An Analysis of Resilience Planning at the Nexus of Food, Energy, Water, and Transportation in Coastal US Cities

Kristin B. Raub [1,2,*,†], Kristine F. Stepenuck [1], Bindu Panikkar [1,2] and Jennie C. Stephens [3]

[1] Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT 05405, USA; kris.stepenuck@uvm.edu (K.F.S.); bindu.panikkar@uvm.edu (B.P.)

[2] Gund Institute for Environment, Burlington, VT 05405, USA

[3] School of Public Policy and Urban Affairs, Northeastern University, Boston, MA 02115, USA; j.stephens@northeastern.edu

[*] Correspondence: kraub@cuahsi.org

[†] Author now with Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI), Cambridge, MA 02140, USA and a Visiting Scholar at the School of Public Policy and Urban Affairs, Northeastern University, Boston, MA 02115, USA.

Abstract: Climate change poses increased risks to coastal communities and the interconnected infrastructure they rely on, including food, energy, water, and transportation (FEWT) systems. Most coastal communities in the US are ill-prepared to address these risks, and resilience planning is inconsistently prioritized and not federally mandated. This study examined the resilience plans of 11 coastal US cities to understand 1. How FEWT systems were considered within resilience plans and, 2. How nexus principles or elements critical to a nexus approach were incorporated within resilience plans. A "Nexus Index" was created to examine the incorporation of nexus principles, which included partnerships and collaborations, reference to other plans or reports, discussion of co-benefits, cascading impacts, and inclusion of interdisciplinary or cross-silo principles. These principles were used to score each action within the resilience plans. Results showed that only eight actions (1% of all actions across the 11 plans) focused on the connections among FEWT systems within the resilience plans. The transportation system was associated with the most actions, followed by the energy system, water system, and the food system. While FEWT systems were not consistently included, there was evidence from the Nexus Index that the plans included elements critical to a nexus approach, such as the inclusion of partnerships and reference to co-benefits with the actions they designed to build resilience. The heterogeneity among the systems that each plan emphasized reflects the heterogeneity among the challenges that each city faces. While context-specific differences in resilience plans across cities are expected, some consistency in addressing certain infrastructural needs and their nexus interactions may greatly benefit and improve the implementation of resilience planning.

Keywords: coastal resilience; resilience plans; food-energy-water-transportation nexus approach; urban resilience; Nexus Index

1. Introduction

Coastal communities are at increased risk from climate change-related threats, such as storms, flooding, fire, and sea-level rise, which are exacerbated by anthropogenic factors. These climate-related hazards also pose extreme risks to our built environment and essential infrastructures such as food, energy, water, and transportation (FEWT) systems [1,2]. Coastal resilience has been defined as "the capacity of the socioeconomic and natural systems in the coastal environment to cope with disturbances, induced by factors such as sea level rise, extreme events and human impacts, by adapting whilst maintaining their essential functions" [3] (p. 1). While there is no standard way to operationalize coastal resilience, it has been applied in terms of coastal communities' decisions to rebuild or relocate after a hurricane [4], to develop frameworks for disaster risk management [5], and to assess the impacts of climate and policy changes on coastal communities [6].

Currently, there are no formal requirements or policies that mandate or incentivize United States cities to engage in resilience planning. In 2013 the Rockefeller Foundation introduced the 100 Resilient Cities (100RC) program and provided funding to selected cities around the globe to hire a chief resilience officer and develop a resilience plan [7]. 100RC charged municipalities with the responsibility to overcome urban resilience challenges from shocks (e.g., hurricanes, flood events, earthquakes) and stresses (e.g., inequality, aging infrastructure, unemployment) as well as physical, social, and economic challenges [8]. Cities were selected to participate in the 100 Resilient Cities program in three waves between 2013 and 2016, participation afforded each city access to a global network. As it takes several years to complete a resilience plan, some cities have not yet published plans. The 100RC program ended in 2019 and was succeeded by the Resilient Cities Network [9].

Coastal community resilience planning efforts could benefit from employing a food-energy-water-transportation (FEWT) nexus approach. FEWT systems are all critical infrastructure necessary for human wellbeing and are essential for the resilience of communities over time. For example, a disaster could cause disruptions to the energy and transportation systems on which the food system relies, thus limiting a community's access to food [10]. The US energy system is highly interconnected and vulnerable to disruptions [11], its disruption impacts nearly all other critical infrastructure [12]. Similarly, water provisioning (both water and wastewater treatment plants) is vulnerable to disturbances to the electrical system, especially during flood events [13]. A nexus approach identifies that relationships and feedbacks between the sectors are inextricably linked and encourages decision-making in coordination with other sectors rather than working in silos [14]. Additionally, sectors can become more efficient if multiple systems are considered together [15]. A FEW nexus approach has been recommended as an effective management strategy of these systems and to efficiently meet the food, energy, water needs of the public and industries [16]. The food-energy-water (FEW) nexus approach has been advocated to address the United Nations Sustainable Development Goals, which include providing food, energy, and water for everyone [17].

Nexus approaches go beyond connections between food, energy, and water systems and include other systems. For example, [15] examined the nexus of water, energy, land use, transportation, and socioeconomic systems to understand sustainable urban systems. To measure urban resilience, [18] connected the FEW nexus to environmental sustainability and equity. The land-water-energy nexus has been studied in agricultural systems [19]. Even outside of explicit nexus approaches, public health has been linked to water infrastructure in the context of flood resilience in coastal cities [20]. A recent study of the FEW nexus in the context of coastal resilience suggested that the FEW nexus approach be expanded to include the transportation system, especially in urban areas [2].

While a few peer-reviewed academic studies have incorporated the FEWT nexus approach within coastal resilience analysis, modeling, and planning [2], no studies have explored how the FEWT nexus is incorporated into coastal resilience planning in practice. Therefore, this study conducts a document analysis of the resilience plans from 11 coastal US cities developed through their inclusion in the 100 Resilient Cities program. The objectives of this study were to find out: 1. How FEWT systems were considered within resilience plans, and 2. How nexus principles or elements critical to a nexus approach were incorporated within resilience plans.

2. Methods

2.1. City Selection

US cities included in the 100 Resilient Cities program that had a publicly available resilience plan (as of September 2020) and that were located along an ocean or gulf were selected for inclusion in this study.

2.2. Data Collection

Resilience plans for each city were analyzed to assess the inclusion of 11 themes. Based on known systems interconnections [2], initial themes included food, energy, water, transportation, communications, health, and proximity to the coast. Four additional themes were added during subsequent analysis including: housing; diversity, equity, inclusion, and justice; economy; and environment. As new themes were identified, previously reviewed plans were reanalyzed to assess for the presence of that theme. Specific words related to each theme (see the codebook provided in Appendix A) and the context in which the themes were incorporated into the plans were assessed (e.g., the energy system was considered to be included if a plan mentioned energy efficiency upgrades to buildings or rooftop solar panels).

2.3. Data Analysis

2.3.1. Defining an "Action" as the Unit of Analysis

Each resilience plan defined visions, goals, actions, and supporting initiatives. Only the content of actions and supporting initiatives (hereby collectively referred to as "actions") were analyzed for this study as they were the most consistent across all the plans and provided the most detail. Other information, such as introductory material, case studies, or supplementary sections were excluded.

2.3.2. Primary of Partial Focus of Each Action

Each of the 11 themes were classified as either a "primary focus" or a "partial focus" of each action. A theme was classified as the "primary focus" if the themes were the central focus of an action, and partial if the theme was only mentioned or incorporated along with many other themes in an action. For example, the food system was deemed the primary focus of Action 89 of the Los Angeles resilience plan: "The City will work with the Los Angeles Food Policy Council (LAFPC) to identify opportunities to increase the resilience of the City's food network for all communities" [21] (p. 142). Whereas food was deemed a partial focus of Action 15 of the Honolulu resilience plan: "Resilience Hubs should be defined by each neighborhood or local community for their own needs and goals, however many are focused on providing the following during a disaster: (1) Emergency shelter during a disaster; (2) A central community gathering/information site and distribution center post-disaster; (3) Renewable energy and energy storage/supply even if the grid is down; (4) Water and food stores; and, (5) Medical supplies" [22] (p. 60) (See the codebook in Appendix A for more information about how systems and themes were classified as primary or partial focus).

2.3.3. The "Nexus Index"

A "Nexus Index" was created to score each action on how many nexus-related components it included. Each action was assigned a score between zero and eight based on the following elements: partnerships and collaborations, reference to another plan or report, consideration of co-benefits (e.g., how a change in one system will benefit another), cascading impacts (e.g., how damage to one system can damage the other systems it is connected to), and inclusion of interdisciplinary or cross-silo principles (e.g., intentionally promoting different fields, disciplines, or departments working together or co-generating solutions). Table 1 provides the scoring criteria for each Nexus Index element. The Nexus Index elements were given different maximum point potentials based on how representative they were of a traditional nexus approach. Partnerships were given a maximum point value of two so that there were three possible point values, which better represent the range in the number of partners listed between the actions. Cascading impacts and interdisciplinary efforts were given a maximum point value of two as they are classic nexus approach elements that imply intent in their use (e.g., Ref. [23]). Other plans and co-benefits were given a maximum point value of one as these elements are cited as being

the advantage of using a nexus approach (e.g., Ref. [17]), while less included in the nexus approach methodology.

Table 1. The scoring criteria and potential point values for each element of the Nexus Index. Each action included within a plan was scored separately, with a maximum score of eight. No points were assigned to an element if the scoring criteria described in the table were not met.

Nexus Index Element	Potential Points	Scoring Criteria
Partnerships and collaborations	0, 1, 2	The number of partners or collaborators reported within each action was recorded. If an action did not name specific partners and referred to "partners" or "collaborators", it was recorded if a singular partner or plural partners were mentioned. A singular partner was recorded as one partner, and plural was recorded as the average number of partners in the plan. The mean number of partners was calculated for each plan. Zero points were assigned if the action included no partners or collaborators, one point if the number of partners was below or equal to the mean, and two points if the number of partners was above the mean.
Other plans	0, 1	One point was assigned for reference to any other plan or report.
Co-benefits	0, 1	One point was assigned for the inclusion of co-benefits (i.e., how the action would benefit other systems).
Cascading impacts (interdependencies)	0, 2	Two points were assigned for the inclusion of cascading impacts (i.e., how damage to one system could negatively impact others).
Interdisciplinary/cross-silo	0, 2	Two points were assigned if the action included the terms cross-silo, interdisciplinary, multidisciplinary, or if the action intentionally sought to bring together multiple departments, fields, or disciplines to advance the action's resilience principles.

The total Nexus Index scores of each plan were then compared across the cities. As each plan had a different number of actions, they each had a different potential Nexus Index score. For example, New York City had 101 actions with a potential Nexus Index score of 808, whereas Boston only had 23 actions or a potential Nexus Index score of 184. Therefore, each city was compared based on the percentage of their total actual Nexus Index score from their total potential Nexus Index score.

2.3.4. Coding Reliability

To ensure coding reliability, a codebook was developed to determine if an action included one of the target systems or themes, if that system or theme was a primary or partial focus, and to define scoring criteria for each element of the Nexus Index (described above). Two coders were given five randomly selected actions and used the codebook to assess inter-coder reliability. The two sets of coded actions were then compared. Coded action sets that were 90% in agreement or higher, were considered reliable. The codebook was updated to account for any disagreement or nuance, and an additional five actions were selected and scored to check for reliability until 90% reliability was accomplished. All actions were then scored following the final codebook guidance. The codebook is included in Appendix A.

3. Results

A total of 11 cities across the US met the inclusion criteria and represented a range of regions: East Coast (Boston, New York City), Mid-Atlantic (Norfolk), South Atlantic (Miami), West Coast (Seattle, Los Angeles, San Francisco, Oakland, Berkley), the Gulf Coast (New Orleans), and an island (Honolulu). Across the 11 cities' resilience plans, 593 actions were identified collectively. The Boston resilience plan included the least number of actions (23 actions) and the New York City resilience plan had the most (101 actions).

3.1. Coastal Considerations

The cities designed a total of 122 actions (21% of all actions) with either a primary or partial focus on the coastal environment. Of these, 59 (10%) had a primary focus on the coastal environment or challenges. These actions were unevenly distributed between the plans; Miami had the most overall actions related to the coastal environment (25 actions, 42% of its actions) and Boston, Berkeley, and Seattle had the least (4 actions each or 17%, 15% and 6% of their total actions, respectively). In total, the cities designed 51 actions with a primary focus on flood risks (either through a flood event or sea-level rise) and only 8 actions with a primary focus on some aspect of their coastal location outside of the context of a flood event. Miami, New York City, New Orleans, and Honolulu each had the most actions with a primary focus on flooding (13, 8, 6, and 6 actions, respectively), while Seattle had no actions relating to flooding. Seattle had four actions (1 primary focus, 3 partial focus) relating to non-flooding related aspects of the coastal environment related to the economic importance of their maritime lands and redoing their waterfront.

The actions with a primary focus on the coastal proximity of the cities include those to develop or take advantage of funding sources for flood protection and implementing or developing other planning efforts. Examples of coastal actions related to funding include Miami's action to demonstrate cost benefits of resilience, which seeks to support the city's need to invest in infrastructure to reduce the risk of flooding [24] and Honolulu's action to increase "flood insurance affordability for O'ahu residents", which seeks to do so through participation in the Community Rating System [22]. Examples of other planning efforts include Oakland's action to "update the Storm Water Master Plan to guide future investment in stormwater management" [25], Miami's action to "Implement Sea Level Rise Strategy" [24], and New Orleans's action to develop a "Master Plan for a Sustainable Coast" [26], for stormwater management and flooding.

3.2. Food, Energy, Water, and Transportation Systems, Individually

Food, energy, water, and transportation systems were unevenly considered in the resilience plans. The transportation system was associated with the most actions, followed by the energy system, water system, and the food system (Table 2).

Food: The food system was one of the least included systems in any of the plans. Out of the 593 actions detailed in the 11 plans, 13 actions (2%) had a primary focus on food and 21 (4%) included only a partial focus (34 total actions, 6%). New York City had the most actions that included the food system (12 total, or 12% of its total actions) and Honolulu had the highest percentage of actions that included the food system (16%, or 7 of 44 actions). Five of the resilience plans had only one action with either a primary or partial focus on the food system San Francisco, Miami, Berkeley, Boston, and Norfolk. The food system was incorporated predominantly in terms of: 1. food access or distribution related to a disaster or hazard event (13 primary or partial focus actions, 2%); 2. food access and affordability under normal conditions (6 primary or partial focus actions, 1%); and 3. food production (7 primary or partial focus actions 1%). For example, food access related to a disaster was addressed through actions such as developing a "resilience hub" or community center that would serve as a shelter and place to distribute resources after a disaster (e.g., Berkeley's action entitled "Create safe (and green) City community centers and care & shelter facilities" [27] and Honolulu's action suggested developing "a network of community resilience hubs" [22]). Food access and affordability were addressed in actions such as those that incentivize food retailers to provide fresh foods or providing families with the means to purchase them. For example, New Orleans's action promoted equitable public health outcomes and included the "Fresh Food Retailer Initiative", which provides loans to food retailers to increase access to fresh foods [26].

Table 2. A summary of the total number of actions with a primary focus (Pm) and partial focus (Pt) on food, energy, water, and transportation systems per plan. The percentages in parentheses represent the percentage of each plan's actions with a primary or partial focus on each action with the total percentages out of the total 593 actions across the 11 plans.

City	Food		Energy		Water		Transportation		Total Actions
	Pm	**Pt**	**Pm**	**Pt**	**Pm**	**Pt**	**Pm**	**Pt**	
Boston	0	1 (4%)	1 (4%)	0	0	0	1 (4%)	0	23
Berkley	0	1 (4%)	6 (22%)	5 (19%)	6 (22%)	4 (15%)	2 (7%)	5 (19%)	27
Oakland	0	2 (5%)	4 (11%)	2 (5%)	0	2 (5%)	1 (3%)	6 (16%)	37
New Orleans	1 (2%)	1 (2%)	4 (10%)	3 (7%)	2 (5%)	5 (12%)	2 (5%)	1 (2%)	41
Norfolk	1 (2%)	0	0	0	0	0	1 (2%)	1 (2%)	42
Honolulu	2 (5%)	5 (11%)	8 (18%)	7 (16%)	4 (9%)	3 (7%)	6 (14%)	7 (16%)	44
San Francisco	1 (2%)	0	0	5 (9%)	4 (7%)	6 (11%)	2 (4%)	7 (13%)	54
Miami	0	1 (2%)	3 (5%)	4 (7%)	1 (2%)	3 (5%)	4 (7%)	6 (10%)	59
Seattle	1 (1%)	2 (3%)	4 (6%)	3 (4%)	0	2 (3%)	11 (16%)	6 (9%)	69
Los Angeles	2 (2%)	1 (1%)	7 (7%)	13 (14%)	7 (7%)	10 (10%)	6 (6%)	15 (16%)	96
New York	5 (5%)	7 (7%)	2 (2%)	19 (19%)	5 (5%)	5 (5%)	16 (16%)	13 (13%)	101
Total primary/partial actions	13 (2%)	21 (4%)	39 (7%)	61 (10%)	29 (5%)	40 (7%)	52 (9%)	67 (11%)	593
Total actions by system	34 (6%)		100 (17%)		69 (12%)		119 (20%)		593

Energy: There were a total of 100 actions (17% of all actions) with either a primary or partial focus on the energy system. New York City, Los Angeles, and Honolulu had the most actions relating to energy (21, 20, and 15 actions, respectively; or 21%, 21%, and 34% of their total actions, respectively), however, Berkeley had the highest percentage of its actions that included energy (41%; or 11 of 27). Conversely, Boston only had one action (4% of its total actions) and Norfolk had none. The energy system was most commonly considered in terms of increasing the use of renewable energy (42 actions, 7% of all actions) and increasing energy efficiency (24 actions, 4% of all actions). Examples of how renewable energy was considered include Miami's action to expand renewable energy in an effort to reduce greenhouse gas emissions [24]. Boston's action also suggested expanding distributed energy to vulnerable communities in the context of implementing a microgrid with distributed generation that would provide an alternative power source if the main grid were disrupted [28]. Seattle's action focused further on reducing costs for seniors and fixed-income residents in the context of energy-saving improvements to homes.

Water: There were a total of 69 actions (12% of all actions) with either a primary or partial focus on the water system. Actions relating to flood events or risk were not included as part of the water system unless they focused on stormwater management infrastructure. The actions predominantly focused on the water system in terms of physical infrastructure (31 actions, 5%) and increasing efficiency/water conservation (16 actions, 3%). Once again, the water system-related actions were not evenly distributed across the resilience plans—Berkeley, San Francisco, and Los Angeles had the highest percentages of their actions that included the water system (37%, 19%, and 18%, respectively). Boston and Norfolk did not have any actions that included the water system. In terms of infrastructure, the actions were commonly about stormwater infrastructure improvements or the deployment of green stormwater infrastructure or upgrading and retrofitting water system infrastructure (e.g., water or wastewater treatment facilities, pipes, reservoirs, etc.). These actions were mostly in the context of reducing flood risk or the consideration of climate change. For example, New York City's resilience plan includes an action to "protect the city's water supply and maintain the reliability and resiliency of the water supply system" [29]. In terms of increasing efficiency, the actions were commonly about upgrading residential or commercial buildings to have more efficient water use. For example, the Honolulu resilience plan has an action entitled "District cooling: Tap the ocean to cool our buildings",

which seeks to use seawater for cooling buildings to conserve energy and potable water on land [22].

Transportation: There were a total of 119 (20%) actions with either a primary or partial focus on the transportation system. New York City had the most actions relating to transportation (29 primary or partial focus actions, 29% of its total actions) and Honolulu had the highest percentage of its actions relating to transportation (30% or 13 of its 44 actions). Boston had the least (1 primary focus action total, 4%, of its total actions) actions that included transportation. Transportation was often included in the plans with actions related to physical infrastructure (30 total actions, 5%), electric and clean fuel vehicles (18 total actions, 3%), and increasing the use of, or expanding access to, public transit (14 total actions, 2%). Examples include Boston's action to "advance resilient transportation systems", which seeks to adapt transportation infrastructure for climate change [28] and Honolulu's action with a goal to "transform the City's public fleet to 100 renewable fuel by 2035" [22]. Examples of actions with a primary focus on public transit include Miami's action that seeks to design a better bus network to increase ridership [24] and Seattle's action to "cultivate a culture of ridership among Seattle's youth", which seeks to provide free public transportation to high school students [30].

Overall, food, energy, water, and transportation systems were not the most common systems included within the 11 resilience plans (Figure 1). Diversity, equity, inclusion, and justice was the most dominant theme across the plans with economy and housing as the second and third most common themes, respectively (Figure 1). Every resilience plan contained actions that incorporated or focused on diversity, equity, and inclusion, with 246 primary or partial focus actions across the 11 plans (41% of all actions). Low-income communities (75 actions, 13%) and racial equity (29 actions, 5%) were the most considered across the resilience plans. There were a total of 191 actions (32% of all actions) that incorporated or focused on the economy. Actions regarding the economy were mostly in terms of job creation and training/preparing residents for jobs (75 actions, 13% of all actions). There were a total of 148 actions (25% of all actions) with either a primary or partial focus on housing. Housing was commonly included in the resilience plans in terms of increasing or promoting housing affordability (53 actions total, 9%) and housing or building upgrades (67 actions total, 11%). San Francisco had the highest percentage of its actions that included housing (44%, or 24 of its 54 actions).
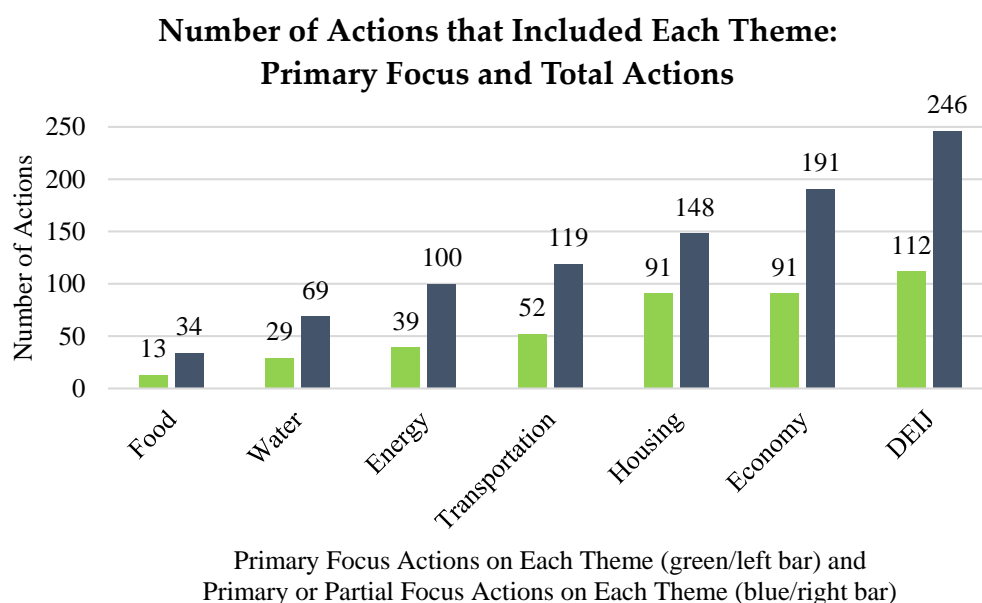
**Number of Actions that Included Each Theme:
Primary Focus and Total Actions**

Primary Focus Actions on Each Theme (green/left bar) and
Primary or Partial Focus Actions on Each Theme (blue/right bar)

Figure 1. A summary of the number of actions with a primary focus and the number of actions with either a primary or partial focus on each theme: food, energy, water, transportation, housing, economy, and diversity, equity, inclusion, & justice (DEIJ).

3.3. The Nexus Index

3.3.1. Nexus of FEWT Systems

There was little evidence that a FEW or FEWT nexus approach was explicitly used when creating the resilience plans. However, 15 actions (3%) considered all 3 or 4 FEWT systems. Of those, eight actions focused on the connections between systems within the action. The other seven incorporated multiple FEWT systems into a single action but did not account for their interconnections. Table 3 provides a summary of the 15 actions. An example of how the systems and their interconnections were included within an action is how Honolulu connected energy, water, and transportation systems. In this action, methane from the wastewater treatment plants would be used as a redundant energy source in case of an infrastructure failure and the methane can also be used to power alternative-fuel vehicles [22]. Conversely, Miami's action entitled "Planning efficiently & effectively together" incorporated energy, water, and transportation systems but did not consider their interconnections. In this action, water, energy, and transportation infrastructure projects would be coordinated to create efficiencies, such as coordinating underground water and energy projects so as to dig up the road just once. Here, there was coordination but no physical linkages between systems.

Table 3. A summary of the actions within the resilience plans that include at least three of the four target food, energy, water, and transportation systems. The context is also provided: if the action was in the context of a disaster and/or if the action included system interdependencies.

#	City	Action Title	Description	Disas.	Sys. Connect.	F	E	W	T
1	Berkeley	Create safe (and green) City community centers and care and shelter facilities	Facilities can distribute food after a disaster, energy and water retrofits will be done along with seismic retrofits.	yes	no	x	x	x	-
2	Berkeley	Establish a regional lifelines council	Lifeline systems are energy, water, transportation, communications that are essential for daily life and disaster response and recovery.	yes	no	-	x	x	x
3	Honolulu	Develop a Network of Community Resilience Hubs	Focused on providing the following during a disaster: shelter, information, energy, water, food, medical supplies.	yes	no	x	x	x	-
4	Honolulu	Ensure access to fuel supplies to aid disaster response and recovery	Fuel needed for transportation, transportation needed for food access and delivery, roads and vehicles needed for post-disaster recovery, backup generators for fuel pumping.	yes	yes	x	x	-	x
5	Honolulu	Expand opportunities for methane capture and re-use	Provides backup power source for wastewater treatment plants from the methane captured on-site, methane for alternative fuel source for vehicles.	yes	yes	-	x	x	x
6	Honolulu	Deploy sustainable roof systems to manage urban heat and rainfall	Rooftop gardens, rainfall harvesting and capture, on-site location for renewable energy generation (solar).	no	no	x	x	x	-
7	Los Angeles	Establish post-disaster restoration targets for critical infrastructure	Critical infrastructure includes water, sewer, electricity, gas, communications, and transportation. Accounts for critical infrastructure interdependencies.	yes	yes	-	x	x	x
8	Los Angeles	Fortify critical lifeline infrastructure and supply chains through continued assessments, coordination, and investment	Analyze risks and interdependencies of water, electricity, fuel, medical goods, pharmaceuticals, transportation lifelines, and supply chains.	no	yes	-	x	x	x
9	Los Angeles	Encourage increased power for critical services	Explore incentives to increase backup power for critical services, such as gas stations, food businesses, hospitals/shelters. Will align with interdependent lifeline systems, such as water.	no	yes	x	x	x	-
10	Miami	Planning efficiently and effectively together	Will coordinate capital projects between the Department of Transportation and Public Works, Water and Sewer Department, and utility companies.	no	no	-	x	x	x

Table 3. *Cont.*

#	City	Action Title	Description	Disas.	Sys. Connect.	F	E	W	T
11	New York City	Adapt the region's infrastructure systems	Transportation systems bring in food and fuel and rely on food stormwater infrastructure. Communications rely on backup power, etc.	no	yes	x	x	x	x
12	New York City	Make triple bottom-line investments in infrastructure and city-owned assets to capture economic, environmental, and social returns	Support a state-of-the-art food production and distribution industry, a nearby wastewater treatment facility could use food scraps from processing plants as a source of energy for the local grid, working with transportation to improve access.	no	yes	x	x	x	x
13	Oakland	Demonstrate the retrofit of a city block using EcoBlock principles	Principles include recycled water to irrigate shared fruit trees and vegetable gardens and landscaping, the greenery will help mitigate the urban heat island effect, integrate energy efficiency into all buildings, will create a solar-powered microgrid with on-site energy generation, EV chargers, water conservation through rooftop water harvesting.	no	yes	x	x	x	x
14	Seattle	Work to develop an earthquake early warning system and explore opportunities to retrofit unreinforced masonry buildings	Installed natural gas shutoff valves in 35 critical City facilities, seismically strengthened fire stations and water reservoirs, SDOT has been upgrading bridges and overpasses through its capital budget.	yes	no	-	x	x	x
15	Seattle	Reduce carbon emissions from the city of Seattle's biggest polluters	Will offer height and floor space incentives for significant upgrades in energy and water use, stormwater management, and transportation efficiency in 20 major renovations to urban centers.	no	no	-	x	x	x

Nearly half (7 of 15 actions) of the FEWT-related actions focused on a disaster or response to an extreme weather event (Table 3). The majority of these actions (6), were centered around energy systems, incorporating how damage to one system could negatively impact other systems. The disaster-related FEWT actions include Honolulu's action to develop a network of community resilience hubs that combines energy, water, and food systems [22]. The community resilience hubs are intended to provide shelter, information distribution, renewable energy storage and supply, water and food, and medical supplies following a disaster. Additionally, six actions (two of which overlap with the 15 FEWT-related actions) considered the cascading impacts that damage to the energy system can have on interdependent systems (Table 4). For example, Los Angeles' action encourages increasing power generation to benefit critical services, which highlights how the energy system can negatively impact services such as gas stations, food businesses, and hospitals, and how the energy system should align with "interdependent lifeline services, including water availability and fire prevention strategies" [21] (p. 139).

Table 4. A summary of the actions that accounted for or included cascading impacts between systems.

#	City	Action Title	Description	Focus
1	Boston	Expand distributed energy to vulnerable communities	Energy redundancy to ensure that critical facilities (grocery stores, pharmacies, senior homes, and affordable housing developments) remain operational during and after extreme weather events.	Energy-centric
2	Honolulu	Increase O'ahu's preparedness utilizing scenario modeling and artificial intelligence	Multi-hazard risk assessment tools can account for multiple hazards and account for cascading effects. AI platforms can aid in the analysis of critical infrastructure, such as where power outages will occur or areas that will need to be evacuated.	Mentioned cascading impacts, used energy as an example.
3	Los Angeles	Encourage increased power for critical services	Explore incentives for backup power for critical services: gas stations, food businesses, hospitals/shelters.	Energy-centric
4	Los Angeles	Expand combined solar and energy storage pilots	Identify opportunities for combined solar and energy storage pilots. Will ensure city facilities remain accessible and operational during an emergency.	Energy-centric
5	New Orleans	Launch a microgrid pilot project	Assessing risks of energy outages to critical infrastructure systems and conducting feasibility studies for backup generation and microgrids.	Energy-centric
6	New York City	Adapt the region's infrastructure systems	Acknowledges how food relies on transportation and transportation relies on a good stormwater infrastructure system. Communications rely on power and access to backup power. Generally, discusses how damage to one system can impact other systems.	Energy- and transportation-centric

3.3.2. The Nexus Index

The Cities of Honolulu and Miami had the highest Nexus Index scores relative to their potential scores, 43% and 42%, respectively. Seattle had the lowest Nexus Index score relative to its potential score, 15%. The Nexus Index scores as they relate to each city's potential score are listed in Table 5 in descending order. The individual elements of the Nexus Index were not evenly observed across the resilience plans. The plans most commonly listed partners and co-benefits, but few considered system interdependencies.

Table 5. The Nexus Index score of each city relative to its potential score as both numeric score and the percent of the potential. Partners (adjusted) refers to the total number of points assigned after adjusting the partners listed per action relative to each plan's mean (0 points for no partners listed, 1 point for partners equal to or less than the mean, 2 points for more partners listed than the mean. Then the points per action were summed for the whole plan). The score of each Nexus Index element is also provided.

City	Total Actions	Nexus Index Element Scores					Total Nexus Index Scores	
		Partners (Adjusted)	Co-Benefits	Cross-Silo	Other Plans	Interdependencies	Nexus Score: Actual (Potential)	Nexus Percentage
Honolulu	44	58	44	14	22	12	150 (352)	43%
Miami	59	84	59	28	25	2	198 (472)	42%
Oakland	37	52	36	13	15	0	116 (296)	39%
Berkeley	27	38	12	16	9	4	79 (216)	37%
Boston	23	31	7	4	12	4	58 (184)	32%
Los Angeles	96	137	29	24	33	16	239 (768)	31%
New Orleans	41	51	19	8	14	2	94 (328)	29%
San Francisco	54	71	10	12	20	4	117 (432)	27%
New York City	101	107	37	22	34	10	211 (808)	26%
Norfolk	42	49	4	2	9	2	66 (336)	20%
Seattle	69	44	12	6	20	0	82 (552)	15%
TOTAL: Actual (Potential, %)	593	722 (1186, 61%)	269 (593, 45%)	149 (1186, 13%)	213 (593, 36%)	56 (1186, 5%)	1410 (4744)	30%

Partnerships: Every resilience plan had actions that highlighted establishing collaborations and partnerships. In terms of partners listed, overall, the plans achieved 61% of their maximum potential score (722 out of a potential 1186 points). Los Angeles, Miami, Berkeley, and Oakland each had the highest percentage of the potential score for the inclusion of partnerships and collaborations (71%, 71%, 70%, and 70%, respectively). Seattle had the lowest percentage of its potential partnerships score with only 32%. As stated within the Honolulu resilience plan, "resilience is going to take unprecedented collaboration" [22] (p. 120). Los Angeles, Oakland, and Berkeley all provided a list of partners for each of their actions and many of Norfolk's actions begin by discussing the partnerships it had formed or planned to form. A few specific examples include San Francisco's action seeking to "Build Partnerships to Advance Resilience" and Miami's action to build a "Resilient 35 in the 305 Network". Miami's 305 Network will:

> "catalyze the resilience work across Miami-Dade County by providing peer exchange and connecting local government practitioners through the planned Resilient 35 in the 305 Network. The 305 Network will facilitate intergovernmental collaborative work among practitioners by enhancing and supporting the sharing of communication and resources between cities in Miami-Dade County to advance resilience work. The 305 Network will support its member cities in their resilience work, develop multi-city collaboration projects, influence the development of policies at the local and regional level, and build a network of trusting relationships between peers" [24] (p. 120)

Co-benefits: The resilience plans demonstrated that authors considered how systems may impact one another more often as a result of co-benefits rather than interdependencies or negative cascading impacts (how damage to one system could negatively impact other connected systems). The plans achieved 45% of their potential score for including co-benefits (269 out of a potential 593 points). In the context of the resilience plan actions, "co-benefits" meant how positive changes in one system would create positive changes in another. Half of the plans (6 of 11) provided a list of co-benefits along with most actions, such as Honolulu's "Resilience Co-Benefits", Oakland's "Benefits to Oakland Residents", and Miami's "How this will help us". For example, the co-benefits described for Honolulu's action entitled "Reduce Taxpayer Expense and Increase Renewable Energy through City-

Wide Energy Performance Contracts" include how retrofit and renewable energy projects will "both reduce reliance on imported oil and natural gas and improve air quality in O'ahu's denser regions" [22] (p. 73).

Referencing Other Plans: The plans achieved 36% of their potential score for referencing other plans or reports (213 out of a potential 593 points). Connecting the actions within the resilience plans to planning efforts within a variety of different fields and contexts shows a willingness to make connections between otherwise siloed sectors. Boston and Honolulu's actions referenced the most other plans or reports and achieved 52% and 50% (respectively) of their potential score for this element of the Nexus Index. Norfolk referenced the least other plans and reports within its actions relative to the potential maximum, 21%. These plans and reports include proposed plans, such as developing a comprehensive post-disaster recovery plan [26] (p. 76), and aligning efforts with national plans, such as Miami aligning with the National HIV Strategy, "Ending the HIV Epidemic: A Plan for America". Other efforts include guides and ordinances, such as Honolulu's Complete Streets Design Manual and Oakland's "No to Coal", an ordinance banning coal from being stored and handled in the city.

Cross-silo efforts: The plans achieved 13% of their potential Nexus Index score for including cross-silo or interagency efforts (149 out of a potential 1186 points). Berkeley had the most actions that included cross-silo or interagency efforts (16 of 27, 30%) and Norfolk had the least (2 of 42, 2%). These cross-silo efforts were related to developing partnerships and collaborations that would leverage overcoming departmental silos and initiating efforts that cross-cut multiple agencies or fields. For example, Berkeley included an action to "implement opportunities for multi-departmental input on major City plans and projects" [27] and Oakland included an action to "open a civic design lab for problem solving across City departments in collaboration with partners" [25].

System interdependencies: The plans only achieved 5% of their potential Nexus Index score for incorporating system interdependencies in terms of dependence on another system or negative cascading impacts (56 of a potential 1186 points). Honolulu had the highest percentage of actions that included system interdependencies (12 of 44, 14%), whereas the Seattle and Oakland resilience plans did not account for systems interdependencies in any of their actions. As shown in Table 5, systems interdependencies were often in terms of how damage to one system could cause damage to other connected systems in terms of negative cascading impacts.

4. Discussion

This study sought to understand how food, energy, water, and transportation (FEWT) systems and their interconnections had been incorporated into US city resilience plans. There are three main conclusions that can be drawn from the analysis of the resilience plans: 1. There was little evidence that a FEWT nexus approach had been used when creating the resilience plans, 2. There was an inconsistent focus on proximity to the coast within the coastal cities' resilience plan actions, and 3. There were inconsistencies in how FEWT systems and the 11 themes were incorporated across the resilience plans.

There was little evidence that a FEWT nexus approach, or general nexus approach, had been used when creating the resilience plans. Low Nexus Index percentages suggest that the cities' resilience plans did not take a nexus approach into consideration. The Honolulu resilience plan had the highest Nexus Index score, which was only 43% of its potential score and the Seattle resilience plan had the lowest (15%). There was an inconsistency in how food, energy, water, and transportation systems were included within the resilience plans, especially in how certain cities entirely excluded them (e.g., Boston had no actions that included water systems and Norfolk had no actions that included energy systems). The elements of the Nexus Index were also not consistently incorporated within the resilience plan actions. Partnerships and co-benefits were the most common applications of nexus principles (61% and 45% of their potential score, respectively), whereas including cross-silo

or interdisciplinary teams or approaches and incorporating systems interdependencies were the least common (13% and 5% of their potential score, respectively).

While the results from this analysis cannot answer why these systems were not consistently included, they do bring into question if a more direct FEWT nexus approach could benefit the development of resilience plan actions. While not a direct employment of a nexus approach, the Nexus Index scores and the elements used to create the Nexus Index indicate that the cities may be receptive to using a nexus approach in resilience planning. A specific FEWT nexus approach encourages planners to consider systems, interconnections, or unanticipated tradeoffs that may have been otherwise overlooked [2,17,31]. Additionally, direct use of a FEWT or other nexus approach could benefit cities by ensuring that certain systems or perspectives are not overlooked. For example, the food system was only included in 6% of the 593 actions despite the documented food insecurity many face in the US [32], which was exacerbated and highlighted by the COVID-19 pandemic [33]. Further research would be needed to understand if the food system (and others) was intentionally minimized when creating resilience plan actions, or if applying a FEW nexus perspective could have been beneficial in ensuring that it was more consistently incorporated along with other systems.

There was an inconsistent focus on proximity to the coast within the coastal cities' resilience plan actions. Coastal hazards are predicted to increase due to climate change, yet only 21% of the actions within the 11 resilience plans had either a primary or partial consideration of the coast. Results suggest two likely options for the lack of emphasis on the coastal environment: 1. That the coastal considerations had been addressed in other planning efforts (and, therefore, not needed within the resilience plan), or, 2. The cities felt that their coastal location was not significant to resilience planning. It is important to note that additional research, including interviews with those who wrote each resilience plan, would be needed to support or refute each speculation.

It is possible that a more central consideration of coastal hazards or challenges could be found in the other planning efforts referenced in the resilience plans, such as Hazard Mitigation Plans or Sea Level Rise Plans. Each city detailed many other planning efforts that their resilience plan builds from or links to (36% of its potential Nexus Index score across plans). Some of these plans were included as actions within the resilience plans, such as the Los Angeles' action that recommended "incorporating sea level rise modeling into local plans" [21] and the New Orleans action entitled "Master Plan for a Sustainable Coast" [26]. Additionally, the amount of background information and details provided for each action varied greatly between plans, from a few sentences to an entire page (or more). This could suggest that the other plans contain the bulk of the actionable information and focus on coastal hazards or the coastal environment.

The other consideration would be that the coastal environment or coastal hazards were not the most pressing hazards or challenges for every city. Or, while coastal hazards are a serious issue, it is not easy to control the uncertain and unpredictable threats to the coast from climate change, instead, protecting the population and coastal infrastructure merits more of an urgent response. This was reflected in the high number of actions across the resilience plans with either a primary or partial focus on housing, the economy, and diversity, equity, inclusion, and justice. However, a recent study of coastal community resilience frameworks in the context of disaster risk management emphasized the need to consider the interconnections between multiple hazards in future frameworks [5].

There were inconsistencies in how FEWT systems and the 11 themes were incorporated across the resilience plans, which reflects the heterogeneity among the challenges that the cities face. FEWT systems and their interconnections were not emphasized in the resilience plans, this might be so because the use of a nexus approach in the context of resilience is relatively new. Nexus research became more frequent in the context of coastal resilience in academic literature only since 2016 [2]. The inconsistency in how FEWT is represented across different resilience action plans may be due to the heterogeneity between cities in terms of geography, history, economic, and political circumstances. Each city faces a

different set of challenges and hazards, which may require them to emphasize different systems or vulnerable communities or populations. These perspectives were reflected in the high number of actions across the resilience plans with either a primary or partial focus on housing, the economy, and diversity, equity, inclusion, and justice. For example, San Francisco's resilience plan had the most actions out of any plan with either a primary or partial focus on housing (24 out of the 593 total actions or, 44% of its own 54 actions), Miami's resilience plan had the most actions with a primary or partial focus on the coastal environment (25 out of the 593 total actions or, 42% of its own 59 actions), and Berkeley, San Francisco, and Los Angeles had the highest percentages of their actions that included the water system (37%, 19%, and 18%, respectively). This is consistent with San Francisco's housing crisis [34], Miami's location atop porous limestone bedrock and pronounced vulnerability to sea level rise [35], and California's water crisis [36–38]. The differences between these coastal cities' resilience plans relate to one of the challenges with resilience; resilience is unique for every situation.

Many of the challenges that were identified in specific locations are reflective of challenges faced by other, often non-coastal communities. One of the key benefits to the heterogeneity between the resilience plans, and the cities themselves, is that there is now a diversity of experiences to draw from when designing future resilience-building actions. For example, while San Francisco has a housing crisis, there is also a housing affordability crisis across the US [39]. One of the key challenges to operationalizing resilience is that there is no established set of actions to draw from. The resilience plans produced from the 100 Resilient Cities program provide a valuable starting point, and as reflected in the resilience plans that reference other cities' efforts, cities are willing to learn from one another even though no two cities are the same. There have now been many actions tried in a variety of contexts, for a variety of systems, and from a variety of perspectives. However, some consistency in addressing certain essential infrastructural needs and their interconnections may greatly benefit and improve the implementation of resilience planning.

5. Limitations and Future Research

One key limitation of this research is that it is difficult to know the areas of expertise or intent of the individuals who wrote the plans. It cannot be known just by reading a plan if its developers had any working knowledge or consideration of FEWT or general nexus approaches and how this knowledge, or lack thereof, contributed to the development of the plan. Additionally, it is unknown how actionable each plan was intended to be or has been since its release. A critical avenue for future research is to interview plan writers to understand their decision-making process and why certain systems were highlighted, others were excluded or minimized, and their perspective on the importance of system interconnections as they relate to resilience building. Additionally, since the plans were written as far back as 2016, interviews with resilience planners could reveal how actionable these plans were and if they have been updated (or plan to be updated).

Additionally, each of these plans followed the Community Resilience Framework that was provided by the 100 Resilient Cities (100RC) program. This common guidance could limit the chances of plan developers adding additional frameworks, such as a nexus approach, to the development of their plans. This could potentially bias the sample of plans to mean that either all plans would incorporate nexus approaches or none of them would. Future research could consider implementing the methodology from this study on resilience planning efforts that were developed outside of the 100RC program.

6. Conclusions

This study sought to understand how the food, energy, water, and transportation nexus had been incorporated into the resilience plans of 11 US coastal cities utilizing a Nexus Index to score resilience plans for how they incorporated nexus principles into their actions. Results suggested that the FEWT nexus approach was not directly used as a methodology and interactions across FEWT systems were inconsistently recognized

within the plans. However, there was evidence that the plans included aspects critical within a FEWT nexus approach, such as the inclusion of partnerships and reference to co-benefits with the actions they designed to build resilience. Additionally, while housing, economy, and diversity, equity, inclusion, and justice were the most dominant perspectives within each plan, the coastal environment was not. It is possible that more direct use of a nexus approach during plan development could ensure that certain systems are given stronger consideration and that systems interconnections are better assessed. In general, the resilience plans written as part of the 100 Resilient Cities program provide a starting point from which other cities can learn. One of the biggest challenges with resilience is how to operationalize it, the actions developed within each resilience plan are each an effort to do exactly this.

Author Contributions: Conceptualization, K.B.R.; Methodology, K.B.R., K.F.S., B.P., and J.C.S.; Validation, K.B.R.; Formal Analysis, K.B.R.; Investigation, K.B.R.; Resources, J.C.S.; Data Curation, K.B.R.; Writing—Original Draft Preparation, K.B.R.; Writing—Review and Editing, K.B.R., K.F.S., B.P., and J.C.S.; Visualization, K.B.R.; Supervision, K.F.S., J.C.S.; Project Administration, K.B.R.; Funding Acquisition, J.C.S. All authors have read and agreed to the published version of the manuscript.

Appendix A. Codebook

Resilience plan actions will contain multiple themes and systems. For example, green infrastructure is often classified both as "flooding" and as "environment" as it can be for stormwater management and is an environmentally friendly solution. The systems and themes (and the criteria for each listed below) must be explicitly used; if they are implied, it does not count.

Only information relating to an action should be coded. Each resilience plan provides different additional information to support the description of the action. Examples of the additional information include a description of co-benefits (sometimes called "How this will help us" or "Resilience Value"), a list of partners and leads, a description of the timeline, performance metrics, and funding sources. Call-out boxes, spotlight features, case studies, and other supplementary material do not count—these are often separated from the material about an action through the use of a different color background or text.

In general, it is recommended that those using this codebook in the future code the actions multiple times in multiple sittings as specific references to the systems or themes can be easy to miss upon initial review.

Appendix A.1. Criteria for Each System or Theme

Appendix A.1.1. Food

- Use of the term food. Agriculture, food production, food retailers, quality of food/nutrition, food reserves (stocking up before an event), supply chains if in the context of food retailers (just a reference to a supply chain does not count).

Appendix A.1.2. Energy

- Use of the term energy. Energy production (solar, wind, etc.), efficiency, smart grid technology and infrastructure, fuel and gas, power outages, physical infrastructure (transformers, powerlines, etc.), biofuels and methane gas generation for energy use, natural gas.

Appendix A.1.3. Water

- Use of the term water. Infrastructure (pipes, treatment facilities), water quality and supply, efficiency, water usage. Stormwater infrastructure (both green and grey/standard) is also classified under "flooding".

Appendix A.1.4. Flooding

- Use of the term flood(ing). Stormwater infrastructure (often in terms of green infrastructure—see "environment" for more detail on green infrastructure) and stormwater management, seawalls/grey infrastructure solutions, sea level rise. This can also include beach renourishment if the action explicitly states it is to combat sea level rise or other flood impacts.

Appendix A.1.5. Coastal

- Use of the term coast(al). Reference to a port or the maritime industry, waterline, flood event or flooding or flood risk, beach, coastline, hurricanes (and other coastal related hazards), sea level rise.
- Note, flooding and coastal are not cross-counted in this analysis but they are coded separately to show the nuance of each.

Appendix A.1.6. Transportation

- Use of the term transportation. Electric vehicles/vehicle electrification, transit-oriented development, roads and infrastructure, busses, public transportation, sidewalks, and walkability. Also includes airports and airport infrastructure.
- Evacuation.
- Supply chains and the transport of goods.
- Often anything to do with mobility—getting people from one place to another.

Appendix A.1.7. Communication

- Use of the term communication, but only communication that relates to a physical infrastructure system (not interpersonal communication or discussions). Internet and communications infrastructure, wi-fi, online platforms/toolkits/mapping/apps (with the thought that if communications/internet goes down, so do these resilience actions). Relating to phone communication and related phone infrastructure.

Appendix A.1.8. Housing

- Use of the term housing. Shelter, getting people back in homes following a disaster, homeowner incentives for upgrades to their residence.
- Homelessness.
- Note, housing and buildings will be coded as one category (later stages), they are separated at this stage to show nuance in coding. Housing is mostly in terms of residential buildings and shelter, whereas buildings are all other types of non-housing related buildings, retrofits, and upgrades (when specifically in the context of structures, housing—does not include a generic upgrade of an area because we cannot know of what).

Appendix A.1.9. Buildings

- Use of the term buildings. Physical upgrades to buildings, efficiencies, retrofits. This is specifically looking at physical structures that are <u>not residential</u> and actions related to these buildings (goes beyond just retrofits, however, that was the most common).
- Only in reference to changes to buildings, not the existence of a structure.
- In the context of backup power, if the action refers to having options "on hand" or "available", this does not count as it does not directly refer to changes to the building itself. However, if the terms "installed" or "upgraded" are used, then it counts as it is changing the building itself.

Appendix A.1.10. Economy

- Use of the term economy. Reference to job creation/training/preparation, reference to boosting the economy, economic development, businesses (creating them, supporting them, protecting them).
- Does include reference to cost/benefit value of actions (e.g., investment of $x will result in $y cost savings). Also includes reference to cost savings, such as how increased utility efficiency will result in cost savings for residents.
- Does not include reference to funding sources (actual or sought) or generating tax revenue.

Appendix A.1.11. Environment

- Use of the term environment. Air quality, water quality, emissions reduction, open space, green infrastructure (excludes just referencing stormwater infrastructure, as in only physical, concrete stormwater strategies, but does include things such as rain gardens and living shorelines), tree planting (often in the context of the urban heat island effect).
- Includes remediation of brownfields.
- Includes restoration of natural systems, such as mangroves and reefs.
- Does not include reference to the built environment.
- Note: Green infrastructure is stormwater/"wet weather" measures that include vegetation and environmentally friendly practices. It does not include "green practices" in general, such as those that relate to renewable energy.

Appendix A.1.12. Diversity, Equity, Inclusion, and Justice

- Use of terms vulnerable communities/underrepresented, specific reference to helping minorities, women, formerly incarcerated, seniors/aging populations, low-income/income-relating decision making, language (e.g., translation services), abilities, race and racial justice, immigrants and immigration. Use of the term justice, including environmental justice.
- Use of the term diversity in the context of human populations either as an acknowledgment or seeking to increase it, etc.
- Acknowledgment of barriers that certain populations face.
- Gentrification, segregation, discrimination, inclusive, bias, hate.
- Homelessness (this is often cross-listed with housing).
- Generally, when an action is attempting equitable provision of services or change—sometimes the simple use of the words "underserved", "vulnerable", or "equitable" and sometimes the entire action will focus on a specific population.

Appendix A.1.13. Health

- Use of the term health. Mental health, hospitals, wellbeing/wellness, trauma services, safety, medical supplies. Emergency Medical Services (EMS), health inspectors.
- Urban heat island effect (because this is primarily a health and wellbeing concern).
- Safety in terms of reducing traffic fatalities or reducing injuries.
- Air quality (typically in terms of emissions reductions to improve air quality).

Appendix A.1.14. Criteria for Determining Primary vs. Partial Focus

- Primary focus is if the theme or system is the central core or focus of the action. First, look at the title of the action. If the theme or system is included within the title, it is often the primary focus of the action.
- One mention or use of the term within the action is a partial focus.
- If more than two systems or themes seem to be the primary focus, it often means that the many systems/themes are each a partial focus. However, if one (or more) is included within the title, that system or theme is a primary focus, if both are included, both are a primary focus. If neither are included in the title, both are a partial focus.
- One of the target systems and themes is not required to be the primary focus of each action, many can be a partial focus.

Appendix A.2. Nexus Index Criteria

There are five categories that comprise the Nexus Index score: partnerships and collaborations, reference to other plans, co-benefits, cascading impacts, and interdisciplinary/cross-silo principles.

Appendix A.2.1. Partnerships and Collaboration

If the action lists partners/collaborators, then provide the number listed (count them). If not, conduct a count of those specified within the action. If the action does not specify specific partners but refers to "partner(s)" generically, record it as "generic" and then either "plural or single" depending on what was described. Look for use of "working with", "partnership", or "collaboration". If the action includes specific partners and a generic statement, record the number of specific partners listed *AND* record generic plural or single. If the action names specific departments/organizations/agencies/groups/private sector institutions, etc., they are included in the tally of partners.

First, check to see if there is an appendix that lists partners. If so, count for each action and then cross-check as you tally the nexus index for each action. Use whichever number is higher. If an action lists "leads" along with patterns, these leads are also counted as partners. Due to the inconsistency in how the term "program" is used within the context of resilience plan actions, programs are not counted as partners UNLESS the text specifically states "work with" or "in partnership", etc. This does not include references to "legislature" unless the text explicitly uses phrases such as "partner with", "collaborate with", or "work with".

0 = no partners or collaborators listed.

"generic" = generic reference to "will seek or work with partners/collaborators". Record if it references a singular partner or plural partners.

= record the actual number of partners or collaborators spelled out in a specific section within an action (we will later score the action as either a 1 or 2 based on the mean number of partners listed per resilience plan).

Appendix A.2.2. Other Plans

Does the action reference another plan, report, ordinance, policy, or other forms of written work? Reference to another plan, strategy, report, ordinance, policy, etc. This is specifically looking at forms of written documentation and does not include other programs, surveys, working groups, etc. If it does not include other programs or referencing a statistic from a report as a citation, this means only count reports or plans that are named within the action. Also, look for policy titles that end in "Act". Also, look for "Assessment" and "Strategy". If referring to a study, if it mentions a report title resulting from the study, then it counts as a plan. If it just references conducting a study with no mention of a written report/summary, then it does not count.

0 = no other plans referenced.

1 = at least one other plan/report referenced.

Appendix A.2.3. Co-Benefits

Does the action reference or discuss how it will benefit another system or theme? Specifically, the benefit needs to be a different theme or system. For example, vehicle electrification will help reduce greenhouse gas emissions or a youth program will indirectly help with job creation (as long as the program was not specifically a job prep program). Also, look for words such as "opportunity"—it could be the action acknowledging how the efforts will benefit another system or theme. Some plans directly list co-benefits or include sections such as "how this will help us"—in which case, each action receives one point for consideration of co-benefits. Look for use of "intended to" with regards to the point of the action.

0 = no reference to benefitting another system or theme.
1 = yes, co-benefits referenced.

Appendix A.2.4. Interdependency/Cascading Impacts

Does the action acknowledge or take into account how damage to one system will negatively impact another? This does not include how a hurricane or other event will damage several systems, it must be about how one system could negatively impact other systems or how one system depends on another. Look for terms such as interdependence, relies on, connections, etc. Interdependency/cascading impacts is only in reference to physical infrastructure systems (food, energy, water, transportation, communications. etc.), how one system cannot operate without another.

0 = no cascading impacts included within the action.
2 = there are cascading impacts referenced.

Appendix A.2.5. Interdisciplinary/Cross-Silo

Does the action include the terms "cross-silo", interdisciplinary, multidisciplinary, or intentionally seek to bring together multiple departments, fields, disciplines to collaborate or work together to advance the actions resilience principles? This is more about intentionally bringing together different groups/perspectives and less about the physical connections between the systems (the physical connections are classified under "cascading impacts"). An action can also list the variety of sectors it will include in a working group (or in the context of improving the coordination of, or just that multiple will be coordinated), etc., but there must be an emphasis on the diversity of who is included. A group of similar entities does not count.

This also includes a discussion of coordinating multiple services from a variety of systems and working across agencies, departments, or other organizational categories that are usually siloed. Integrated approach to infrastructure planning. Only listing multiple collaborators from different groups does not count unless they are specifically calling attention to their intent to promote collaboration between diverse departments/fields/etc. This falls under the general criteria of explicit or implied inclusion of a system, theme, or criteria, the action must articulate an intent to promote interdisciplinarity.

0 = no explicit inclusion of interdisciplinary or cross-silo principles
2 = includes interdisciplinary/multidisciplinary/cross-silo principles

References

1. Dargin, J.; Berk, A.; Mostafavi, A. Assessment of household-level food-energy-water nexus vulnerability during disasters. *Sustain. Cities Soc.* **2020**, *62*, 1–23. [CrossRef]
2. Raub, K.B.; Stepenuck, K.F.; Panikkar, B. Exploring the Food-Energy-Water Nexus Approach to Enhance Coastal Community Resilience Research and Planning. *Glob. Sustain.* **2021**. no accepted with revision.
3. Masselink, G.; Lazarus, E. Defining Coastal Resilience. *Water* **2019**, *11*, 2587. [CrossRef]
4. Binder, S.B.; Baker, C.K.; Barile, J.P. Rebuild or Relocate? Resilience and Postdisaster Decision-Making After Hurricane Sandy. *Am. J. Community Psychol.* **2015**, *56*, 180–196. [CrossRef] [PubMed]
5. Almutairi, A.; Mourshed, M.; Ameen, R.F.M. Coastal community resilience frameworks for disaster risk management. *Nat. Hazards* **2020**, *101*, 595–630. [CrossRef]

6. Mills, A.K.; Bolte, J.P.; Ruggiero, P.; Serafin, K.A.; Lipiec, E.; Corcoran, P.; Stevenson, J.; Zanocco, C.; Lach, D. Exploring the impacts of climate and policy changes on coastal community resilience: Simulating alternative future scenarios. *Environ. Model. Softw.* **2018**, *109*, 80–92. [CrossRef]

7. 100 Resilient Cities. About Us. Available online: http://www.100resilientcities.org/about-us#/-_/ (accessed on 25 August 2020).

8. Zebrowski, C. Acting local, thinking global: Globalizing resilience through 100 Resilient Cities. *New Perspect.* **2020**, *28*, 71–88. [CrossRef]

9. Resilient Cities Network. Available online: https://resilientcitiesnetwork.org/ (accessed on 6 November 2020).

10. Paci-Green, R.; Berardi, G. Do global food systems have an Achilles heel? The potential for regional food systems to support resilience in regional disasters. *J. Environ. Stud. Sci.* **2015**, *5*, 685–698. [CrossRef]

11. Roege, P.E.; Collier, Z.A.; Mancillas, J.; McDonagh, J.A.; Linkov, I. Metrics for energy resilience. *Energy Policy* **2014**, *72*, 249–256. [CrossRef]

12. De Bruijn, K.M.; Maran, C.; Zygnerski, M.; Jurado, J.; Burzel, A.; Jeuken, C.; Obeysekera, J. Flood Resilience of Critical Infrastructure: Approach and Method Applied to Fort Lauderdale, Florida. *Water* **2019**, *11*, 517. [CrossRef]

13. Romero-Lankao, P.; Norton, R. Interdependencies and Risk to People and Critical Food, Energy, and Water Systems: 2013 Flood, Boulder, Colorado, USA. *Earth's Future* **2018**, *6*, 1616–1629. [CrossRef]

14. Belinskij, A. Water-Energy-Food Nexus within the Framework of International Water Law. *Water* **2015**, *7*, 5396–5415. [CrossRef]

15. Minne, E.A.; Crittenden, J.C.; Pandit, A.; Jeong, H.; James, J.A.; Lu, Z.; Xu, M.; French, S.; Subrahmanyam, M.; Noonan, D.; et al. Water, energy, land use, transportation and socioeconomic nexus: A blue print for more sustainable urban systems. In Proceedings of the 2011 IEEE International Symposium on Sustainable Systems and Technology, Chicago, IL, USA, 16–18 May 2011; pp. 1–4. [CrossRef]

16. Zhang, P.; Zhang, L.; Chang, Y.; Xu, M.; Hao, Y.; Liang, S.; Liu, G.; Yang, Z.; Wang, C. Food-energy-water (FEW) nexus for urban sustainability: A comprehensive review. *Resour. Conserv. Recycl.* **2019**, *142*, 215–224. [CrossRef]

17. Liu, J.; Hull, V.; Godfray, H.C.J.; Tilman, D.; Gleick, P.; Hoff, H.; Pahl-Wostl, C.; Xu, Z.; Chung, M.G.; Sun, J.; et al. Nexus approaches to global sustainable development. *Nat. Sustain.* **2018**, *1*, 466–476. [CrossRef]

18. Schlör, H.; Venghaus, S.; Hake, J.-F. The FEW-Nexus city index—Measuring urban resilience. *Appl. Energy* **2018**, *210*, 382–392. [CrossRef]

19. Fan, X.; Zhang, W.; Chen, W.; Chen, B. Land–water–energy nexus in agricultural management for greenhouse gas mitigation. *Appl. Energy* **2020**, *265*, 114796. [CrossRef]

20. Allen, T.R.; Crawford, T.; Montz, B.; Whitehead, J.; Lovelace, S.; Hanks, A.D.; Christensen, A.R.; Kearney, G.D. Linking Water Infrastructure, Public Health, and Sea Level Rise: Integrated Assessment of Flood Resilience in Coastal Cities. *Public Work. Manag. Policy* **2018**, *24*, 110–139. [CrossRef]

21. City of Los Angeles, Resilient Los Angeles. 2018. Available online: https://resilientcitiesnetwork.org/downloadable_resources/Network/Los-Angeles-Resilience-Strategy-English.pdf (accessed on 6 May 2021).

22. City and County of Honolulu, Ola: O'ahu Resilience Strategy. 2019. Available online: https://resilientcitiesnetwork.org/downloadable_resources/Network/Honolulu-Resilience-Strategy-English.pdf (accessed on 6 May 2021).

23. Leck, H.; Conway, D.; Bradshaw, M.; Rees, J.A. Tracing the Water–Energy–Food Nexus: Description, Theory and Practice. *Geogr. Compass* **2015**, *9*, 445–460. [CrossRef]

24. Miami-Dade County, City of Miami, and City of Miami Beach, Resilient305: Resilient Greater Miami & The Beaches. 2019. Available online: https://resilientcitiesnetwork.org/downloadable_resources/Network/Greater-Miami-Resilience-Strategy-English.pdf (accessed on 6 May 2021).

25. City of Oakland, Resilient Oakland: It Takes a Town to Thrive. 2016. Available online: https://resilientcitiesnetwork.org/downloadable_resources/Network/Oakland-Resilience-Strategy-English.pdf (accessed on 6 May 2021).

26. City of New Orleans, Resilient New Orleans: Strategic Actions to Shape Our Future City. 2015. Available online: https://resilientcitiesnetwork.org/downloadable_resources/Network/New-Orleans-Resilience-Strategy-English.pdf (accessed on 6 May 2021).

27. City of Berkeley, Berkeley Resilience Strategy: A Strategic Preparedness Plan for Berkeley, a Community Known for Inclusiveness and Innovation. 2016. Available online: https://resilientcitiesnetwork.org/downloadable_resources/Network/Berkeley-Resilience-Strategy-English.pdf (accessed on 6 May 2021).

28. City of Boston, Resilient Boston: An Equitable and Connected City. 2017. Available online: https://resilientcitiesnetwork.org/downloadable_resources/Network/Boston-Resilience-Strategy-English.pdf (accessed on 6 May 2021).

29. City of New York, One New York: The Plan for a Strong and Just City. 2015. Available online: https://resilientcitiesnetwork.org/downloadable_resources/Network/New-York-City-Resilience-Strategy-English.pdf (accessed on 6 May 2021).

30. City of Seattle, Seattle-Future City: Resilience Roadmap. 2019. Available online: https://resilientcitiesnetwork.org/downloadable_resources/Network/Seattle-Resilience-Strategy-English.pdf (accessed on 6 May 2021).

31. Whitney, E.; Schnabel, W.E.; Aggarwal, S.; Huang, D.; Wies, R.W.; Karenzi, J.; Huntington, H.P.; Schmidt, J.I.; Dotson, A. MicroFEWs: A Food–Energy–Water Systems Approach to Renewable Energy Decisions in Islanded Microgrid Communities in Rural Alaska. *Environ. Eng. Sci.* **2019**, *36*, 843–849. [CrossRef]

32. Alaimo, K. Food Insecurity in the United States. *Top. Clin. Nutr.* **2005**, *20*, 281–298. [CrossRef]

33. Wolfson, J.A.; Leung, C.W. Food Insecurity and COVID-19: Disparities in Early Effects for US Adults. *Nutrients* **2020**, *12*, 1648. [CrossRef] [PubMed]
34. Caldararo, N. The Housing Crisis and Homelessness: A San Francisco Ethnography. *Urbanities* **2017**, *7*, 3–21.
35. Molinaroli, E.; Guerzoni, S.; Suman, D. Do the Adaptations of Venice and Miami to Sea Level Rise Offer Lessons for Other Vulnerable Coastal Cities? *Environ. Manag.* **2019**, *64*, 391–415. [CrossRef] [PubMed]
36. Chung, F.; Kelly, K.; Guivetchi, K. Averting a California Water Crisis. *J. Water Resour. Plan. Manag.* **2002**, *128*, 237–239. [CrossRef]
37. Pincetl, S.; Porse, E.; Cheng, D. Fragmented Flows: Water Supply in Los Angeles County. *Environ. Manag.* **2016**, *58*, 208–222. [CrossRef] [PubMed]
38. Tanaka, S.K.; Zhu, T.; Lund, J.R.; Howitt, R.E.; Jenkins, M.W.; Pulido-Velazquez, M.; Tauber, M.; Ritzema, R.S.; Ferreira, I.C. Climate Warming and Water Management Adaptation for California. *Clim. Chang.* **2006**, *76*, 361–387. [CrossRef]
39. Rohe, W.M. Tackling the Housing Affordability Crisis. *Hous. Policy Debate* **2017**, *27*, 490–494. [CrossRef]