한국수자원학회 Hydroinformatics 분과 세미나

Water-Energy-Food Nexus Modeling

경희대학교 강두선 교수

2016. 6. 8

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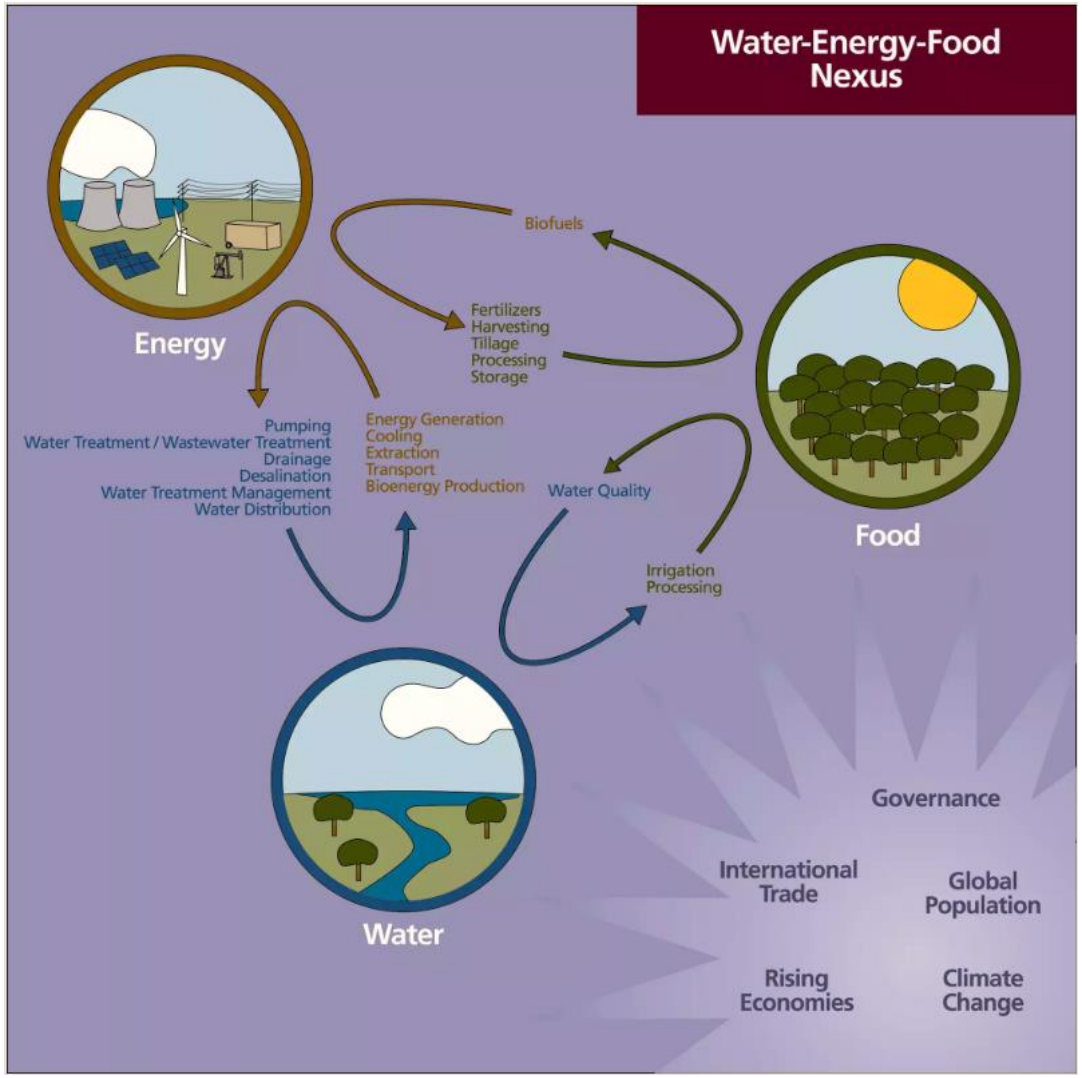
1. W-E-F Nexus의 정의 및 배경

WEF Nexus의 정의



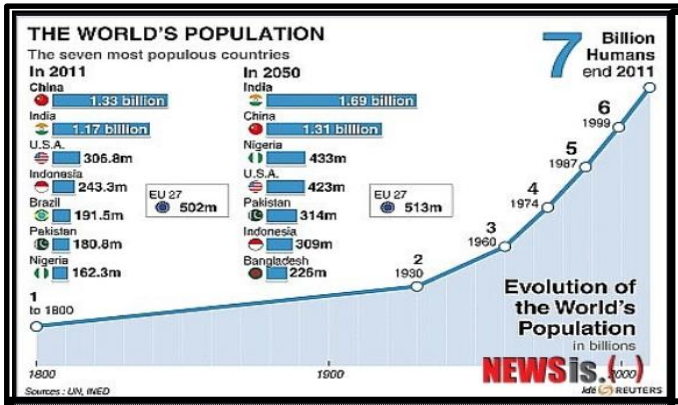
W – E – F Nexus란?

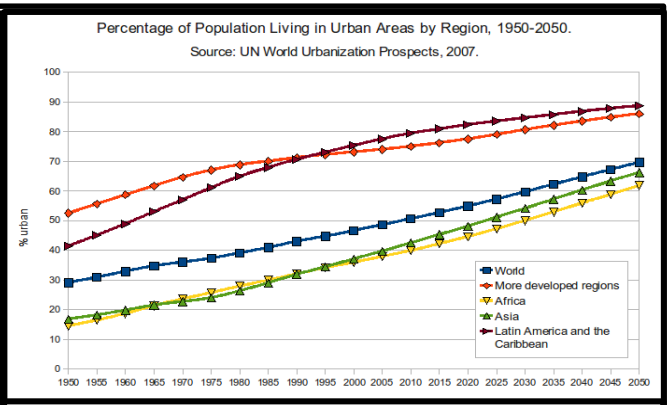
- 물(W), 에너지(E), 식량(F) 자원간의 상호연계 및 상호작용
- 각 자원의 생산, 이용 및 개발 과정에서 관여하는 타 자원의 정성적, 정량적 관계 규명
- 국가 및 지역 단위에서 각 자원의 활용, 공급 네트워크를 파악하고, 보다 효율적인 활용방안 탐색
- 연계성으로 인한 자원 부족의 위협 전이 및 증폭 현상과 잉여 자원을 활용한 공급원 확보, 경제적 가치 증대 등 지역별 배경에 따라 Nexus 연구의 방향성이 다양함
- 각 자원간의 영향 및 관계에 따라 다음의 6가지 Activity로 구분할 수 있음
  - ✓ Water for Energy
  - ✓ Water for Food
  - ✓ Energy for Water
  - ✓ Energy for Food
  - ✓ Food for Water
  - ✓ Food for Energy

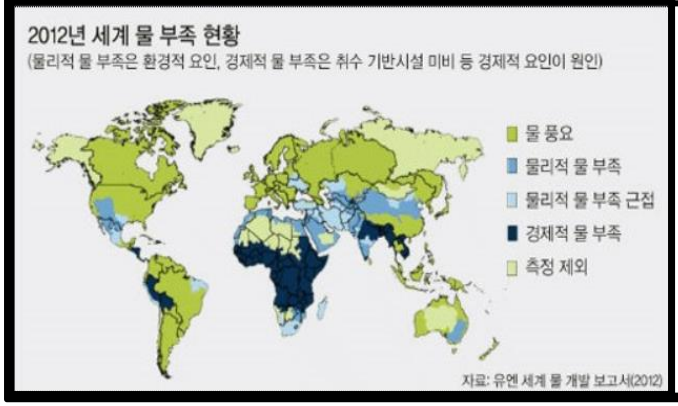
1. W-E-F Nexus의 정의 및 배경

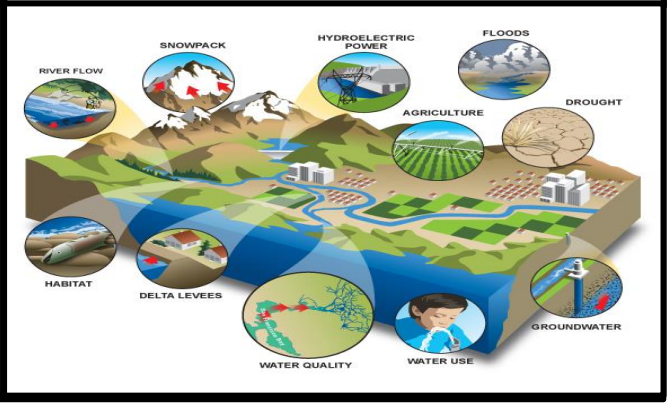
WEF Nexus의 Driving Factors

요 인	현 황
기후변화	국내 및 세계 각지에서 이상 기후, 재난 등으로 인한 자원 수급 환경 변화
자원고갈	다양한 사회, 경제, 환경적 요인으로 인한 자원 고갈 및 편중 문제 심화
인구증가	지속적인 세계 인구 증가 추세로 인한 자원 사용량 및 부족량 증가
생활패턴 변화	현대 생활패턴 및 소비 형태 변화로 자원간 간접 소비 증가







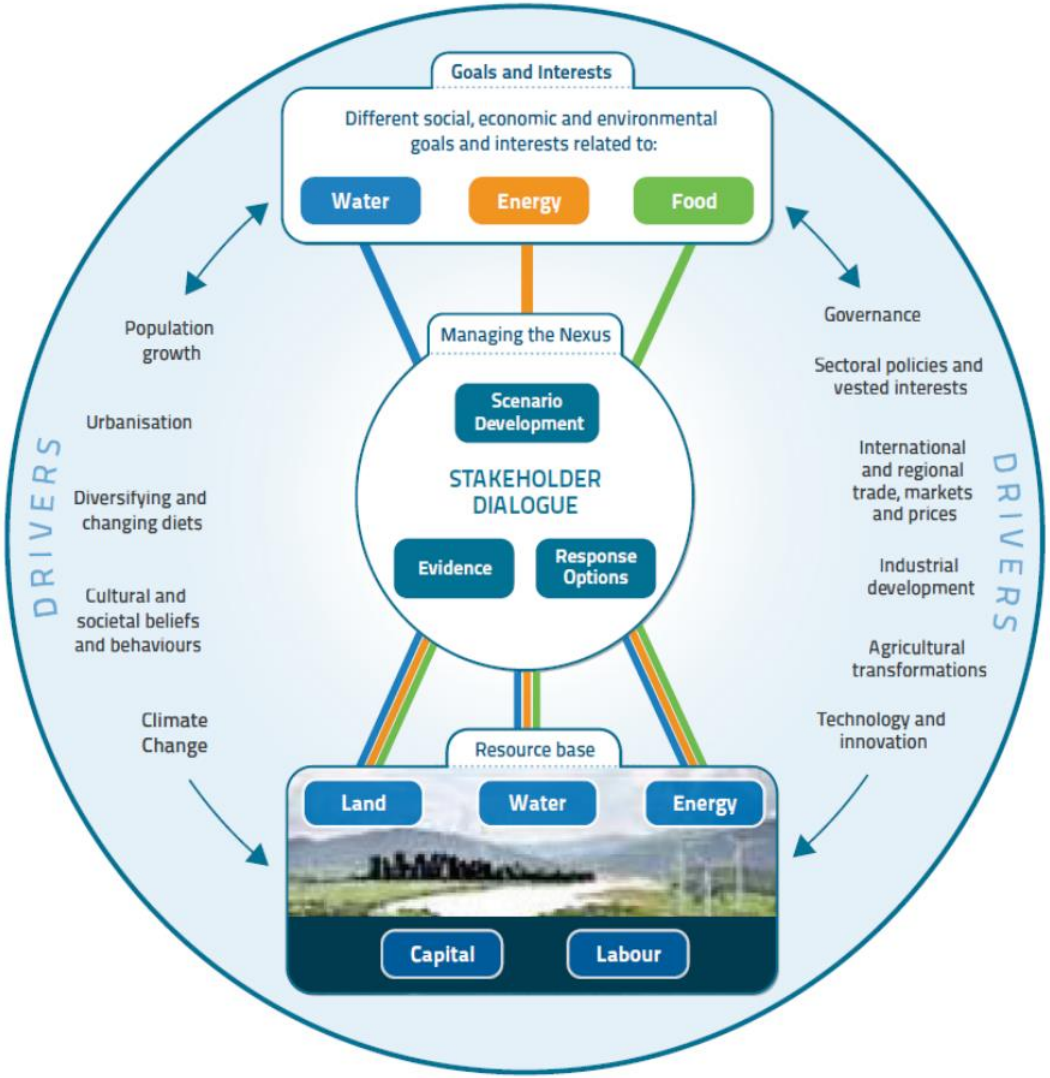


- W-E-F 자원의 통합관리 및 연계해석

- 각 자원의 이용에 따른 통합 자원의 장기적 변화 예측
- 자원 수급상황 변동에 따른 사회, 경제적 영향 평가
- 자원의 교류, 활용, 개발 등 다양한 관련 정책을 위한 기초자료 제공

1. W-E-F Nexus의 정의 및 배경

WEF Nexus의 구성요소



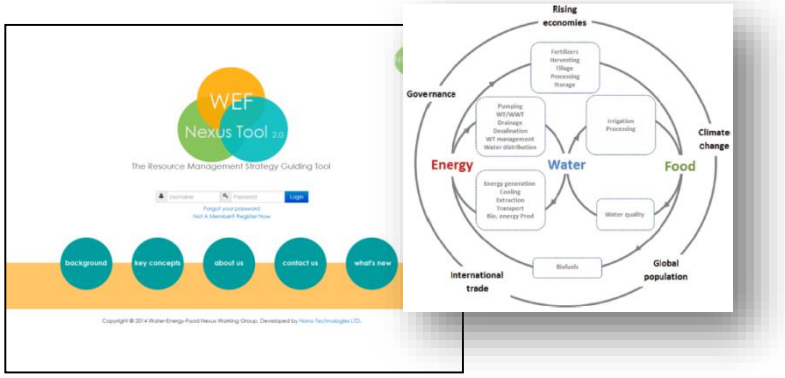
W-E-F Nexus Elements/Functions	
Elements	▪ 자원의 지속적인 개발과 생산(Production) ▪ 자원 공급, 활용 등 관리기술 및 배분(Supply) ▪ 합리적이고 절제된 자원의 소모(Consumption) ▪ 장기적인 자원 정책 및 계획(Policy) ▪ 다양한 자원 위협으로부터의 대응(Research)
Functions	▪ 자원 현황 및 이용효율 파악(Measurement) ▪ 자원 시장의 장기적 예측 및 전망(Estimation) ▪ 단일화된 자원 가치 산정(Evaluation) ▪ 자원을 둘러싼 분쟁 조정 및 예방(Governance) ▪ 자원 이용 효율의 극대화(Efficiency)

2. 연구의 필요성 및 목표

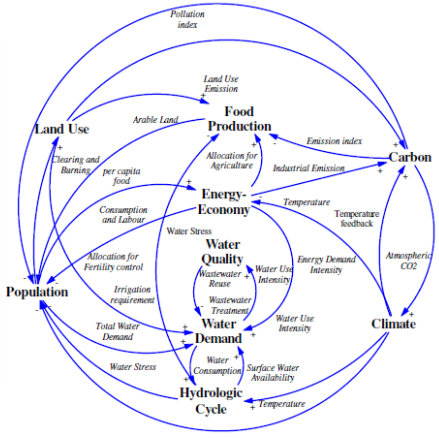
WEF Nexus 해석모형의 필요성

- 물(W), 에너지(E), 식량(F) – 각 자원의 양(Quantity) 및 질(Quality)적 변화는 다른 자원에 영향을 미치며 자원간 연계 뿐만 아니라 기후변화와 환경에도 영향 (…often it is invisible…)
- 각 자원간 상호연계 및 상호작용을 정량적으로 해석할 수 있는 모형 개발이 필요함
- 모형을 이용한 자원의 연계관리 또는 통합관리 체계를 마련해 미래 자원의 확보와 이용 효율 및 지속가능성 증대 도모
- 국가 정책, 제도 마련을 위한 의사결정도구로써의 역할 수행 가능
- 지역간, 국가간 효율적인 자원 배분을 위한 최적 분배 모의 필요
- 해외 Nexus 모형개발 사례 : WEF Nexus Tool 2.0, ANEMI, MuSIASEM, etc

  ➔ 국내외 적용이 가능한 (국산)일반화 모형 개발이 필요



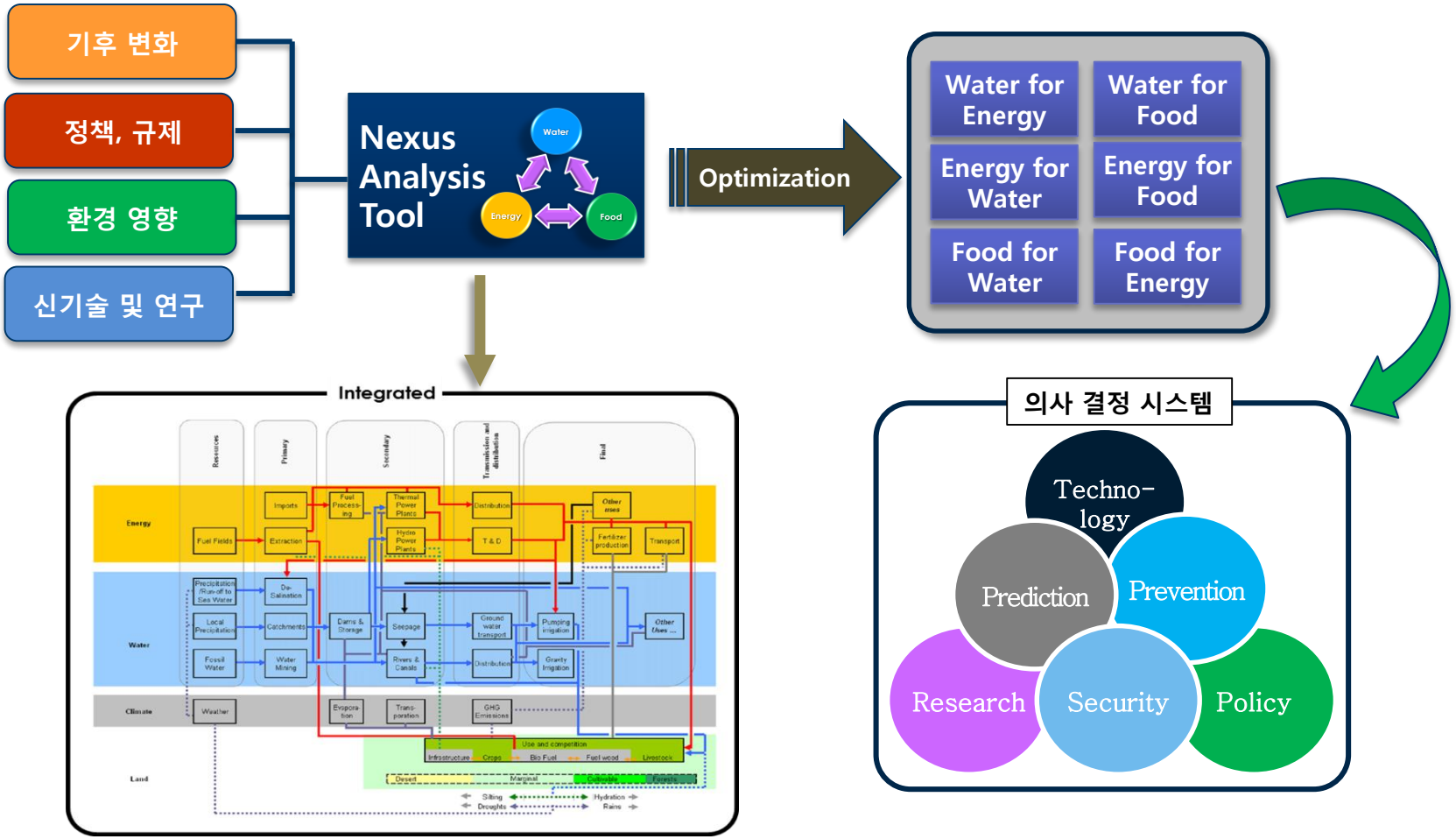
WEF Nexus Tool (http://www.wefnexustool.com)



ANEMI Model Diagram

2. 연구의 필요성 및 목표

기술적 연구 목표 – 물, 에너지, 식량 자원간 연계해석 및 자원안보 평가모형 개발



3. 국내외 기존 연구사례

World Focus Stream in W-E-F Nexus

1972
The Limits to Growth
(Meadows, et al.)

1976
The Provision of Energy Service:
Water, Energy, Land, Material, Manpower
(Grenon and Lapillone)

2000
Millennium Development Goals
(United Nations)

2005
Section 979 of The Energy Policy Act of 2005
(U.S. Department of Energy)

2011
Bonn2011 Conference :
The Water, Energy and Food Security Nexus, Solutions for the Green Economy
(Stockholm Environment Institute)

2012
Rio+20; United Nations Conference on Sustainable Development (United Nations)

2013
Policy Forum Berlin2013:
"Realizing the Water, Energy and Food Security Nexus"
(Federal Ministry for Economic Cooperation and Development of Germany)

2015
7th World Water Forum

Sustainable Development Goals (SDGs) (UN 2015)

3. 국내외 기존 연구사례

문헌 수집을 통한 국제 연구동향 파악

Category	Number of papers/reports/articles
Definition/Background	56
Data/Statistics/Standard Values	11
Concept and Modelling	22
Applications and Implementations worldwide	35
Future development opportunity	6
Policy related	6
Total	136

국내 연구동향 (2016)

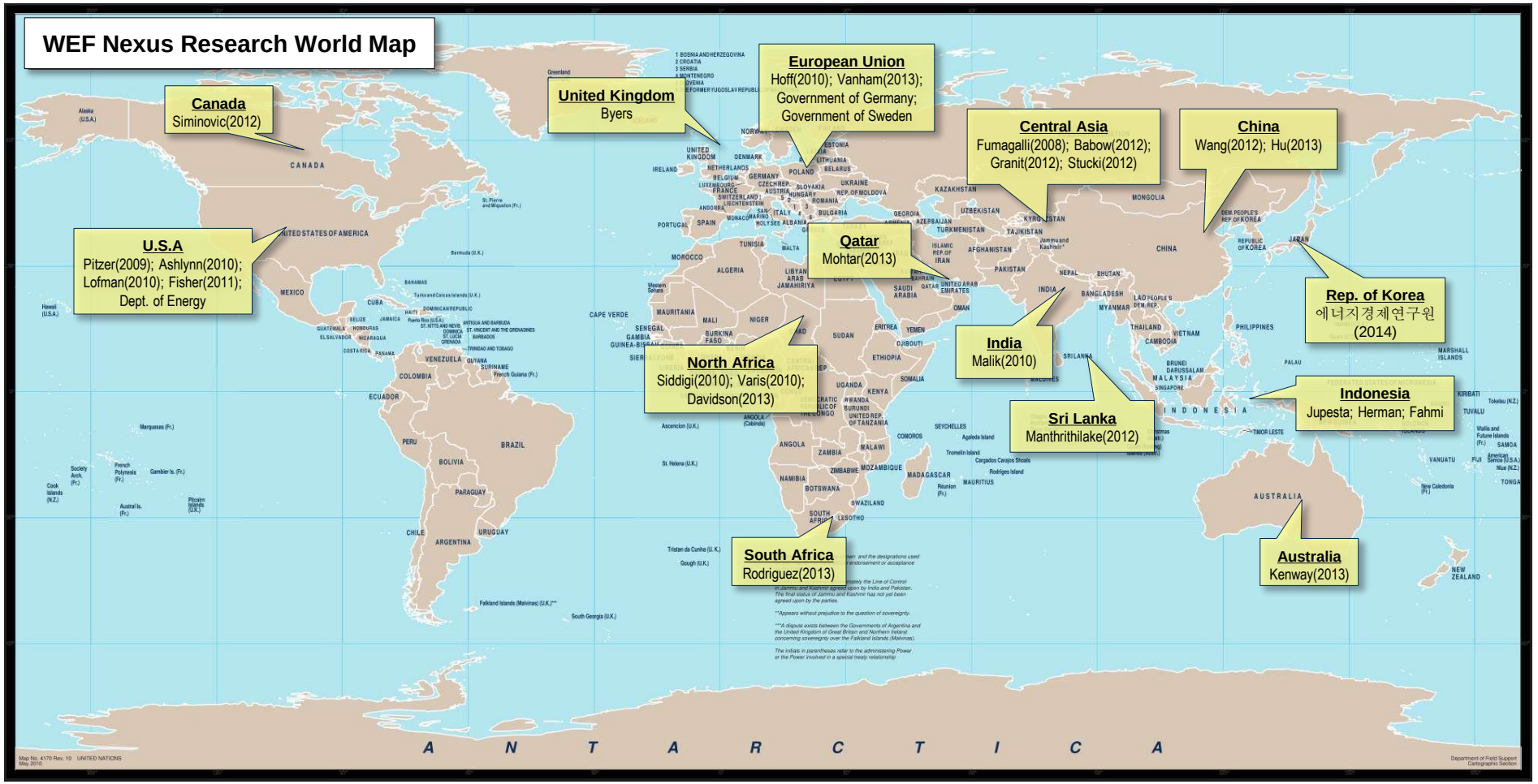
- W-E-F Nexus의 개념 및 필요성에 대한 정책적 보고서 수준의 수행 단계
- 각 자원 부처별 일부 연구 사례가 있으나 본격적인 연계 및 공공 연구수행 사례 미흡
- 2015 세계 물 포럼 및 국제 컨퍼런스 등을 통해 확산되어, 연구 수행을 위한 목적, 추진전략 수립 중

대응방안

- **국제 연구동향에 따르면, W-E-F Nexus의 정의 및 개념연구가 수차례 진행된 바 있으며, 모형 개발 및 적용 단계에 진입 중인 것으로 파악**
- **전세계적으로 다양한 모형의 개발과 적용 시도에도 불구하고, 최적화, 구체적 효과 제시, 정책적 지원 시스템 구축 등 고차원적인 Nexus 기술의 도입이 이뤄지지 않은 만큼 국내에서도 발빠른 대처가 요구됨**

3. 국내외 기존 연구사례

지역별 연구동향 (Applications worldwide since 2008)

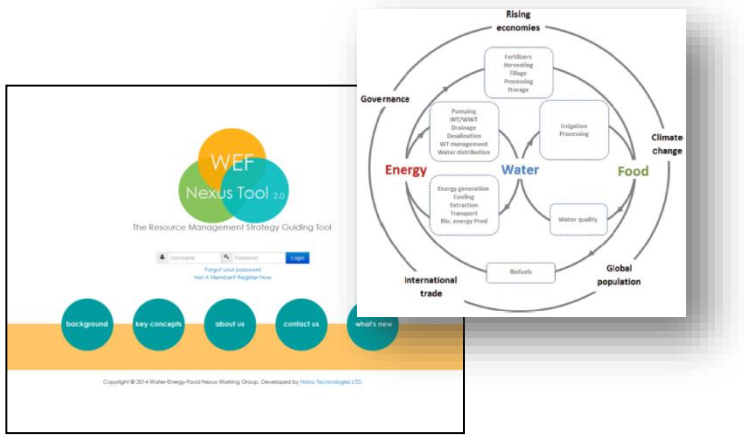


* 대륙별/국가별 대표적 연구 실적

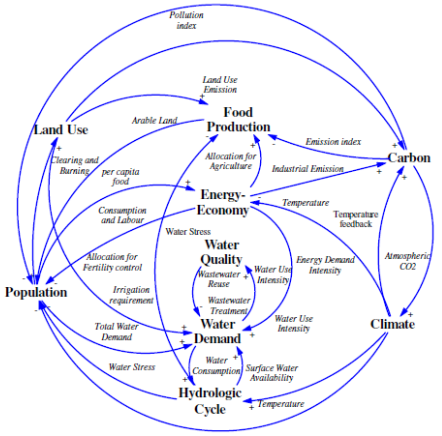
3. 국내외 기존 연구사례

W-E-F Nexus Models and Tools

Model	Year	Author / User	Applied Country	Summary
WEF Nexus Tool 2.0	2013	Rabi H. Mohtar, Bassel T. Daher	Qatar	Calculate the need of water & energy for food supplied in Qatar
ANEMI	2011	Mohammad K. Akhtar, Jacob Wibe, Slobodan P. Simon ovic, Jim MacGee	Canada	A system dynamic model for Analyzing the behavior of the social-energy-economy-climate system
MuSIASEM	2013	Mario Giampietro et.al	Mauritius; India; South Africa	Diagnostic or simulation model to analyze the WEF nexus considering heterogeneous factors
IMPACT WATER		Tingju Zhu, Claudia Ringler, Ximing Cai	Vietnam	Analyze the relation of global food supply and demand wi th the groundwater pumping and energy cost
WESim	2012	Heater Cooley, Matthew Heberg er, Lucy Allen, Robert Wilkinson	USA	Scenario-based planning model to analyze the effect of w ater system changes to energy uses and greenhouse gas emissions



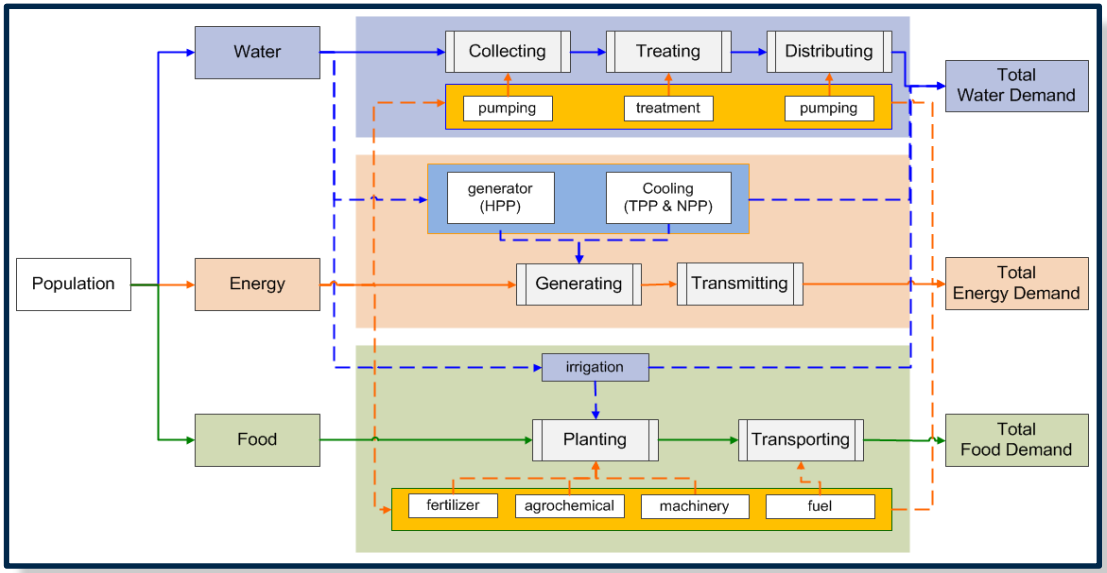
WEF Nexus Tool (http://www.wefnexustool.com)

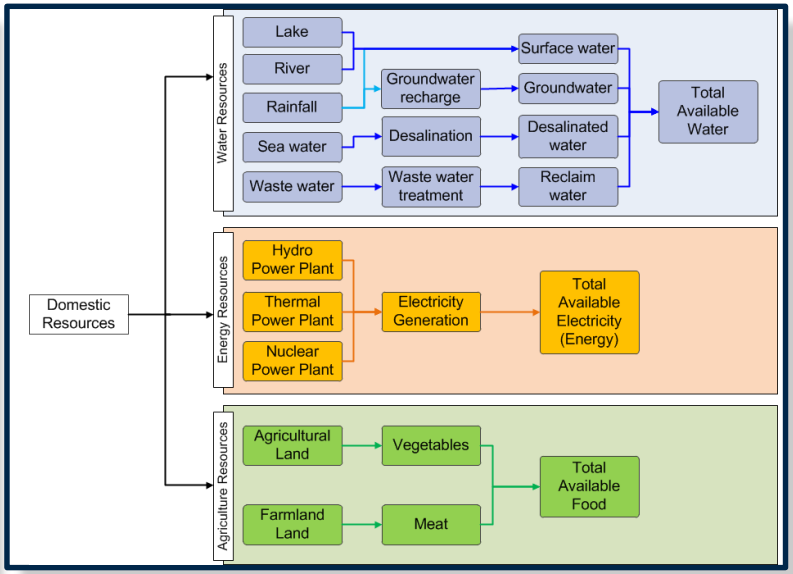


ANEMI Model Diagram

4. W-E-F Nexus Modeling

W-E-F Nexus Simulation Model Concept



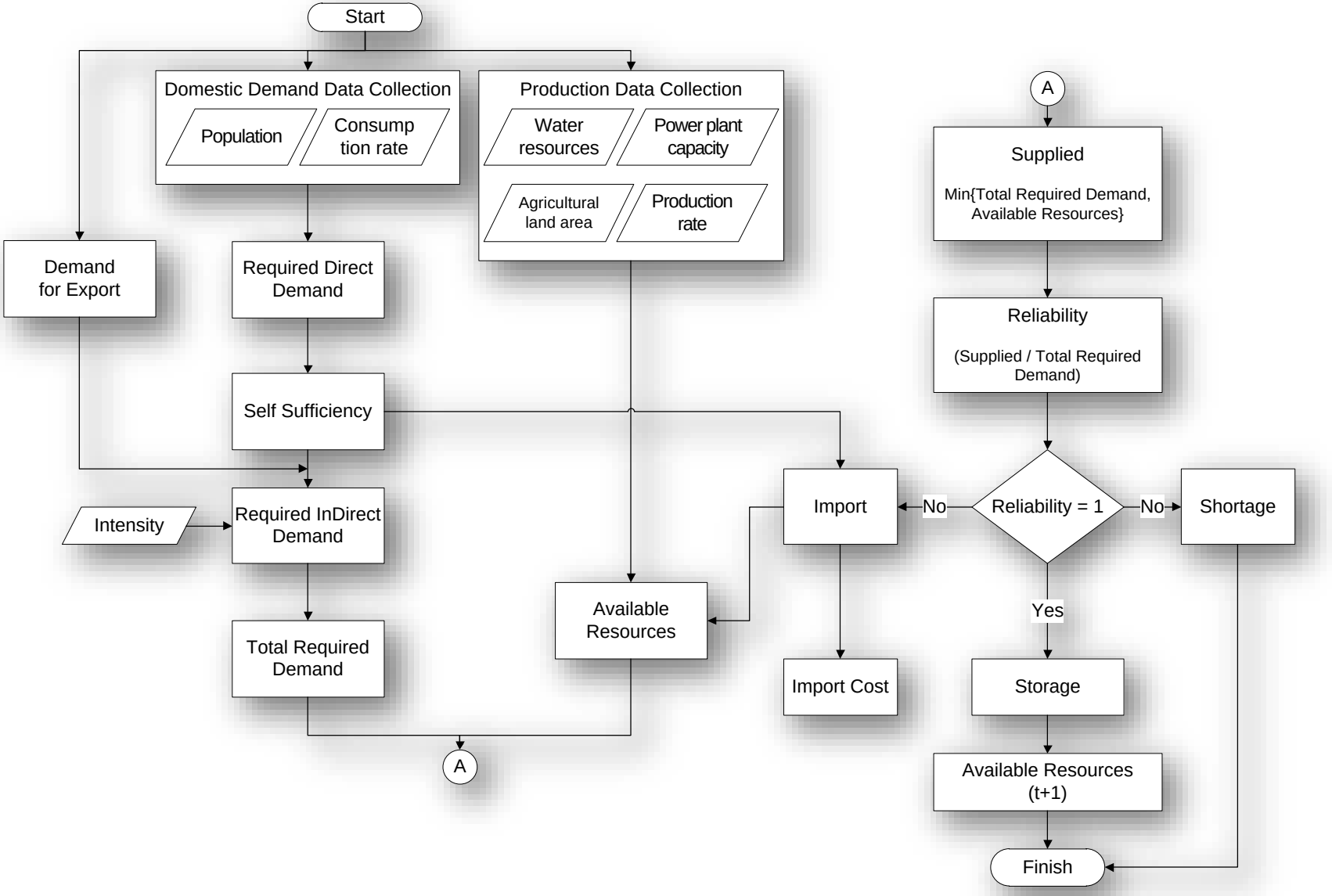


▪ **각 자원의 공급과정에 따른 타 자원의 연계해석 모듈 구성**

- 자원 별 직접/간접 수요량 및 총 수요량의 예측과 산정
- 자원 별 세부 공급원을 분류하고, 총 공급 가능량 산정
- 장기적인 수요/공급 예측을 통해 공급 안정성 평가

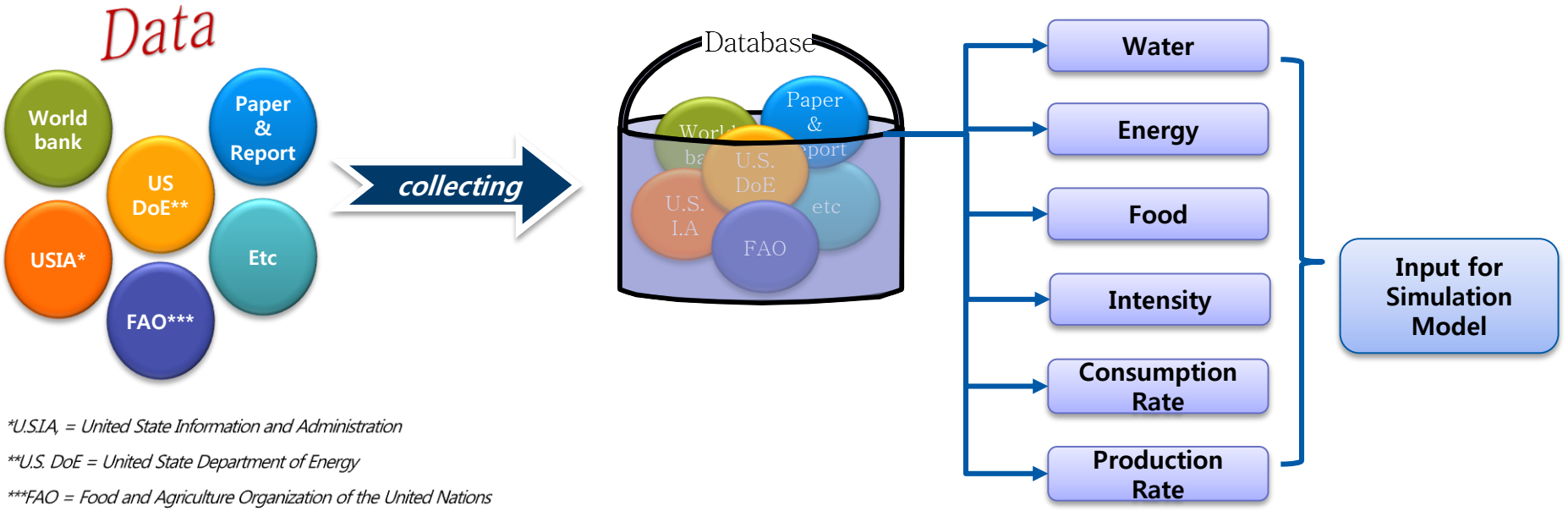
4. W-E-F Nexus Modeling

W-E-F Model Scheme



4. W-E-F Nexus Modeling

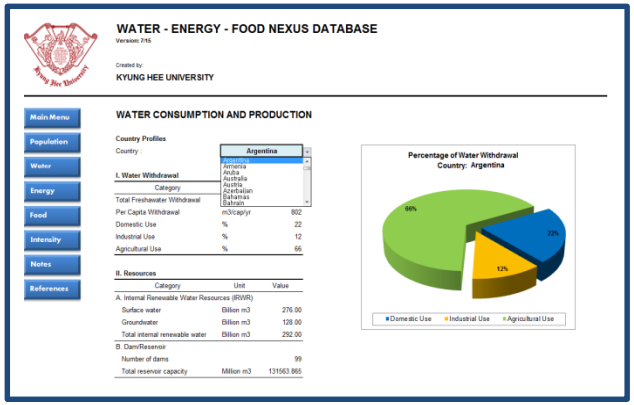
W-E-F Nexus D/B 구축

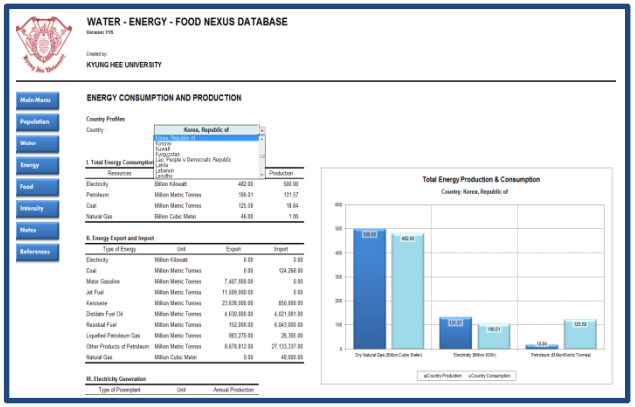


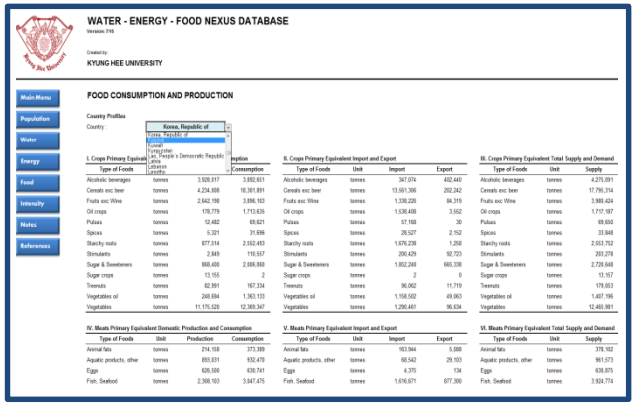
*U.S.I.A, = United State Information and Administration

**U.S. DoE = United State Department of Energy

***FAO = Food and Agriculture Organization of the United Nations







4. W-E-F Nexus Modeling

W-E-F Nexus D/B Layout(1)

- W-E-F 각 자원의 국가별, 연도별 공급/수요 특성 등 1차적인 분석결과 제시

WATER - ENERGY - FOOD NEXUS DATABASE

Version: 7/15

Created by:

KYUNG HEE UNIVERSITY

Main Menu | Population | Water | Energy | Food | Intensity | Rate | Notes | References

WATER CONSUMPTION AND PRODUCTION

Country Profiles

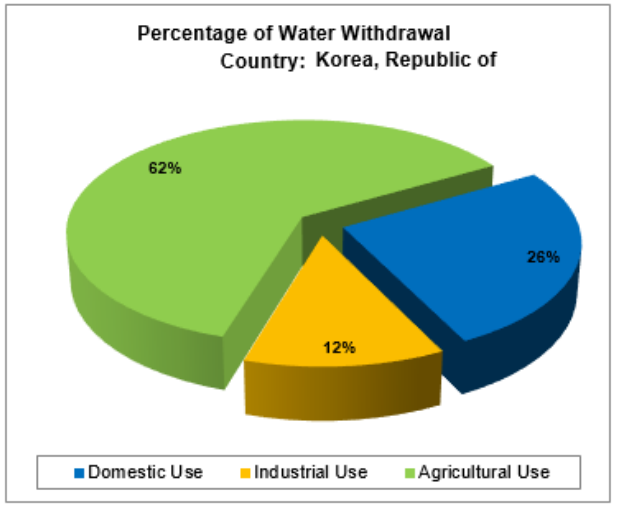
Country : Korea, Republic of

I. Water Withdrawal

Category	Unit	Value
Total Freshawater Withdrawal	Billion m3	25.47
Per Capita Withdrawal	m3/cap/yr	525
Domestic Use	%	26
Industrial Use	%	12
Agricultural Use	%	62

II. Resources

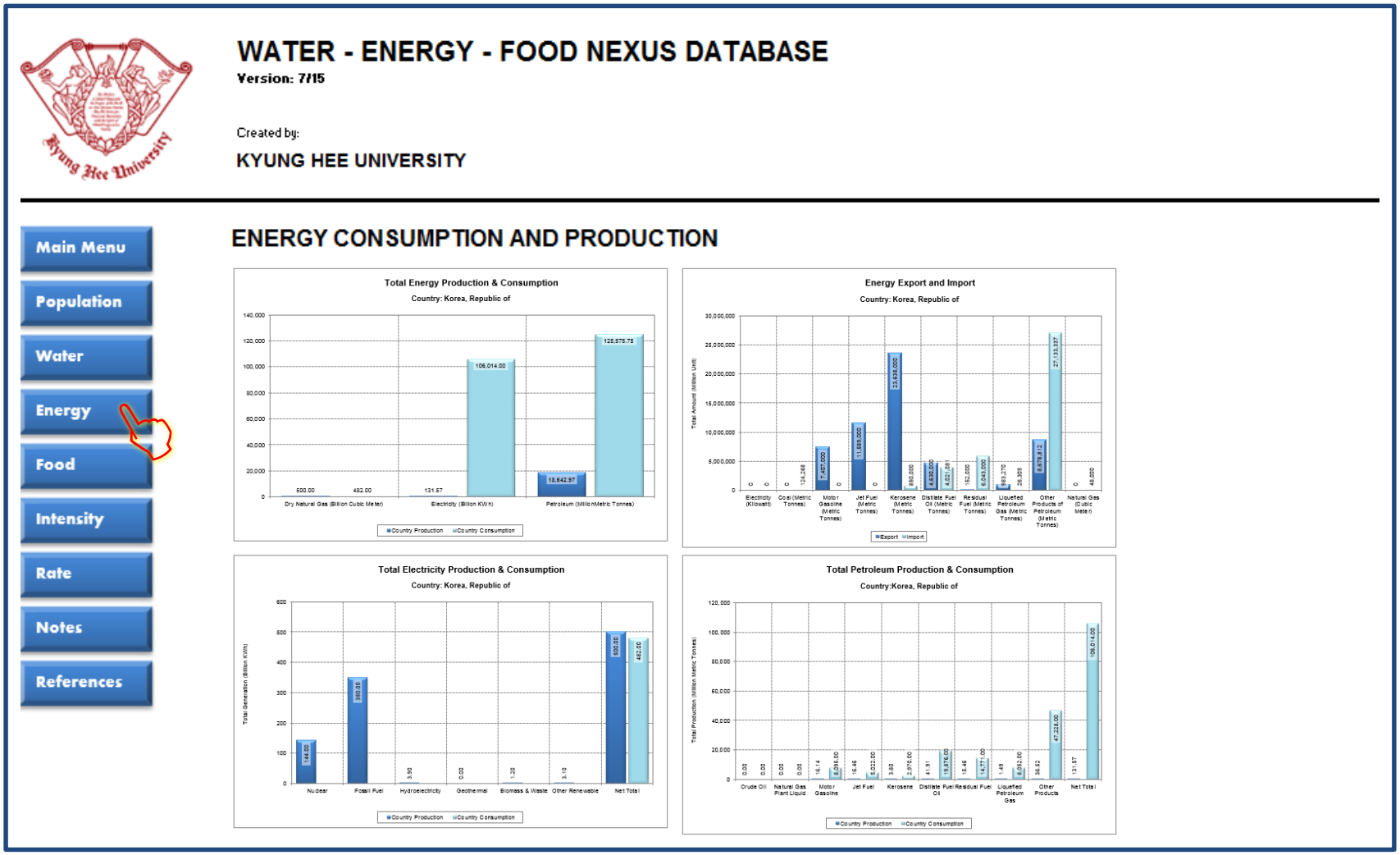
Category	Unit	Value
A. Internal Renewable Water Resources (IRWR)		
Surface water	Billion m3	62.25
Groundwater	Billion m3	13.30
Total internal renewable water	Billion m3	64.85
B. Dam/Reservoir		
Number of dams		54
Total reservoir capacity	Million m3	15698.914



4. W-E-F Nexus Modeling

W-E-F Nexus D/B Layout(2)

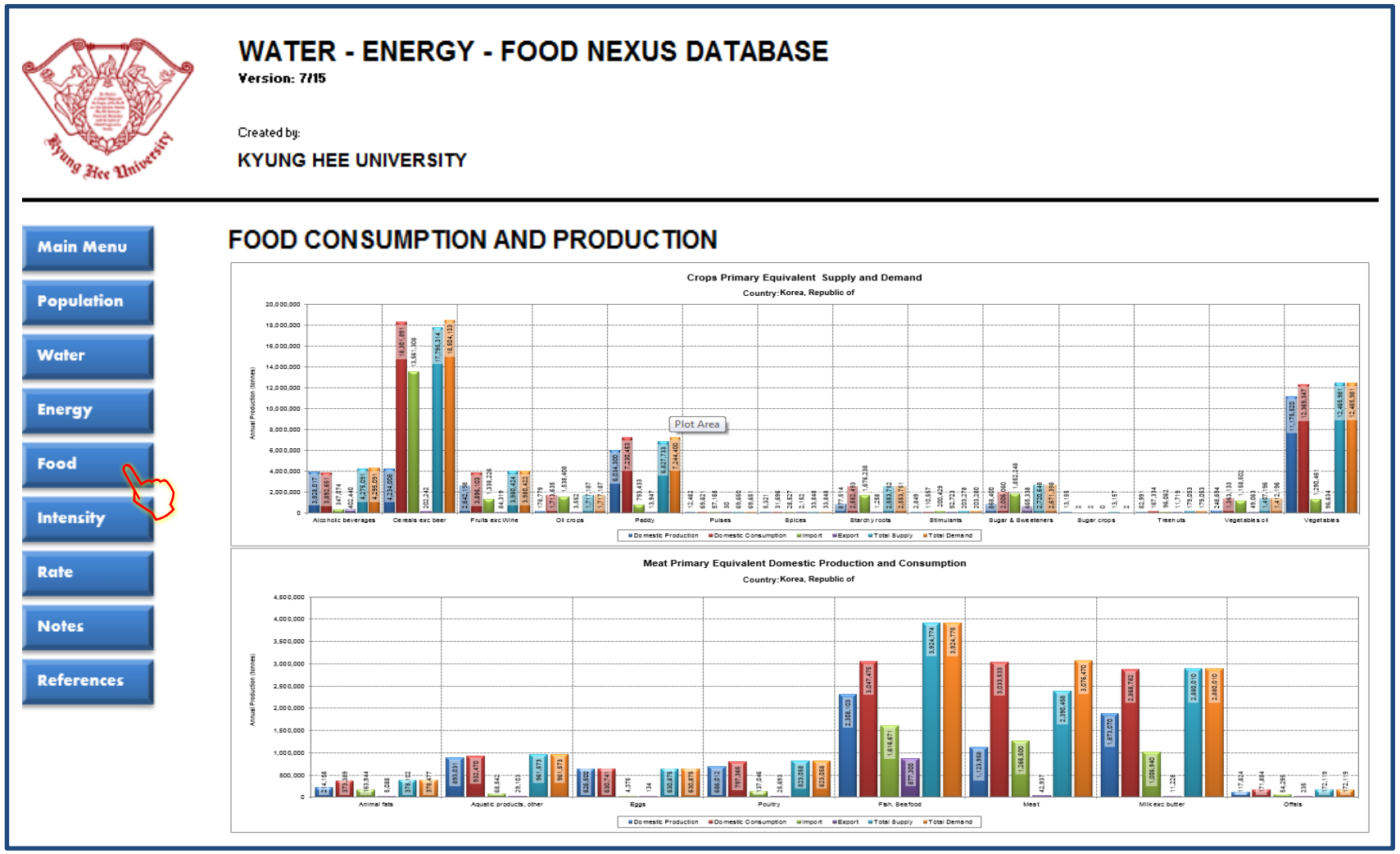
- W-E-F 각 자원의 국가별, 연도별 공급/수요 특성 등 1차적인 분석결과 제시



4. W-E-F Nexus Modeling

W-E-F Nexus D/B Layout(3)

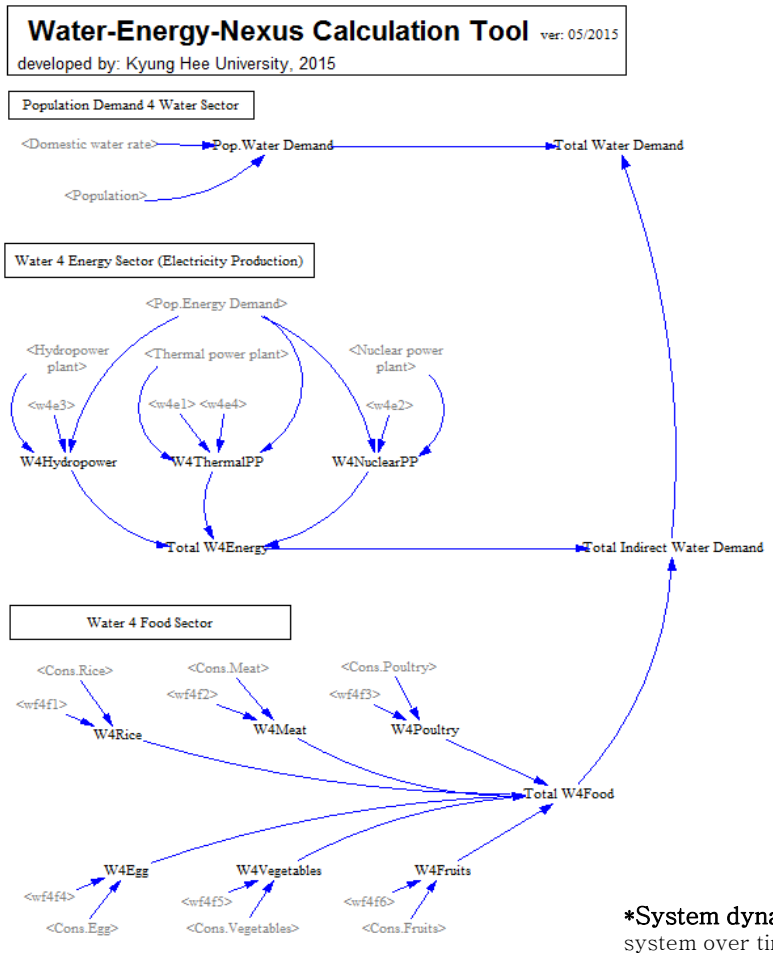
- W-E-F 각 자원의 국가별, 연도별 공급/수요 특성 등 1차적인 분석결과 제시

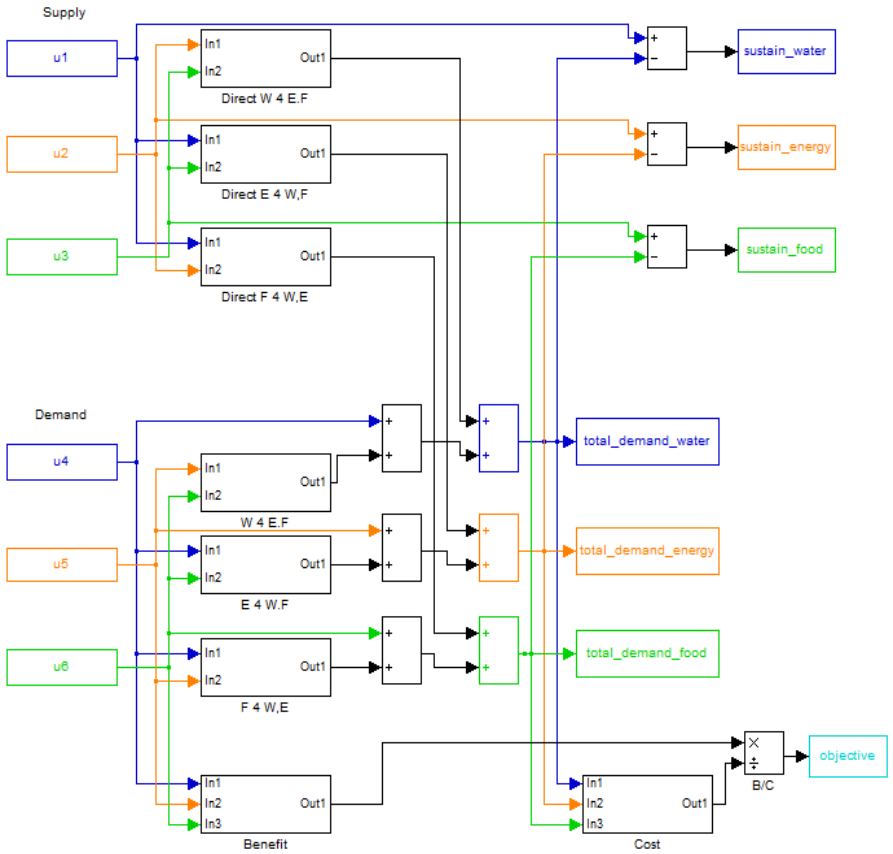


4. W-E-F Nexus Modeling

System Dynamics Model (Vensim & Simulink)

Vensim **VS** Simulink

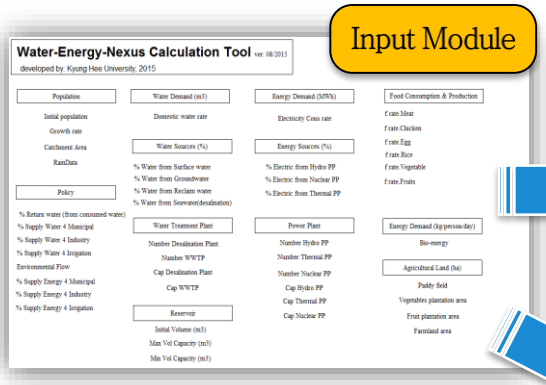




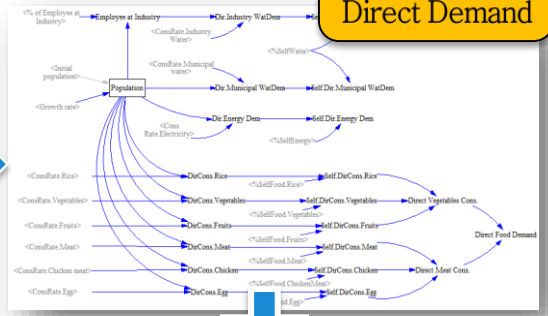
*System dynamics model (시스템 동적 모형) : an approach to understanding the behavior of complex system over time. It deals with internal feedback loops and time delays of system components. The difference with other approach is the use of feedback loops and stocks and flows.

4. W-E-F Nexus Modeling

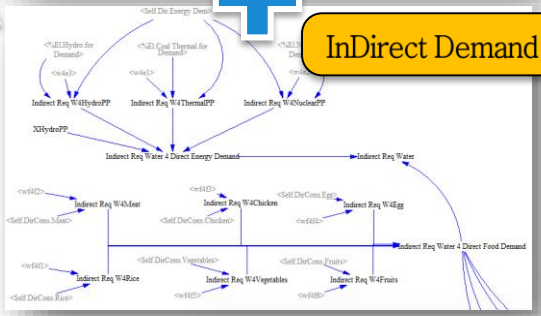
W-E-F Nexus 해석모형 개발 (System Dynamics Model - Vensim)



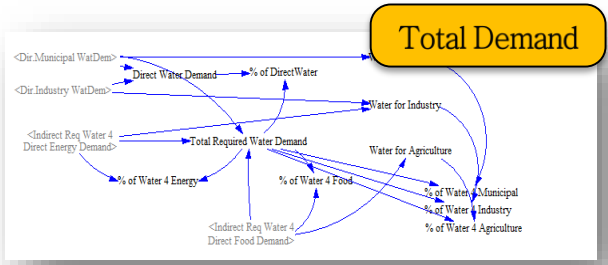
Input Module



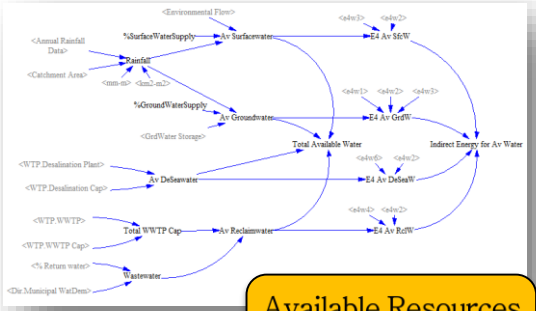
Direct Demand



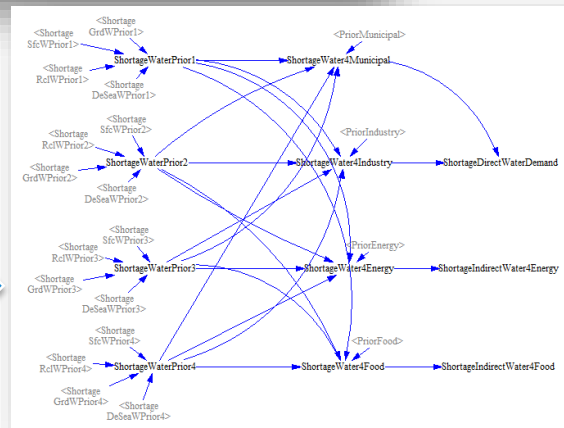
InDirect Demand

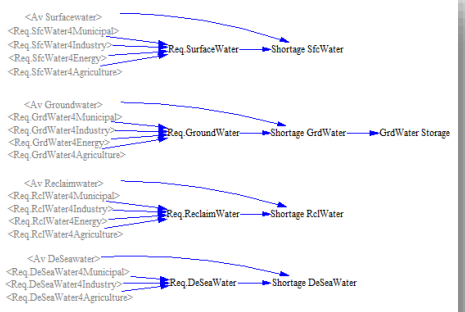


Total Demand



Available Resources





Shortage & Reliability

4. W-E-F Nexus Modeling

Linkage between Database and Vensim Model

Population
- Population
- Growth rate
- Workers

Water
- Withdrawal
- Available Resources

Intensity
- Water for energy & food
- Energy for water & food

Energy
- Power plant
- Capacity

Consumption Rate
- Water
- Energy
- Food

Food
- Farmland area
- Production, consumption
- Export, Import

Production Rate
- Water
- Energy
- Food

Summary

E for VENSIM BASIC DATA

Country	Korea, Republic of
Initial Year	2012
Simulation duration [years]	30

Year		2012
Annual Rainfall	[mm]	1526.719231
Population	[inhabitant]	50,004,441
Annual growth	[%]	1.33
Workers in industry	[%]	12.27
Catchment area	[km2]	100,030.00
Reservoir Capacity	[m3]	15,698,914,000
Groundwater	[m3]	13,300,000,000

Water Limitation

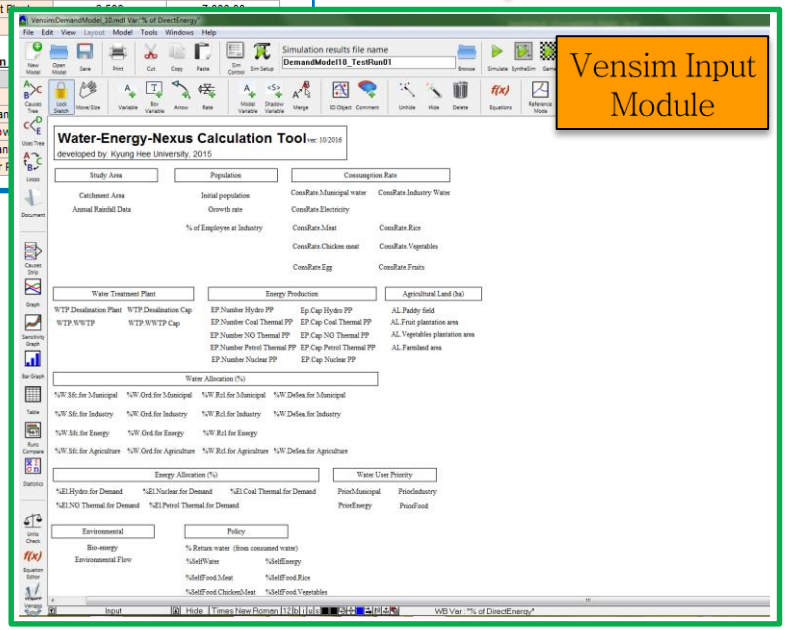
Limitation	Number of Unit	Value
Minimum Level of Reservoir	[% of Reservoir Cap]	35.0
Maximum Level of Reservoir	[% of Reservoir Cap]	100.0
Initial Level of Reservoir	[% of Reservoir Cap]	50.0
Minimum Level of Groundwater	[% of Groundwater]	80.0
Return water for Reclaim water	[% of Consumed Municipal Water]	40.0
Environmental Flow	[% of Surface water]	5.0

Water Treatment Plant

Type	Number of Unit	Capacity/Unit (m3)
Water Treatment Plant		
Waste Water Treatment P		
Desalination Plant		

Electricity Generation

Type
Hydro Power Plant
Coal Thermal Power Plan
Natural Gas Thermal Pov
Fuel Thermal Power Plan
Nuclear Thermal Power F



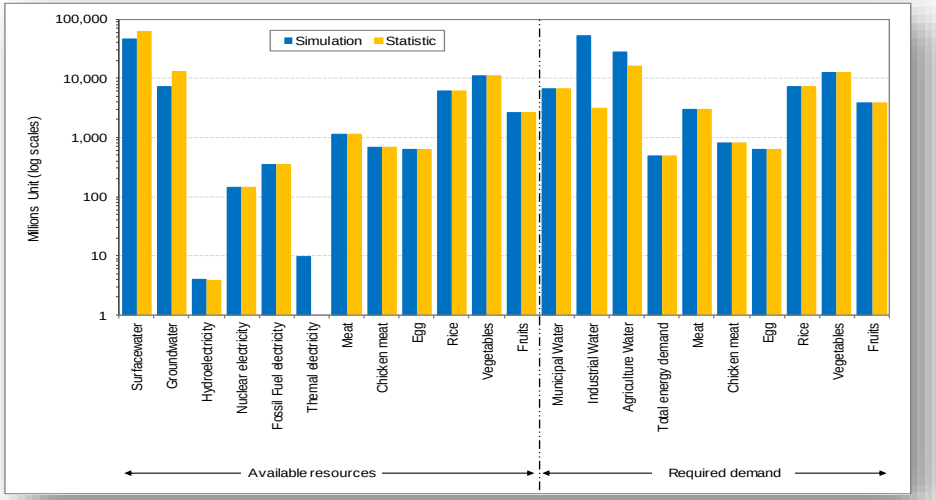
Vensim Input Module

Input:
- Initial population & annual growth
- Available area
- Consumption & production rate
- Water footprint & intensity

4. W-E-F Nexus Modeling

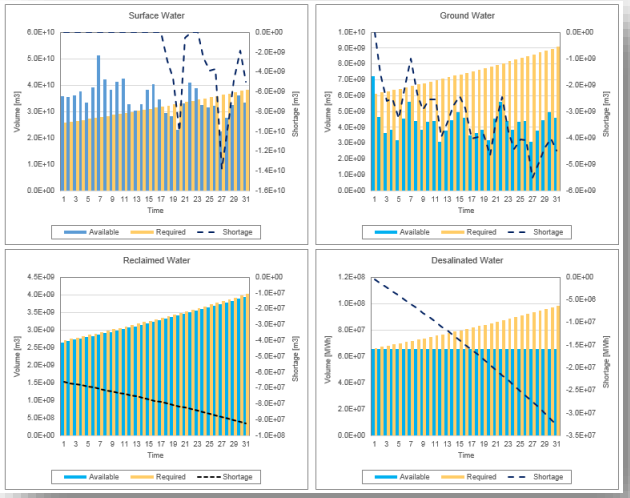
Application – Water-Energy-Food Balance

(i) Verification @yr 2012



(ii) Available & Required Energy

(iii) Available & Required Water

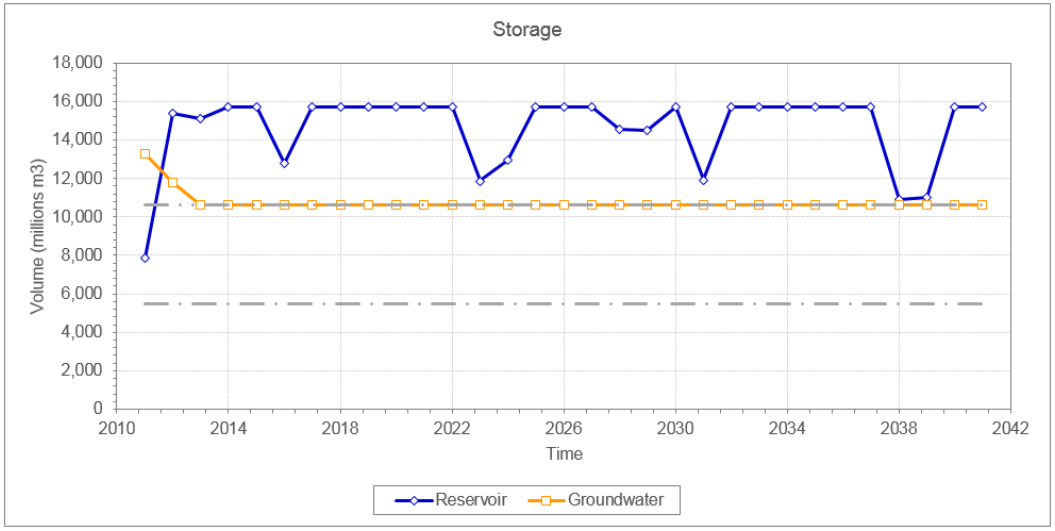


(iv) Available & Required Food

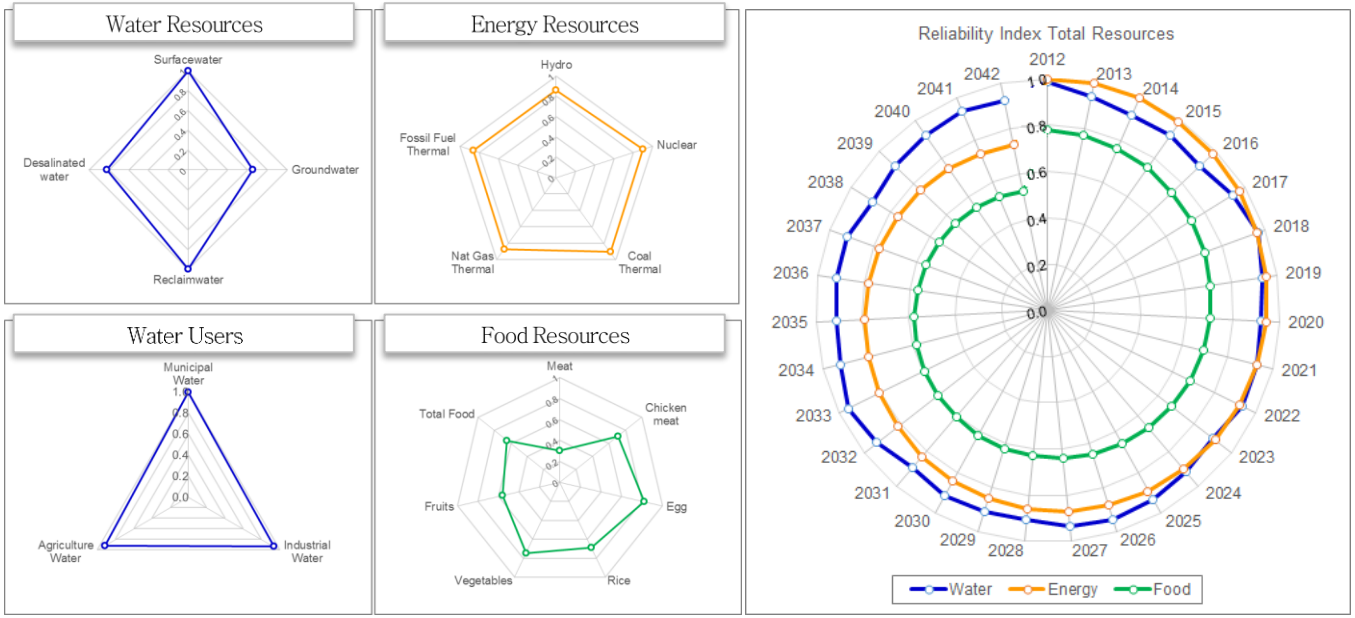
4. W-E-F Nexus Modeling

Application – Storage and Reliability

Storage



Reliability Index



4. W-E-F Nexus Modeling

Application of Scenarios

1) **Base Scenario:** simulation using data from database
2) **Scenario 1:** Addition of power plant capacity to increase available electricity (started at 2025)
3) **Scenario 2:** Addition of agriculture land area to increase self sufficiency (started at 2030).

**Note: the additions were extremely done at same time, just to give a clear effect in entire model.*

Results from base simulation

Additional capacity for Scenario 1

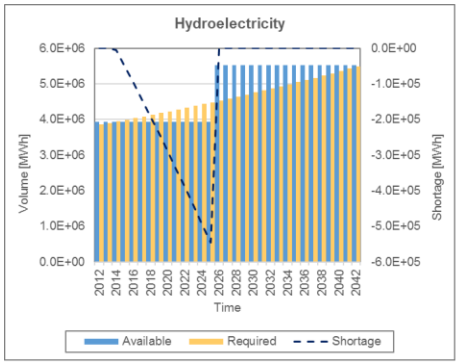
Power plant	Base capacity (MW)	Additional capacity (MW)
Hydropower	450	↑ 180
Coal	720	↑ 220
Natural Gas	400	↑ 150
Fossil Fuel	39,000	↑ 15,500
Nuclear	16,440	↑ 5,300

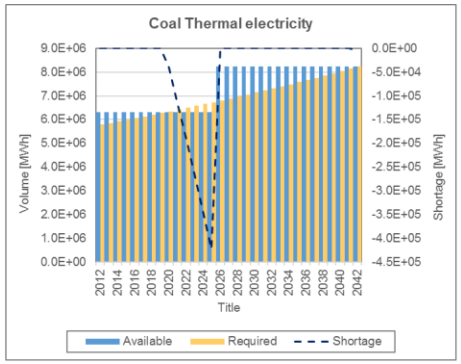
Additional area for Scenario 2

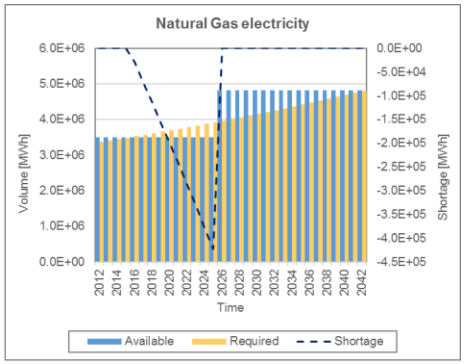
Farm area	Base area (ha)	Additional area (ha)
Paddy field	853,823	↑ 670,000
Fruit plantation	33,680	↑ 40,000
Vegetable plantation	1,488,000	↑ 960,000

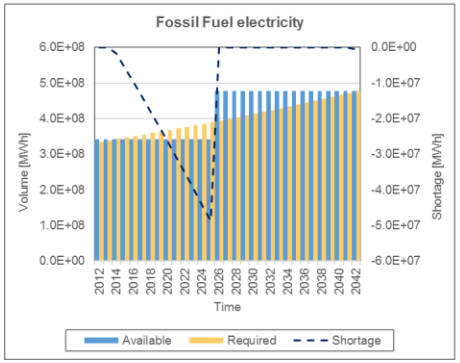
4. W-E-F Nexus Modeling

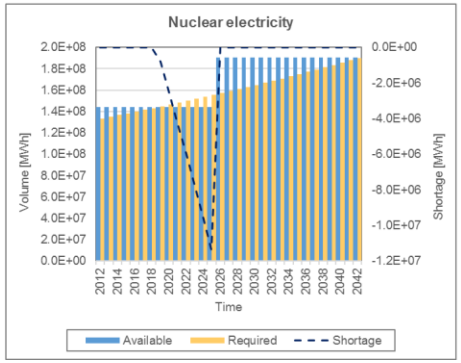
Application – Results (Scenario 1)











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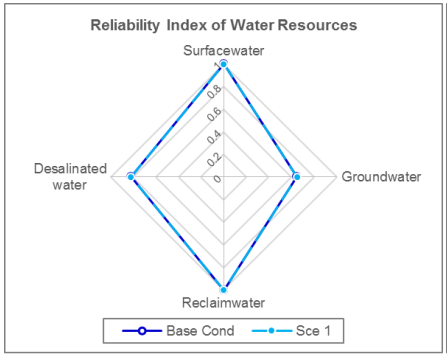
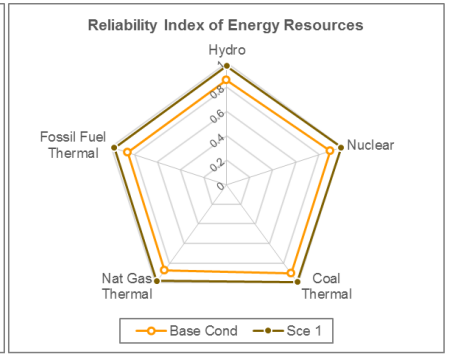
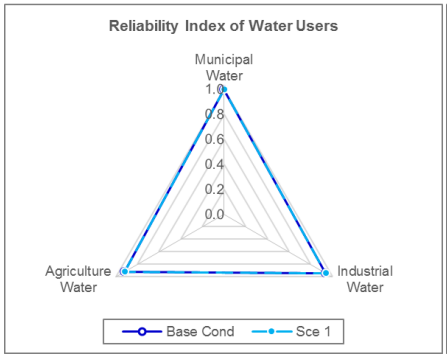
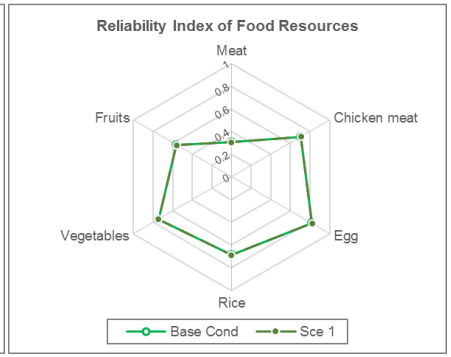


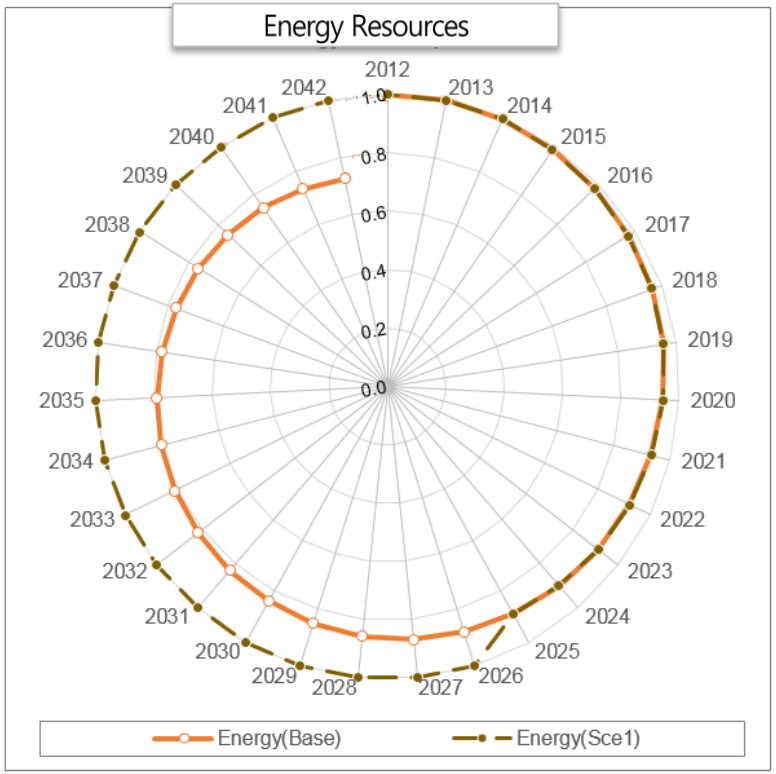


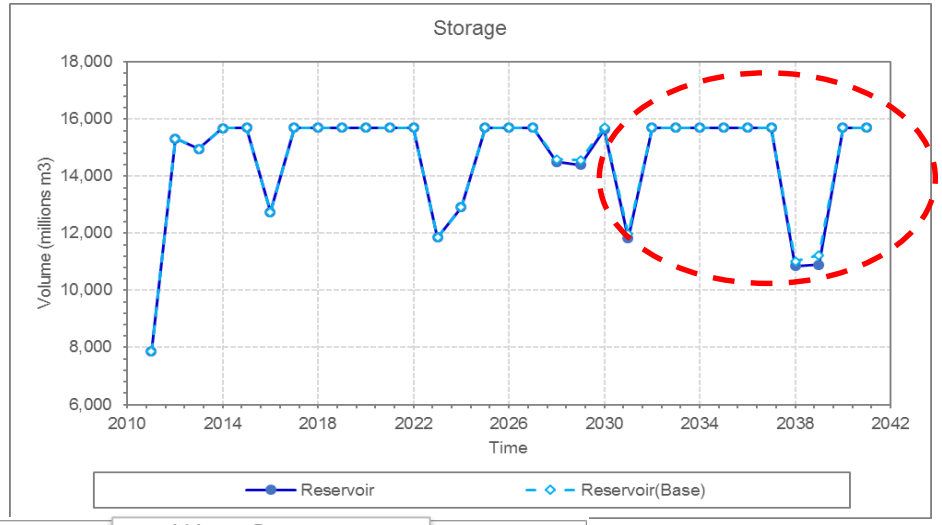


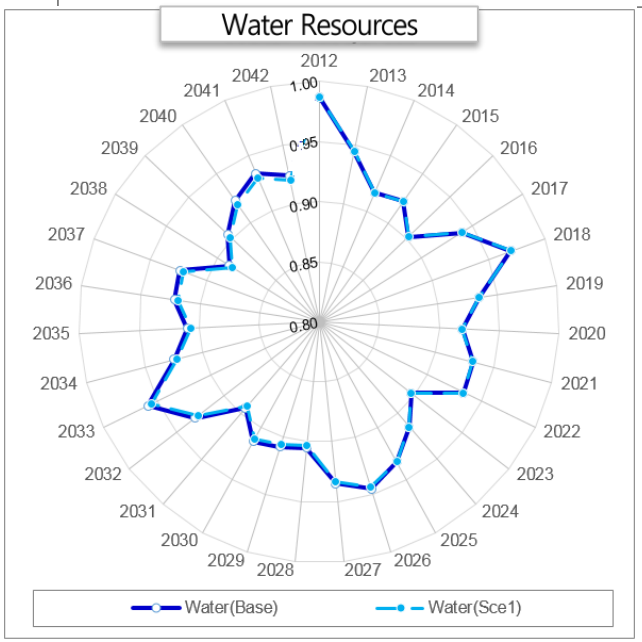


4. W-E-F Nexus Modeling

Application – Results (Scenario 1)

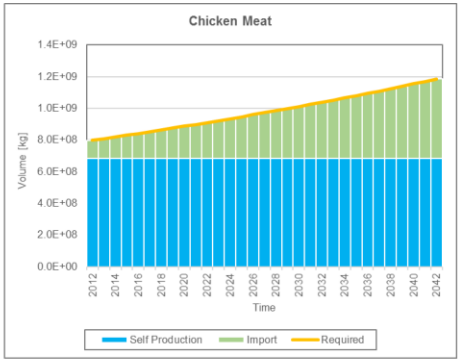


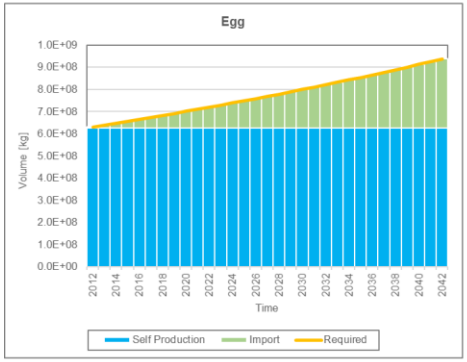


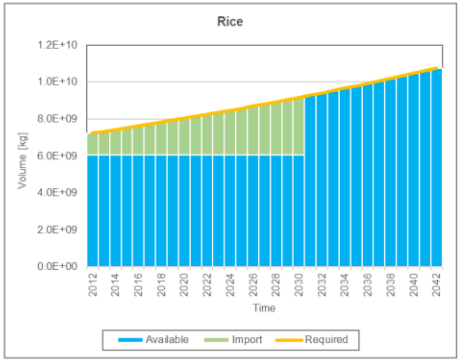


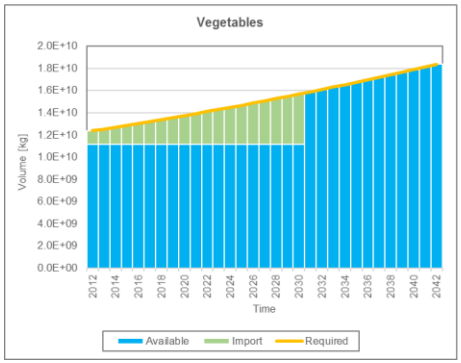
4. W-E-F Nexus Modeling

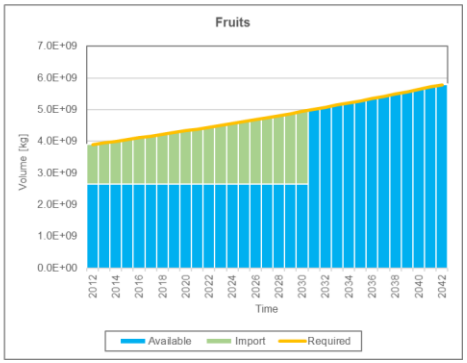
Application – Results (Scenario 2)











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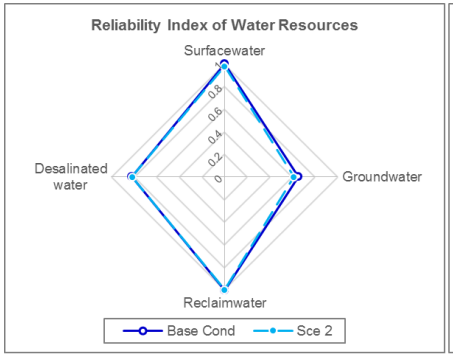
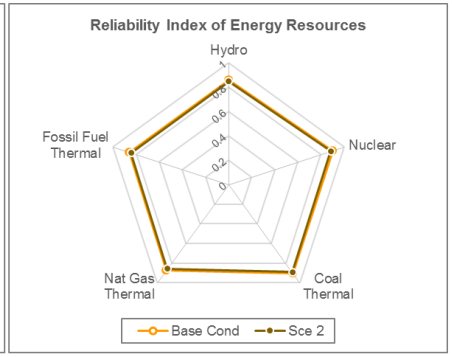
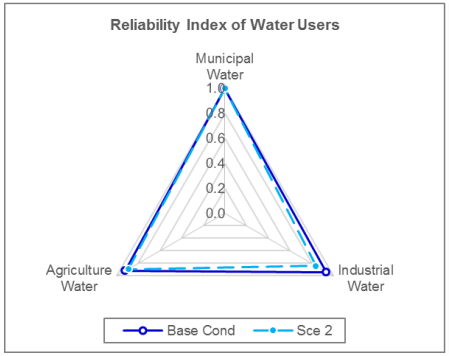
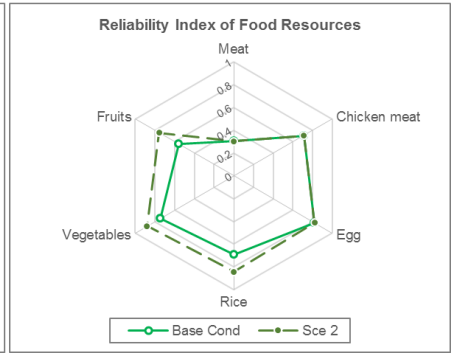


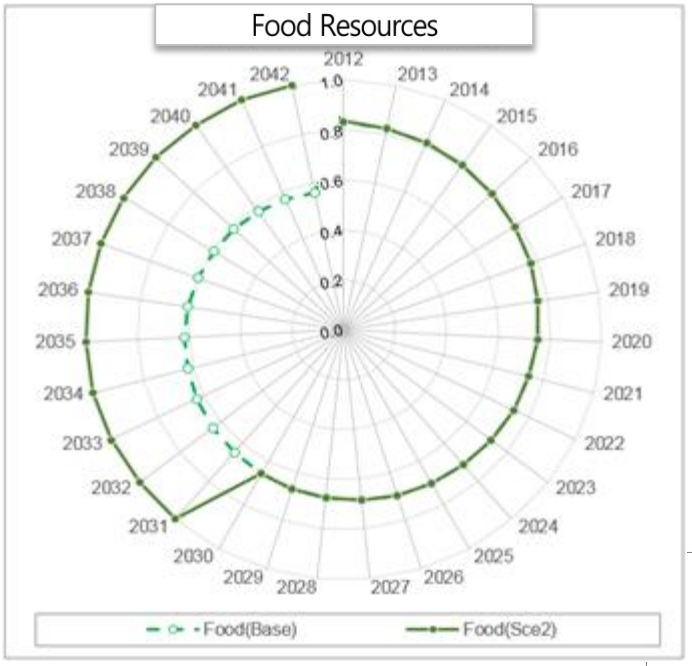


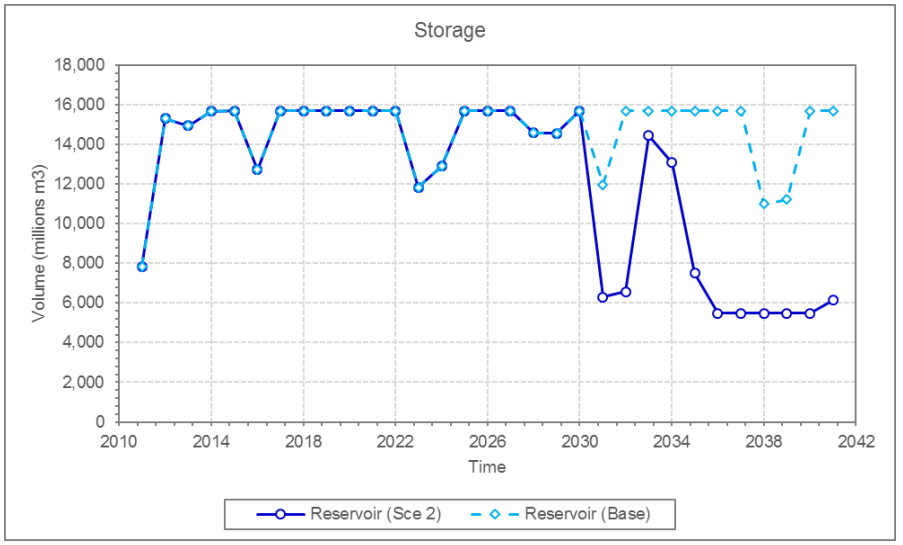


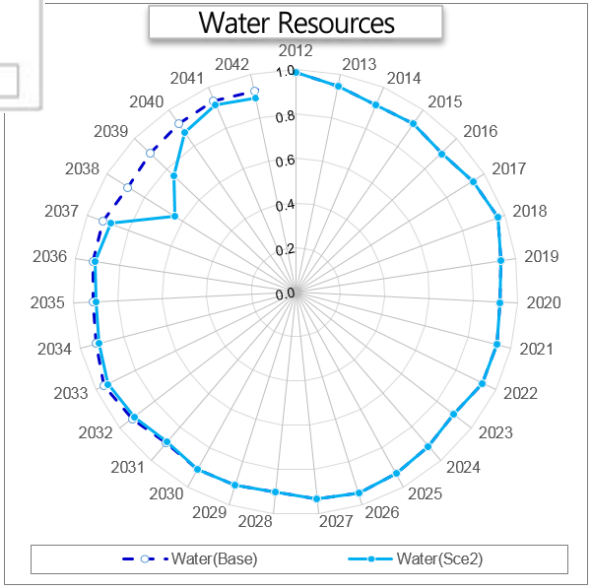


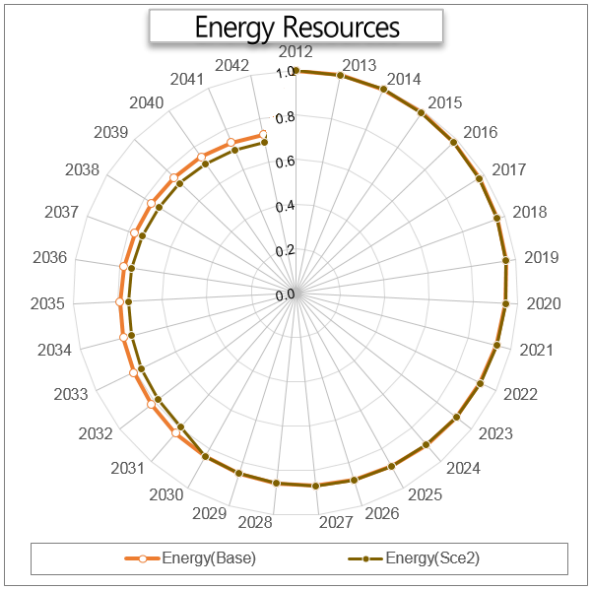
4. W-E-F Nexus Modeling

Application – Results (Scenario 2)









5. Future Developments

Trading & Optimization Module

적용 대상 선정

⇩

공급, 수요 등 초기값 설정

⇩

시나리오 생성

⇩

W-E-F 연계 해석

⇩

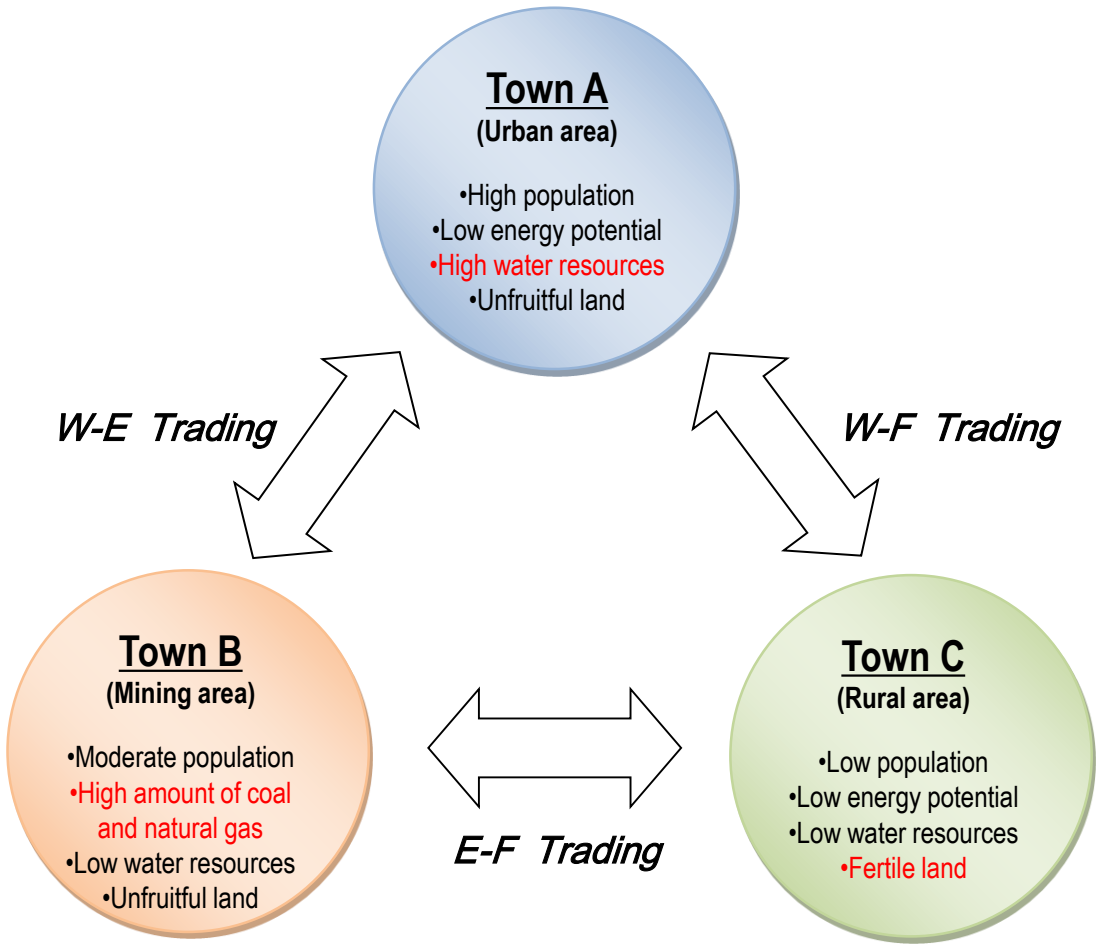
자원 거래 모듈 적용

⇩

최적화 기법 적용
(비용, 우선순위 등)

⇩

W-E-F 자원의
최적 배분 및 거래



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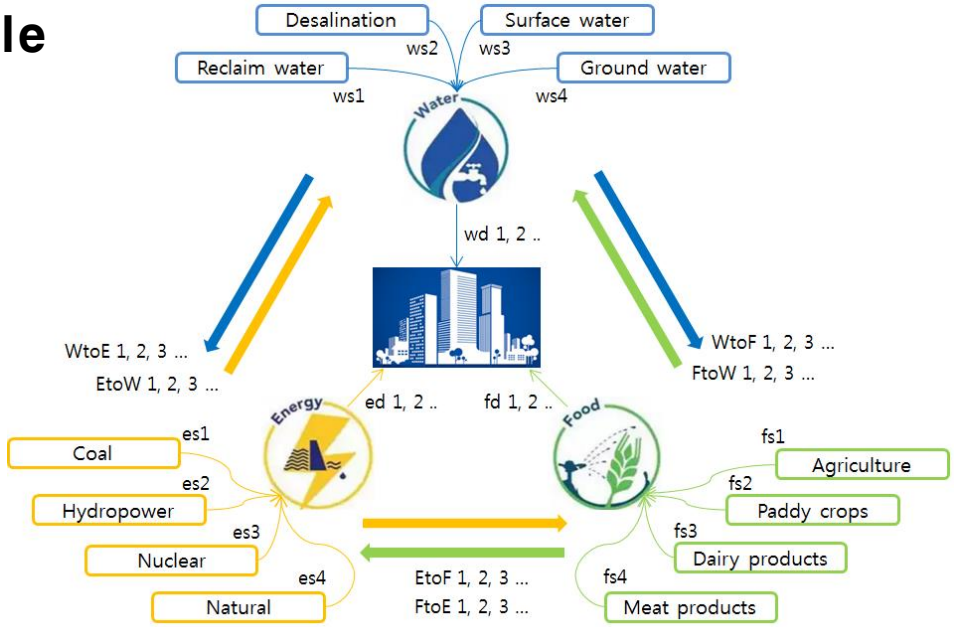

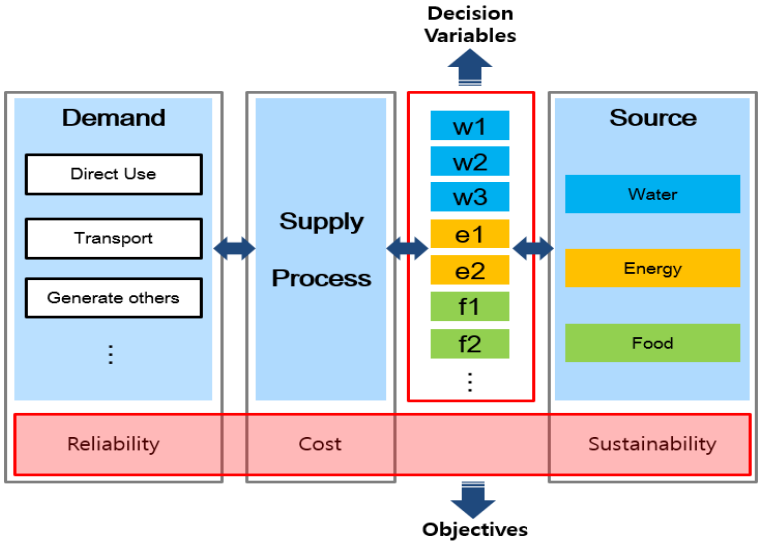

5. Future Developments

Trading & Optimization Module

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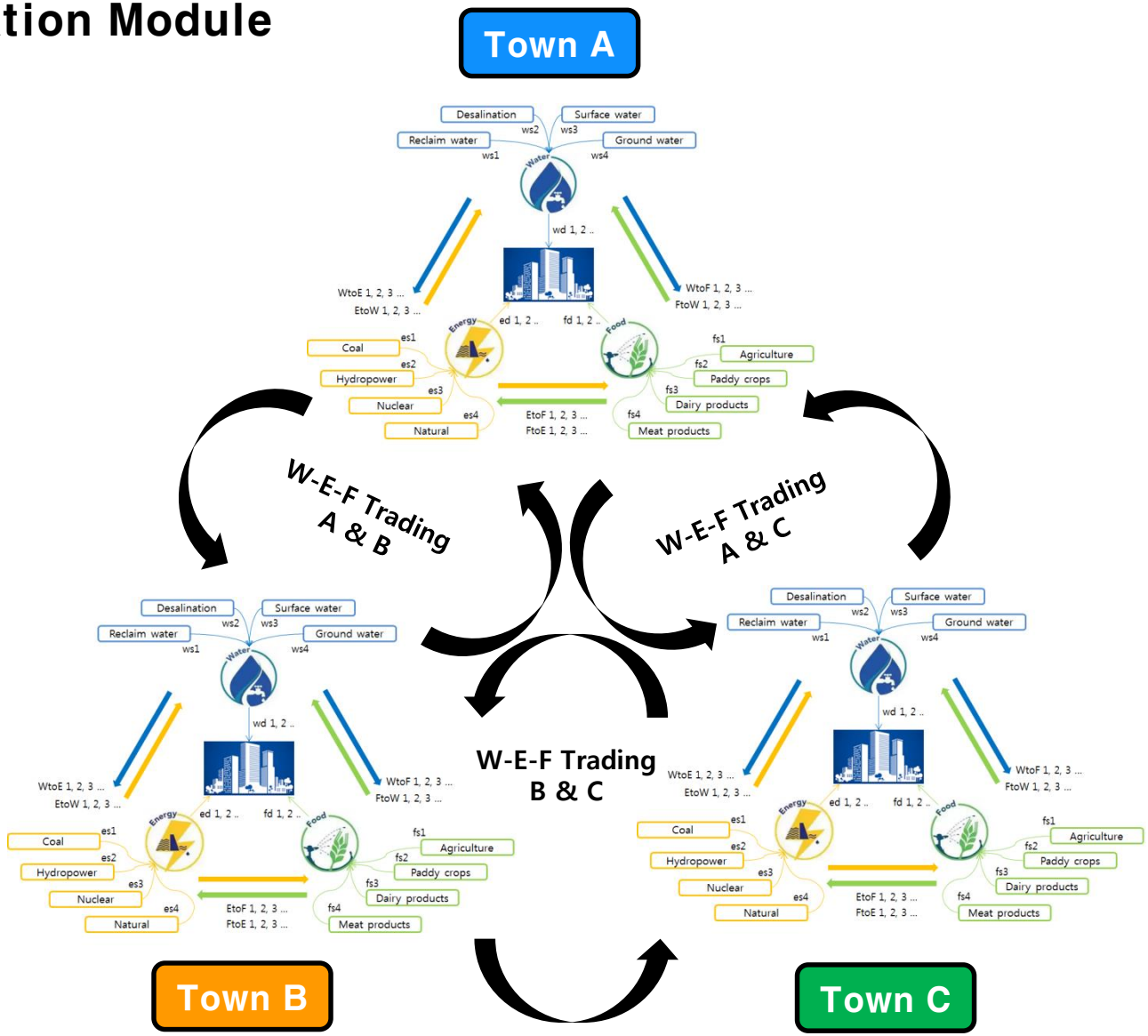
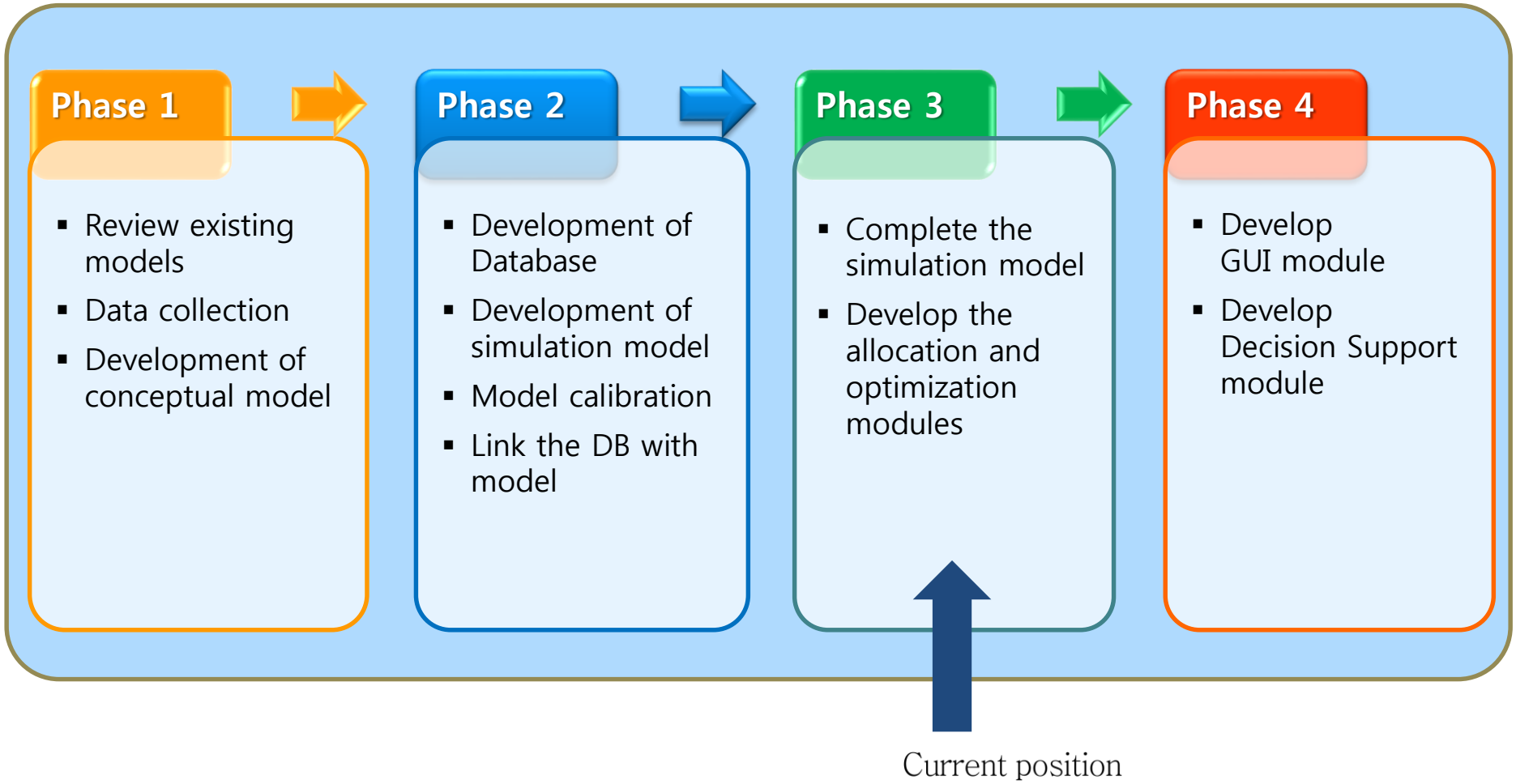


5. Future Developments

Development steps of W-E-F Nexus Model



5. Conclusions

Future Development

1) Local level

➔ Detailing the simulation into a local level (cities/province)

2) Climate change effect

➔ Include the climate change effect as internal parameter of the model

3) Economic-engineering approach

➔ Improve the simulation by considering the economic aspect of resource allocation

4) Government policy

➔ Add government policy as a parameter or boundary in the model

5) Optimization capability

➔ Develop the optimization algorithm to find optimum and sustainable management

5. Conclusions

- A system dynamics model was developed to simulate nation-wide W-E-F nexus;
- Each resource's shortage, reliability for both demand and supply sides are simulated;
- Scenario analyses can foresee the future conditions and provide insights to the required structural/non-structural preparedness plans;
- The model can be improved and expanded for local-trading practice and resources optimization;
- The model can be used as a decision support tool for policy and infrastructure development; and
- The database and model can be expanded for global implementation.

Thank You

Water-Energy-Food Nexus Simulation Model

경희대학교 사회기반시스템공학과

강두선교수

(doosunkang@gmail.com)