Multi-level vulnerability analysis of the Dutch electricity infrastructure to extreme weather events

L. Andrew Bollinger

PhD candidate
Faculty of Technology, Policy & Management
Delft University of Technology
The Netherlands

Supervisors:
Prof. Dr. M.P.C. Weijnen
Dr. G.P.J. Dijkema
Dr. I. Nikolic

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Deltas in Times of Climate Change II
Rotterdam, The Netherlands

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Knowledge for Climate

Problem

Climate change and electricity infrastructures

2012 Hurricane Sandy (USA)
8.5 million customers without power

2012 blackouts in India
620 million people without power

2013 Christmas floods (UK)
50,000 homes without power
Partial loss of electricity at Gatwick Airport

2003 European heat wave
France shuts down the equivalent of 4 nuclear power stations
"Code red" situation in the Netherlands

Research question: How can we support the development of a climate-resilient electricity infrastructure in the Netherlands?

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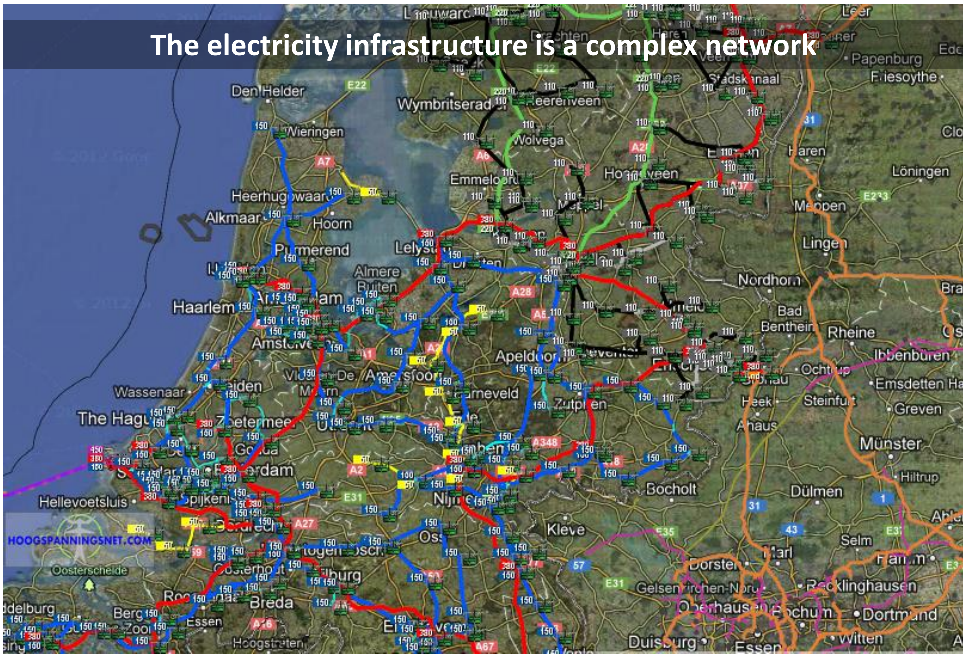
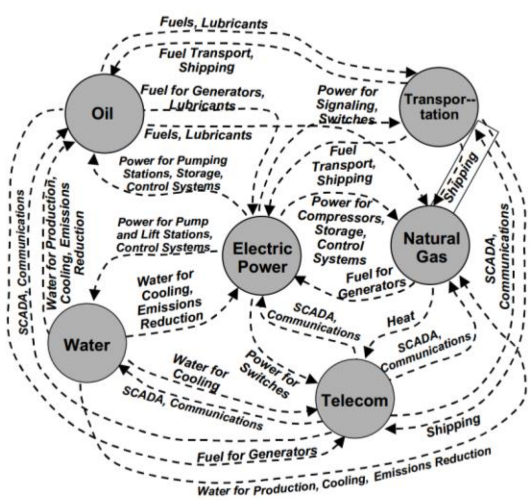
First…



Second...

The electricity infrastructure has interdependencies with other infrastructure networks



Source: Little, 2004

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2 case studies

1. **Assessing the extreme weather resilience of the Dutch electricity transmission infrastructure** (Complexity of the electricity infrastructure)
2. **Assessing the flood vulnerability of a multi-infrastructure system in North Rotterdam** (Interdependencies of the electricity infrastructure)

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Case study 1

The Dutch electricity transmission infrastructure

- One of the most reliable electricity systems in Europe
- Average interruption time (2010) = 33.7 minutes[1]
- In 2012, weather caused only 0.6 % of total interruptions[2]

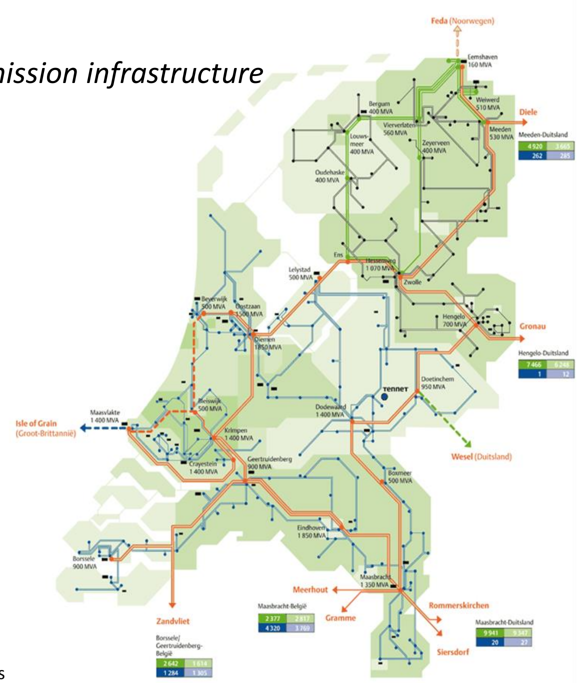

Image source: TenneT TSO

[1] Compared to a European average of 112 minutes
[2] Source: Netbeheer Nederland and Movares Energy, 2013

Case study 1
Floods & heat waves

Image source: National Grid, 2010

Flood vulnerability
of electrical substations

Possible adaptation:
Enhanced substation flood defenses

Possible adaptation:
Demand-side management

Heat wave vulnerability
of power plants

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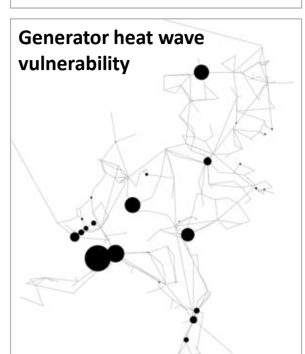
Analysis of vulnerability of infrastructure components

1. Substation flood vulnerability

- Based on maximum projected water depths under a range of flood scenarios and the protection heights of substations.



2. Generator heat wave vulnerability

- Accounts for generator type, cooling water source (coastal/inland) and cooling equipment

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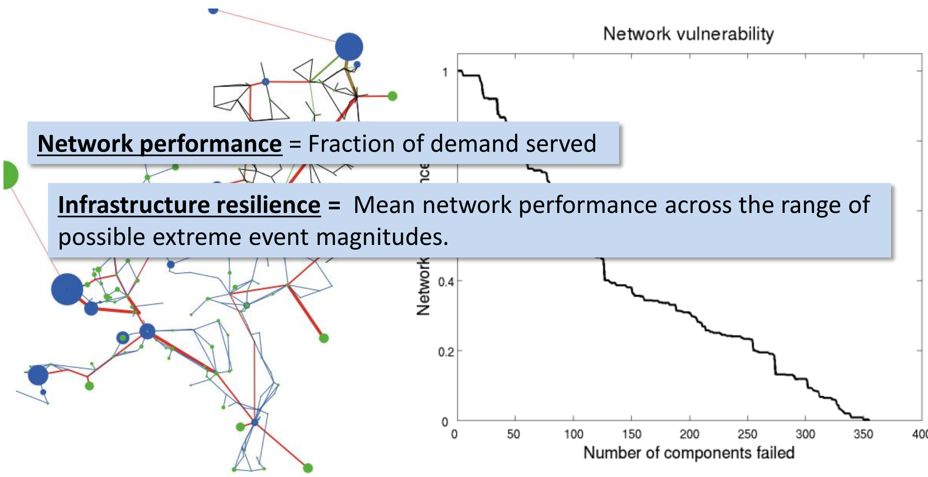
Technique – structural vulnerability analysis

Involves evaluating patterns of degradation in network performance resulting from successive component failures.



<u>Network performance</u> = Fraction of demand served

<u>Infrastructure resilience</u> = Mean network performance across the range of possible extreme event magnitudes.

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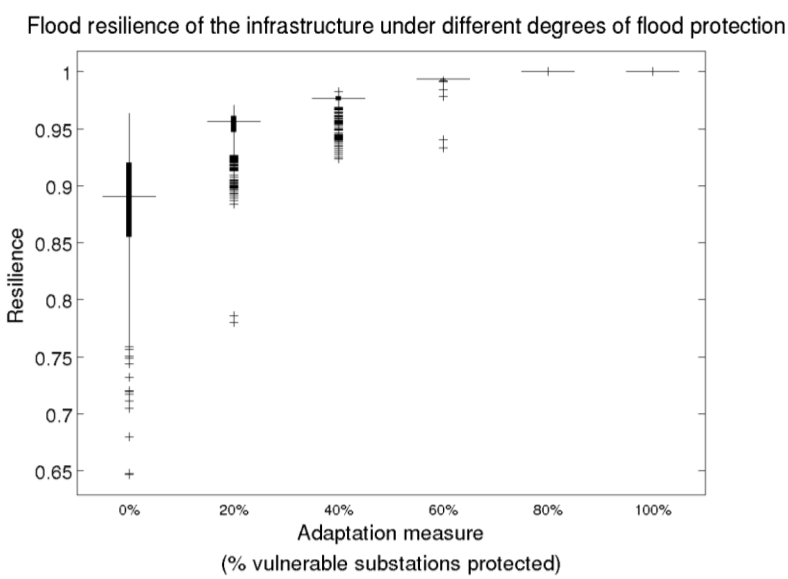
Flood resilience assessment results



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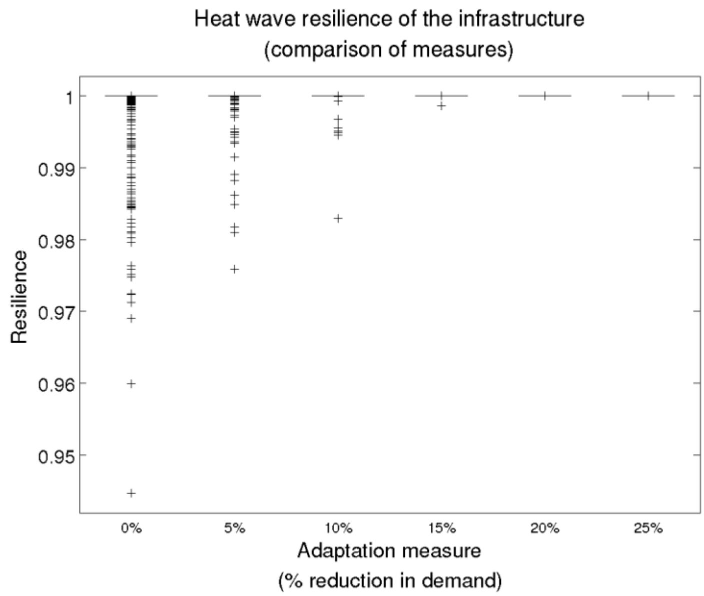
Heat wave resilience assessment results



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Case study 1 – Conclusions

1. The modeled infrastructure displays :
   - some vulnerability to both flood and heat wave events,
   - less vulnerability to heat wave events than flood events.
   - a generally high level of resilience
2. Most of the tested adaptation measures demonstrate a clear ability to reduce or eliminate vulnerability.
3. The tested adaptation measures show decreasing returns with increasing degrees of adaptation.

Limitations:

- Exclusion of distribution grids and their flood protection levels
- Assumptions in assessing component vulnerability (e.g. substation protection heights)
- Ignore certain aspects of power system dynamics (e.g. short circuit currents, power system harmonics)

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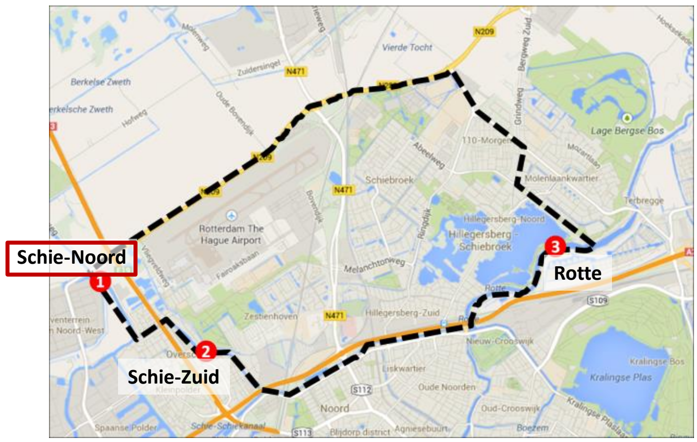
Case study 2

Analysis of the effects of infrastructure interconnectedness in the case of a North Rotterdam dike breach

Study area and studied dike breach locations



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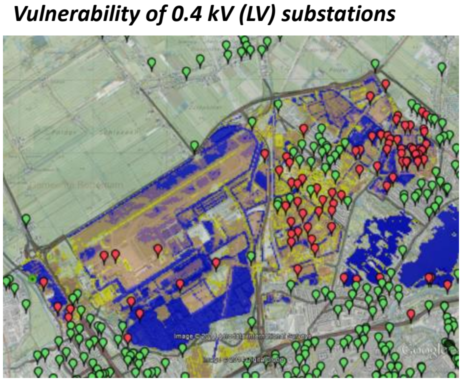
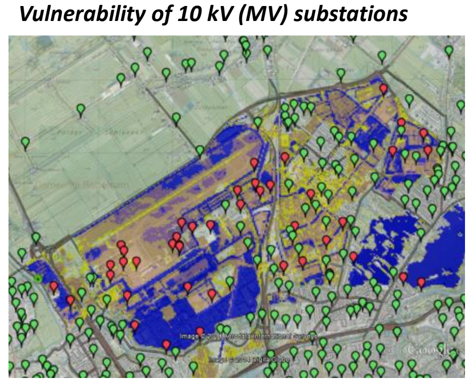
Analysis of substation flood vulnerability

Vulnerability of 0.4 kV (LV) substations



85 substations vulnerable

Vulnerability of 10 kV (MV) substations



42 substations vulnerable

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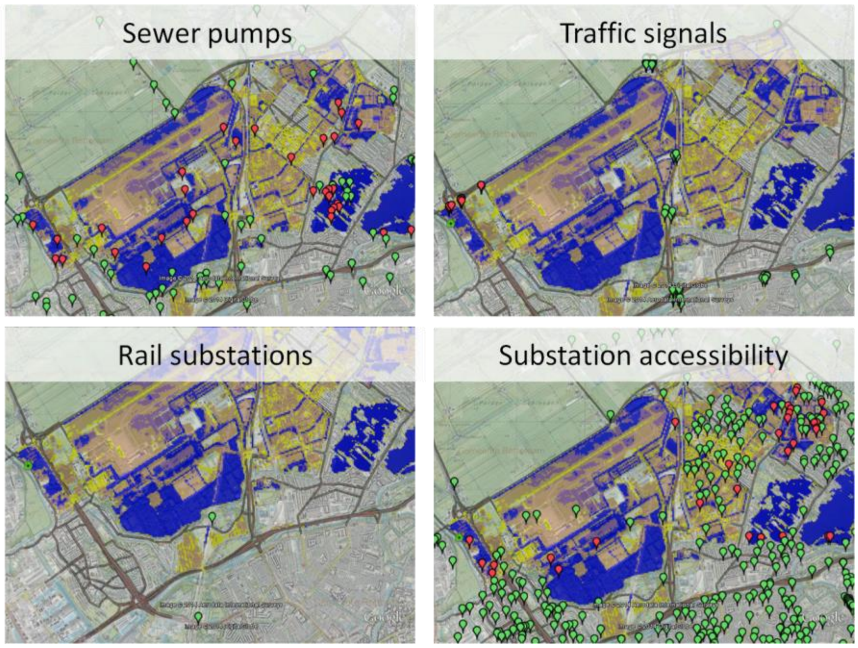
Secondary infrastructure vulnerabilities



Case study 2 – Key results

In the case of an extended Schie-Noord dike breach (>120hrs):

- A significant proportion of both MV and LV substations are vulnerable.
- A significant proportion (~23%) of sewer pumps in the study region could lose grid power.
- 6 traffic signals in the west corner of the study region could lose grid power.
- The 2 rail substations in the study region are not likely to be affected.
- A handful of LV and MV substations could be inaccessible by road (preliminary result).

Possible measures:

- Portable (temporary) sewer pumps
- Backup power to traffic signals
- Portable (temporary) generators
- Remote shutdown capability of low-voltage substations

Some overall recommendations

1. Assess the flood protection levels of electrical substations
In reducing the vulnerability of the electricity infrastructure to floods, substations should be a key element of focus.

2. Promote investments in distributed generation
Distributed generation improves the geographical diversity of electricity production and reduces the average network distance between locations of generation and consumption, both of which reduce vulnerability.

3. Encourage reductions in electricity demand (growth)
Low rates of demand growth lead to greater levels of buffer capacity in transmission and generation, reducing the system-wide consequences of extreme weather-induced failures.

4. Simulate multi-infrastructure systems
Simulation is essential to facilitate the identification of robust measures for fostering resilient multi-infrastructure systems.

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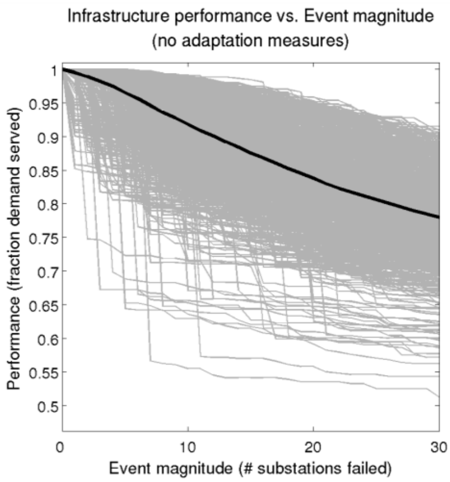
Contact:

L. Andrew Bollinger
Delft University of Technology
Faculty of Technology, Policy and Management
Email: L.A.Bollinger@tudelft.nl

Flood resilience assessment results



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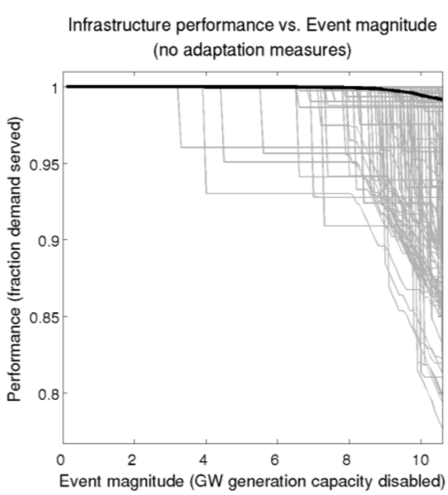
Heat wave resilience assessment results



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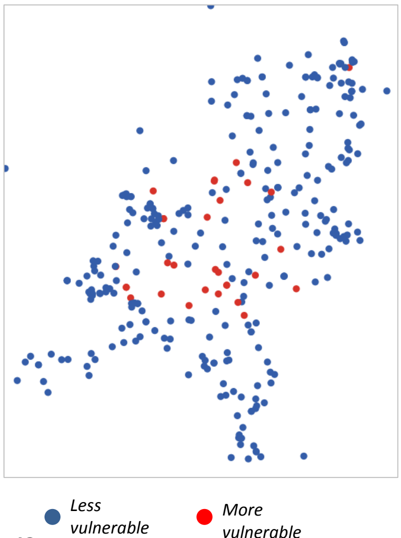
Preliminary analysis of vulnerability of infrastructure components

Flood vulnerability of transmission substations



Heat wave vulnerability of production locations

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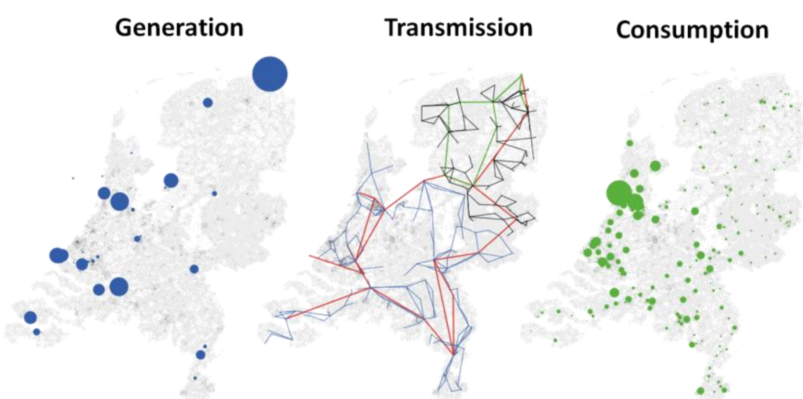
Case study 1 – Representation of the Dutch electricity infrastructure



- *86 generators > 10 MW*
- *402 transmission lines*
- *4 different voltage levels*
- *320 substations*
- *9 interconnectors*
- *238 distribution grids*

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