A systems-of-systems approach to National Infrastructure Assessment

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Infrastructure Transitions Research Consortium (ITRC)
http://www.itrc.org.uk

The ITRC is a consortium of seven UK universities:
- University of Oxford
- Newcastle University
- University of Southampton
- Cardiff University
- University of Cambridge
- University of Leeds
- University of Sussex

- ITRC was funded by EPSRC from 2011-2015 (£4.7 million)
- MISTRAL is the new £5.3million Grant from EPSRC funding ITRC from 2016-2020

Aim:
To develop and demonstrate a new generation of simulation models and tools to inform the analysis, planning and design of national infrastructure

Major components of ITRC Research

1. National infrastructure database and visualisation tools
2. Economics and governance of national infrastructure
3. National infrastructure vulnerability, risk and resilience analysis
4. System-of-systems analysis to inform long term planning, investment and design for national infrastructure

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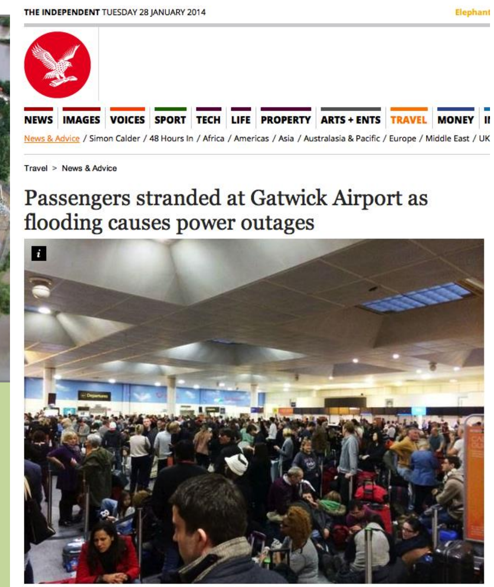
NISMOD: National Infrastructure Systems MODel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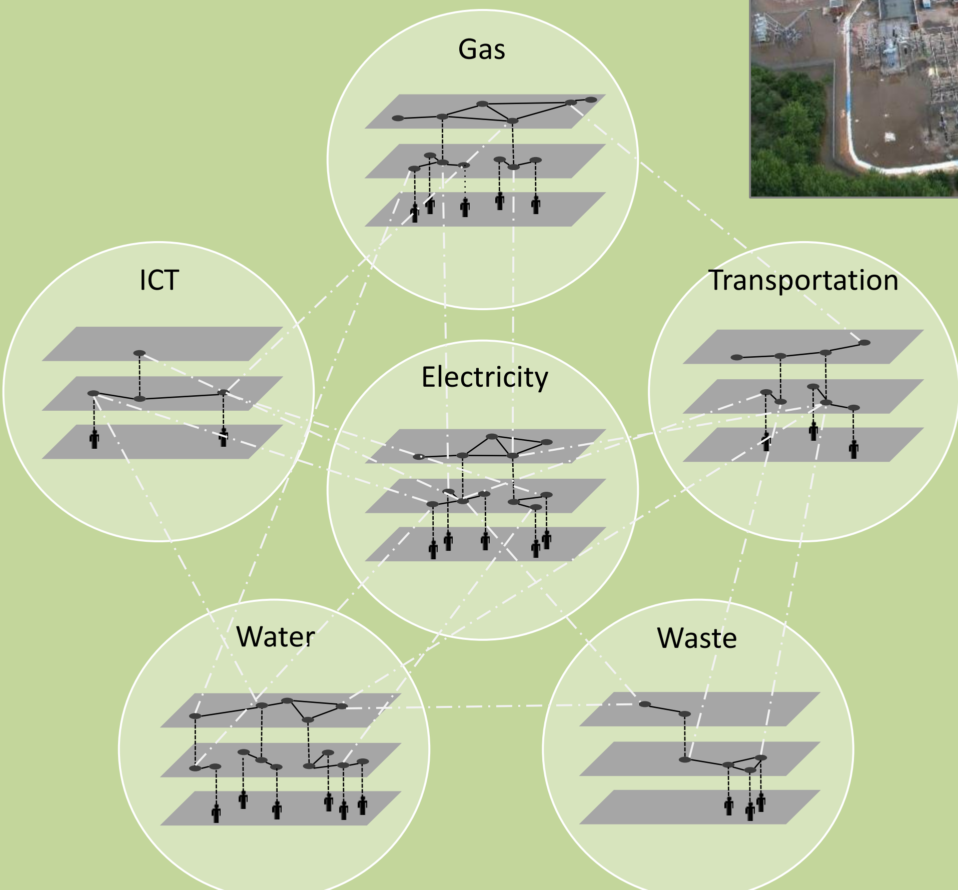
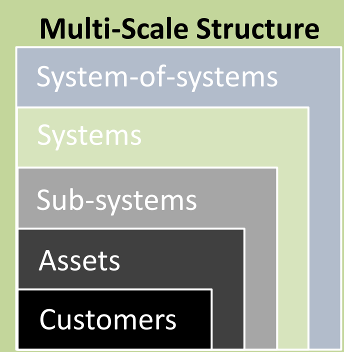
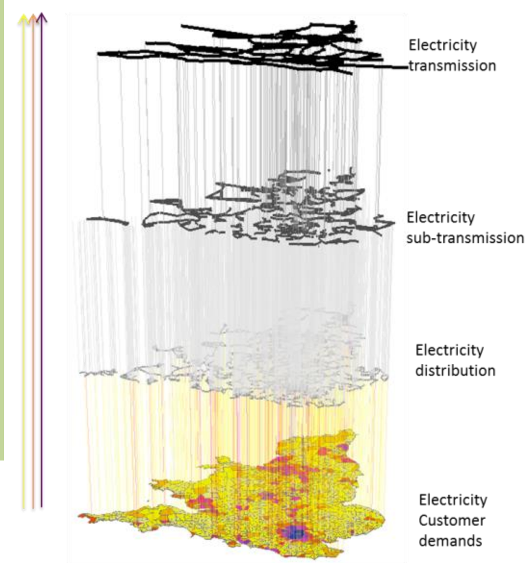
Passengers stranded at Gatwick Airport as flooding causes power outages

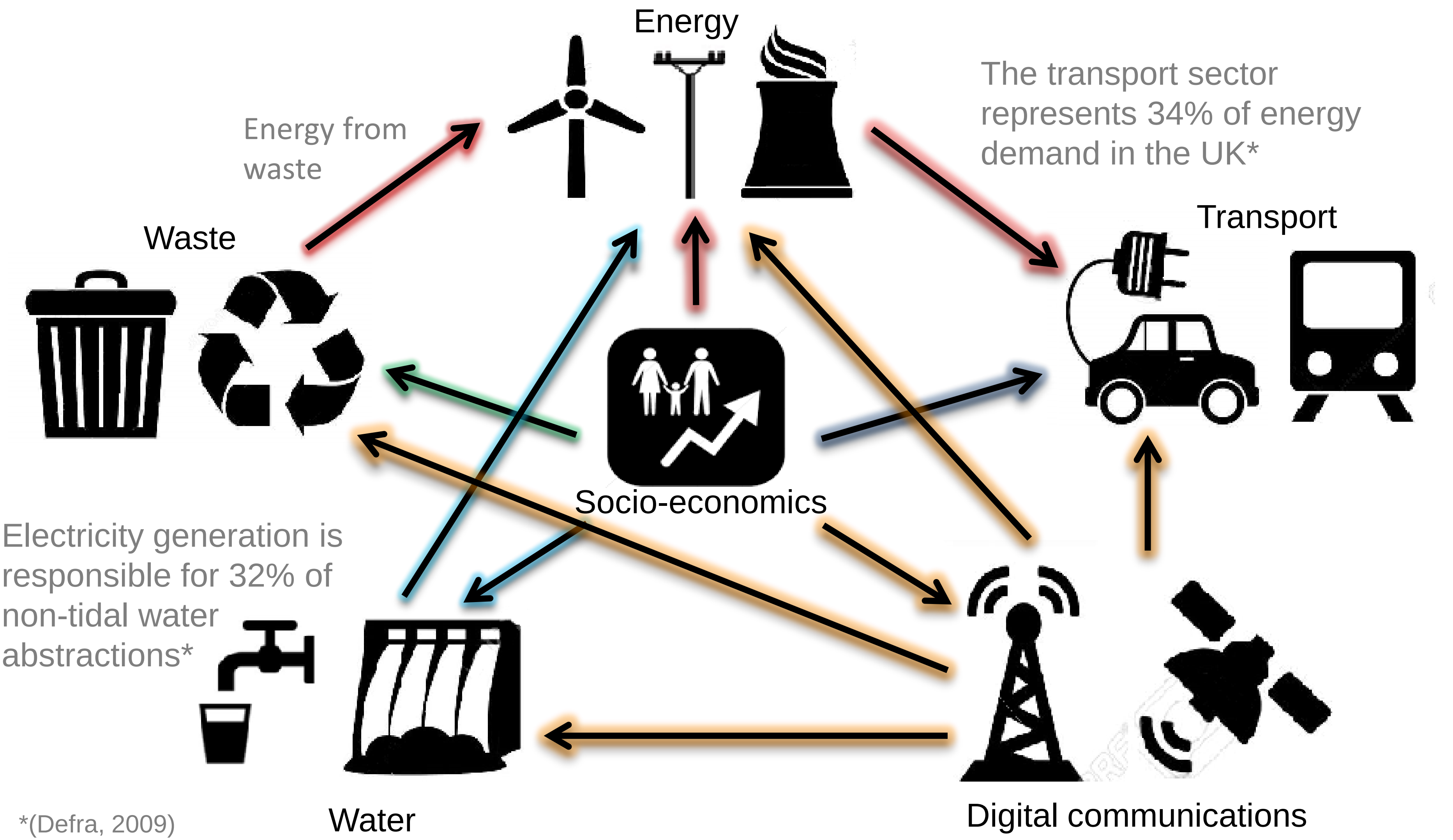






System-of-systems

NISMOD: National Infrastructure Systems MODel



*(Defra, 2009)

System-of-systems

NISMOD: National Infrastructure Systems MODel

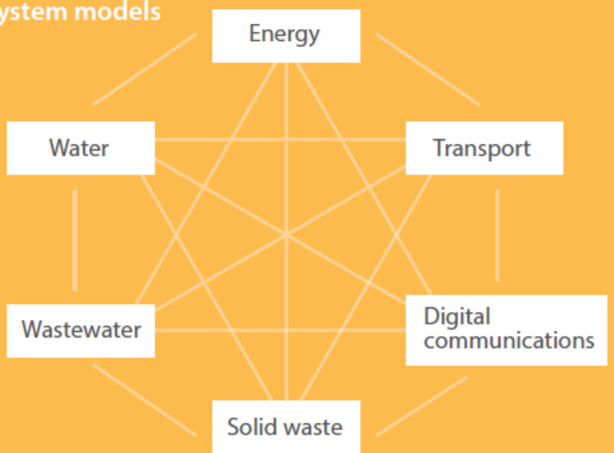
Scenarios

- Population
- Economy
- Technology
- Climate

Strategies of infrastructure provision

- New infrastructure
- Improved efficiency
- Demand management
- Spatial planning

Interdependent infrastructure system models



Metrics of future infrastructure performance

- Service delivery
- Capacity margin
- Cost
- Carbon emissions

System-of-systems

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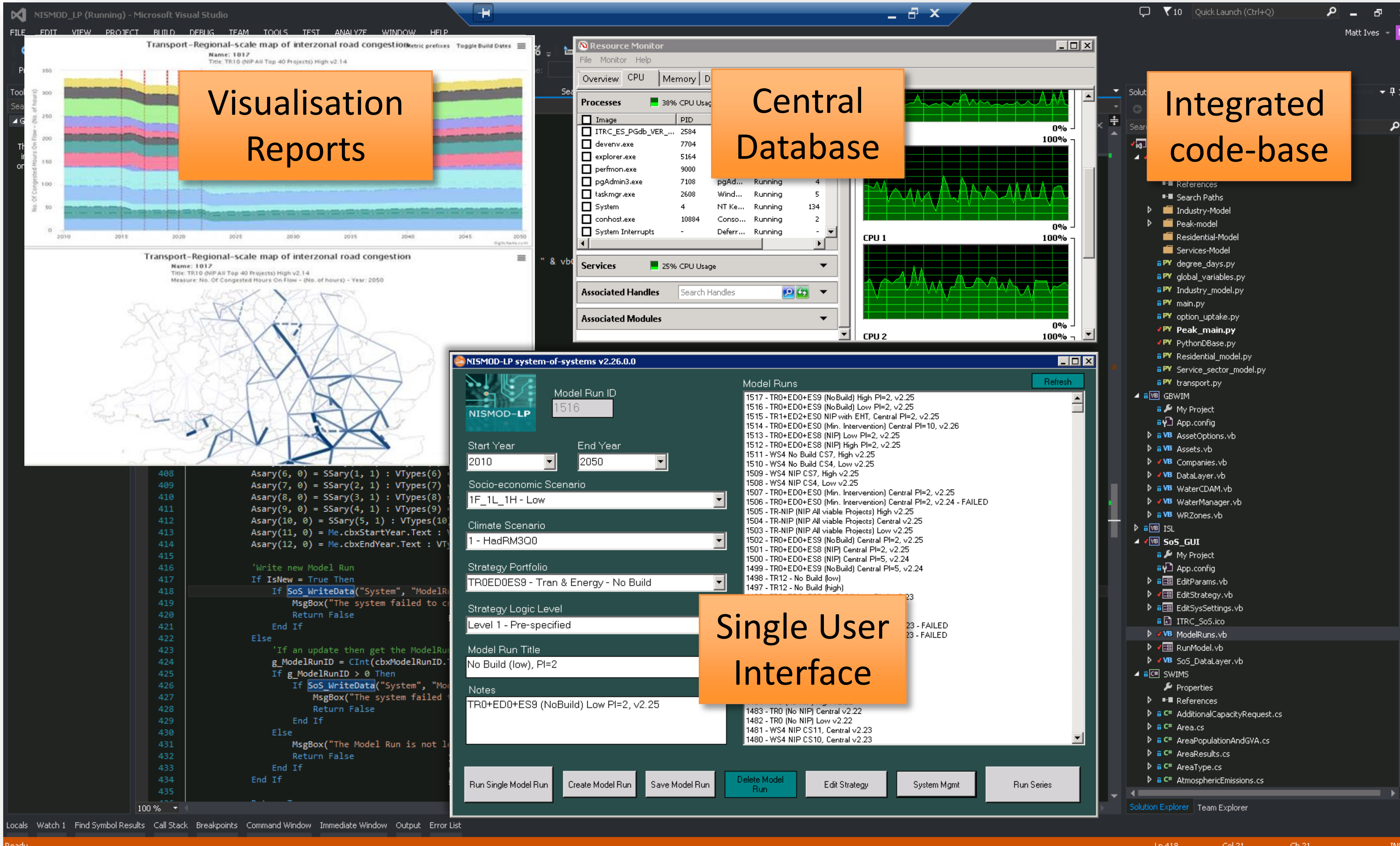
NISMOD: National Infrastructure Systems MODel

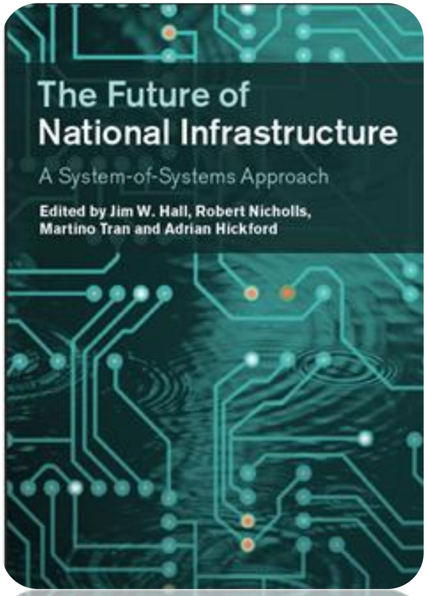


EPSRC
Engineering and Physical Sciences Research Council

Infrastructure Transitions Research Consortium

The ITRC has used NISMOD to:

- Analyse four alternative national infrastructure strategies, which are described in *The Future of National Infrastructure*
- Analyse the performance of the £430bn pipeline of projects in the 2014/15 National Infrastructure Plan
- Map critical infrastructure 'hotspots' for Infrastructure UK
- Analyse future demand for electricity in the context of distributed renewables, for National Grid
- Map points of vulnerability in the transport network as part of DfT's response to the Transport Resilience Review
- Conduct the analysis for the National Needs Assessment being led by Sir John Armitt



Collaborating organizations

Infrastructure UK
Environment Agency
Committee on Climate Change Adaptation
National Rail
nationalgrid
National Infrastructure Commission
Department for Transport

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ITRC mistral: Transforming national infrastructure choices worldwide

Adapting, applying and testing the concepts and methodologies we have developed in the UK to other countries

Inform the planning of infrastructure investments in new contexts:

- Developed economies
- Emerging economies
- Least developed countries
- Post-disaster and post-conflict situations

Growing relationships with:

- UN
- World Bank
- DfID

UNOPS

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Some challenges

Past problems associated with infrastructure development in developing, post-disaster and post-conflict countries:

- No systems-based national infrastructure strategy or program
- A wide dichotomy between demand and supply
- Political, economic, social and technical challenges
- Designs that are inappropriate to the needs and context
- A lack of standard rules and oversight for project procurement
- Inability to capitalise on opportunities to 'build back better' following disaster/conflict
- Many donor-funded projects are unmaintained and/or underutilised due to lack of funds to pay for operation and maintenance costs
- Large portions of project materials and expertise are sourced from outside the country with overdesign that allow the leakage of funds.
- High numbers of abandoned projects: e.g. a 2011 report in Nigeria found 11,866 abandoned capital projects that will require £27bn to complete

NISMOD: National Infrastructure Systems MODel

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The NISMOD assessment process

- Define the current system
- Review the possible future needs for infrastructure services
- Develop the long term vision for national infrastructure
- Identify strategic alternatives for delivering the vision
- Analyse the scale and timing of strategic alternatives required to address infrastructure needs
- Recommend adaptive pathways of policies and investments

The NISMOD assessment platform

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NISMOD Process

Define the current system

Assess possible future needs for infrastructure services

Develop the long term vision for national infrastructure

Identify strategic alternatives for delivering the vision

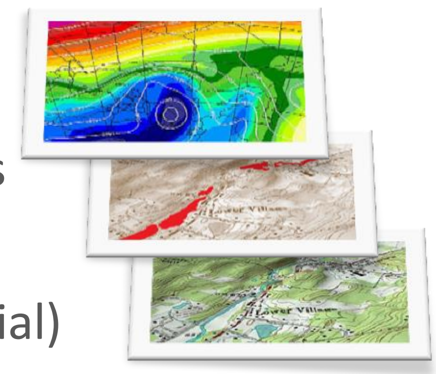
Analyse the scale and timing of strategic alternatives required to address infrastructure needs

Recommend adaptive pathways of policies and investments

NISMOD Process

Define the current system

- Review of the geographical context:
  - Geographical context (maps, topography)
  - Geospatial environmental data e.g. natural hazards
  - Population (geographical)
  - Economic activities (including government and social)



- Review of local infrastructure systems:
  - Asset and network layers for infrastructure sectors: energy, transport, digital coms, water, waste)
  - Asset characteristics: capacity, condition, age

- Review of the governance structures in which infrastructure decisions are made

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NISMOD Process

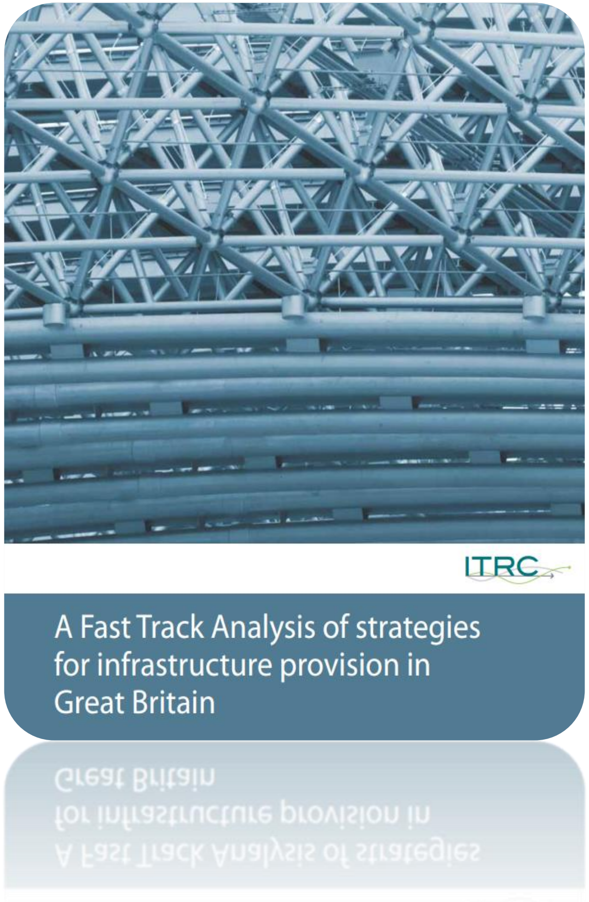
Assess possible future needs for infrastructure services

Fast Track Analysis

- Assess present day needs for infrastructure services
  - Per capita demands
  - Per unit demands from the economy

- Assess drivers of future needs
  - Scenarios of future population and economic status
  - Per capita and per unit demands from the economy
  - Environmental change

- Assess of current Infrastructure system



NISMOD Process

Develop the long term vision for national infrastructure

- Presentation of Fast Track Analysis to stakeholders
- Validating our representation of the current system
- Provide metrics around possible future strategies

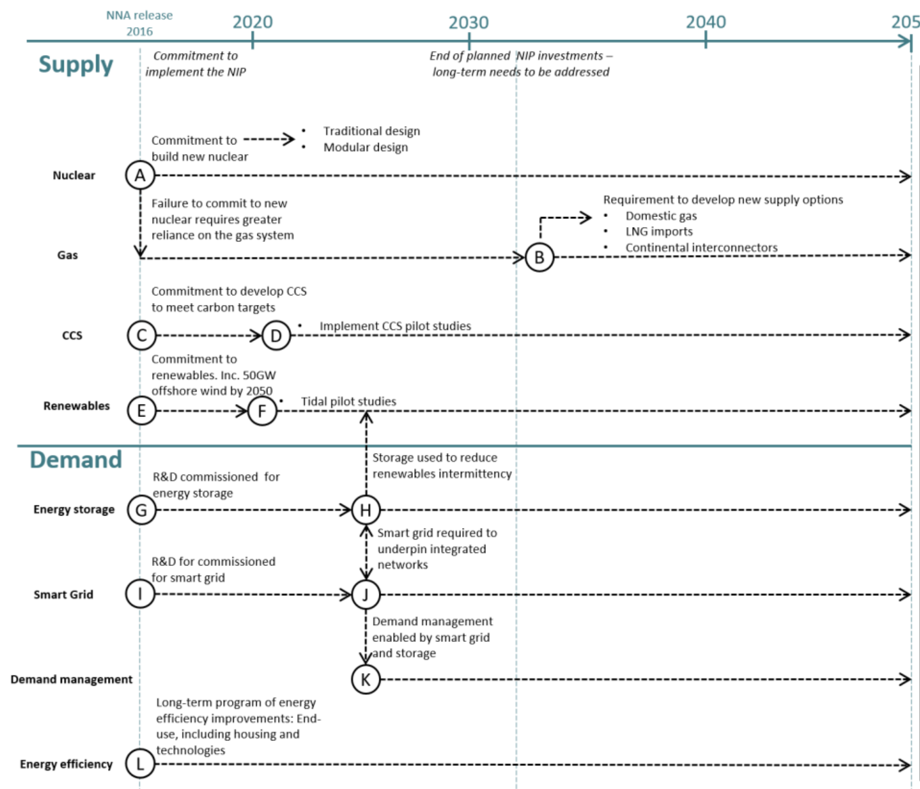
Identify strategic alternatives for delivering the vision

- Vision and goals for future infrastructure systems:
  - Sector-specific targets
  - Cross-sectoral goals
  - Investment and policy options (supply and demand side)

Analyse the scale and timing of strategic alternatives required to address infrastructure needs

- Exploring investment and policy options and trade-offs
- Prioritising investments
- Identifying key investment decision points

NNA – Energy Sector Decision Points



Key Decision Points

A	Commitment to new nuclear at build rate of 1.5GW/year. Traditional or modular design
B	New gas supply infrastructure required: Domestic, LNG or continental imports
C	Commitment to CCS to meet carbon targets and keep options open for a gas future
D	Implement pilot CCS projects
E	Commit to portfolio of low carbon renewables. Includes 50GW of offshore wind by 2050
F	Implement tidal energy pilot projects
G	Commit to R&D for energy storage to enable long-term benefit
H	Deploy storage as part of a managed grid to fully exploit intermittent renewables
I	Commit to R&D for the smart grid to enable long-term benefit
J	Deploy smart grid with storage to enable demand management and renewables integration
K	Introduce demand management schemes using enabling technologies
L	Commit to long-term energy efficiency improvements.

NISMOD Process

Recommend adaptive pathways of policies and investments

- Iterative process towards a final recommendation
- Developing adaptive pathways relevant to context:
  - Acknowledging that goals could be at multiple scales
  - .. involve multiple-actors
  - … and multiple criteria (not all of which are included in the model)

SUSTAINABLE DEVELOPMENT GOALS

NISMOD: National Infrastructure Systems MODel

The NISMOD assessment process

- Define the current system
- Review the possible future needs for infrastructure services
- Develop the long term vision for national infrastructure
- Identify strategic alternatives for delivering the vision
- Analyse the scale and timing of strategic alternatives required to address infrastructure needs
- Recommend adaptive pathways of policies and investments

The NISMOD assessment platform

NISMOD assessment platform

1. Geographical system definition
2. Needs for infrastructure services
3. Infrastructure system functionality
4. Strategies for infrastructure provision

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1. Geographical system definition

A set of GIS layers that set out the current infrastructure system and the contextual factors relevant to that system.

1a Infrastructure system:

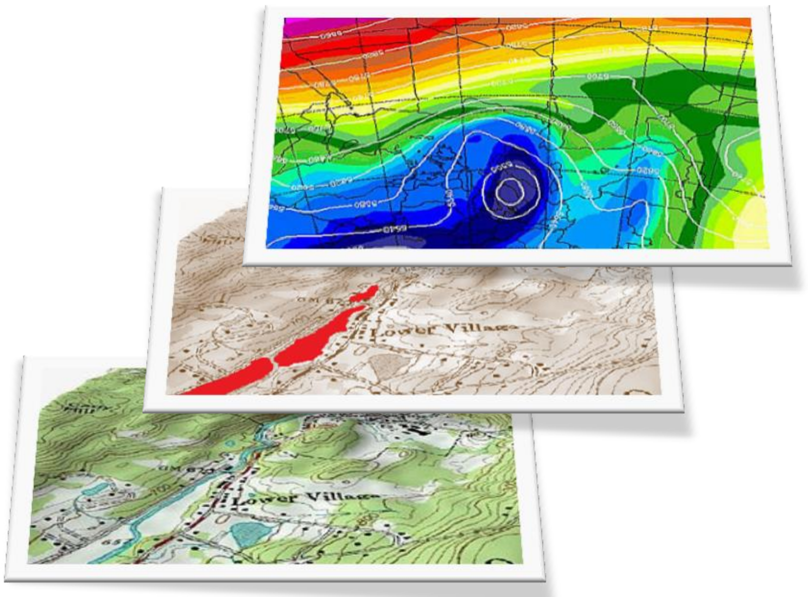
- Asset and network layers for infrastructure sectors: energy, transport, digital coms, water, waste)
- Asset characteristics: capacity, condition, age

1b Geographical context:

- Maps, photos
- Topography
- Geospatial environmental data e.g. natural hazards

1c Socio-economic data:

- Population (geographical)
- Economic activities (including government and social)



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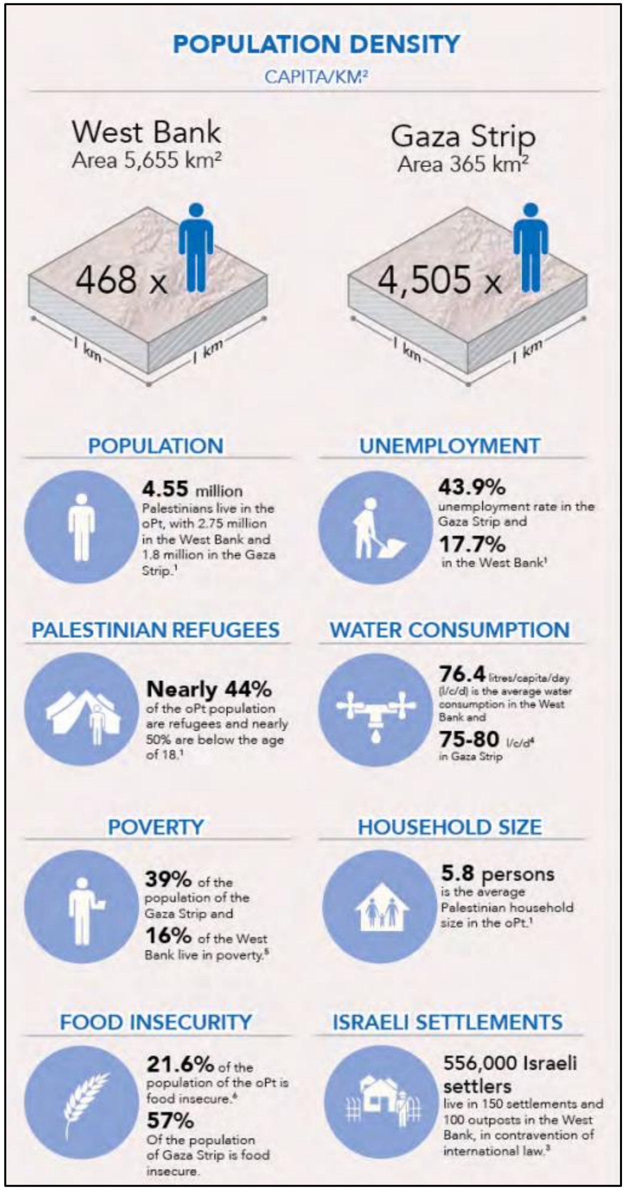
2. Needs for infrastructure services



2a Present needs for infrastructure services

- Per capita demands
- Per unit demands from the economy

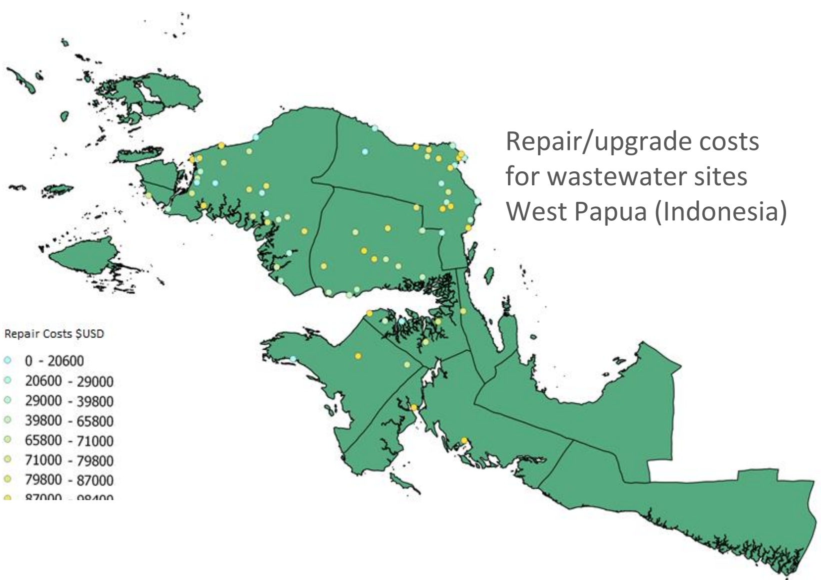
2b Drivers of future needs

- Scenarios of future population and economic status
- Scenarios of climate change

3. Infrastructure system functionality

Geographical Asset/network representation of system function, based on the data in 1a.

- Supply points i.e. energy, water, waste water, solid waste
- Connectivity capacity and current usage e.g. capacity and usage of highway network
- Allocation of demand to assets (sink sites) and network.
- Source-sink connectivity



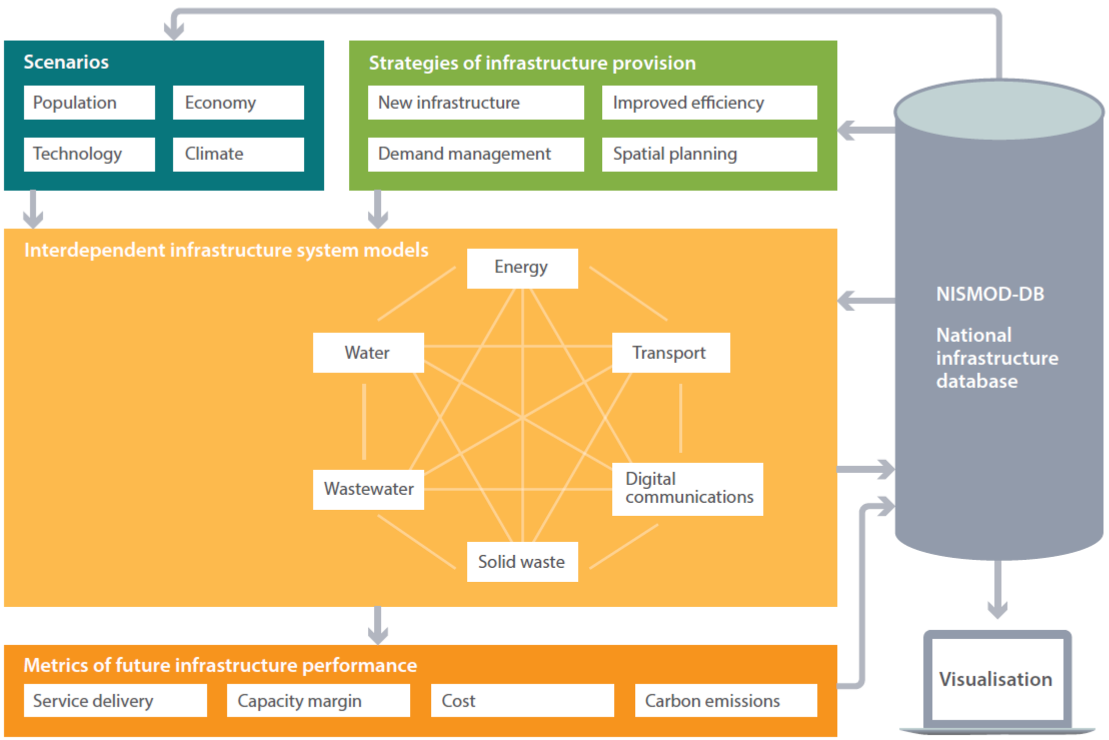
Repair/upgrade costs for wastewater sites West Papua (Indonesia)

This will enable:

- A definition of current capacity margins. Where are the capacity constraints, at present and in the future.
- Analysis of network vulnerabilities and infrastructure hotspots

4. Strategies for infrastructure provision

- Vision and goals for the infrastructure system (levels of ambition)
- Sector-specific targets
- Investment and policy options (supply and demand side)
- Analyse options to achieve goals/targets, including possible variants
- Estimate costs: capital, operation, environmental



NISMOD:
National
Infrastructure
Systems
MODel

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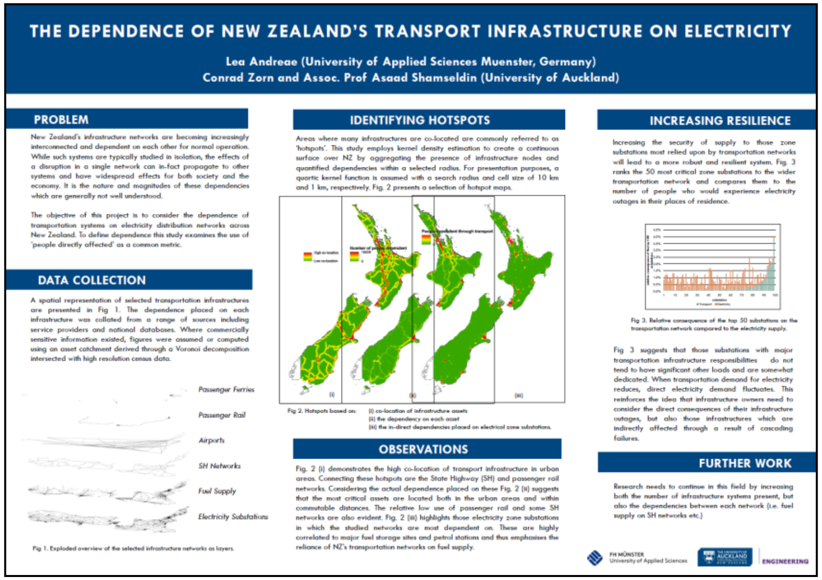
Current international applications

New Zealand



THE DEPENDENCE OF NEW ZEALAND'S TRANSPORT INFRASTRUCTURE ON ELECTRICITY

Lea Andreae (University of Applied Sciences Muenster, Germany)
Conrad Zorn and Assoc. Prof Asaad Shamseldin (University of Auckland)

PROBLEM

New Zealand's infrastructure networks are becoming increasingly interconnected and dependent on each other for normal operation. While such systems are typically studied in isolation, the effects of a disruption in a single network can in-fact propagate to other systems and have widespread effects for both society and the economy. It is the nature and magnitudes of these dependencies which are generally not well understood.

The objective of this project is to consider the dependence of transportation systems on electricity distribution networks across New Zealand. To define dependence this study examines the use of 'people directly affected' as a common metric.

DATA COLLECTION

A spatial representation of selected transportation infrastructures are presented in Fig 1. The dependence placed on each infrastructure was collated from a range of sources including service providers and national databases. Where commercially sensitive information existed, figures were assumed or computed using an asset catchment derived through a Voronoi decomposition intersected with high resolution census data.

Passenger Ferries
Passenger Rail
Airports
SH Networks
Fuel Supply
Electricity Substations

Fig 1. Exploded overview of the selected infrastructure networks as layers.

IDENTIFYING HOTSPOTS

Areas where many infrastructures are co-located are commonly referred to as 'hotspots'. This study employs kernel density estimation to create a continuous surface over NZ by aggregating the presence of infrastructure nodes and quantified dependencies within a selected radius. For presentation purposes, a quartic kernel function is assumed with a search radius and cell size of 10 km and 1 km, respectively. Fig. 2 presents a selection of hotspot maps.

Fig 2. Hotspots based on: (i) co-location of infrastructure assets
(ii) the dependency on each asset
(iii) the in-direct dependencies placed on electrical zone substations.

OBSERVATIONS

Fig. 2 (i) demonstrates the high co-location of transport infrastructure in urban areas. Connecting these hotspots are the State Highway (SH) and passenger rail networks. Considering the actual dependence placed on these Fig. 2 (ii) suggests that the most critical assets are located both in the urban areas and within commutable distances. The relative low use of passenger rail and some SH networks are also evident. Fig. 2 (iii) highlights those electricity zone substations in which the studied networks are most dependent on. These are highly correlated to major fuel storage sites and petrol stations and thus emphasises the reliance of NZ's transportation networks on fuel supply.

INCREASING RESILIENCE

Increasing the security of supply to those zone substations most relied upon by transportation networks will lead to a more robust and resilient system. Fig. 3 ranks the 50 most critical zone substations to the wider transportation network and compares them to the number of people who would experience electricity outages in their places of residence.

Fig 3. Relative consequence of the top 50 substations on the transportation network compared to the electricity supply.

Fig 3 suggests that those substations with major transportation infrastructure responsibilities do not tend to have significant other loads and are somewhat dedicated. When transportation demand for electricity reduces, direct electricity demand fluctuates. This reinforces the idea that infrastructure owners need to consider the direct consequences of their infrastructure outages, but also those infrastructures which are indirectly affected through a result of cascading failures.

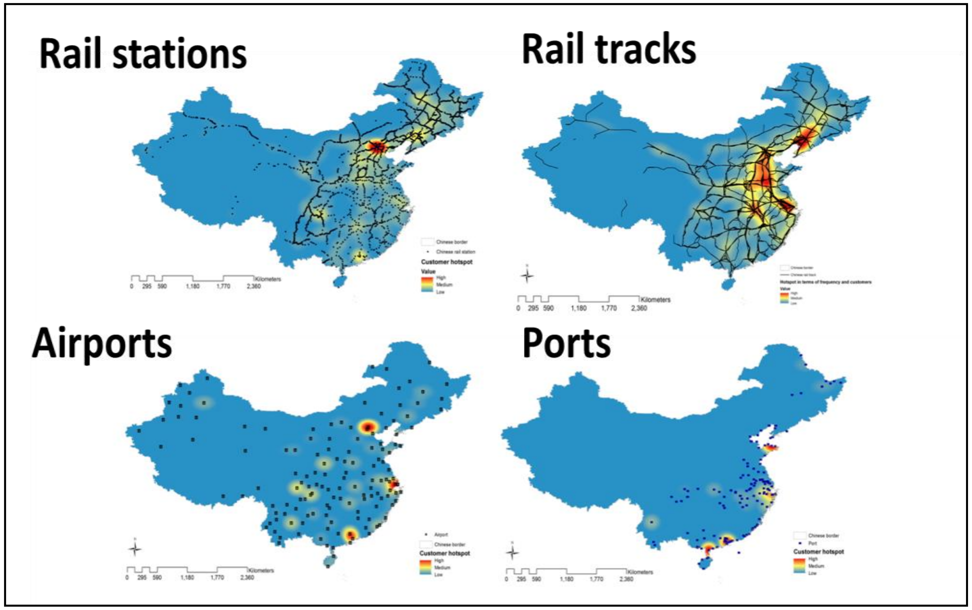
FURTHER WORK

Research needs to continue in this field by increasing both the number of infrastructure systems present, but also the dependencies between each network (i.e. fuel supply on SH networks etc.)

FH MÜNSTER University of Applied Sciences
THE UNIVERSITY OF AUCKLAND
ENGINEERING

Dubai

China



Palestine

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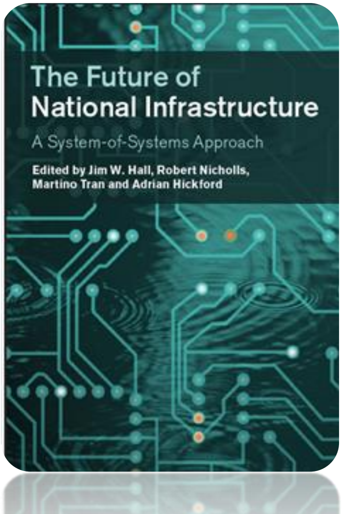
Summary

- A system-of-systems infrastructure assessment framework
- Consisting of a development process and a modelling platform (NISMOD)
- Assess infrastructure risks/costs through resilience and robustness analysis
- Incorporates uncertainty around socio-economic and climatic change
- Develop a vision for national infrastructure provision
- A platform to enable discussions around priorities and value for money
- Capacity to provide evidence-based advice to ‘build back better’



Any questions? Please contact me at:
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1991–2016 25 Anniversary
Celebrating 25 Years of the Environmental Change Institute
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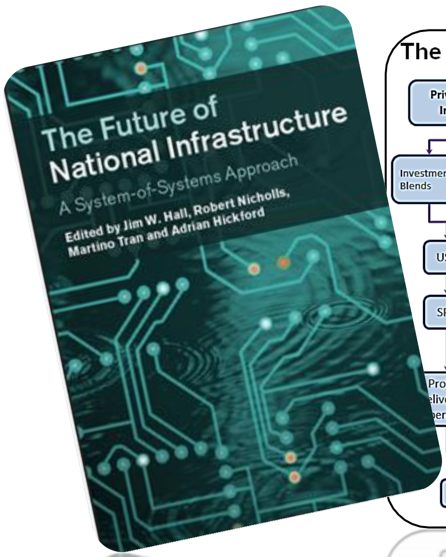

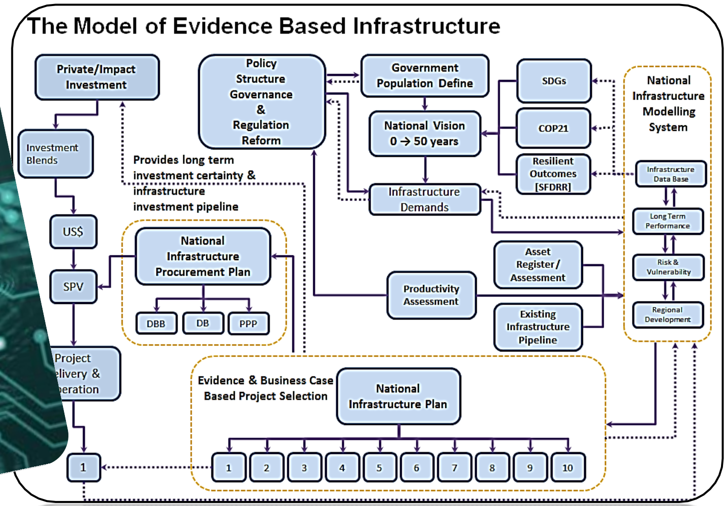

Evidence Based Infrastructure Development

1991–2016 25 Anniversary
Celebrating 25 Years of the Environmental *Change* Institute
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"We Are the First Generation that Can End Poverty, the Last that Can End Climate Change"

- UN Secretary General Ban Ki-moon

$70,000,000,000,000

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COP21 • CMP11
PARIS 2015
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UN CLIMATE CHANGE CONFERENCE

SUSTAINABLE DEVELOPMENT GOALS

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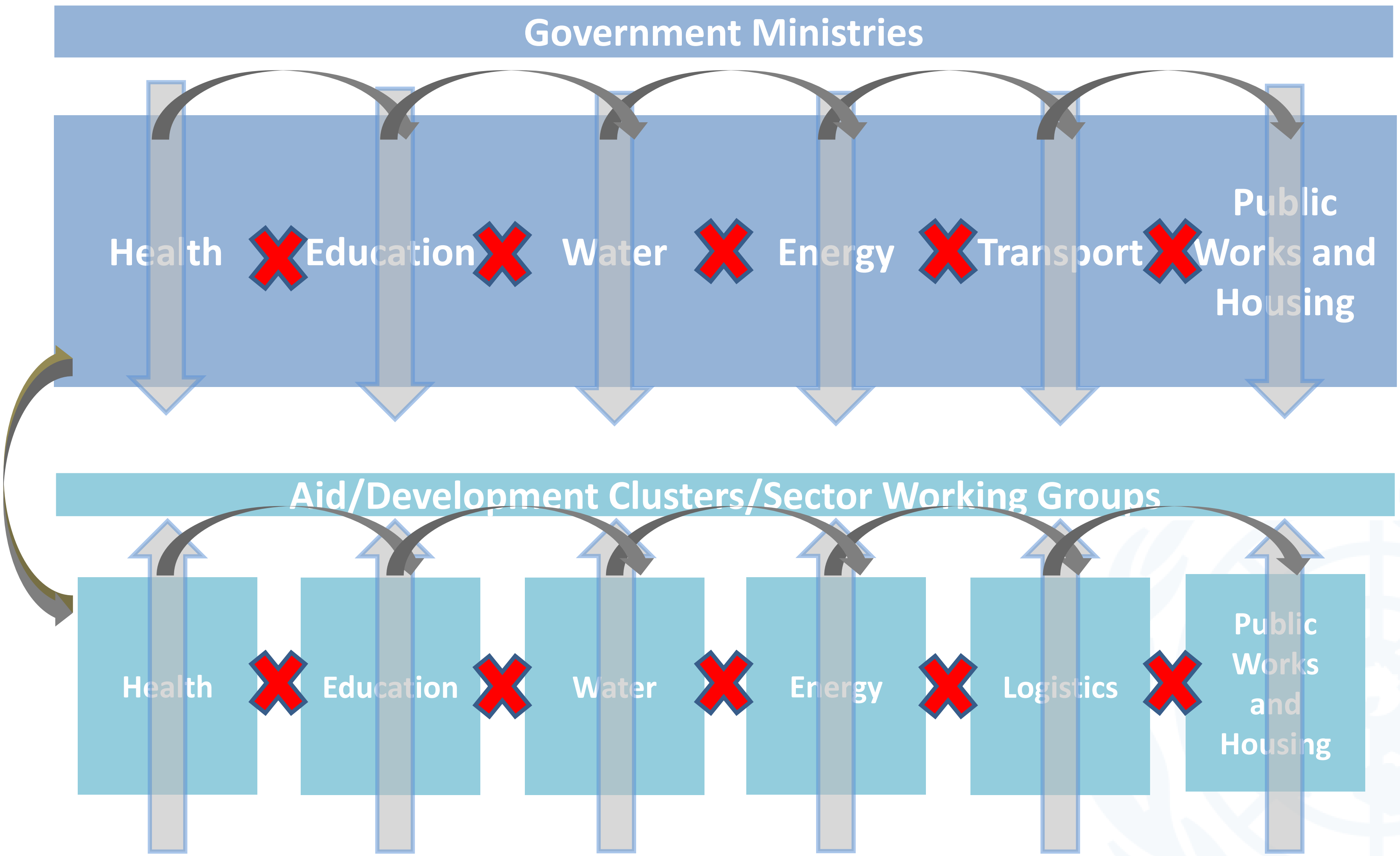
The Silo Approach



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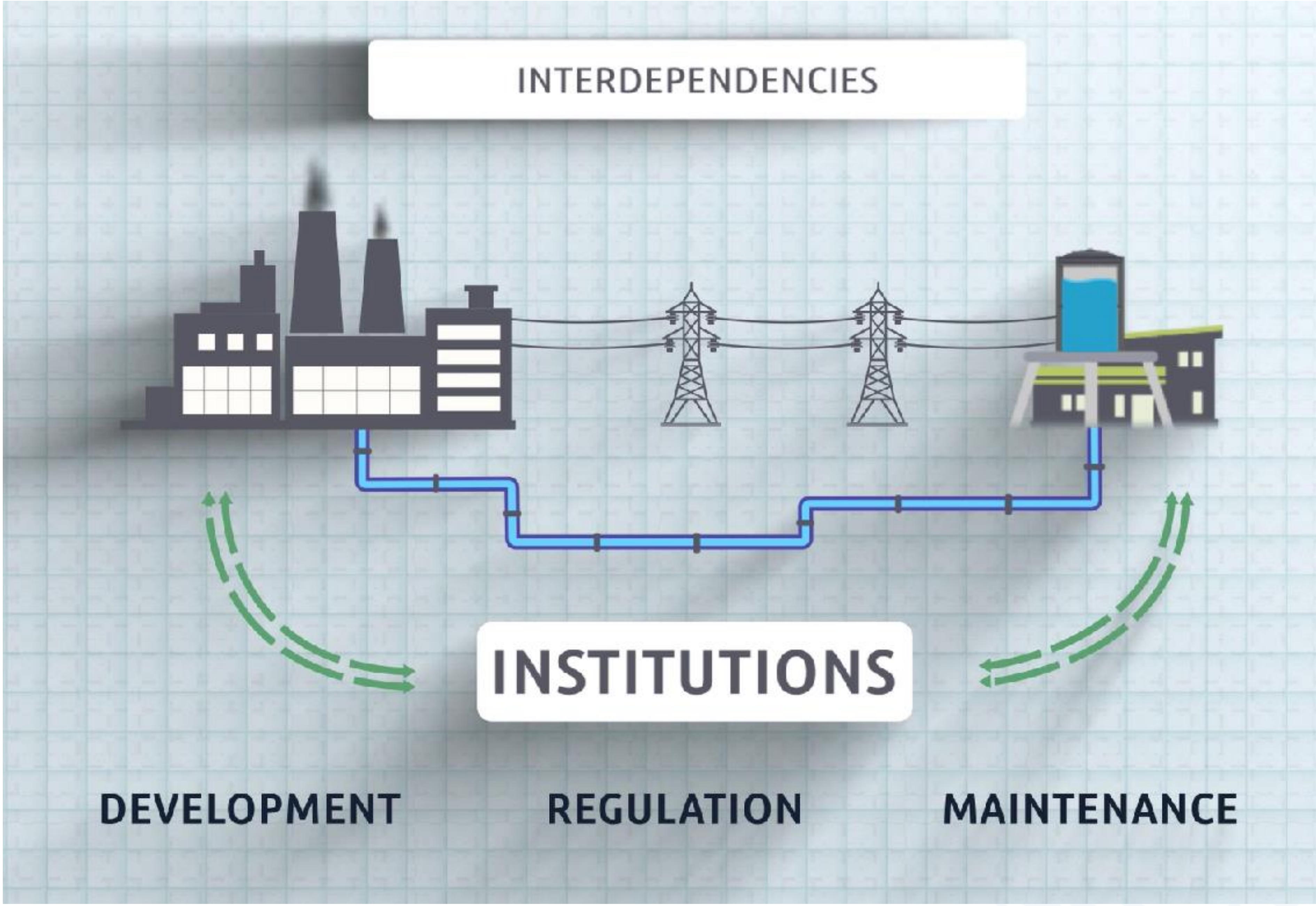
INTERDEPENDENCIES
INSTITUTIONS
DEVELOPMENT
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MAINTENANCE

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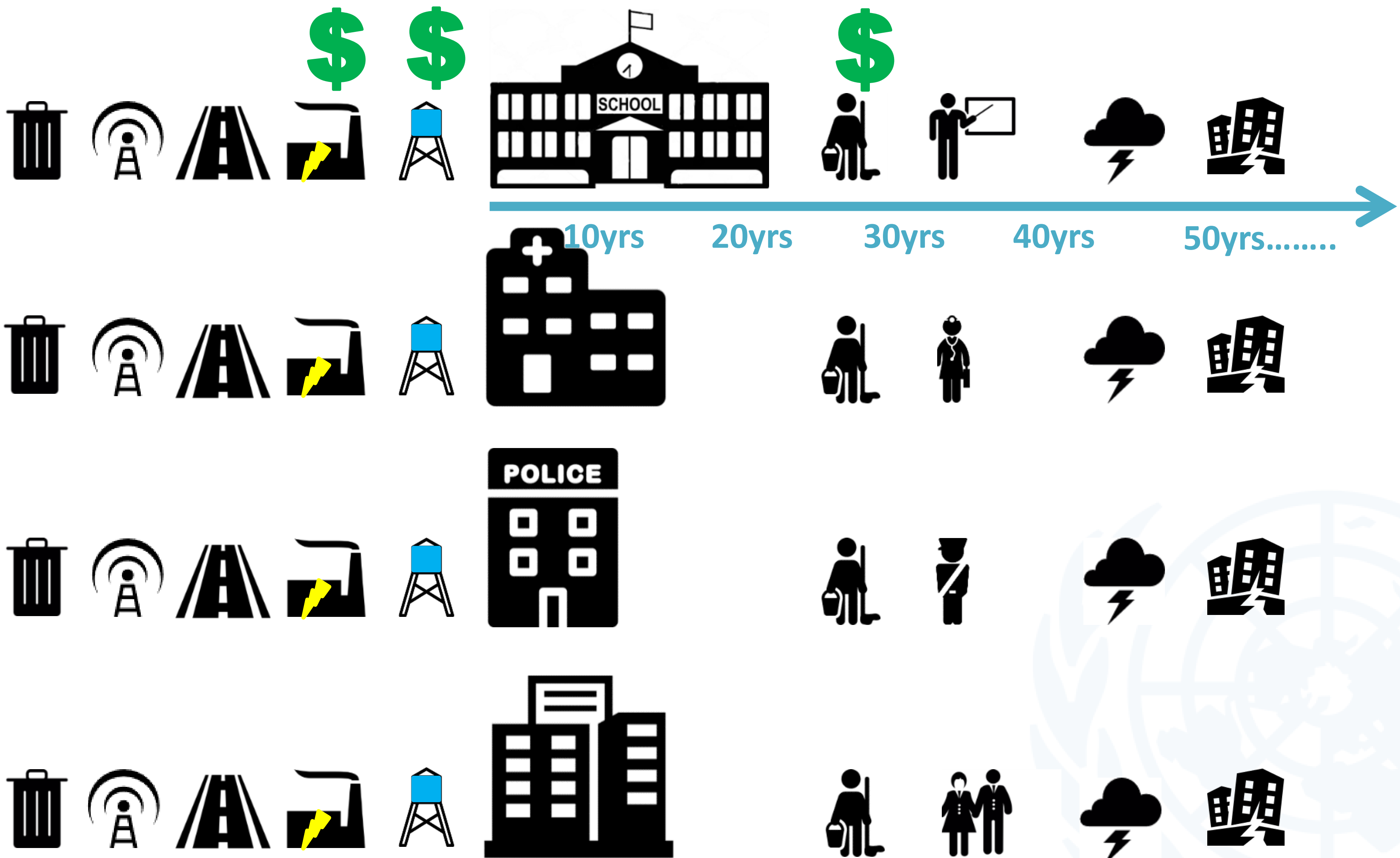
Interdependencies



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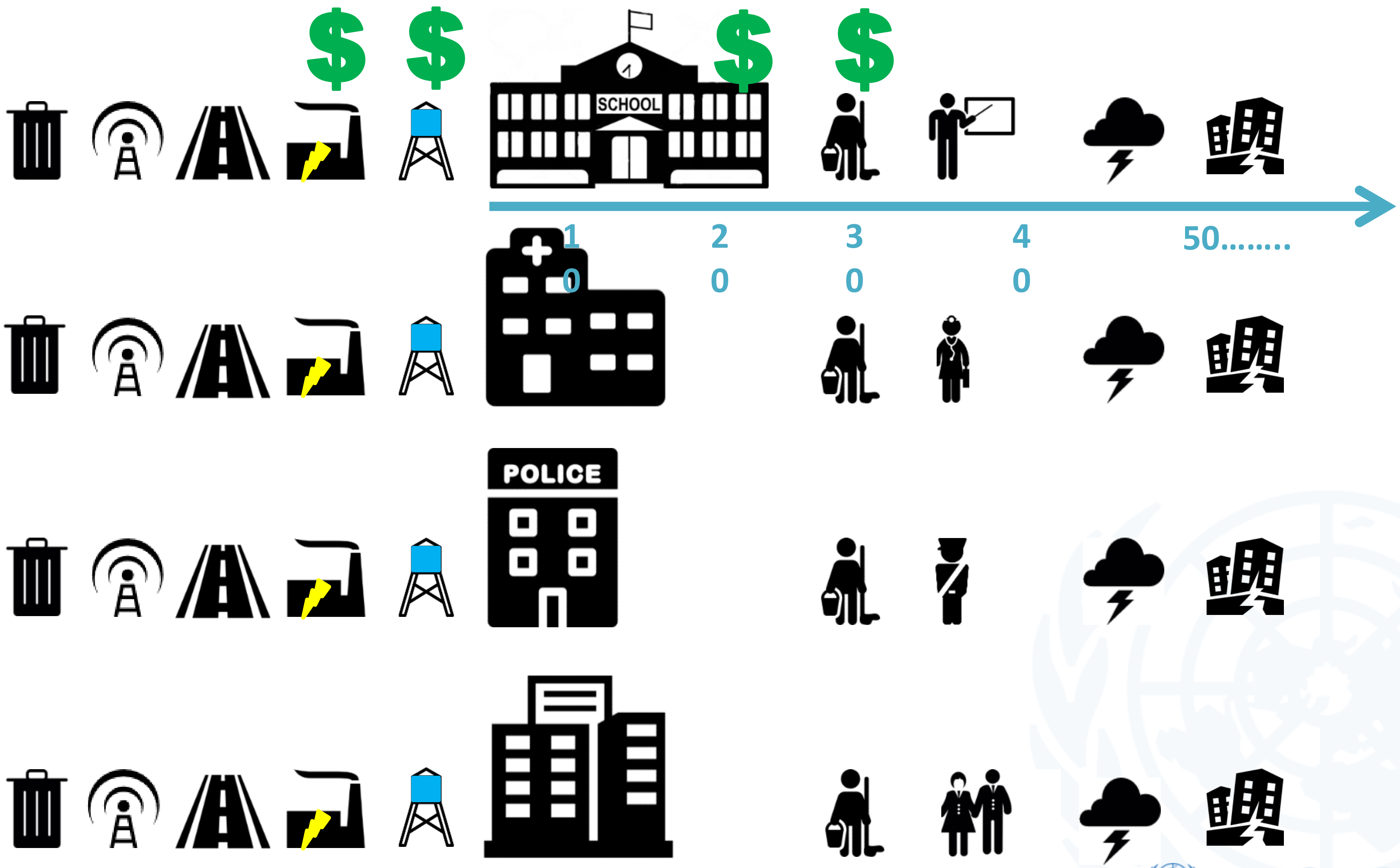
Interdependencies



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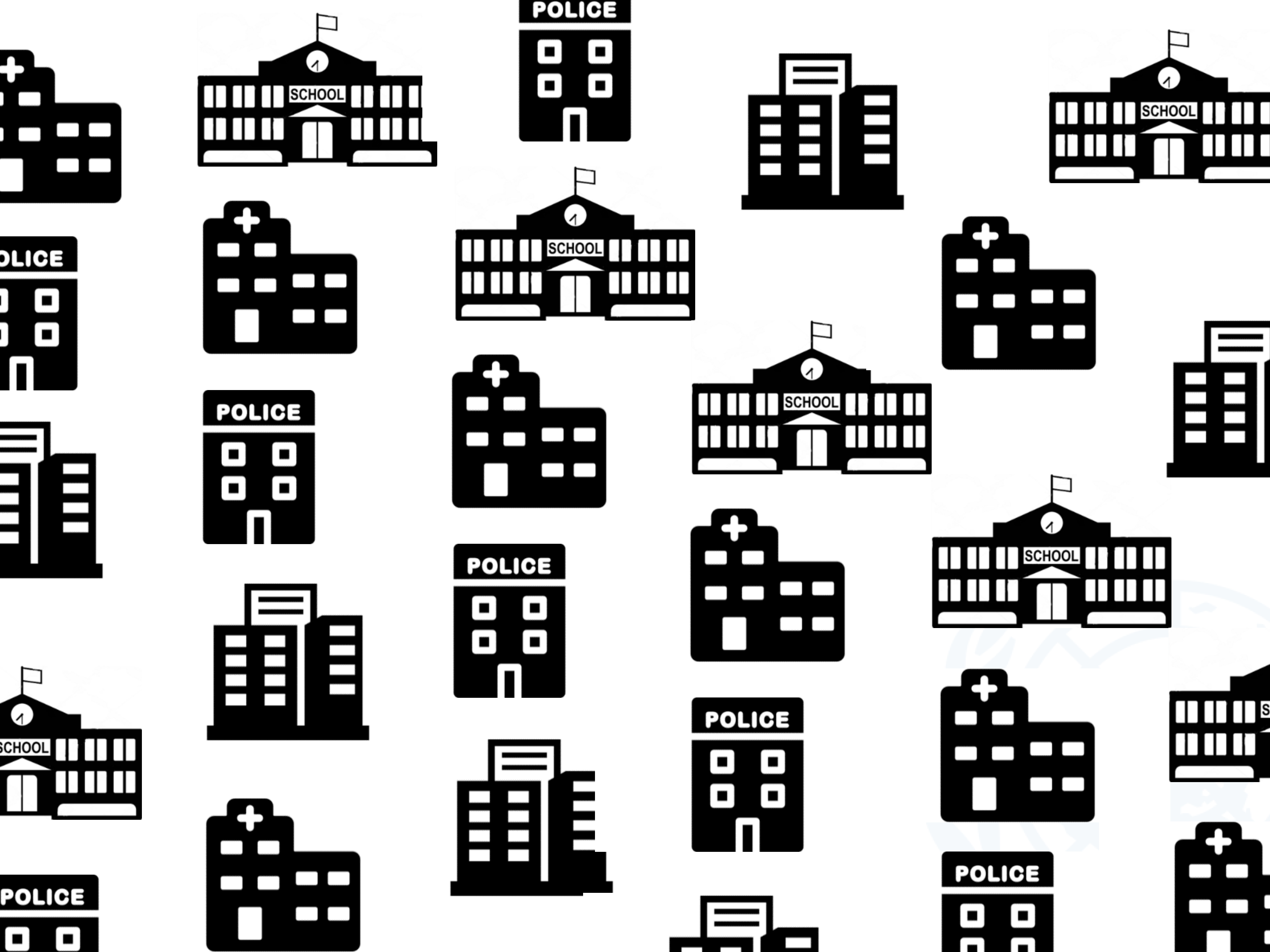
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Failed projects wasted opportunities

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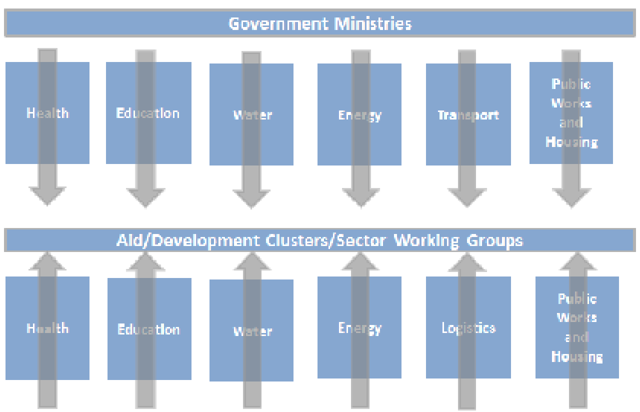
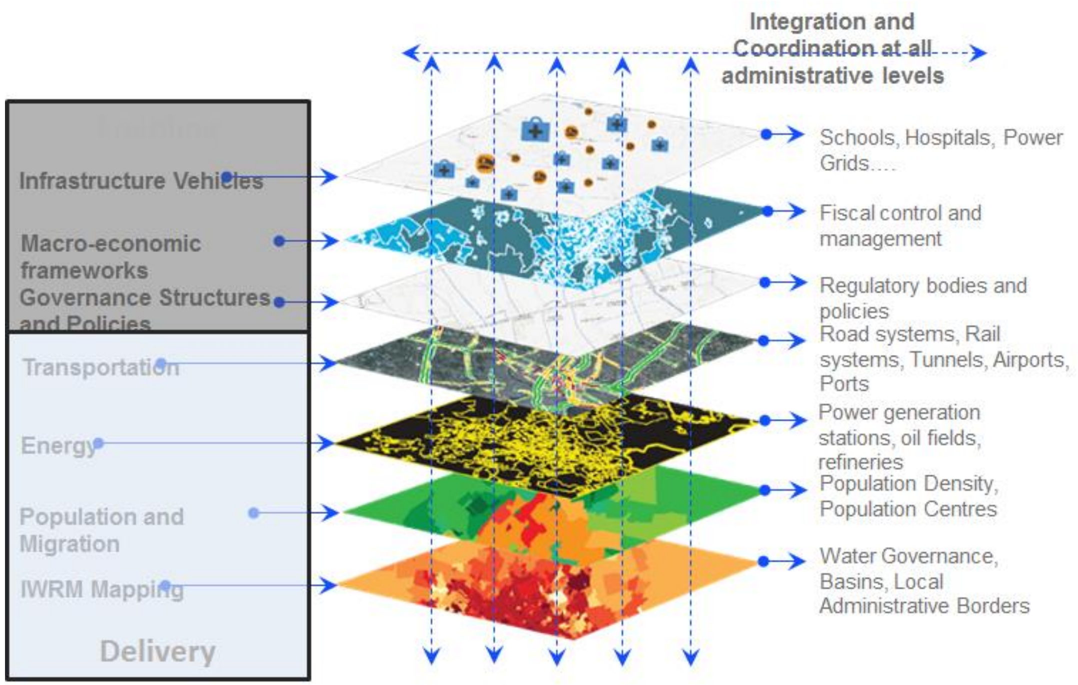
Paradigm Shift

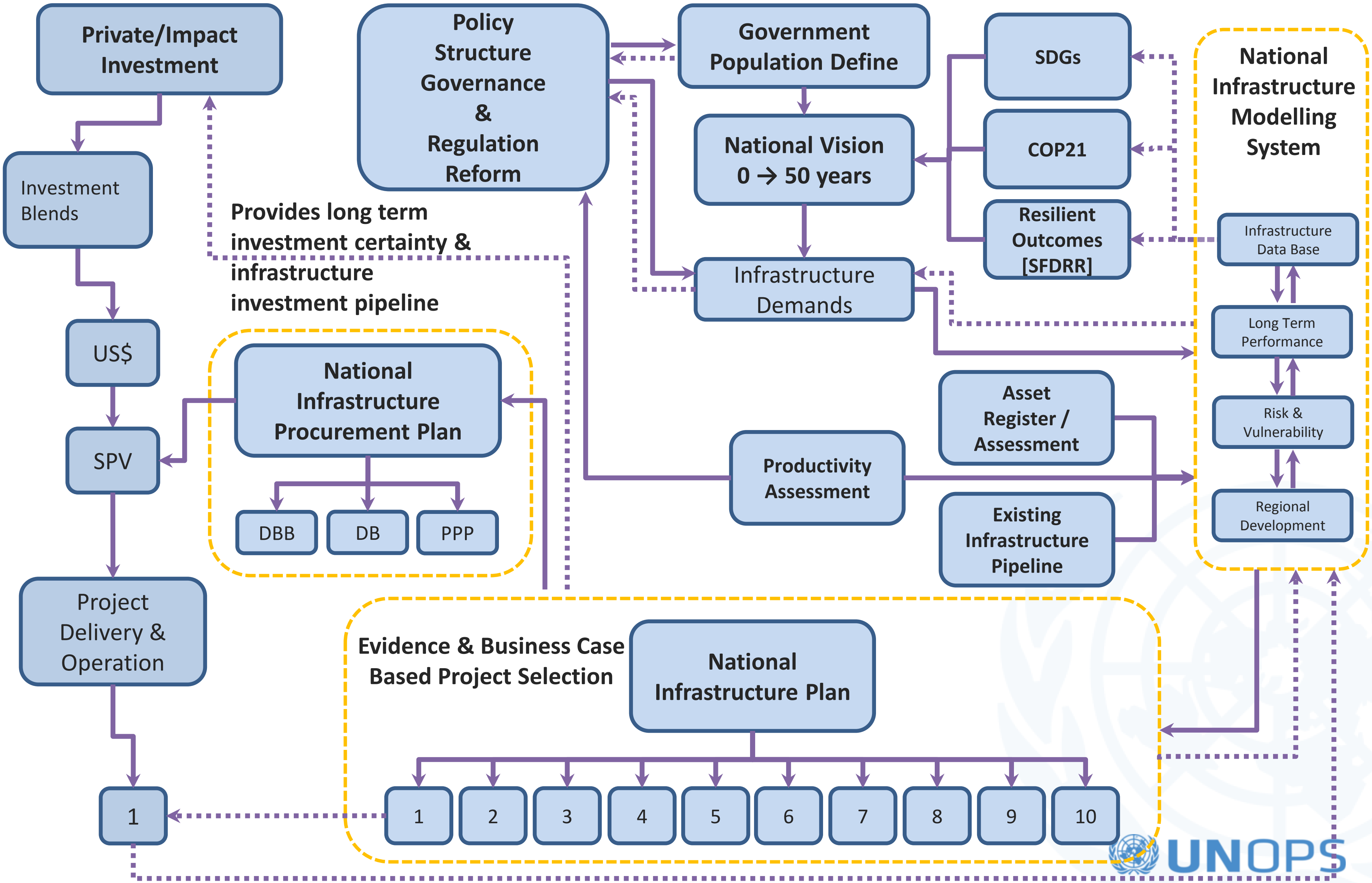
"We can no longer afford to work in Silo's"

- UN Secretary General Ban Ki-moon





The Model of Evidence Based Infrastructure Development



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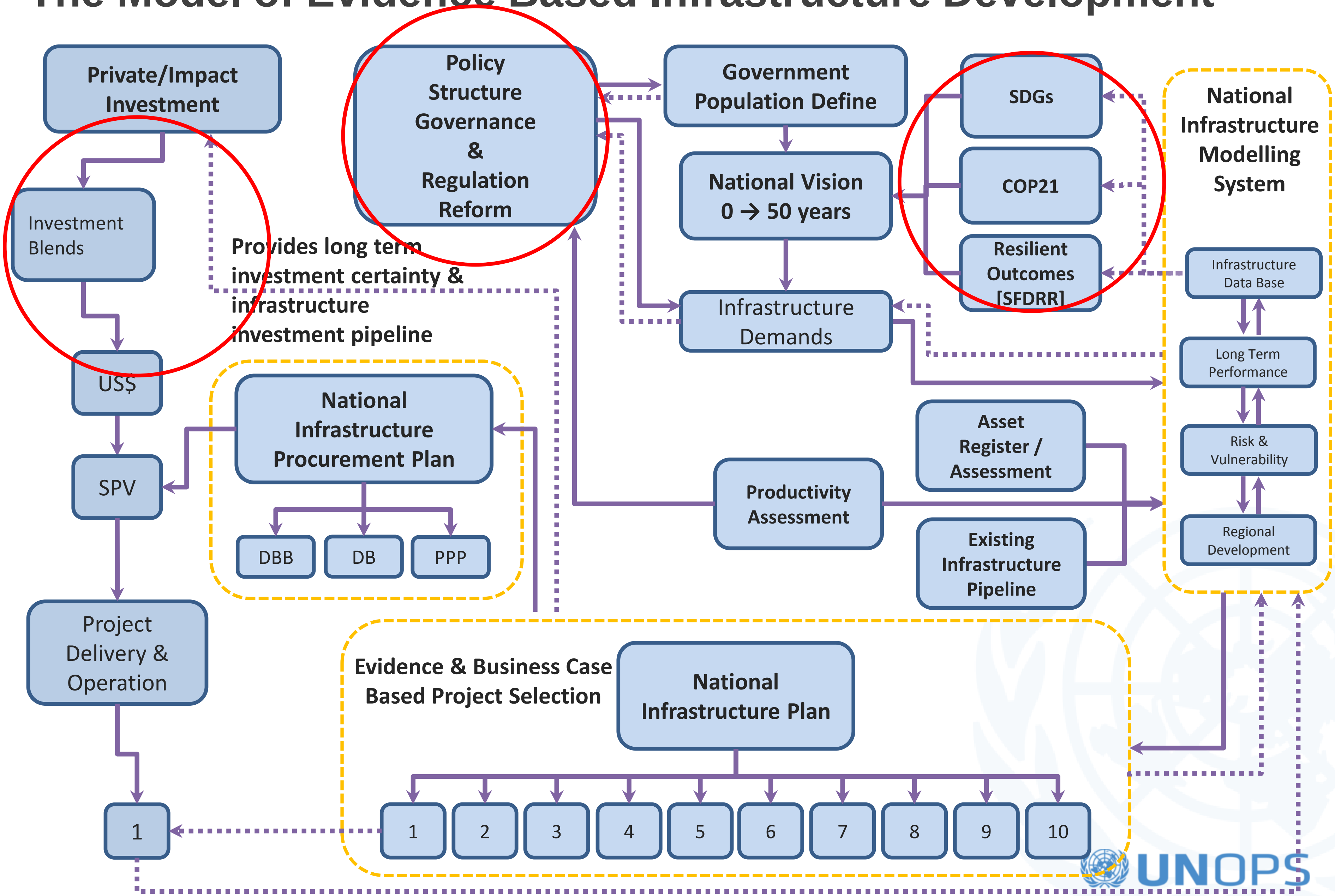
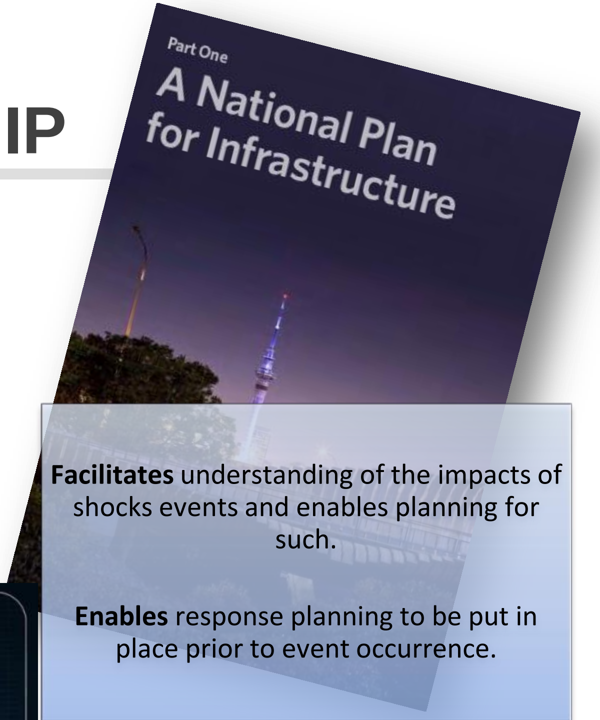


Benefits of Long Term Planning and NIP



Provides long term certainty for investment decision making:

Absolute requirement to attracting private sector investment at scale.

De-links political will and interest from the decision making and investment in infrastructure.

Links infrastructure development to the long term socio-economic improvement and development of countries.

Facilitates understanding of the impacts of shocks events and enables planning for such.

Enables response planning to be put in place prior to event occurrence.

Is flexible and should be continuously updated:

"No plan survives first contact."

Ability to effectively plan for and achieve SDG and COP21 requirements.

Enables evidence based decision making for sound infrastructure investments that maximise socio economic benefit and protect the environment

Working to support Varying Capacities

Must Have

Nice to Have

Best to Have

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“Let us move from silos to synergy, supported by data, long-term planning and a will to do things differently.”

- UN Secretary General Ban Ki-moon

Questions?