Managing Water Losses from Water-Energy Nexus Perspective

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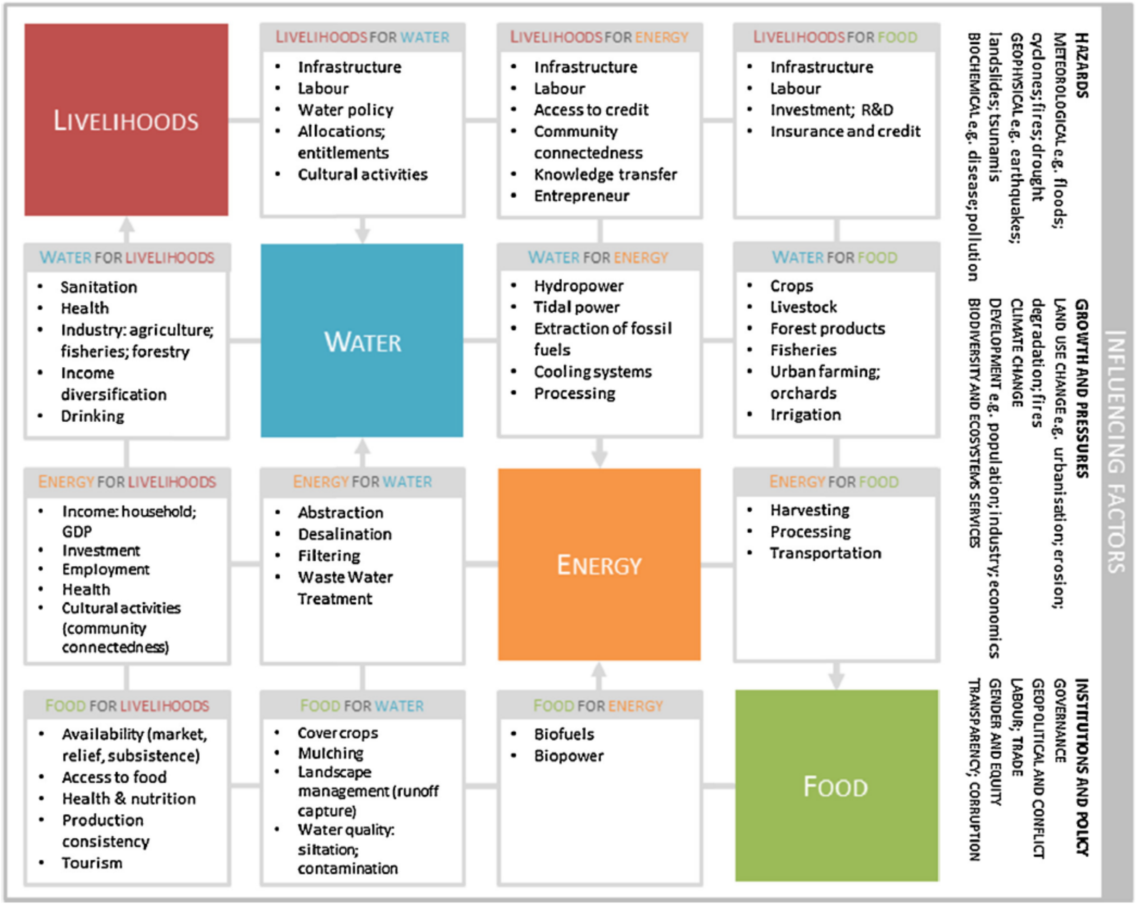
1. Introduction

1.1 Definition of Nexus
1.2 Meaning of Nexus

1.1 Definition of Nexus

- Nexus represents the interlinkages and interdependencies between sectors such as water, energy, food, land use, climate, and environment.
- Nexus has been highly postulated by researchers and decision-makers

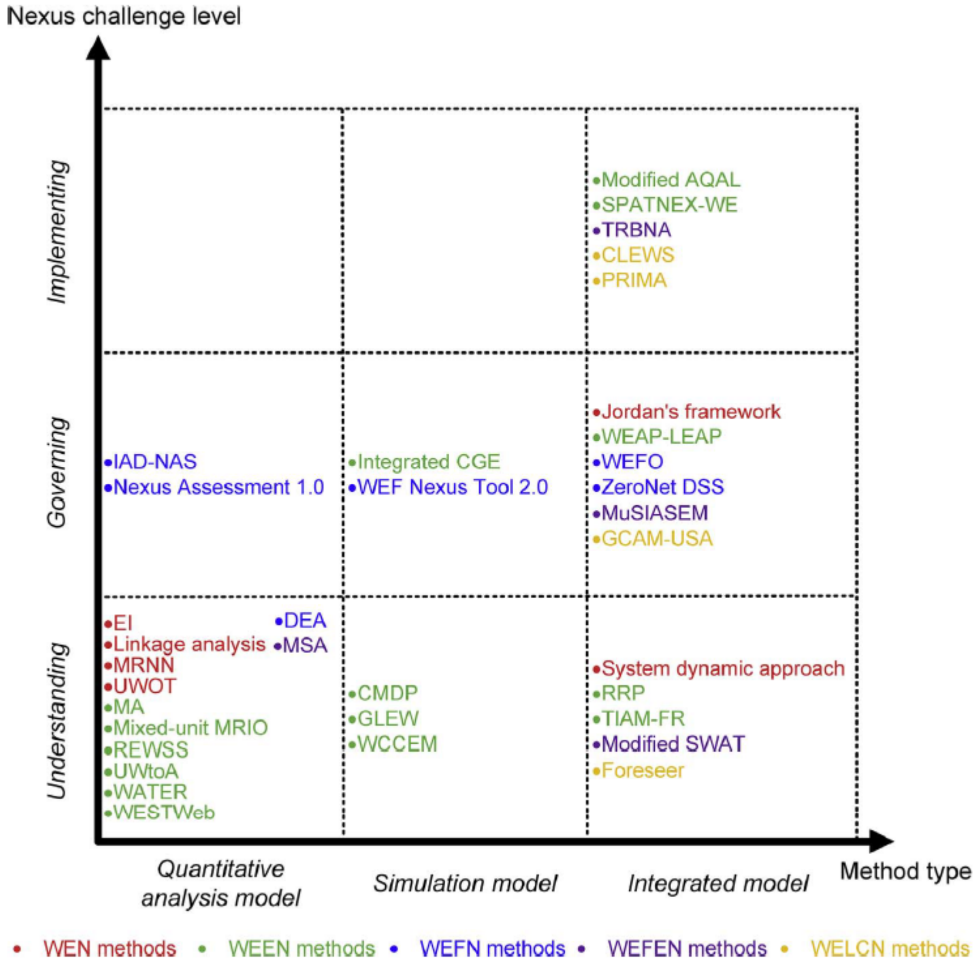


[Examples of fundamental internal and external factors]

Source : Biggs et al. (2015)

1.2 Meaning of Nexus

- **Nexus makes the decision-making process more sustainable by identifying potential synergies and minimizing trade-offs between sectors**



[Analysis of the reviewed 35 macro-level nexus methods according to their nexus scope, model type and nexus challenge level]

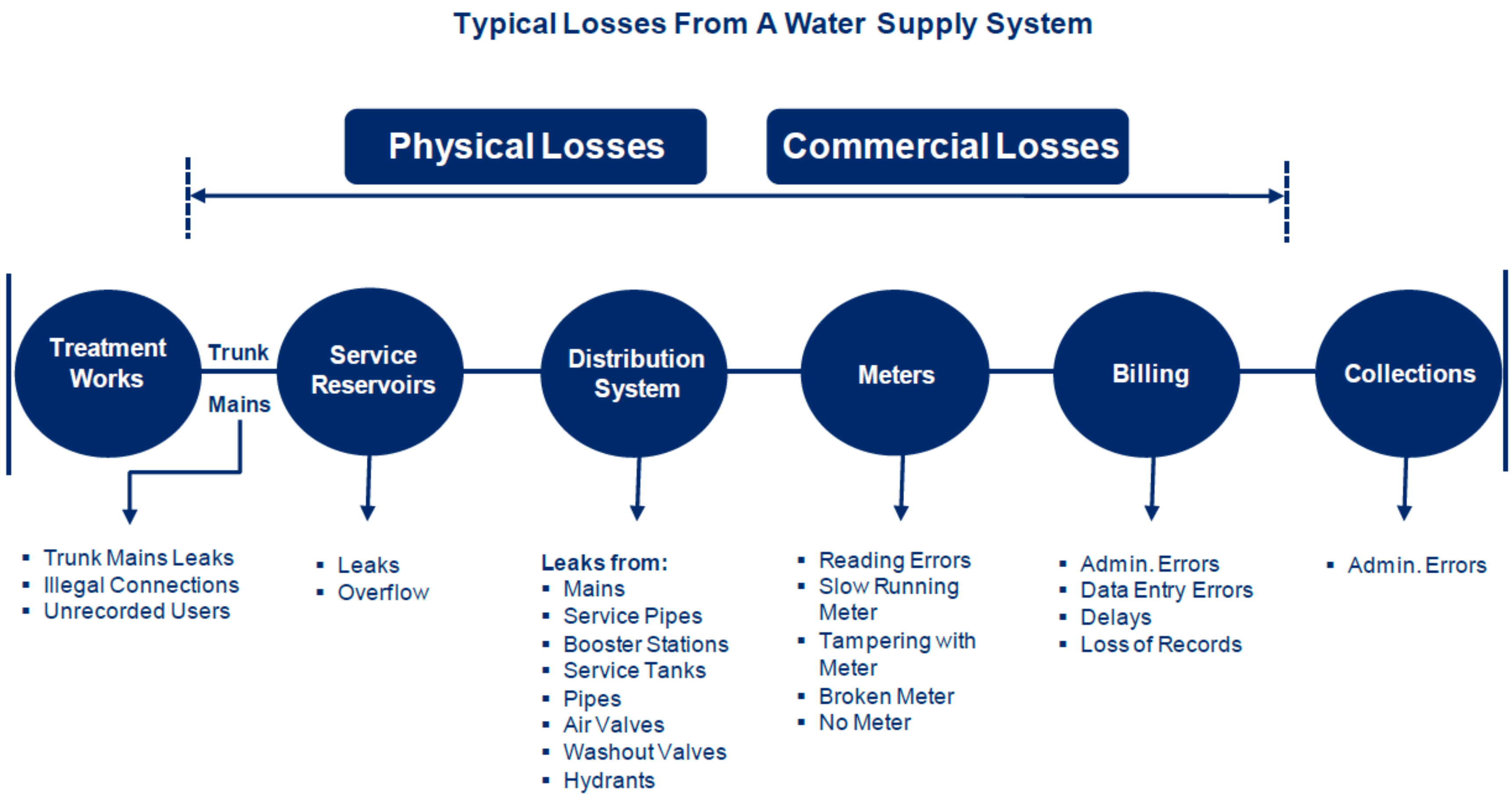
Source : Dai et al. (2018)

2. Water Loss Management

2.1 Classification of Water Losses in Network
2.2 General Water Loss Mgmt. Strategies and Programs
2.3 Water Loss Mgmt. from Nexus Perspective

2.1 Classification of Water Losses in Network

- **Water losses are classified as apparent losses** (meter inaccuracy, data handling error, unauthorized consumption) **and real loss** (background leakage, burst)

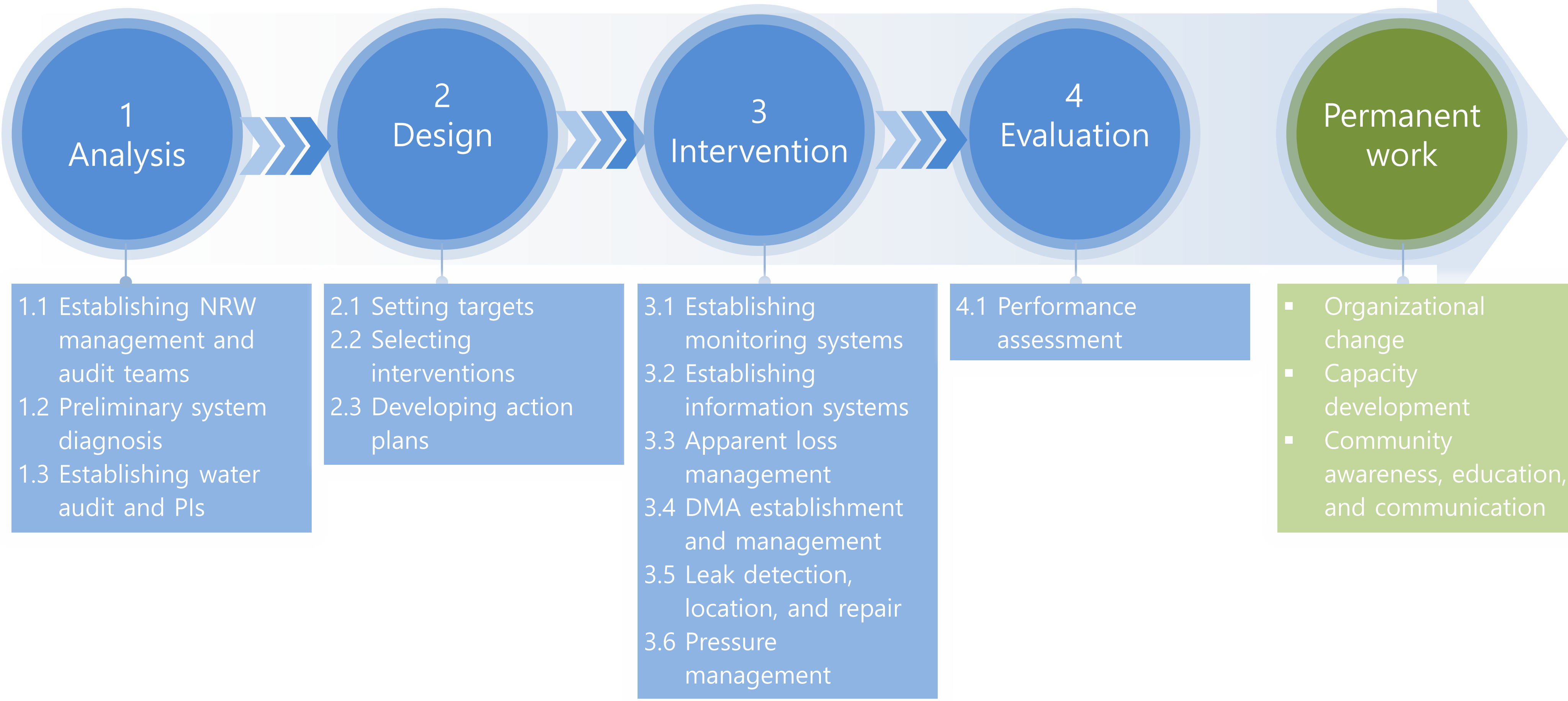


[Chart to Help Staff Understand NRW Components]

Source : Farley et al. (2008)

2.2 General Water Loss Management Strategies and Programs

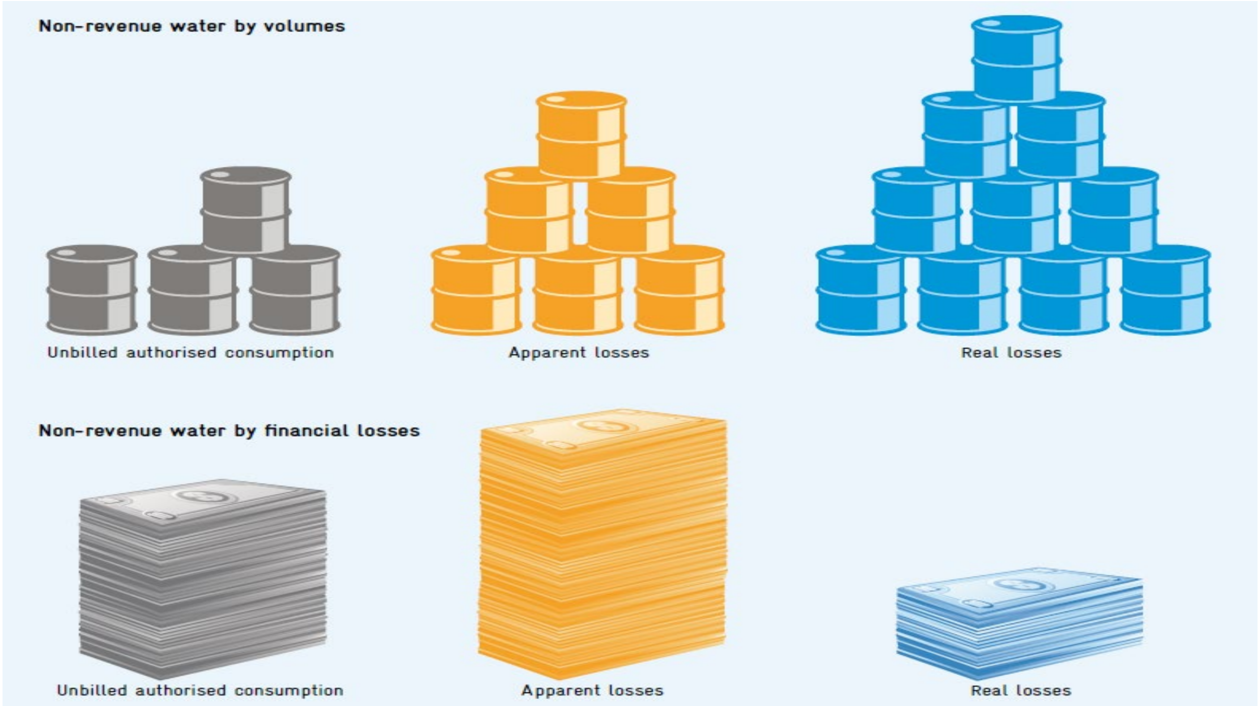
- **Water loss management requires flexible, holistic, and customized strategies and programs**
- **Minimizing apparent losses should take precedence over reducing real losses**



[Process of Water Loss Control Program]

2.3 Water Loss Management from Nexus Perspective

- Is the same water loss management strategy valid from a Nexus perspective?
- Is it possible to quantify the amount of resources consumed and moved between sectors according to each strategy?
- Is there any difference in strategy according to urban conditions (e.g., water network length, water/sewage treatment processes)?



[Examples of Possible Volumetric and Financial Distributions of Loss]

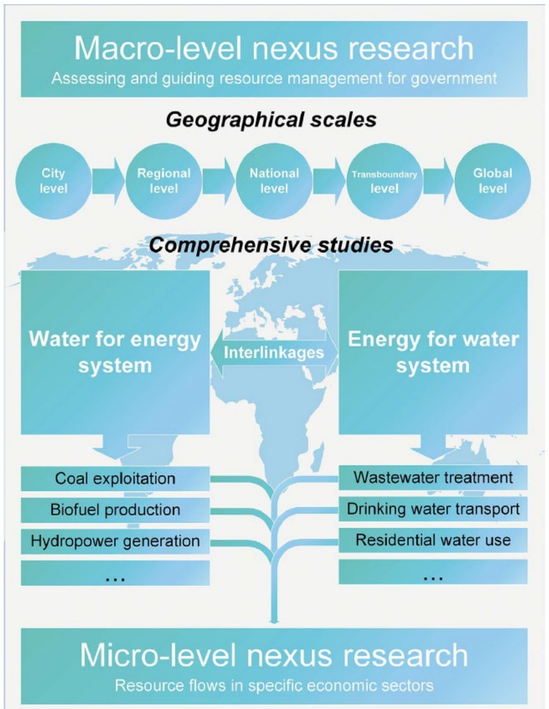
Source: GIZ (2011)

3. Methodology & Model Building

3.1 Nexus Analysis Form
3.2 Nexus Analysis Methodology
3.3 Direction and Purpose of Research
3.4 System Components
3.5 Setting Parameters
3.6 Model Building

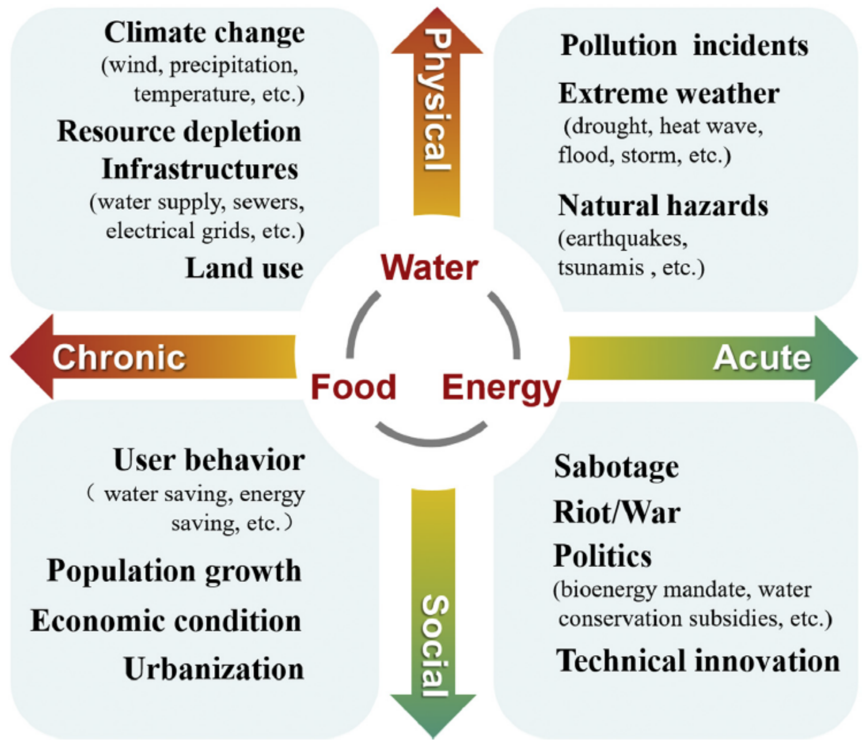
3.1 Nexus Analysis Form

- **Nexus has various forms depending on the scope** (sector, spatial scope, microscopic/macroscopic) **and purpose** (analytical level, one-sided/mutual impact, internal/external impact analysis)
- **Defining system scopes and clarifying objectives during the model building phase is critical to goal-oriented analysis and decision making**



[The conceptual framework of the macro-level and the micro-level nexus studies]

Source : Dai et al. (2018)



[The classification of external factors]

Source : Zhang et al. (2018)

3.2 Nexus Analysis Methodology

- **Unfortunately, there is no general approach for Nexus analysis**
- **Appropriate methodologies differ depending on the scope and purpose of the Nexus study discussed**

Classification	Discipline	Methods
Qualitative	Social science	Questionnaire Survey
		Ontology engineering
	-	Integrated Maps
Quantitative	Economy	Input output analysis
		Computable general equilibrium model
		Econometric model
	-	Ecological network analysis
	-	Integrated indices
	Environment management	Benefit-cost analysis (BCA)
		Life cycle assessment
	System analysis	System dynamics model
	-	Agent-based modeling
	Statistics	Statistical application
	Physical model	Physical models
	Integrated model	Integrated modeling
	-	Optimization management models

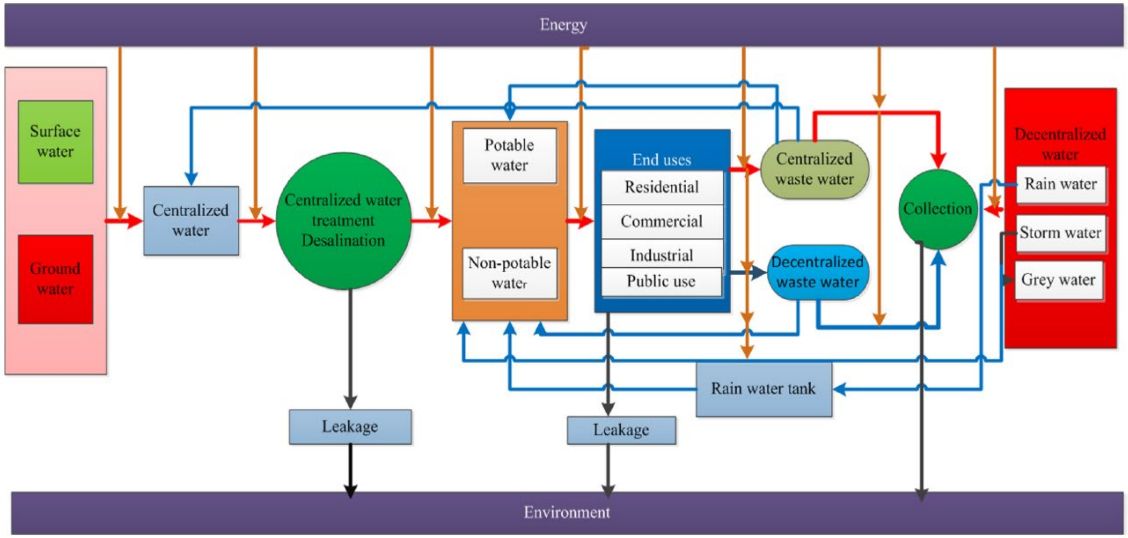
3.3 Direction and Purpose of Research

- **Establishment of the research direction (sector, spatial scope, interconnectivity, research level and mechanism) of urban water system WEE Nexus model using system dynamics**
- **Applying water footprints, total energy use, and total CO_2 equivalent emission as Nexus evaluation indicators**

Items	Nexus Model Development Direction
Sector	- Water, energy, environment
Spatial scope	- Urban level
Interconnectivity	- Macroscopic
Research level	- Understanding
Mechanism	- Internal impact analysis - One-way (water → energy, environment) effect analysis: Building a water-driven Nexus
Indicators	- Water footprints, total energy use, total CO_2 equivalent emission
Objectives	- Deriving optimal water loss management strategies based on the current status of energy intensity in urban water cycle systems and the current status of water loss

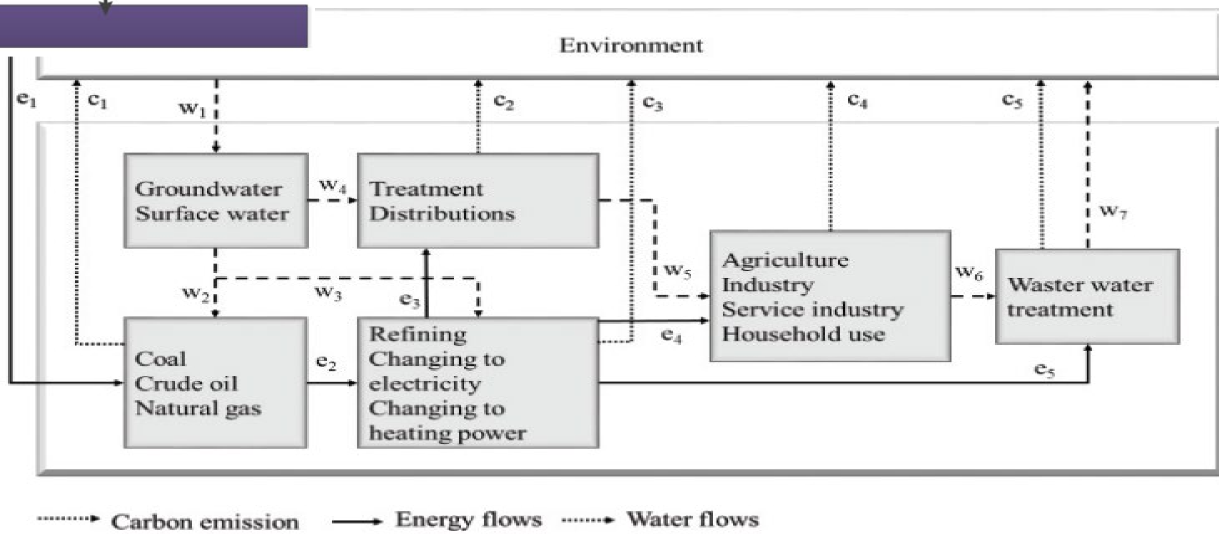
3.4 System Components

- Considering the processes and causality of water intake, water conveyance, water treatment, water distribution, water use, sewage collection, sewage treatment, reuse, discharge, etc.



[Proposed framework for urban water system]

Source : Wakeel et al. (2016)



[Simplified energy-water-carbon nexus system in city]

Source : Duan & Chen (2016)

3.4 System Components

	Shrestha et al. (2017)	Zarghami & Akbariyeh (2012)	Stercke et al. (2018)
Water resource	- Surface water (-)	- Surface water (-) - Ground water (-)	- Surface water (-)
Intake / Conveyance & transmission	O	X	X
Water treatment	- Chemicals for water treatment (+)	X	X
Distribution	O	X	X
Groundwater recharging	X	- Returned water (-) - Natural recharge (-) - Natural discharge (+) - Water extraction (+)	X
Other water resources	- Reclaimed water	O	O
Population	- Population growth rate (-) - Residential water use (+)	- Birth (birth rate) (-) - Death (death rate) (-) - Migration (migration rate) (-) - Landscape demand (+) - Domestic demand (+)	- Birth rate (-) - Death rate (+) - Immigration rate (-) - Emigration rate (+)
Water losses	- Water loss	- Leak rate (-) - Loss reduction (+)	- Distribution leakage rate (-)
Water reuse	- Residential water use (-) - Commercial water use (-) - Institutional water use (-) - Industrial water use (-) - Golf and parks water (-) - Agricultural land (-)	- Industrial demand (-) - Landscape demand (-) - Domestic demand (-) - Other demand	- Water-only end uses (-) - Water0energy end uses (-)
Sewage collection	- Infiltration inflow (-) - Reclaimed water (+) - Chemicals for WW treatment (+) - Biosolids transportation (+)	X	X
Wastewater treatment	O	X	X

3.5 Setting Parameters: Energy intensity, CO_2 equivalent

- In addition to the components of the urban water cycle system, the process of high resource usage and movement should be considered as an important components

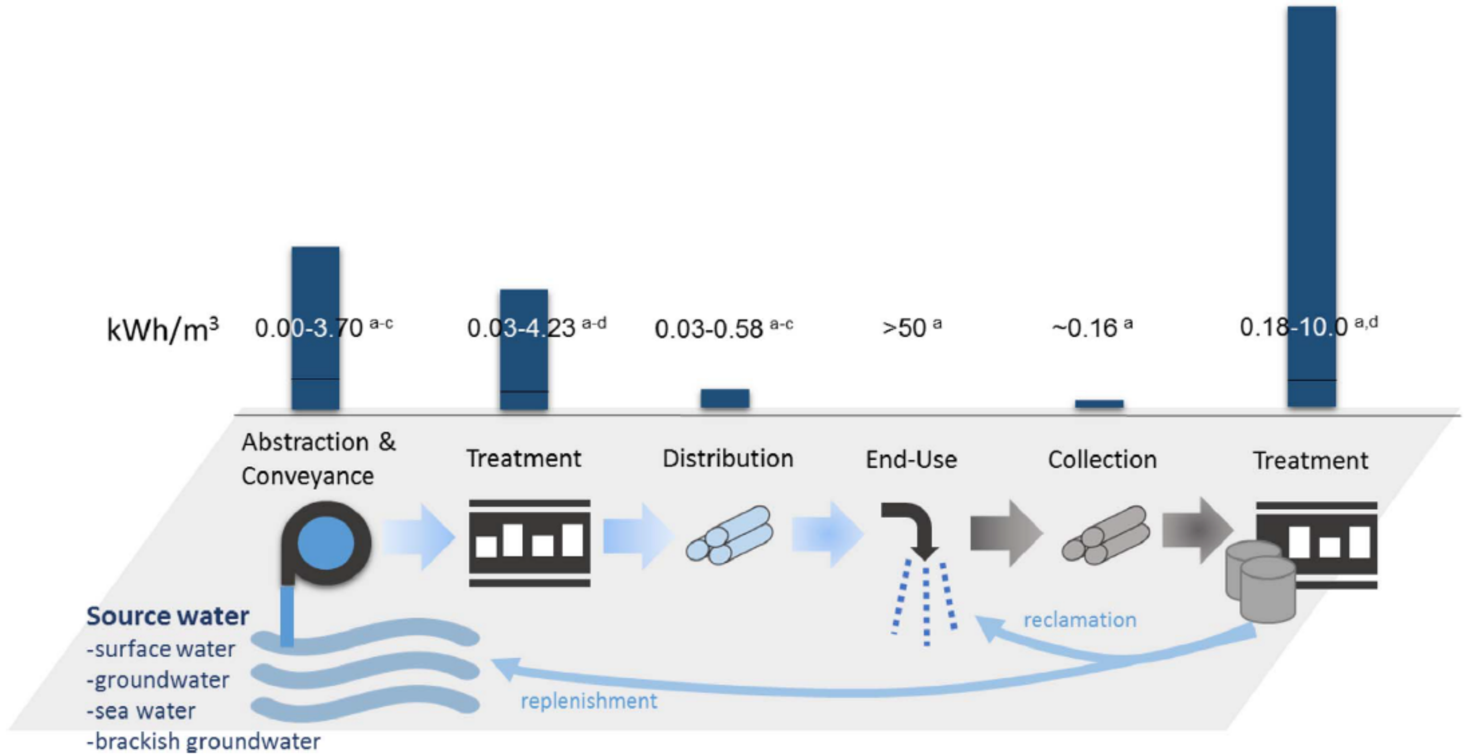


Fig. 1. Ranges of energy intensity within an urban water cycle using average values of benchmarking studies. This figure also illustrates selected urban water systems used in this study, including water abstraction and conveyance, potable water treatment, potable water distribution, wastewater collection and wastewater treatment, but excluding the end-use stage. Brackish groundwater or seawater desalination is included in the water treatment system. Data sources: [a] typical reported values for major regions of the USA, Australia, and Sweden [22]; [b] based on authors' calculations for California and Germany [23]; [c] based on a study conducted in California [24]; [d] based on a study conducted in the USA [25].

[Ranges of energy intensity within an urban water cycle using average values of benchmarking studies]

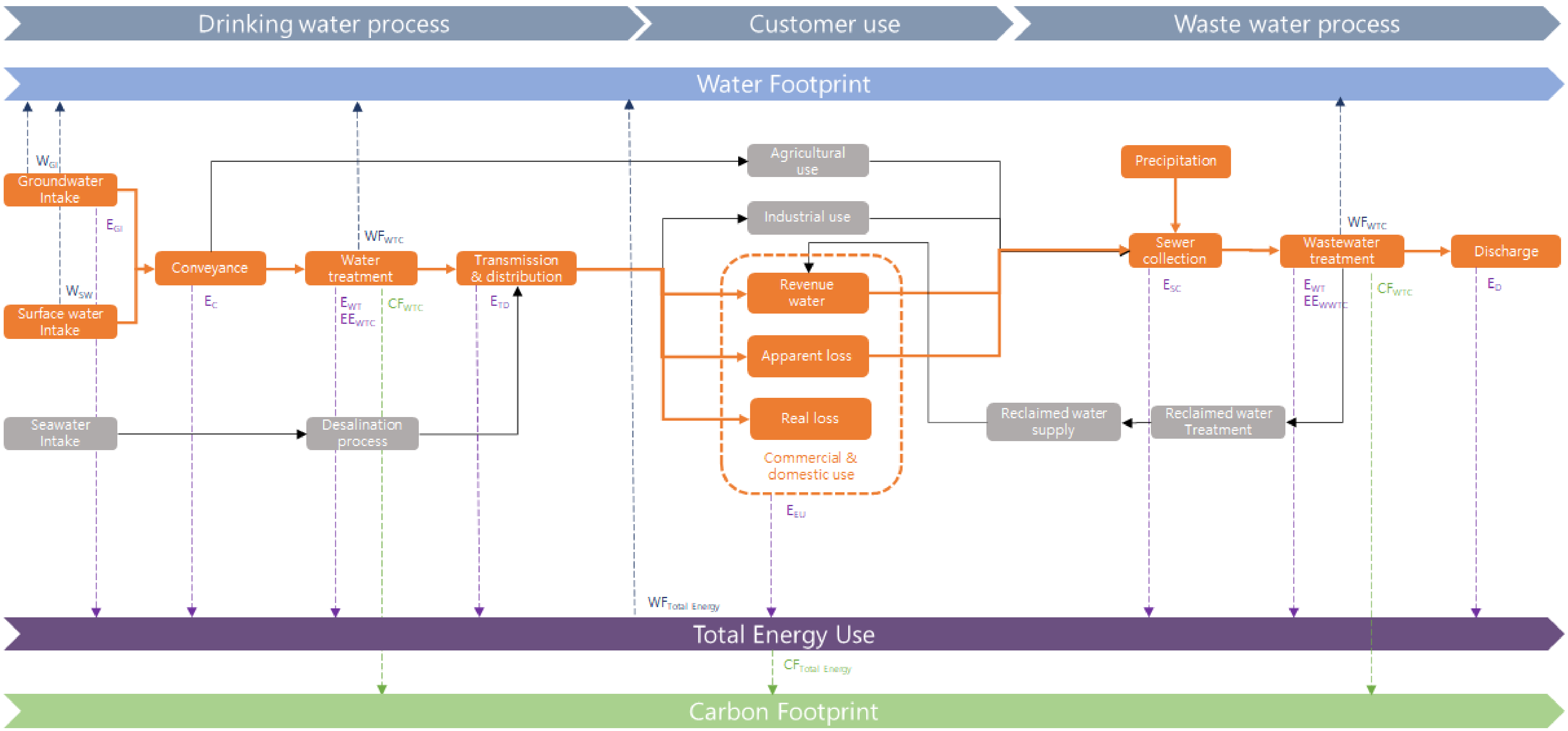
Source : Lee et al. (2017)

3.5 Setting Parameters: Energy intensity, CO_2 equivalent

Process	Energy intensity (kWh/m³)	Reference
Intake	0.0027~0.05	- Rothausen & Conway (2011), Nelson et al. (2009)
Conveyance & transmission	0.21~4.07	- Wilkinson (2000), Dale (2004), Anderson (2006), Stokes and Horvath (2009), Scott et al. (2009), Raluy et al. (2005), Muñoz et al. (2010)
Water treatment	0.01~16.4 (Surface water & ground water)	- Cammerman (2009), Muñoz et al. (2010), Kneppers et al. (2009), WEF (2009), Cheng (2002), Friedrich et al. (2009), Kenway et al. (2008), Lundie et al. (2004), Wang et al. (2016), Li et al. (2016), Wakeel et al. (2016), Miller et al. (2013), Tan et al. (2015), Tan et al. (2015), Lemos et al. (2013), Venkatesh & Brattebø (2011), Hardy et al. (2012), Amores et al. (2013), Zappone et al. (2014), Lassaux et al. (2007), Mo et al. (2014), Hardberger et al. (2009), Racoviceanu et al. (2007), Maas (2009)
	0~8.14 (Conventional process)	- Kelin et al. (2005)
	0.36~68.69 (Desalination)	- Park & Bennett (2010), Cooley et al. (2006), National Research Council (2008), Younos & Tulou (2005)
Distribution	0.2~4.9	- Wakeel et al.(2016)
Use	1.5~50	- Apostolidis, 2010
Sewage collection		
Wastewater treatment	0.05~7.50	- Friedrich et al. (2009), Kenway et al. (2008), Lundie et al. (2004), Wang et al. (2016), Li et al. (2016), Wakeel et al. (2016), Miller et al. (2013), Mizuta & Shimada (2010), Cheng (2002), Lemos et al. (2013), Venkatesh & Brattebø (2011), Hardy et al. (2012), Amores et al. (2013), Zappone et al. (2014), Lassaux et al. (2007), Mo et al. (2014), Hardberger et al. (2009), Racoviceanu et al. (2007)
Reuse	0.72~3.8 (Centralized system)	- Munoz et al. (2010), Gruenspecht et al. (2010), Coffey (2006), Anderson (2006), Apostolidis (2010), GPSC (2006), Knight et al. (2007)
	1.7~4.5 (Decentralized system)	- Apostolidis (2010)
Discharge	0.02	- Apostolidis (2010)

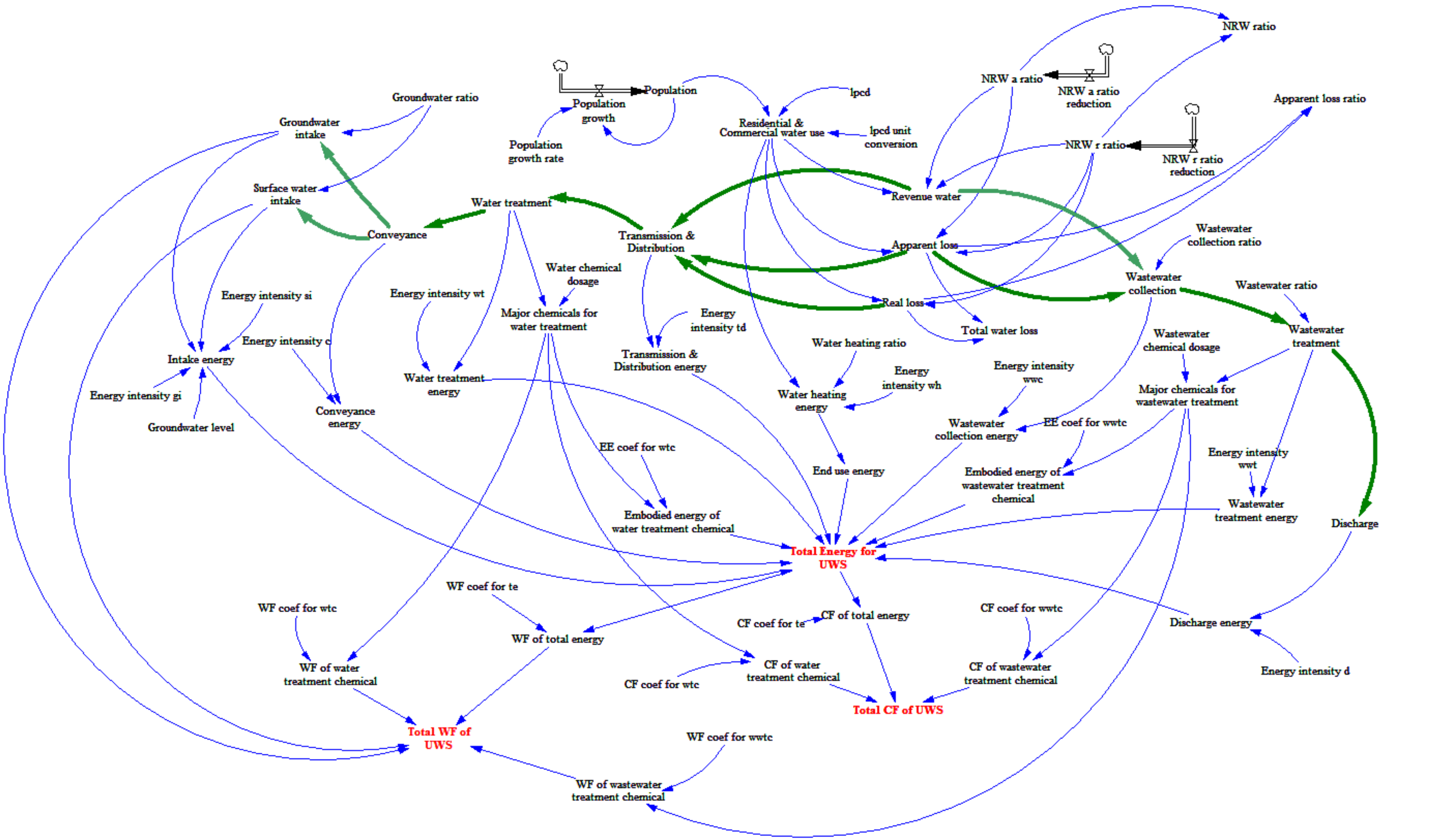
3.6 Model Building

- **Considering water intake** (groundwater/surface water), **water treatment, distribution, water use** (municipal and commercial), **sewage collection, WW treatment and discharge as main process**



[WEE Nexus Model Structure]

3.6 Model Building



[Causal Loop Diagram of WEE Nexus Model]

4. Modelling & Results

4.1 Modelling Scenarios
4.2 Scenario Analysis Results

4.1 Modelling Scenarios

- **Deriving the optimized water loss control strategy and analyzing resources movement between sectors according to various energy intensity and the current status of water loss** (NRW, ratio of real loss and apparent loss)
- **Performing analysis based on 12 scenarios**

Water losses / **Energy intensity**	**Good condition**	**High NRW-Low AL**	**High NRW-Medium AL**	**High NRW-High AL**
Low EI	S 1-0	S 1-1	S 1-2	S 1-3
Medium EI	S 2-0	S 2-1	S 2-2	S 2-3
High EI	S 3-0	S 3-1	S 3-2	S 3-3

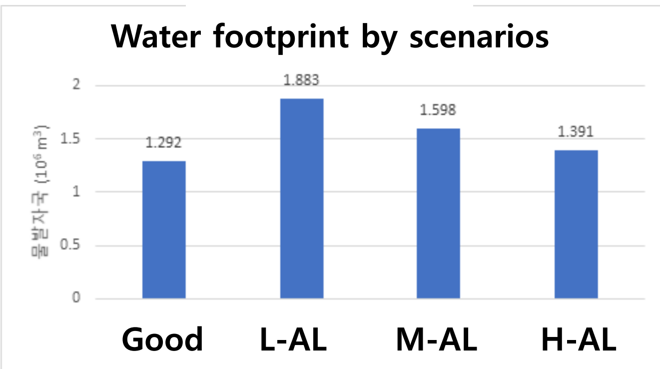
4.1 Modelling Scenarios

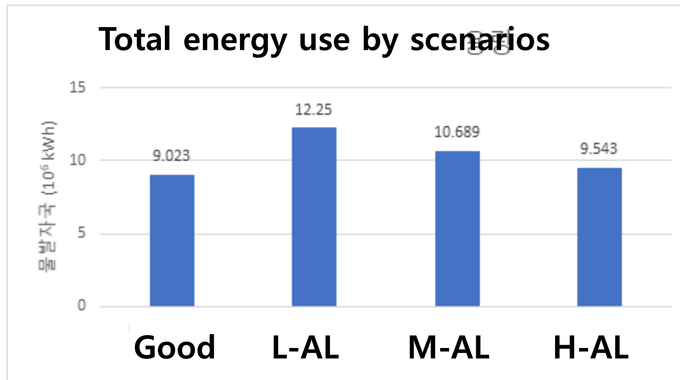
Urban water cycle	Parameter	High NRW-Low AL	High NRW-Medium AL	High NRW-High AL
Intake	Energy intensity	0.0027	0.0027	0.0027
	Groundwater level	20	40	60
	Groundwater ratio	0.1	0.5	0.9
Conveyance & transmission	Energy intensity	0.2	2.1	4
Water treatment	Energy intensity	0.2	0.6	1
Water distribution	Energy intensity	0.2	0.5	0.8
Use	Energy intensity	50	50	50
	Hot water usage ratio	0.01	0.02	0.03
Sewage collection	Energy intensity	0	0	0
	Sewage collection ratio	0.9	0.9	0.9
Wastewater treatment	Energy intensity	0.3	0.65	1
	WW treatment ratio	0.9	0.9	0.9
Discharge	Energy intensity	0.02	0.02	0.02

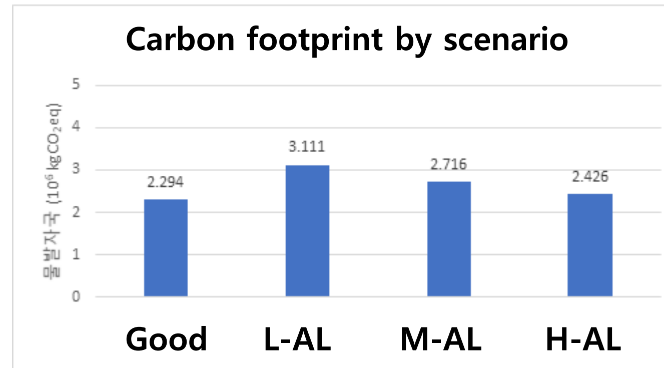
	Apparent losses (NRW a)				Real losses (NRW r)			
	Initial value	Final value	Reduction rate (1/month)	Month of final value	Initial value	Final value	Reduction rate (1/month)	Month of final value
Good condition	0.01	0.01	0	-	0.19	0.19	0	-
High NRW-Low AL	0.05	0.01	0.00067	60	0.45	0.19	0.00433	60
High NRW-Medium AL	0.15	0.01	0.00233	60	0.35	0.19	0.00267	60
High NRW-High AL	0.25	0.01	0.004	60	0.25	0.19	0.001	60

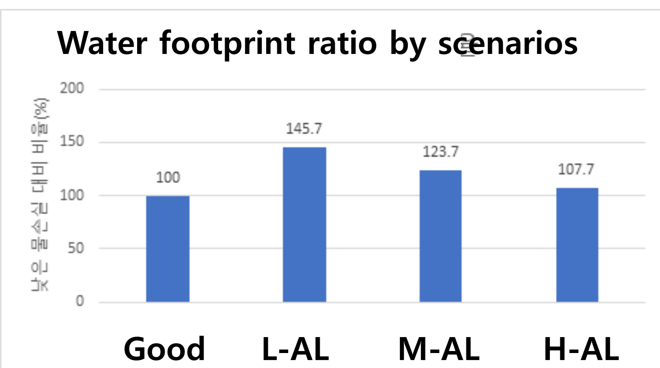
4.2 Scenario Analysis Results: By Leakage Status

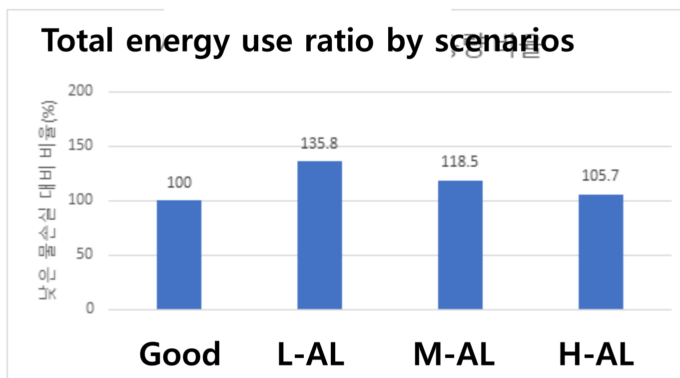
- Water footprint, total energy and carbon footprint showed the highest values in High NRW - Low AL case
- General strategy focus on High NRW – High Al case however, Hight NRW – Low AL case should prevail from Nexus perspective

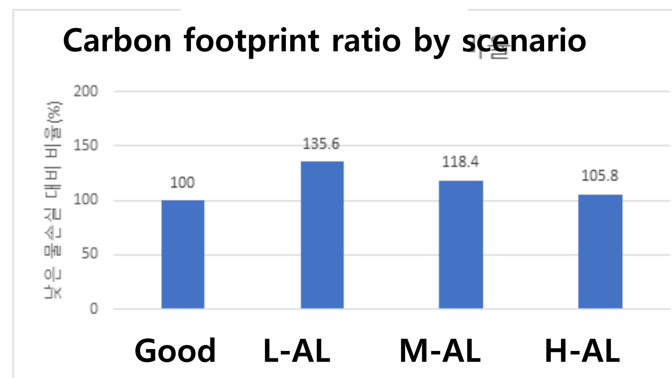






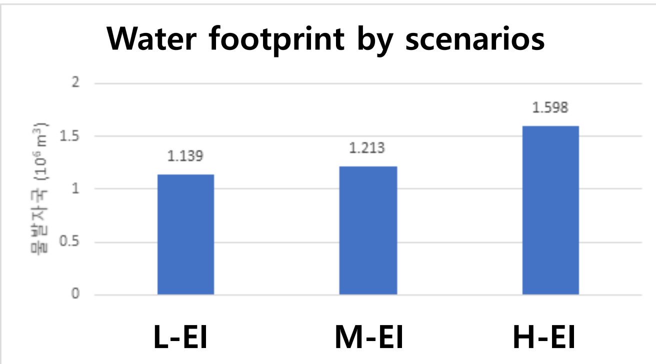


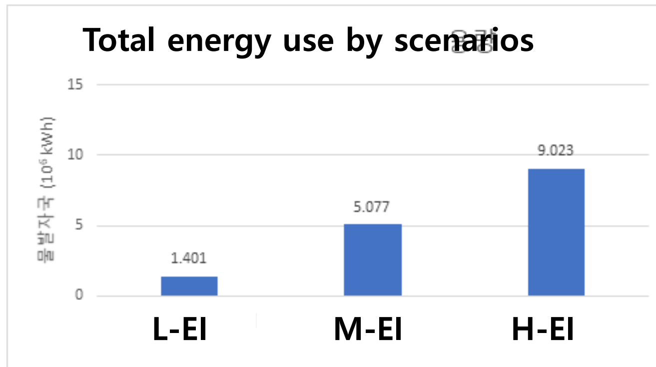


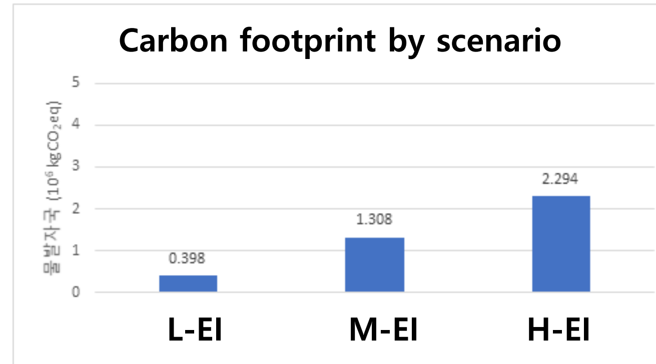


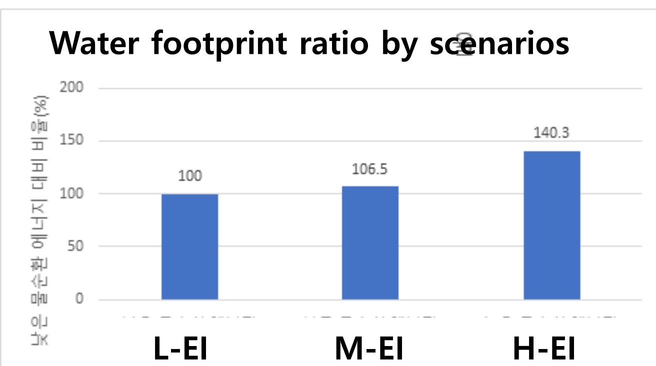
4.2 Scenario Analysis Results: By Energy Intensity

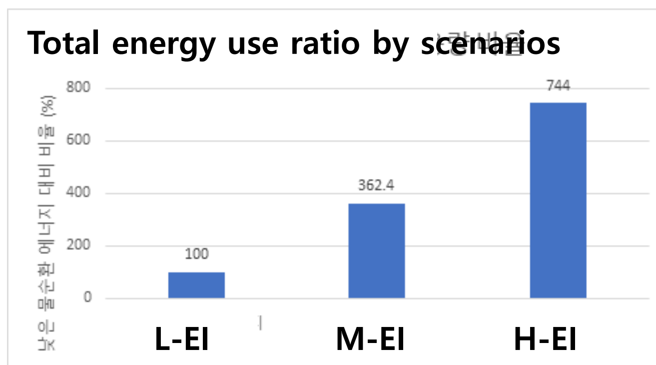
- As the city's water energy intensity increased, so did the water footprint, and the total energy consumption, compared to the water footprint, increased dramatically

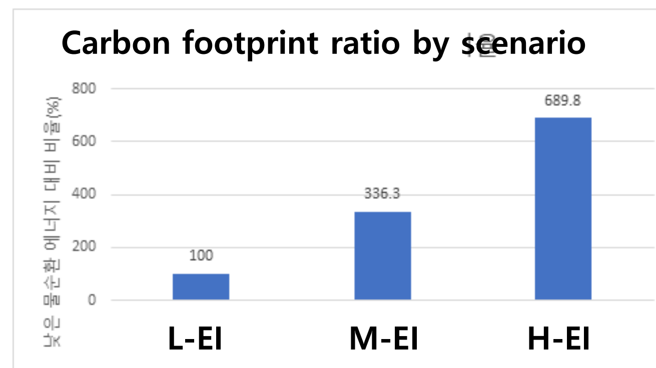






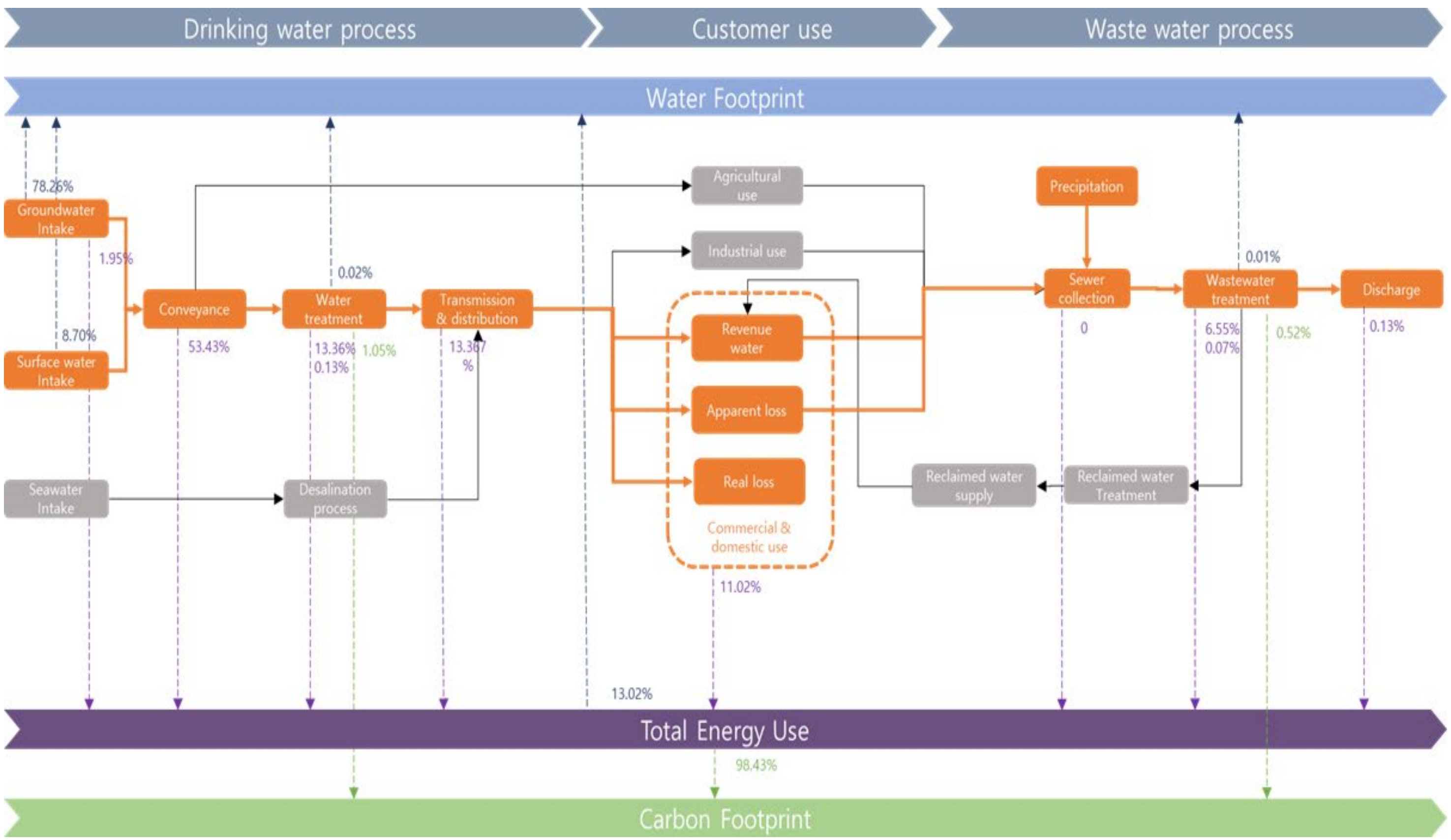






4.2 Scenario Analysis Results: By Urban Water Cycle Process

- The water intake which directly use as water accounts for 87.21% of the total water footprint
- The majority of energy use is in the order of conveyance & transmission, water distribution, water use
- Carbon footprint is similar to energy use



5. Take Home Messages

5 Take Home Messages

- Reducing apparent losses was prioritized in the conventional economic-oriented water loss control program

  ➡ However, handling real losses takes a top priority from the Nexus perspective

- It was proved that the energy intensity for unit urban water cycle had a significant impact on resource consumption and transfer.

  ➡ Therefore, it should be considered as an essential factor to be analyzed in advance.

- A sustainable, systematic, and feasible water loss management is expected to be possible through this generalized and holistic urban WEE Nexus model

Thank you