RESEARCH ARTICLE

Development of an integrated smart water grid model as a portfolio of climate smart cities

Kwi-Gon Kim*
Division of Landscape Architecture and Regional System Engineering, Seoul National University, Seoul, Korea

Abstract: Currently, there is no overarching model to integrating city planning, smart water techniques and climate change. After reviewing the existing literatures on the theoretical framework of smart water grid, this paper describes three case studies focusing on innovative technology placement and network of smart water grids in Fiji Islands, Nepal and the Philippines. Then, based on the case study results, and examples from experiments made by other cities around the world, this study develops an alternative smart grid development pattern scenario model. The model shows the ecology-water-energy-climate change nexus which allows for simulating and predicting the effects of a smart water grid on the urban ecosystem and net carbon emissions.
Keywords: climate smart city, integrated smart water grid, water leak detection, energy saving, water quality, climate change, sensor placement, nexus, IOT

*Correspondence to: Kwi-Gon Kim, Division of Landscape Architecture and Regional System Engineering, Seoul National University, Seoul Korea. Email: kwigon@snu.ac.kr.

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1. Introduction

Climate-driven water scarcity combined with increasing demand for water in particular at city level can become a major threat to the economy. Water supply, stormwater drainage, wastewater collection and treatment, as well as quality and quantity management of natural water resources need to be efficiently secured or, where necessary, improved in line with the water cycle[1] .Only through a paradigm shift from fragmented towards integrated urban water management can economic development, social balance and ecological integrity be secured[2].

This paper offers a new way to describe the relationship between technology, resource management, and sustainable water infrastructures.. Describing the relationship in terms of what each contributes to a smart water grid, it goes on to show how this grid can combine ecology, climate change, water and ICT for efficient, circular and sustainable water resources management; including production, transportation and distribution. The paper suggests this concept of smart water grid helps to solve a number of problems related to water shortage, climate change and integrated management of water, energy and disaster. Very recently, an increasing number of companies have begun to look at their water footprint, and some agencies predicted that public companies wo soon be required to disclose water efficiency in their annual reports (Public Utilities Board Singapore 2016)[3].

2. Climate Smart Cities and Smart Water Grid - A Framework and Components

2.1. Challenges and Opportunities

Smart water grid can be seen as a portfolio from a climate smart city perspective. For over three decades, the notions of green cities, eco-cities, climate resilient cities and cleaner cities have been evolving and tested to address the challenges the cities, the citizens and the planet face and mitigate the threats to cities and by city expansion. However, these approaches have tended to be disconnected, spot or sectoral initiatives rather than fully integrated and coordinated to drive city planning. In addition, financing has remained a major challenge, deterrent and a Gordian Knot. Yet, the rapid expansion in urbanization and urban dwellers whereby in about 30 years close to 70% of the world population will be living in cities, is forcing policy makers, researchers, techniques, planners, civil society and the world community to roll up their sleeves and waste no time in finding new viable and affordable options and taking actions to deal constructively with this unavoidable reality.

In parallel, the world has witnessed an explosion and revolution in terms of technological development and especially in the fields of ICT and IOT based and supported innovation, opening an infinite world of options and permeating all fields of activity. "Connectivity" has become the new trend.

This is the digital age[4]. Due to the variety of ICTs lead innovations and improvements which have been implemented under the smart city label, it is difficult to distil a precise definition of a smart city. The Smart City Council (2014) defines a smart city as one that has simple, easy, practical digital technology embedded across all city functions[5].

In the context of climate change, the planning process has to recognize the need for ongoing adaptation, flexibility, and resilience.

Resilience is defined by Walker and Salt as the ability of an ecosystem to withstand or recover from disturbance or stress[6].Disturbance, such as drought, heat, cold, flood, disease and changes in species, influences or impairs an ecosystems capacity to perform specific functions and provide ecosystem services.

Climate resilient and low-carbon smart cities can be defined as ones that have digitalized connections of all sectors and functions, in which everything is directly or indirectly connected, supporting sustainability, resiliency, circularity, efficiency and connectivity of the city. It incorporates climate change mitigation and adaptation policy goals at each stage of the planning process and in urban policies.

A smart water grid system contributes to such urban sustainability, resiliency, circularity, efficiency and connectivity a lot, and thus to achieve the goals of climate smart cities[2].

The growing global population requires constant urban water infrastructure development, while at the same time global warming demands massive investment to mitigate future climate change. We live in a modern digital world. Sustainable connect-tech provides new opportunities for changing the ways in which services are delivered to citizens within cities to make them more efficient, cost-effective and to enhance both the planning and management processes, while trying to address the challenges posed by climate change. In addition, digital job opportunities can be provided by true digital water grids for digital economy.

2.2. The Relation between Water and the Smart Grid: Framework and Components

A water infrastructure can become smart with a smart grid in two ways, namely, smart framework and components.

2.2.1. Smart Framework for Water Grids

The smart water grid, from data capture and management to the digital water system innovation, allows the introduction of smart solutions to water shortage and other related issues. In this study, a new integrated smart water grid system is proposed to improve the network structure and function of the system and to move away from traditional thinking to improve the quality of life (Table 1). The integrated or enlarged grid framework is the expansion of conventional smart water grid, which addresses the issues of symbiotic eco-sustainability and climate responsiveness together with smartness. Concern is often expressed regarding the impact of smart technology on urban decision making because high-tech smart cities tend to be dominated by the thoughts and approaches of techno-optimists. Typical frameworks of conventional smart water grids are shown in Figures 1 and 2. It is expected that the proposed enlarged model enables to contribute to achieve the goals of Post-2015 Sustainable Development Goals (SDGs), Paris Climate Agreement, Fourth Industrial Revolution and New Urban Agenda (NUA) as well at the city level, especially for emerging countries.

2.2.2. Smart Components of Water Grids

Smart cities are embracing smart grid because, as the old monolithic, centralized model has broken down, the new technologies collectively allow the energy system to do more[8].

The smart grid is an advanced digital two-way power flow capable of self-healing, and it shows the trait of adaptive, resilient, and sustainable, with foresight for prediction under different uncertainties. It is equipped for interoperability with present and future standards of components, devices, and system that are cyber-secured against malicious attack[9,10]. The smart grid transformation is now taking place mainly in the energy sector. This transformation suggests how other smart city systems might also evolve. The enlarged smart water grid (SWG) combines water and information and communication technology (ICT) for sustainable, smart, and climate resilient and responsive water resources management including production, transportation, and distribution. It aims at providing connections between surface water (mobility), drinking water, hot water, process water, resource water and waste water plant. For the surface water, land mosaics and green- blue infrastructure in the watershed area can be part of this network connectivity, which is called the green- blue grids or ecogrids. The green-blue grids consisting of planted watercourses and bodies of water could complete the network (CNRS sagascience). In this way, water can be a green asset. It helps to solve problems with water shortage, climate change, and integrated management of water, energy and disaster[2].

However, currently there is no overarching model for integrating green and blue infrastructure networks into the smart water grid[11].As shown in Figure 1 and Figure 2, this study proposes how the second architectural framework is partitioned into subsystems with layers of intelligence and technology and new tools and innovations by using an overlay method at the city scale (Table 3). It involves ecological mapping, digital connect-tech and carbon overlay.

Table 1. Exemplar of SMART innovation challenges

	Monolithic water model	Conventional smart water grid model	Innovative smart water grid model
City applications	*Wide application exist in techno- cities	*Increasing applications exist in smart cities	*New applications are encouraged in climate smart cities
Thoughts and driving forces	*Individual technique-oriented thinking at the site level; reductionism; individualism	*System thinking at the area wide level or water plant level; connectivity; techno-optimism	*Multiple water resources management thinking at the urban and regional watershed level; smart climate urbanism; holistic collectivism
	*The 3rd Industrial Revolution	*Post – 2015 SDGs	*Paris Climate Agreement; The 4th Industrial Revolution
Goals	*To promote single technology- oriented water business and industry	*To provide more efficient and smart connected systems between surface water, drinking water, hot water, process water, reclaimed water, resource water and waste water plant	*To build expanded connections between water grids, eco-grids and climate grids for more sustainable, resilient, and circular water production, consumption and resource water management system
Network structures : Framework	*Disconnected, spot or sectoral network structures rather than fully integrated and coordinated network of water system	*Limited to optimize network structures between water producers and consumers	*Expanded network structures to combine ecology, climate change water and ICT infrastructures
	*Uni-directional framework	*Bi-directional framework	*Multi-directional framework
Technology applications : components	*Use of a computing platform technique as a set of processing machine in a single dedicated computer room working in silo; a single "Virtual" computation program	*Optimization techniques for processing and data integrated "Virtual" computation program	*Techniques to maximize potential of ecology-water-energy-climate connections and leveraging our greatest assets with more use of advanced technology such as IoT, big data, satellite imagery, cloud computing, AI, etc.
Potential markets, job opportunities and cost of time	*Isolated or fragmented infrastructure developments create a set of single technology market and job opportunity	*Digital job opportunities are provided by true digital water grids in the form of digital economy with multi technology markets	*More job opportunities could be increasing considerably by integrated water grid in the area of digitalized climate economy
	*Short-term payback period with environmental and climate externalities	*Medium-term payback with less environmental and climate externalities	*Long-term payback with high level of integration of technology, environment, energy and climate

Figure 1. Conceptual diagram for smart water grid. [7]

3. Current Limitations and Deficiencies of Isolated Models

Current limitations or deficiencies of isolated or fragmented models can be addressed in the areas of city applications, thoughts and driving forces, goals, network structures, technology applications, and potential markets, job opportunities and cost of time as shown in Table 1. The table aims to differentiate monolithic and conventional water grid model from the proposed enlarged model. This paper attempts reorienting water resource planning and management towards the integrated water resource management (IWRM) in combination with traditional water management with cutting-edge ICT such as IOT and AI technology. IWRM has been defined by the Global Water Partnership (GWP) as "a process which promotes the coordinated development and management of water, land and related sources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems." This definition provides criteria that serve to discuss current limitations of isolated models (Table 1).

The following is the key limitations of the current models according to the definition of IWRM and ICT application:

- The expansion of water infrastructure that breaks up national, regional and urban habitat connectivity
- Lack of real time on-line tele-monitoring system
- No early warning system for emergency caused by climate change
- Inefficient use of water for farming irrigation and toilet, etc.
- Lack of acceptance and understanding of system dynamics for smart grids based on system thinking
- Not enough research, innovation and new thinking

- Lack of standards and skills
- Failure to meet the needs of people involved often a problem
- Lack of investment by the water industry
- Use of high- powered single functional gauge
- Separate information, data and control centers for water resource planning and management
- Low efficiency distribution due to isolated or fragmented water management system
- Important water loss due to leakage
- Important energy consumption for production, transportation and distribution
- Industries of separated process
- Poor forecasting capacity of demand supply balancing

The proposed integrated smart water grid model is still a growing area. Its potential is not yet fully exploited. Key features to be addressed by the proposed model to address the limitations and deficiencies of current models can be summarized as follows:

- To develop goal matrix optimization by advanced techniques such as cloud computing and big data analytics supported by AI and IOT
- To aggregate multiple water sources into some new form with new potential
- To have an increasing part of total water needs met by decentralized water supply, while still maintaining an integrated whole approach, planning and overall management
- To deploy networked meters and sensors coinciding with the revolution in the IWRM technologies and network technology for water supply interfacing and total technology
- To establish IOT virtual connection platform based on the nexus concept and approaches
- To develop wide area real time tele-monitoring system (TMS) for real time information and data
- To develop grids from power to multi-utility (electricity, water, irrigation, gas, chilled water, etc.)
- To utilize IOT and cloud computing technology for integrated master controller
- To strengthen interfacing and connectivity between smart water meters, grid intelligence and utility IT
- To promote the nexus between energy, food, natural resources including biodiversity, water, and ecosystem goods and services, etc.

Smart grid has the function of prediction under different uncertainties as described earlier on. Therefore, smart water grid can be used for integrating the goals of symbiotic eco-sustainability, smartness and climate responsiveness shown in Figure 8 in a consistent decision- making framework and assembling grid pattern options into future scenarios for evaluating its effects on the given goals.

Prediction and optimization are key areas for the integrated smart water grids. Application of urban intelligence computer algorithm with right data or dynamic urban water modeling with mathematical predictive algorithm has become a clear prospect. The application results can be used to assess effects of energy-water- climate-ecosystem nexus and optimize the efficiency of subsystems such as energy system, water system, and transportation systems, and so on as well as the delivery of several classes of city services.

Even though it is possible in theory, actual evaluation of the quality and basis of any such prediction is still hard to do on a city-wide scale, because it requires significant empirical research, innovations and investment.

However, by bringing in powerful and well-designed data gathering and analysis tools, by the integration of more pertinent parameters and variables in a consistent way, it is expected that the analysis outcomes will better equip the planners and managers to set up, monitor, adjust and evaluate the benefits and efficiencies of the smart grid systems with greater accuracy and a ”just on time” approach.

4. An Example of Smart Water Grid for Case Studies

Many references on smart water grid models are being published[10,12–17] Amongst them, Figure 2 shows a water grid platform with fresh and reclaimed water cycles with zero water discharge, and bi-directional data flow for water and energy within the water grids and between grids and the central management structure is shown in Figure 3.

The roll of a system of smart management technology across the water network including water suppliers, water treatment facilities and distribution networks has contributed to effectively form a smart water grid. Huge advances in water management and water conservation can be achieved by the system.

Figures 2 and 3 are selected to show components of a typical smart water grid (substantive issues), data flow of water and energy within the water grids and between grids, and the central management structure (procedural issues). These figures have been used to develop a guide which was distributed to case study participants to help describe how SWG in their cities looks like. The figures are being used as a prototype for an enlarged smart water grid system.

This framework was utilized in case studies as a tool that serves to guide water loss, energy consumption, and water quality analysis. The major features of the framework are that smart water grid is expressed in micro-grids, meso-grids and macro-grids in a given watershed area. One of the key points to note is that big data macro platform (smart cloud) of water and energy should be broken into meso-platform and micro- platform for different levels of grids.

This framework is a highly organized methodology, and as such, it helps to ensure systematic and all-inclusive approaches. But very little emphasis is given to smart technologies used in smart water grids. Therefore, this paper tries to improve the framework with integrated solutions to smart water grid, as described in “2.2.1 smart framework”.

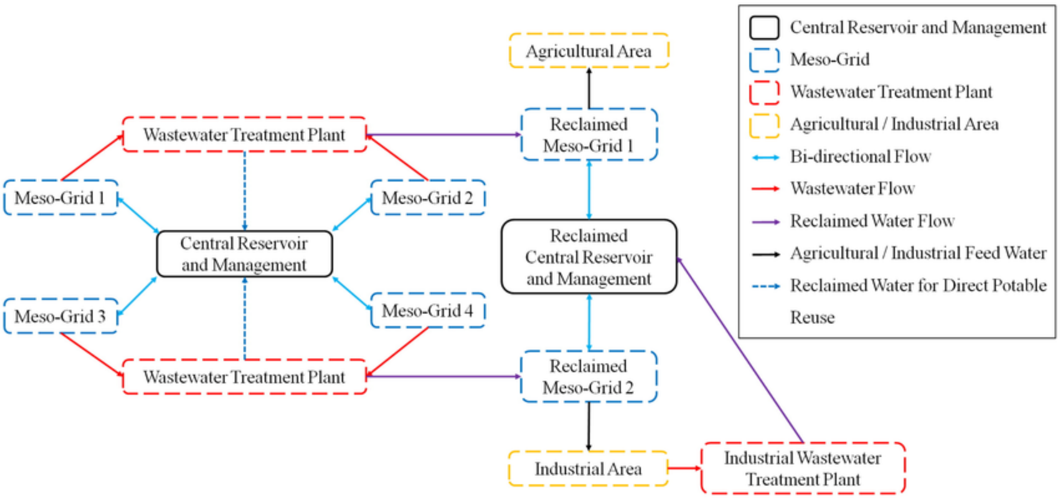

Figure 2. Water grid platform: fresh and reclaimed water cycles with zero water discharge [16].

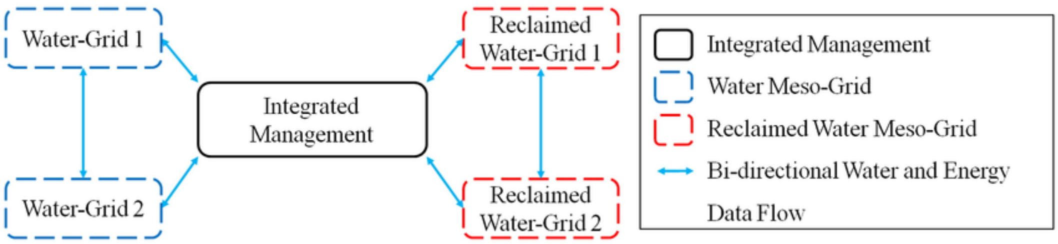

Figure 3. Bi-direction data flow water and energy within the water grids and between grids and the central management structure
Source: Lee SW, Sarp S, Jeon D and Kim JH, 2014, Smart water grid: the future water management platform, Desalination and Water Treatment, 55:2, 339-346.

The smart grid framework or platform as shown Figures 1 and 2 will be tested with case studies in the next section to show how effective it is.

5. Case Studies of Smart Water Grid System

Let me now consider three simplified smart water grid proposals based on the framework of digital technique placement and network discussed in the previous section. This study selected technology to show different systems of smart connect-tech across the water network.

This section is a summary of the outcomes of the workshop produced by the members of the International Urban Training Center (IUTC) Smart Grid Planning Team. The author developed the workshop guide and supervised the workshop. The Fiji Islands team worked on a water loss issue. Energy consumption was selected for Nepal and Water quality for the Philippines. Overall, the workshop aimed to provide a better understanding of the role and potential of SWG approaches and practices in IWRM.

5.1. Proposal on Smart Grid for the Reduction of Water Loss, Fiji Islands

The Fiji team developed smart grid solutions for water loss because the water loss is a big challenge in the urban and rural areas of Fiji Islands.

Figure 3 presents a smart grid solution for water loss using new pipes, smart pressure management reading devices, and smart telemetry meters. It is important to analyze how robust the grid is and how much the results change if spatial components and attribute components are modified. The main features of the proposed system can be summarized as follows:

1 . In a spatial smart grid model, the study area boundary directly impacts water loss.
2 . The issue related to connectivity extension is the way in which distances between facilities including the piping network and devices are calculated.
3 . Smart grid data has both a spatial component and an attribute component. The digital devices should have the correct location and the collected attributes including smart sensors and pressure meters to ensure the results of the smart grid model valid.

5.2. Proposal on Smart Water Grid for Energy Savings, Kathmandu Valley, Nepal

The Nepal team focused on the development of a SWG for energy conservation.

The proposal includes smart pumps, smart valves, pressure meter, smart power transformers, bio-sensors, TOD

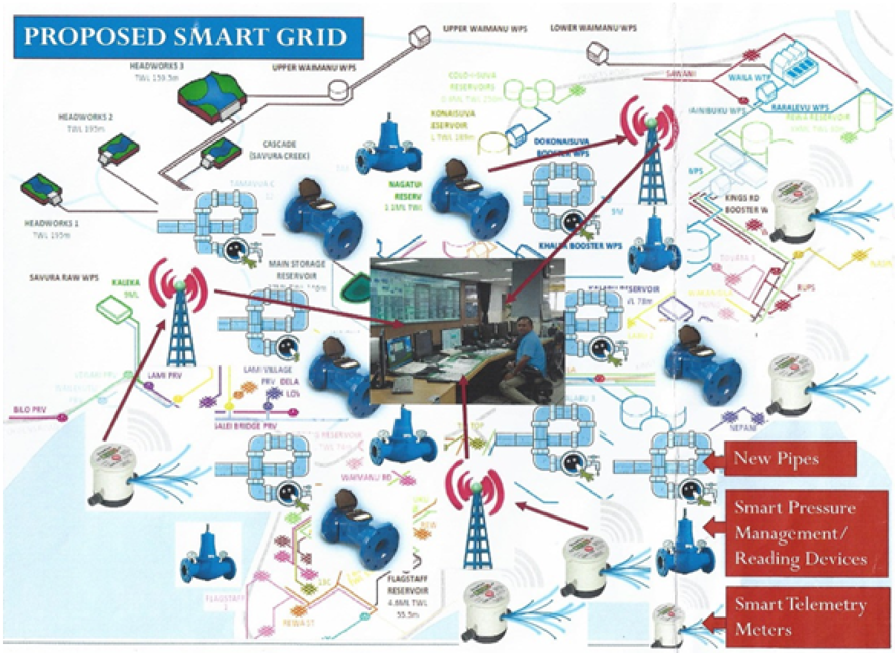

Figure 4. Proposed smart grid solution for water loss in Fiji Island

energy meters as well as an ICT supported integrated control system for the deep tube well (Figure 4).

It is important to note that smart connect-tech will be employed in this proposal to connect each smart water grid activity with the integrated control system shown in the middle of the proposal.

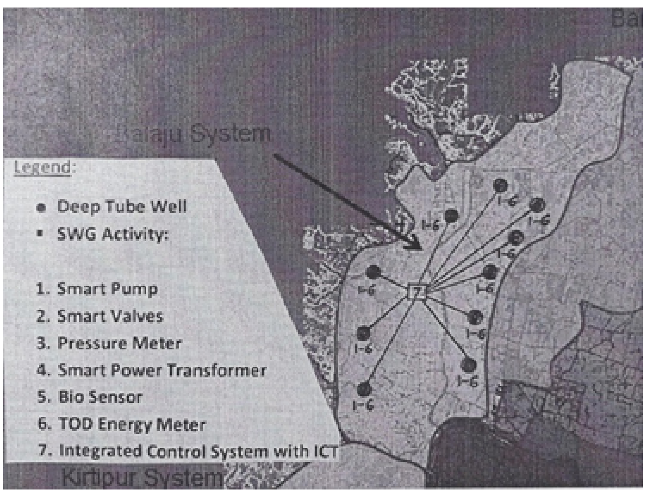

Figure 5. Proposal on smart water grid for energy savings, Kathmandu valley, Nepal

Table 2 shows the possible energy cost savings after application of the smart water grid (SWG) until 2030. Based on Table 2, total energy cost savings by 2030 is expected to be 4,500 USD per month for ten tube well stations.

It is suggested that current and future research efforts are needed to provide information, investment and benefits relevant to the operation of the SWG.

5.3. Proposal on Smart Water Grid for Water Quality, Kidapawan City, the Philippines

The action plan developed aims at a better control of water quality through a SWG. Figure 6 presents a proposal for a smart water grid for water quality. The details of the proposal are:

- The grid system is used to connect water source & treatment, waste water treatment plants (4), smart sensors (20), sub-control systems (2), centralized control system (1) and flood warning devices (10).
- It is important to note that the number of smart-tech and devices employed for the system should be considered according to individual circumstances, and level of knowledge and technologies.

One of the attractive features of the proposals is that the use of smart devices can be expanded or contracted, that is, the number of devices can be increased or decreased from Table 2 which contains the variance of digital connect-tech. Some of key criticisms revealed by the case studies are as follows:

- As the current smart water grid model is based on smart technology-ICT-wire and/or wireless sensor network, it may result in a losing long-term eco-sustainability and climate responsiveness associated with water production, transportation and distribution activities.
- A bias in technology interest for techno-optimists may lead to ignoring alternative avenues of promising climate smart city development.
- People would prefer alternative grid systems they can

Table 2. Savings in energy consumption at tube wells

Monitoring Tube Well Station	Water Production Per Month, million litre	Energy Consumption Per Month, kilowatt	Energy Charge Per Month, $USD	Energy Cost Saving After Application of SWG within 2030, $USD
MK-1	3	1800	360	324
MK-2	3	1800	360	324
MK-3	4	2400	480	432
MK-4	4.5	2500	500	450
MK-5	4.5	2500	500	450
MK-6	6	2700	540	486
MK-7	7	2800	560	504
MK-8	7.5	2900	580	522
MK-9	8	3000	600	540
MK-10	5	2600	520	468
Total	45	25000	5000	4500

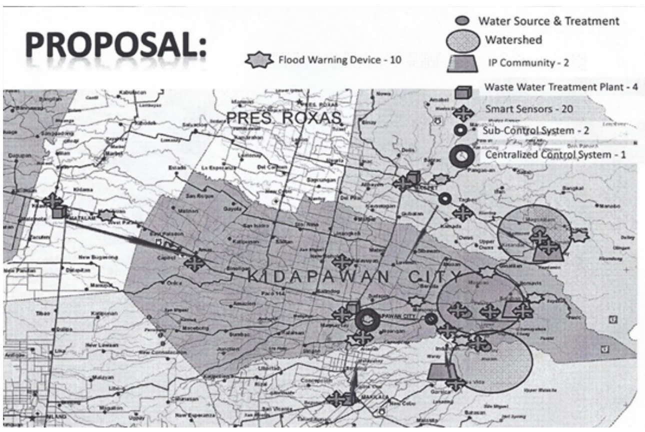

Figure 6. Proposal on smart water grid for water quality, MKWD, Kidapawan city, the Philippines

participate to shape rather than a technically planned system.

Some elements I have extracted and major findings from the case studies can be summarized as follows:

- To develop spatial smart water grid models for describing land and ecosystem features based on spatial science.
- To analyze how robust; that is, how much the results change if spatial components and attribute components are modified with big data analytics.
- To refine cost-benefit analysis to quantify the intangible and long-term costs and benefits of a particular smart water grid project.

The findings imply the importance and value of space-based smart grid model considering environmental and climatic factors, or land features in a given watershed area. There are some lessons learned from the case studies about how to maximize technical potentials of energy and water saving and to sustainably manage quantity and quality of water with smart water grids. While one workshop cannot be considered as bringing all the answers and validation of the proposed model, it still provides some very pertinent insights and initial validation that justifies further exploration and refinement of the model.

6. Refinement of the Framework toward Integrated Water Resources Management

This section addresses practical implications of smart water grid case studies on integrated water resources management (IWRM) and suggests an alternate model. The case study results reveal that in general very little attention is given to providing a systematic framework regarding the overall smart grid design. There is a need for developing a new open water grid framework to address land development, and climate change mitigation and adaptation parameters for IWRM. IWRM has been defined by the Global Water Partnership (GWP) as “a process which promotes the coordinated development and management of water, land and related sources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems”.

In the context of building capacity for smart grid projects, cities require GIS and GPS, and related virtual visualization technologies to support the interdisciplinary process of smart water grid planning. This study develops three simple overlay maps that consolidate spatially referenced information and help planners recognize relationships and patterns on the smart water grid landscape. Table 3 shows components of overlay approach to climate resilient and low-carbon smart cities which provide a valuable means for identification of options. (Green Building Council)[18]. A more common and especially useful application of overlay mapping involves mapping of the capacity of existing water infrastructure and comparing this with the projected demand for water services with support from big data, and dynamic scenarios for decision making.

This study based on case study results, proposes an alternate smart water grid development scenario model as a decision making support system (Figure 8). As can be seen in Figure 7, different layers of sub-smart grid system can be assembled into integrated smart water grid development patterns and project scenarios for the political goals of IWRM from climate smart city perspective to offer “the whole of the system” vision at the city level. In Figure 7,

Table 3. Savings in energy consumption at tube wells

Ecological mapping overlay (Options)	**Digital connect-tech overlay (Options)**	**Carbon overlay (Options)**
· Land Development - Land use zoning - Protected areas	· Mobile Techniques - iPhone - smart phone	· Smart housing carbon footprint · Shopping carbon footprint by social media(internet behavioral change)
- Flood prone areas - Mitigation - Renewable energy - Carbon capture and utilization - Carbon storage - Carbon forests · Adaptation - Natural ground surface (natural wetlands) - Mangrove plantation - LID(Rain gardens) · Physical Infrastructure - Drinking water - Waste water - Landfill site - Food waste treatment - Other solid waste infrastructure	· Sensors - LED lighting sensor - CO2sensor - Car navigation system · Intelligent CCTV - GIS-based CCTV monitoring for crime · Safety - Disaster (natural & human-induced) - Automatic disaster - Water level perceiving system - Flooding · Meters for metering - Electricity consumption - Water consumption - City gas · Energy & heat density mapping · Monitoring for operation and maintenance(control tower)	· Smart connected factory carbon footprint · Smart parking carbon footprint · Smart hospital carbon footprint · Traffic flow organization carbon footprint · Intelligent digital signage carbon
Integrated superimposed synthesized map	Integrated superimposed synthesized map	Total amount of carbon footprint & carbon reduction Risk reduction

ecological cases contribute to analyze land suitability and carrying capacity of the grid system while smart connect-tech cases are provided for the technology development roadmap for each step of smart water grid system. Carbon overlay is to calculate the total greenhouse gas emissions associated with the construction and operation of grid systems. This model can used to generate and evaluate integrated smart water grid planning options in the broad context of climate smart cities.

In addition to the advanced technical issues discussed so far, the rising issues dealt with in this study include environmental externalities of water infrastructure development and climate change impacts. There are some big picture challenges we need to internalize.

The major feature of the integrated approach is a network-type analysis of rising issues and solutions in an aggregated manner. This network analysis is similar to interaction matrix approach which identifies various interrelationships between the goals, subsystems and water management activities, and effects associated with grid operation, and advanced technology application[19]. The integrated analysis of potential risks associated with it, is a critical component of this approach. Figure 8 makes use of a stepped matrix. The steps involved in use of the matrix in Figure 8 are as follows:

1 Enter the matrix at the upper left-hand corner under the political goals. In this example, the matrix is 3 political goals of IWRM. They are symbiotic eco-sustainability, smartness and climate responsiveness.
2 Read to the right. The cases that may result in grid pattern options are shown at "Ecology, technology and climate case in a grid pattern". Relate grid pattern options to ecological suitability, network connectivity and climate change impacts associated with water.
3 An arrow (→) indicates that a relationship exists between grid pattern options (network connectivity), and ecological corridor and climate change impact matrix.
4 In the column "Grid patterns assembled into scenarios" is grid options for ecology, technology and climate case, which are assembled or superimposed into city or regional smart water grid scenarios in a given watershed area.

This study develops the integrated SWG data platform in order to address data requirements for use of alternate smart water grid development scenario model (Figure 8). This platform captures in particular the following types of information that are often deficient in traditional scenario:

1 Functional data
   a Weather forecasts

b Real time water quality and quantity monitoring data
c Land features; Algorithm to creative land cover classification layers using very high resolution imagery
d Water pollution data ,etc.

2 Non-functional data (environmental externality data)
a CO_2 reduction for urban CDM
b Environmental impacts
c Impact of geospatial information smart technologies in our daily lives, etc.

3 CAD (Computer Aided Design) Data
a Data produced by GIS and virtual visualization
b "Geospatial", or location- based data using global positioning systems (GPS)
c Real time water flow and distribution maps
d Topographical maps, etc.

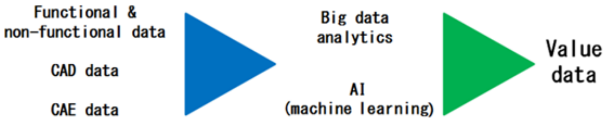

Figure 7. The integrated SWG data platform

These data can be used to develop "A Big Data- based Water Consumption Diagnosis Platform" supported by artificial intelligence (AI)[20,21]. This platform can enable to measure real- time water consumption pattern by water use only through big data analytics supported by AI. Cost and availability of data may be challenges. The platform involves three separate actions. The first action is to collect data from different sources of water use including billing data of water. The second action is to combine the data with a series of overlay maps depicting environmental and climatic factors, or land features in the form of CAD data. Overlay techniques utilizing digitalization for more effective data analysis have been developed[22].

The third action is to identify water consumption pattern of buildings or districts by using algorithm for automatic division of water consumption by different use. This platform can provide information on water consumption efficiency which can be used to prepare an efficient water saving policy. This platform can be enlarged to include energy consumption pattern in water sector, and environmental and climate change impacts of water infrastructure development.

Another feature of the integrated approach is to include potential components of a blue infrastructure for water-related ecosystem goods and services (European Union 2013). Blue grids can be based on urban hydrological elements which include rainwater, precipitation, surface (running) water, groundwater, park- like water plants, canal, natural river system, pond, lake, and grey water from buildings and water plants within a watershed area.

When it comes to addressing civic problems, one of today's buzzword is resilience related to climate change impacts. The United Nations office for disaster risk reduction recently launched a Making Cities Resilient program. Books are being published, conferences are being held, and around the world, resilience is being encouraged. The resilience movement is becoming a global movement.

In general, resilience is defined by Walker and Salt (2006) as the ability for an ecosystem to withstand or recover from disturbance or stress[6]. Disturbance such as drought, heat, cold, flood, disease, and changes in species all influence or impact an ecosystems capacity to perform specific functions and provide ecosystem services. On the other hand, urban resilience is defined as the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter kinds of chronic stresses and acute shocks they experience[23].

A city is a complex system. Therefore, in this paper, a precautionary but positive approach to water development is adopted which aims not just to avoid further climate change but also to reduce risks and enhance the resilience of ecosystems and communities as can be seen in Figure 7. Cities now use urban smart grids to become more efficient and sustainable, and less polluting; or to generate economic activity; or to enhance social equity; or with redundancy built in, to become more resilient[8]. As such the proposed smart grid approach goes way beyond the simple sectoral management of water, looking into first the integrated management of all water related subsectors and in linking the management of all water related subsectors with the larger issues of climate change responsiveness with other sectors(e.g. power..) and the overall welfare of city dwellers.

The benefits of the proposed model are as follows:

- Provide overarching prosperity to the cities and communities
- Establish ecology, water, ICT and climate change nexus
- Promote public participation to shape alternative smart water grid systems
- Use sensor placement optimization to achieve political goals of IWRM
- Provide integrated solutions for climate smart cities from a water perspective

The use of novel and inexpensive smart water sensors and meters, in which in turn would catalyze the growth of the Internet of Things could drive an intelligent infrastructure. Such a digitalized ubiquitous measurement and communication presumably would enable a much deeper understanding of complex grid system. In turn, this information would drive actionable real time management of water resources, efficiency improvement, and lead to new markets and capabilities for attaining those key pillars of sustainability, resiliency, circularity, efficiency, and connectivity of the system.

By considering the entire urban and regional watershed holistically, the smart water grid system can collectively

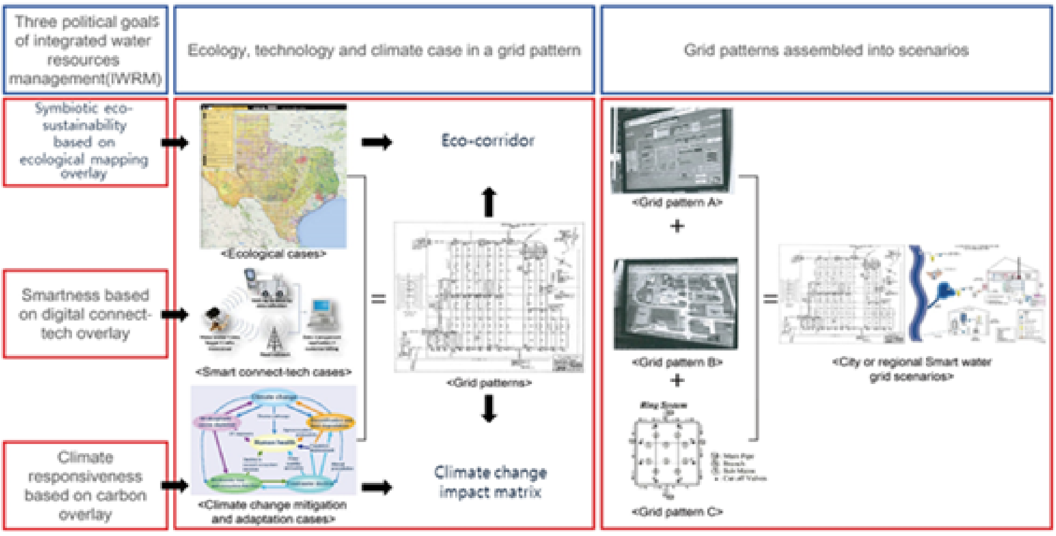

Figure 8. Alternate smart water grid development scenario model: The nature of technology should be symbiotic not unidirectional, and low-carbon and less vulnerable technology applications

review all the various efforts towards sustainability, resiliency, circularity, efficiency and connectivity and begin to prioritize and coordinate ongoing initiatives, to drive integrated solutions. Such systems thinking employed in this study, coupled with long term strategic planning and visioning are essential in developing an integrated water management system.

Obviously, there is a question on what the IOT and AI infrastructure landscape will look like in 10 years. While many benefits can be anticipated from the use of AI and IOT, a critical element will also be keeping identifying and looking for solutions to address potential challenges associated with the use and possible dependency on AI and IOT.

As also indicated, the proposed model at this stage by bringing a more comprehensive, integrated approach and vision supported by new enhanced technology is believed to be a radical new step in addressing key issues related to water management in a climate threatened environment [24]. It is still in the early stages, and takes into account several ground testings which point in the same direction, but it will definitely gain into accuracy and effectiveness with the expansion of relevant practical further ground testings. We believe it brings-even in this early stage-the benefit of providing a solid platform for a new approach and further debate testing, refinement and applications, as well as opening the debate on the potential benefits and challenges brought in by the use and potential dependency on AI.

7. Conclusions

Schwab (2016) predicted for the Fourth Industrial Revolution that “Waternet”, the internet of pipes, will employ sensors in the water system to monitor flows an [25]. This study provides proposals of innovation smart water grid planning but tries to adopt a rather easy, simple and pragmatic approach. It starts with the description of smart-tech based framework and components of water grid systems currently being pursued in smart water grid industry and contributes to smart water grid planning research by applying the innovation planning framework to case studies. The results reveal that preferences for innovation planning differ in ways that are linked with political goals of water resources management. Based on these findings, this study suggests an integrated smart water grid planning model based on multi-goal achievement matrix. By integrating technical smartness goal into symbiotic eco-sustainability in harmony with nature and climate responsiveness goals, smart grid can be optimized and an important portfolio of climate smart cities can be produced to meet water requirements for climate smart cities.

The term integrated smart water grid can entail both digital-only brands and traditional players of water resources management that are transforming their business with digital techniques [26]. The proposed model is just one of the aspects of a fully integrated smart city planning that requires that all sectors must be interconnected and integrated to avoid the current fragmentation, overlaps, contradictions and multiple, redundant cost centers. Future work on the proposed model entails the following actions:

- Use the proposed model for integrating various goals in consistent decision making framework
- Develop a big data image with a digitalized overlay connected over water industry standard platforms
- Engage the citizens through the use of e-governance and use sensor placement optimization to achieve political goals of IWRM through easy access to water-related data and information
- Develop sectoral dynamic models to increase the functionality of the proposed system which involves

spatial and temporal processes

This is a new subject. The proposed model is still in the early development stage. It is believed that this model is a good starting point. This paper is a reflection of the author's belief that urban water resources planners and managers must gain a firm understanding of the depth and breadth of concepts and approaches of relationships between the symbiotic eco-sustainability, technical smartness, and climate responsiveness that are fundamental to their disciplines.

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