. The lower level of awareness on LP in Arab countries has led to lower implementation than other supply-chain management practices. Studies on this theme suggest a need for increased studies in the corporate world to incorporate waste reduction in their strategic management.

5.10. Religion

Qatar has been studied for its rapid social and economic transformation. However, few studies focus on the role of Islam in influencing consumption behavior. One study conducted a survey targeting Muslim consumers in a university in Qatar and found that there is a sense of ethical consumption behavior [106]. The Islamic philosophy of moderation or "wastiya" encourages sharing resources rather than unnecessary wastage based on the Quranic quote [7:31], "Eat and drink but waste not by excess; Verily Allah loves not the excessive", which teaches Muslims to take heed of careless consumption. Another study conducted interviews with experts who preached or practiced Eco-Islam in various countries, including Qatar [107]. Eco-Islam is a concept that links environmental ethics to Islamic teachings. The study discusses the individual responsibility that is placed on environmentalism in Islam. The representative from EcoMENA, based in Qatar, explained

the basis of their knowledge-based initiative that publishes articles based on the environmental perspective in Islam. Alternatively, the Islamic concepts of "Kamaliyat" and "Tarafiyyat" relate to luxury goods classified as improving quality of life and extravagances leading to waste. The former implies that luxury goods are halal, if not for showing-off purposes. In the case of Qatar, affluent Qataris consume luxurious items as a social norm, which means if it is not meant for a lifestyle of arrogance, overindulgence, or wastage, then the consumption of luxury goods is prevailed to increase [108]. The Islamic concepts on wastage could be efficiently used for awareness purposes, although currently no studies mention the need or use of such techniques.

Table 1. Thematic significances, research gaps, and priority rank.

Themes	Significance	Research Gaps	Priority Rank
Waste to value	• Applications for energy, agriculture, and water treatment • Carbon capturing technologies and green technologies are researched • Value added products include char, oil, and gas • Positives include landfill aversion • Chars could be use as fertilizers, removal of dyes, and animal feeds	• Mixed wastes/MSW not studied • Techno-economic analysis for feasibility required • Survey studies to understand public opinion • Energy and electricity from wastes using clean technologies • Lifecycle assessments are essential for cradle-to-grave analysis of products • Real water-treatment and real agriculture studies are required • Recycle landfill wastes for value-added products • Opportunity to research construction wastes to value • Incorporating circular economy narrative is essential • Increase efficiency and safety of waste-to-value technologies • Develop market for wastes (construction, electronic waste) and value-added products in the country using subsidies	4
Management	• Some statistics of waste generated are reported, most goes to landfills • Recycling philosophy approach is suggested • Recycling fees, increased subsidies for unrecyclable wastes, and delegation of management units • Culture of waste generation is an imminent issue • Energy from solid wastes is low compared to developed countries • Food, electronic, construction, medical waste generation, and management challenges are discussed	• Lack of multidisciplinary approach • Yearly statistics on waste generation is unavailable—therefore, trends cannot be studied • Analyze the impact of R&D on management decisions • Enhance culture of 3Rs using national awareness programs in communities • Need for collaboration amongst various government entities to ensure holistic approach (food security, waste minimization, energy efficiency)	5
Food	• Changing reforms for addressing food waste behavior by changing economic and regulatory reforms • Reducing food waste and leftovers is included in national food dietary guidelines • Consumer behavior studied during Ramadan and COVID-19 pandemic showed different factorial effects	• Need for EFW nexus studies to ensure reduced food waste generation and enhanced food security • More studies on the environmental burden of various waste management scenarios	4

Table 1. *Cont.*

Themes	Significance	Research Gaps	Priority Rank
Construction	• Recycling wastes for aggregates have been researched • Few construction and demolition management studies even though there is an increase due to the World Cup and a surge in construction	• Amendment to construction standards based on recycled construction wastes • Increased strength and durability of aggregates study • Environmental impact assessments of construction wastes to include recycling wastes • Existing construction wastes recycling • Incorporating supply chain and green construction waste alternatives studies • Ways to change the culture of waste generation for the different wastes and optimum waste management route • Improve concrete aggregates using other wastes (plastic)	4
Sustainability and Environment	• New urban city of Lusail has sustainable infrastructure for waste collection and transportation • Generally, waste and carbon reduction initiatives positively impact finances • Globally, Qatar is not a better performer, but in the Arab world, it is better	• SDG incorporation within companies and how to make it one of the best performing countries • Sustainable treatment of wastes and wastewater	3
Sports	• First carbon neutral FIFA World Cup 2022 to be held in Qatar • A challenging position for a sustainable and green economy legacy • Recyclable material was used to build Ras Abu Aboud Stadium	• Effect of the World Cup on national solid waste management during and after	2
Plastic	• Plastic recovery facilities are required to address the increased plastic generated • Microplastics presence has been found in the marine environment	• Appropriate ways to effectively separate different types of plastics and better recycling facilities • Microplastics generation and management in Qatar • Plastics lifecycle studies and supply chain and economics • Alternatives to plastics could be developed or imported, but lifecycle assessment to better understand the situation	2
Economics	• The environmental Kuznets curve hypothesis uses the ecological footprint to quantify resources consumed and waste generated in Qatar	• Updated and detailed economic studies are essential • More focus on SDGs for sustainable development of markets—Qatar-specific studies • Environmental, social, and governance criteria studies in various companies in Qatar	3
Supply chain	• Lean production–manufacturing without waste for supply management practices rather than others • Green logistics, including recycling, energy recovery, and avoiding landfills to be integrated into supply-chain management	• A holistic approach proposal for the supply chain, especially for construction and industrial projects	3
Religion	• Islamic philosophy on avoiding wastage and awareness • Environmentalism in Islam	• No studies on bettering environmentalism in the Islamic country based on Islamic philosophy for awareness	1

6. Finding and Recommendations

The research conducted in Qatar on waste management is varied, ranging from studies understanding how value can be created from waste to the relevance of waste generation

and management part of religion. The variance in thematic areas reflects the interest in the subject across various disciplines, including the sciences, engineering, social sciences, economics, supply chain, and religion. The variety also causes the discussion on the topic quite challenging since the main issue in proper waste management is a holistic approach, especially in the case of Qatar with accelerated waste generation. Furthermore, the current research status and associated prospects for many of the projects require significant technological development to attain sustainable solid waste management in the state for the long run. The discussion that follows is divided into two parts: (i) a summary of current literature and (ii) recommendations that are based on the significance and research gaps in this study.

6.1. Summary of Current Literature

The ten themes discussed in the previous section covered waste to value generation, construction, management, food, sustainability and environment, plastics, sports, economics, supply chain, and religion. The most studied theme is waste to value, with the most number of publications, which shows there is increasing interest (and research grants) to work on creating economic value from the increasing waste generated. Using waste for energy, agriculture, and water treatment, which are all important requirements in the country, has the potential to generate economic value and addresses the issue for solutions to sustainable energy, agricultural growth, and water-treatment applications using inexpensive and readily available waste feedstocks. Most of the studies focused on using single wastes, including agricultural and industrial wastes (such as biosolids or wastewater sludge). What is missing is a systems perspective of waste. Based on available evidence, compared to other countries, Qatar is not doing as well in terms of the Sustainable Development Goals, but is faring much better than some of its peers in the Middle East. Additionally, Qatar's concerns are unique, such as construction projects and associated waste generation and management. New urban cities have waste collection and transportation incorporated into their design (e.g., Lusail City), and the majority of the carbon reduction initiatives in the corporate world has proven to reduce finances. Most construction waste management research shows that the country has attempted to use recycled waste as aggregates for varied applications, including concrete; however, none of the studied materials reached the Qatar Construction Specifications. Therefore, either the durability needs to be increased or the standards decreased. With significant infrastructure projects due to the hosting of the World Cup in 2022, waste management is an increasing concern. While there are notable positive examples, economic studies related to waste management are scarce. The country's ecological footprint is high, requiring resource efficiency, resource production, and elimination of waste-adding activities. Lean production, which ensures manufacturing processes occur without waste rather than any other supply-chain management, needs to be promoted. As for food waste, the consumer behavior studies reflect various factors that aid in the increased food waste, including financial status and overproduction (in buffets), although the country's dietary guidelines are one of the only ones in the world that requires reduced food wastes and leftovers. Furthermore, the Islamic philosophy of moderation of resources and avoiding wastage and extravagances that lead to waste further reinstates the importance of appropriate waste management via reducing waste. Plastic has received recent attention; studies show a need for better plastic recovery facilities and microplastics quantification and management in Qatar.

6.2. Recommendations

With increasing industrialization, urbanization, and associated waste generation, comes the need for efficient solid waste management strategies. New technological advancements can increase efficiency and suitability for energy and material recovery from wastes, including thermal technologies and biotechnology. A number of World Bank initiatives since the 2000 have prioritized solid waste management. For example, in Morocco, about 500 million USD improved citizen engagement and transparency, and strengthened

the private sector partnerships and accountability [3]. Investments in Bosnia and Herzegovina have increased access to waste management for up to 66% of the population, from 25%. Such advancements required a multisectoral approach, which connects human wellbeing with other sectors. Technological advancement (for energy recovery and specific waste treatment), legal and policy design and implementation (to improve the current waste management scenario), and citizen engagement (to increase awareness on wastes generation) are three key areas of improvement for efficient waste management. Additionally, understanding the issue at the source level is necessary for strategic management. Table 1 summarizes the significance and research gaps from this study that can be utilized as recommendations for waste management in the country. Additionally, a prioritization rank has been given to the ten themes based on the urgency to work on the research gaps that will aid in sustainable solid waste management in the country. The rank ranges from 1 to 5, with 5 being the highest priority rank. Category 5 implies that effective waste management and control needs an effective operating and wide-ranging management structure for the scale of the wastes generated and the numerous opportunity categories that exist. The items in category 4 represent the development of utilization/recycling/reuse of the larger waste generation paths—construction waste, food waste (often up to 40% of MSW)—and their subsequent conversion to value added products. Group 3 incorporates sustainability and environment, economics, and supply-chain management and analysis. These grouped categories can result in the optimization of the applications categories, which cover minimizing damage to the environment, economic cost minimization by better systems design, and the optimization of supply-chain distances and transportation costs. Group 2 highlights special events that offer special opportunities and challenges to study waste management, control/generation/minimization and applications: for example, the upcoming FIFA World Cup in Qatar. A second category 2 component is waste plastics. Although bearing strong similarities to category 4 in terms of quantities generated, these nonbiodegradable wastes have already been attracting a considerable amount of research attention for recycling/reprocessing/thermal treatment and the search for alternatives. Thus, several waste plastic schemes are well into the development stage. Religion is an important way of life and its inclusion as a waste management item is certainly important but is in alignment with most of the waste management alternatives included in this review.

For research, significant progress could be made if more studies proposed how the study would help waste management in Qatar. In the 82 articles analyzed, ranging over 10 themes, the number of articles from a multidisciplinary approach is lacking, despite it being critical for system strengthening. While some claim recycling is a better choice, some prioritize creating value-added products from waste, without engaging across areas or conducting efficiency or impact assessments. A comparative or comprehensive study based on the technical, economic, and social perspectives is what is required for the State of Qatar to manage its waste efficiently. Some waste-to-value studies need to focus on mixed wastes, especially considering the highest fraction of municipal solid wastes and other industrial wastes. Alternatively, separating wastes to create value could work if the separation and the transportation to the various facilities are in order. Techno-economic feasibility, environmental impact assessments, and lifecycle assessment studies are essential to holistically understanding waste management scenarios. For example, the feasibility of importing plastic alternatives or developing our biodegradable materials on a large scale is important. Especially when waste to value-added products is utilized, the public's opinion needs to be studied through survey studies. Real-world application studies could further convince the public of the importance of using wastes for water treatment and agriculture. To do this, data are required, but it is not always updated, especially regarding the amount of solid waste generated every year, making it challenging to understand trends.

Since the construction sector is quite prominent in Qatar, additional studies are needed to focus on supply-chain management in this sector, finding alternatives to durable and recycled or green aggregates for concrete. Other main wastes, including electronic wastes, plastics, microplastics, and industrial specific wastes, should be further studied, with an

orientation toward actionable solutions for improvement. As hosting sporting events are a key part of Qatar's vision, the effect of waste generation and management due to mega-events (both before and during) is necessary. The impact of such events and the Qatar National Vision and its implications for the sustainable development goals need to be studied in depth. Additionally, the feasibility of incorporating the SDG goals into various companies, institutions, and industries should be studied. Awareness of SDGs and environmentalism in Islam is necessary; therefore, the best way to accomplish that needs to be studied.

7. Conclusions

Globally, millions of tons of waste are generated annually, with the amount of waste rapidly increasing and its management expected to worsen. Qatar produces about 1.8 kg per day (60% organic), but the recycling sector is underdeveloped (<15%), and most is sent to landfills (>50%). This study presents the results of a systematic literature review on the waste management in Qatar using research drawn from the academic platforms of ProQuest and SCOPUS. A total of 82 articles were thematically coded into ten groups: (1) waste to value, (2) management, (3) food, (4) construction, (5) sustainability and environment, (6) sports (7) plastic, (8) economics, (9) supply chain, and (10) religion. Most of the studies (about 42%) were published by institutions within Qatar. After analyzing the significance of the themes and research gaps, the main recommendations include a holistic approach to address the increasing waste generation, including government and private sector entities, researchers, and the community, involving decisions using research and development and community awareness. Additionally, main wastes, including construction, food, plastic, and electronic wastes, require specific attention since the cause of generation and management varies according to the type of waste. Additionally, technological advancement (for energy recovery and specific waste treatment), legal and policy design and implementation (to improve the current waste management scenario and developing market for recycled wastes), and citizen engagement (to increase awareness of waste generation) are three crucial and complementary areas of improvement for efficient waste management. Promising technologies to generate value-added products, such as pyrolysis, have immense potential for utilizing the various waste feedstocks efficiently and often economically. The time required to implement such technologies require stakeholders' involvement and interest, whereby appropriate solutions can serve the purpose of sustainable solid waste management in the country. The immense monetary input in waste management research in the past few years to attain the Qatar National Vision should bring positive outcomes.

Author Contributions: Conceptualization, S.M. and S.Z.; methodology, L.C.; formal analysis, S.M. and S.Z.; writing—original draft preparation, S.M.; writing—review and editing, L.C. and G.M.; visualization, S.M.; supervision, L.C.; project administration, G.M. All authors have read and agreed to the published version of the manuscript.

Funding: Open Access funding provided by the Qatar National Library.

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

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