Foreword

ISNGI 2014 will deliver the opportunity for sharing ongoing research and develop avenues for exploring the grand challenge ‘Can we imagine resilient infrastructure systems that can meet the needs of twice today’s population with half today’s resources while providing better liveability for all?’ The foundation for this event was laid by ISNGI 2013 which was held at the SMART Infrastructure Facility, University of Wollongong, NSW, Australia.

Future infrastructure in all countries needs to be fit for purpose in order to support societal development in a changing world. Present assumptions about how infrastructure systems respond to changing societal needs and factors such as extreme events, security of energy, water and food supply, impact on the economy and exploitation of innovative technology have been challenged and found wanting. Implementation of the vision encompassed by ISNGI 2014 will provide leadership and support for the development and growth of a coherent, world class, infrastructure research community, which engages academia, industry and citizens in a joint venture that drives innovation and value creation.

The contributions selected by the Academic and Scientific Committees, who I thank for their hard work and diligent scrutiny, are totally in accord with the ISNGI vision and move the state of knowledge forward to a significant extent.

Attending ISNGI 2014 is an opportunity for everyone involved in infrastructure research and development for the future to meet their peers, engage in cutting edge discussion and ensure that their activities are informed by the best research and thinking in this vital field of endeavour.

I look forward to meeting you at ISNGI 2014 which I know will be a very successful event.

Professor Brian Collins, CB, FREng
Chair Academic Committee, ISNGI 2014
Professor of Engineering Policy, University College London
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Jürgen Czernohorszky
Member of Vienna City Parliament and Specialist in the Smart Cities

Pavel Kabat
Director General and Chief Executive Officer of IIASA, member of the Leadership Council for the United Nations Sustainable Development Solutions Network and Professor of Earth System Science at Wageningen University

Garry Bowditch
Chief Executive Officer, SMART Infrastructure Facility
University of Wollongong

Richard de Neufville
Professor of Engineering Systems and of Civil and Environmental Engineering, Massachusetts Institute of Technology

Angelika Winkler
Deputy Head, Department of Urban Planning and Transport Planning in Vienna

Jim Watson
Professor and Research Director of the UK Energy Research Centre

Peter Bakker
President of the World Business Council for Sustainable Development

Bruce Beck
Professor and Eminent Scholar on Environmental Systems and Analysis
Warnell School of Forestry and Natural Resources, The University of Georgia

Nebojsa Nakicenovic
Deputy Director General and Deputy Chief Executive Officer of IIASA, Professor of Energy Economics at the Vienna University of Technology and Director of Global Energy Assessment (GEA)

Chris Barrett
Executive Director and Professor of Computer Science, Virginia Bioinformatics Institute, Virginia Tech
# Programme

**LOCATIONS**

**Registration**  
Laxenburg Conference Centre Lobby.

**Key Note Presentations**  
Marschallzimmer 1 in Laxenburg Conference Centre.

**Parallel sessions**  
Refer to programme below.

**Breaks and lunches**  
Ovalersaal in the Laxenburg Conference Centre.

**Gala Dinner**  
Restaurant Gallo Rosso which is within walking distance of Laxenburg Palace.

All rooms are located in close proximity to each other. You will have been supplied a map of the site and directions will be clearly signposted to and from each location.

## Tuesday 30 September 2014

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<td>08:30</td>
<td>Registration and breakfast</td>
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<tr>
<td>09:00</td>
<td>Welcome and Introduction from IIASA</td>
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<tr>
<td></td>
<td><strong>Pavel Kabat</strong></td>
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<td>Director General and Chief Executive Officer of IIASA, member of the</td>
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<td>Leadership Council for the United Nations Sustainable Development</td>
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<td>Solutions Network and Professor of Earth System Science at Wageningen</td>
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<td>University</td>
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<tr>
<td>09:15</td>
<td>Opening address, City of Vienna</td>
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<td></td>
<td><strong>Jürgen Czemohorszky</strong></td>
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<td>Member of Vienna City Parliament and Specialist in the Smart Cities</td>
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<td>09:30</td>
<td>ISNGI 2014</td>
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<td></td>
<td><strong>Brian Collins</strong></td>
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<td>Professor of Engineering Policy, UCL and Chair of ISNGI 2014 Academic Committee</td>
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<tr>
<td>09:45</td>
<td>The impact of ISNGI 2013 on Australia’s infrastructure community</td>
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<td><strong>Garry Bowditch</strong></td>
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<td>Chief Executive Officer, SMART Infrastructure Facility, University of</td>
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<td>Wollongong</td>
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<td>10:15</td>
<td><strong>Key Note: Flexibility in engineering design, introduced by Brian Collins</strong></td>
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<td><strong>Richard de Neufville</strong></td>
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<td>Professor of Engineering Systems and of Civil and Environmental</td>
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<td>Engineering, Massachusetts Institute of Technology</td>
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<tr>
<td>10:45</td>
<td><strong>Morning coffee</strong></td>
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<tr>
<td>11:15</td>
<td><strong>Key Note: Smart City Vienna, concept and practice, introduced by Pavel Kabat</strong></td>
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<td><strong>Angelika Winkler</strong></td>
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<td>Resilience and Reliability of Infrastructures</td>
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<td>Infrastructure and the City</td>
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<td>Infrastructure Finance and Economics — Part 1</td>
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<td>Lunch</td>
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<td>13:15</td>
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<tr>
<td>14.15</td>
<td>Launch of ISNGI 2013 conference proceedings</td>
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<td>Key Note: Governing infrastructure interdependencies, introduced by Jim Hall</td>
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## PARALLEL SESSIONS

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<tr>
<td>15.00</td>
<td><strong>Infrastructure Resilience and Performance</strong></td>
<td>Marschallzimmer 1</td>
<td>Liz Varga</td>
<td>Service performance indicators for infrastructure investment</td>
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<td><strong>Infrastructure and the City – Part 2</strong></td>
<td>Gvishiani Room</td>
<td>Nick Tyler</td>
<td>Integrated resource planning for a Chinese urban development</td>
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<td><strong>Infrastructure Finance and Economics – Part 2</strong></td>
<td>Wodak Room</td>
<td>Tim Brady</td>
<td>Financial transmission rights (FTR) as a congestion management scheme in electricity transmission: Strategic behaviour in a coupled FTR — electricity market model</td>
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<td><strong>Visualisation tools for multi-perspective, cross-sector, long-term infrastructure performance evaluation</strong></td>
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<td><strong>Transmission capacity as a Common-Pool Resource: the case of gas interconnector capacity</strong></td>
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<td>16.30</td>
<td><strong>Afternoon tea</strong></td>
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<td>17.00</td>
<td>Panel Discussion: The need for adaptation</td>
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<td><strong>Anne O’Neil, Jeremy Liu, Neil Hoose and Ceasar McDowell</strong></td>
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<td>18.00</td>
<td><strong>Key Note: Title to be confirmed, introduced by Pavel Kabat</strong></td>
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<td><strong>Peter Bakker</strong> President of the World Business Council for Sustainable Development</td>
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<tr>
<td>18.30</td>
<td>Panel Discussion; Moderator Pavel Kabat</td>
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<td><strong>Peter Bakker, Brian Collins, Bruce Beck, Garry Bowditch, Richard de Neufville, Jim Watson, Chris Barrett</strong></td>
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<td>19.00</td>
<td><strong>Drinks followed by Gala Dinner</strong></td>
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**Wednesday 1 October 2014**

**09.00** Welcome address  
Jim Hall  
Professor of Climate and Environmental Risks, Director, Environmental Change Institute, University of Oxford and ISNGI 2014 Academic Committee

**09.15** Key Note: City infrastructure: resilience and antifragility in coupled human-built-natural environments, introduced by JoAnne Bayer  
Bruce Beck  
Professor and Eminent Scholar on Environmental Systems and Analysis, Warnell School of Forestry and Natural Resources, The University of Georgia

**PARALLEL SESSIONS**

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| 09.45 | Infrastructure Interdependence — Part 1     | Marschallzimmer 1 | Jim Hall          | Establishing a common language of infrastructure interdependency  
Neil Carhart  
It's the little things that count…  
Sara Adhitya |
|       | Infrastructure Provision and Social Needs — Part 1 | Gvishiani Room    | Tim Broyd         | Planned adaptation in design and testing of critical infrastructure:  
The case of flood safety in the Netherlands  
Arthur Petersen |
|       | Infrastructure and Extreme Events — Part 1  | Wodak Room        | Pascal Perez      | An analysis of the vulnerability of power grids to extreme space weather using complex network theory  
Roberta Piccinelli |
|       | Adaptation and resilience of interdependent infrastructure systems: a complex systems perspective  
Liz Varga |                     |                   | Simulating impacts of extreme weather events on urban transport infrastructure in the UK  
Alistair Ford |
|       | The coherence problem: Mapping the theory and delivery of infrastructure resilience across concept, form, function, and experienced value  
Paul Jeffrey |                     |                   |                                                                     |
|       | Integrated infrastructure modelling — managing interdependencies with a generic approach  
Beate Dirks |                     |                   |                                                                     |
|       | Consumer and community in the future electricity network: an insight from smart grid projects in Europe  
Julija Vasiljevska |                     |                   |                                                                     |

**11.00** Morning coffee
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<td><strong>Infrastructure Interdependence — Part 2</strong></td>
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<td><strong>Infrastructure Provision and Social Needs — Part 2</strong></td>
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<td><strong>Infrastructure and Extreme Events — Part 2</strong></td>
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<td><strong>Christopher Rogers</strong></td>
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<td><strong>Jennifer Schooling</strong></td>
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<td><strong>Darryl Farber</strong></td>
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<td><strong>Andrew Bollinger</strong> for Yashar Araghi**</td>
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<td><strong>Xi Hu</strong></td>
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<td><strong>Marianne Zeyringer</strong></td>
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<td><strong>Elizabeth Anne Williams</strong></td>
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<td><strong>Pascal Perez</strong></td>
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| 13.00 | **Lunch** |

<p>| 14.00 | <strong>Key Note: Historical evolution of infrastructures and future perspectives: with special focus on energy systems technology, introduced by Margot Weijnen</strong> |
|       | Nebojsa Nakicenovic        |
|       | Deputy Director General and Deputy Chief Executive Officer of IIASA, Professor of Energy Economics at the Vienna University of Technology and Director of Global Energy Assessment (GEA) |</p>
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<td>14.30</td>
<td><strong>Infrastructure Interdependence — Part 3</strong></td>
<td>Patrick Godfrey</td>
<td>Marschallzimmer 1</td>
<td>视频</td>
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<td><strong>Multi-Level and Transnational Governance Issues</strong></td>
<td>Jim Bentley</td>
<td>Gvishani Room</td>
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<td><strong>Special Session: Past and future energy infrastructures in the global south — Perspectives for decentralization</strong></td>
<td>Jennifer Schooling</td>
<td>Wodak Room</td>
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<td>Carbon capture clustering: the case for coordinated approaches to address freshwater use concerns</td>
<td>Edward Byers</td>
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<td>Emergence of district-heating networks; barriers and enablers in the development process</td>
<td>Katy Roelich</td>
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<td>Improving engineering governance for large infrastructure projects</td>
<td>Peter Campbell</td>
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<td>Evaluating the opportunity of a flexible approach in designing the integration of a geothermal energy system in new buildings</td>
<td>Claudio Martani</td>
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<td>奥托夫·K·瓦尔特</td>
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<td>Towards a co-evolutionary model of demographics and infrastructure</td>
<td>Mark Birkin</td>
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<td>西巴斯克·格霍和马蒂亚斯·科普克</td>
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<td>An interdisciplinary approach for the assessment and implementation of resilient and flexible water supply infrastructure under changing or unstable conditions</td>
<td>Wolfgang K Walter</td>
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<td>A system complexity approach to swarm electrification</td>
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<td>16.30</td>
<td><strong>Key Note: Governance, resilience and dynamics of interdependent human populations, introduced by Brian Collins</strong></td>
<td>Chris Barrett</td>
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<td>Chris Barrett</td>
<td>Executive Director and Professor, Virginia Bioinformatics Institute</td>
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<td>17.00</td>
<td><strong>Closing speeches</strong></td>
<td>Pavel Kabat and Brian Collins</td>
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<td>17.30</td>
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<td>19.00</td>
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ENHANCING INFRASTRUCTURE RESILIENCE UNDER CONDITIONS OF INCOMPLETE KNOWLEDGE OF INTERDEPENDENCIES

L Andrew Bollinger and Gerard PJ Dijkema
Faculty of Technology, Policy and Management, TU Delft, Netherlands

Today’s infrastructures — such as road, rail, gas, electricity and ICT — are highly interdependent, and may best be viewed as multi-infrastructure systems. A key challenge in seeking to enhance the resilience of multi-infrastructure systems in practice relates to the fact that many interdependencies may be unknown to the operators of these infrastructures.

How can we foster infrastructure resilience lacking complete knowledge of interdependencies? In addressing this question, we conceptualize the situation of a hypothetical infrastructure operator faced with incomplete knowledge of the interdependencies to which his infrastructure is exposed. Using a computer model which explicitly represents failure propagations and cascades within a multi-infrastructure system, we seek to identify robust investment strategies on the part of the operator to enhance infrastructure resilience.

Our results show that a strategy of constructing redundant interdependencies may be the most robust option for a financially constrained infrastructure operator. These results are specific to the infrastructure configuration tested. However, the developed model may be tailored to the conditions of real-world infrastructure operators faced with a similar dilemma, ultimately helping to foster resilient infrastructures in an uncertain world.

RESILIENCE OF HIERARCHICAL CRITICAL INFRASTRUCTURE NETWORKS

Craig Robson, Stuart Barr, Philip James and Alistair Ford
Newcastle University, UK

Concern over the resilience of critical infrastructure networks has increased dramatically over the last decade due to a number of well documented failures and the significant disruption associated with these. This has led to a large body of research that has adopted graph-theoretic based analysis in order to try and improve our understanding of infrastructure network resilience. Many studies have asserted that infrastructure networks possess a scale-free topology which is robust to random failures but sensitive to targeted attacks at highly connected hubs. However, many studies have ignored that many networks in addition to their topological connectivity may be organised either logically or spatially in a hierarchical system which may significantly change their response to perturbations when taken into account. In this paper we explore if hierarchical network models exhibit significantly different higher-order topological characteristics compared to other network structures and how this impacts on their resilience to a number of different failure types. This is achieved by investigating a suite of synthetic networks as well as a suite of “real world” critical spatial infrastructure networks.
MODELLING INTERDEPENDENT CASCADING FAILURES IN REAL WORLD COMPLEX NETWORKS USING A FUNCTIONAL DEPENDENCY MODEL

Sarah Dunn, Matthew Holmes and Sean Wilkinson
Newcastle University, UK

Infrastructure systems are becoming increasingly complex and interdependent. As a result our ability to predict the likelihood of large-scale failure of these systems has significantly diminished and the consequence of this is that we now have a greatly increased risk of devastating impacts to society.

Traditionally these systems have been analysed using physically-based models. However, this approach can only provide information for a specific network and is limited by the number of scenarios that can be tested. In an attempt to overcome this shortcoming, many studies have used network graph theory to provide an alternative analysis approach. This approach has tended to consider infrastructure systems in isolation, but has recently considered the analysis of interdependent networks through combination with percolation theory. However, these studies have focused on the analysis of synthetic networks and tend to only consider the topology of the system.

In this paper we develop a new analysis approach, based upon network theory, but accounting for the hierarchical structure and functional dependency observed in real world infrastructure networks. We apply this method to two real world networks, to show that it can be used to quantify the impact that failures within an electricity network have upon a dependent water network.

DESIGNING A SOLID WASTE INFRASTRUCTURE MANAGEMENT MODEL FOR INTEGRATION INTO A NATIONAL INFRASTRUCTURE SYSTEM-OF-SYSTEMS

Matthew Ivesa, Jon Coellob, David Turnerc, Geoff Watsond, Anne Stringfellowa and Jim Hallb
aUniversity of Oxford Environmental Change Institute, ITRC, UK
bUniversity of Southampton, UK
cSolid Waste Infrastructure Management Model (SWIM) was designed to model the solid waste infrastructure requirements for any area's waste stream, from its generation to collection, treatment and disposal. Furthermore, the SWIM system allows an area's waste treatment capacity requirements to be forecast into the future to help decision makers choose the right solid waste infrastructure given their goals, constraints and ideas about future socio-economic conditions. Finally, the SWIM model was also designed to be flexible enough to fit within a larger UK national infrastructure system-of-systems model. To achieve such flexibility the SWIM model was carefully designed using object-oriented programming (OOP) principles. In documenting this design methodology we hope to demonstrate how applying OOP enables such models to be developed so that they are not only more flexible and more easily incorporated into other, more complex modelling efforts but also more easily understood by system experts and end-users.
I-11: SUSTAINABLE SUPERCORRIDOR

Linda Samuels
University of Arizona, USA

Recently enacted Federal transportation legislation known as MAP-21 — Moving Ahead for Progress in the 21st Century — has brought renewed attention to a proposed interstate corridor connecting Las Vegas, Phoenix and Tucson, Arizona. Part of the much larger Interstate 11 proposal linking Mexico and Canada (otherwise known as the CANAMEX or Intermountain West Corridor), a new type of corridor has the potential to signal a break from the 1950s model of road building and the start of a new, technologically advanced and sustainably minded network of smart infrastructure. Using I-11 as a case study, the intent of this larger research effort is to explore three key ways otherwise status quo infrastructure can be transformed into innovative sustainable solutions: by intervening in the design and planning process, by transforming the existing monofunctional freeway prototype, and by evolving the freeway paradigm from an “engineering only” to a “sustainability first” model. In collaboration with partner schools along the route (University of Arizona, Arizona State University, and University of Nevada, Las Vegas), researchers and design affiliates from architecture, planning, landscape architecture, engineering, and environmental studies are co-investigating the possibilities of transforming the proposed I-11 freeway from a limited use, auto-dominant roadway into a sustainable, multi-functional, ecologically and socio-economically focused Super corridor. This presentation will focus on seven sites selected between Casa Grande and Nogales, Arizona and the next generation infrastructure prototype design proposals developed in the 2014 interdisciplinary urban design studio.

EXTENDED DEFINITION OF CAPACITY IN AIRPORT SYSTEMS

Miguel Mujica Mota and Geert Boosten
Amsterdam University of Applied Science, Netherlands

Nowadays the main airports throughout the world are suffering because their capacity are getting close to saturation due to the air traffic which is still increasing besides the economic crisis and oil prices. In addition, the forecasts predict an increase in air traffic of at least 3.6% until 2020. This situation makes very important to come up with solutions to alleviate capacity congestions in the main airports throughout the world. Capacity has been perceived traditionally as the factor to be addressed in airport systems and it is faced through a technical perspective. In this paper we propose to change the mind-set and view capacity of airport systems taking other factors than pure technical ones. The discussion is illustrated with the example of Schiphol Airport.
MATERIAL FLOW ANALYSIS: OUTCOME FOCUS (MFA: OF) FOR ELUCIDATING THE ROLE OF INFRASTRUCTURE IN THE DEVELOPMENT OF A LIVEABLE CITY

Susan Lee, Dexter Hunt, Joanne Leach and Christopher Rogers
Liveable Cities, University of Birmingham, UK

Engineered infrastructures (i.e., utilities, transport & digital) underpin modern society. Delivering services via these is especially challenging in cities where differing infrastructures form a web of interdependencies. There must be a step change in how infrastructures deliver services to cities, if those cities are to be liveable in the future (i.e., provide for citizen wellbeing, produce less CO2 & ensure the security of the resources they use). Material Flow Analysis (MFA) is a useful methodology for understanding how infrastructures transfer resources to, within and from cities and contribute to the city’s metabolism. Liveable Cities, a five-year research programme was established to identify & test radical engineering interventions leading to liveable cities of the future. In this paper, the authors propose an outcome-focussed variation on the MFA methodology (MFA: OF), evidenced through work on the resource flows of Birmingham, UK. These flows include water, energy, food & carbon-intensive materials (e.g., steel, paper, glass), as well as their associated waste. The contribution MFA: OF makes to elucidating the interactions & interdependencies between the flows is highlighted and suggestions are made for how it can contribute to the (radical) rethinking of the engineered infrastructure associated with such flows.

BUILDING PROGRESSIVE CONFIDENCE: THE TRANSITION FROM PROJECT TO OPERATIONAL OPENING IN THE CASE OF A MAJOR NEW INTERNATIONAL AIRPORT TERMINAL

Vedran Zerjav, Andrew Davies, Andrew Edkins and Philip Jones

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bPJ Professional Management Solutions Ltd.

The purpose of an infrastructure system is to deliver a variety of services to end users over long periods of time. One of the biggest challenges in the design and construction of new infrastructure facilities is the transition or handover from the project to operations. This is particularly the case for infrastructural assets that are complex in their operations such as energy generation plants, airports, ships and aircraft carriers, or hospitals. A variety of commissioning, testing, systems integration and operational readiness procedures have to be put in place to ensure a smooth handover to end users and operators. This paper presents an ongoing empirical study that investigates the challenge of delivering the operational outcomes of Heathrow Terminal 2 (T2), a major international airport hub terminal. The study consists of site observations, four preliminary and 15 in-depth interviews with highly knowledgeable informants in key positions concerning the delivery of the project and airport services to the end-users. Preliminary findings indicate that a specific form of high reliability focus which our participants called ‘progressive confidence’ is essential for the smooth transition from project to operations. The emergent findings suggest that this process comprises specific aspects of organisational learning, the notion of the “flip” between the project and operations and approaches for dealing with change. The findings suggest the importance of further research into the issues of operational readiness and transitioning towards the handover of complex infrastructure projects.
MUNICIPAL ENERGY COMPANIES IN THE UK: MOTIVATIONS AND BARRIERS
Katy Roelich and Catherine Bale
University of Leeds, UK

Municipal energy companies have the potential to contribute to low-carbon transition but could also deliver a wider range of benefits, such as fuel poverty reduction and economic growth. There are myriad ways that municipalities could engage in energy provision, however, local authorities face challenges related to matching their motivations to appropriate business models which are exacerbated by unsupportive policy and regulation. More effective decision support tools are required, in addition to changes in policy and regulation, to exploit the potential social and environmental benefits offered by municipal energy companies. An interdisciplinary approach is needed to take this initial work forward to explore business models that match actor motivations and a more complex definition of value.

PORTFOLIO INFRASTRUCTURE INVESTMENTS: AN ANALYSIS OF THE EUROPEAN AND UK CASES
Athina Panayiotou and Francesca Medda
QASAR Lab, University College London, UK

Infrastructure has been receiving much attention in recent years. Investment banks and fund managers are increasingly promoting the investment characteristics of infrastructure assets and they argue that investing in infrastructure should be ideal for institutional investors such as pension funds. However, the claim lacks empirical support. We suggest that the limited research on infrastructure is mainly due to scant empirical data. The objectives of this paper are to examine the significance of economic infrastructure as an asset class by assessing the investment characteristics and performance of infrastructure indexes in Europe and UK from 2000-2014, to analyse how an infrastructure portfolio should be constructed and to determine whether the private sector should invest in an infrastructure portfolio containing a variety of infrastructure sectors or if the private sector should invest in one specific sector only.
Imagining resilient infrastructure systems that can meet the needs of twice today’s population with half today’s resources while providing better liveability for all, raises issues of productivity and cost control, project selection and prioritisation, financing and pricing, demand management, economic regulation and governance, and several other policy issues as much as it raises various demographic, technological and engineering challenges. Our paper will report analysis of the costs of providing public infrastructure in Australia over time and across state jurisdictions, with an initial ‘Phase I’ focus on public (taxpayer-funded) roads and public rail.

The study has three participating jurisdictions (being the Australian states of New South Wales, Victoria and Queensland) as well as some participation from other Australian states and the Federal Government. The transport and/or infrastructure departments in each of the three states are supplying (or have already supplied) 15-25 case studies of public infrastructure projects (road and rail) during the period 1990-2010. These case studies will be matched and compared, both within and across jurisdictions over time (time series analysis) and by similar characteristics within the same time period (benchmarking analysis).

A second, more qualitative, approach is to undertake a series of relatively informal interviews as well as issuing a questionnaire. This avenue of inquiry is designed to ‘fill in the gaps’ where data collection and/or retention for major infrastructure projects have been poor or where it is difficult to identify regulatory cost drivers (such as environmental and planning requirements) from the available data.
SERVICE PERFORMANCE INDICATORS FOR INFRASTRUCTURE INVESTMENT

Richard Sharp
Arup Pty Ltd, Australia

Infrastructure systems serving modern economies are highly complex, highly interconnected, and often highly interactive. The result is increased complexity in investment decision-making, and increased challenges in prioritising that investment. However, this prioritisation is vital to developing a long-term, sound, robust and achievable pipeline of national infrastructure.

One key to effective, objective and prudent investment prioritisation is understanding the real performance of infrastructure. Many metrics are employed to this end, and many are imposed by governments or regulators, but often these metrics relate only to inputs or outputs in a production process. Whilst these metrics may be useful for delivery agencies, they largely fail to address the real expectations or requirements of infrastructure users — quality of service, safety, reliability, and resilience.

What is required is a set of metrics which address not outputs but outcomes — that is, how well does the infrastructure network meet service needs? This paper reports on a study undertaken at a national level, to identify service needs across a range of infrastructure sectors, to assess service performance metrics in use, and to show how they or other suitable metrics can be used to prioritise investment decisions across sectors and jurisdictions.

VISUALISATION TOOLS FOR MULTI-PERSPECTIVE, CROSS-SECTOR, LONG-TERM INFRASTRUCTURE PERFORMANCE EVALUATION

David Alderson*, Stuart Barra, Martino Tran, Jim Hall, Alex Otto, Adrian Hickford and Edward Byers*

*Newcastle University, UK

Across different infrastructure sectors there are systems that help to monitor the current and near-future operation and performance of a particular system. Whilst Supervisory Control and Data Acquisition (SCADA) systems are critical to maintaining acceptable levels of functionality, they do not provide insights over the longer timescales across which strategic investment decisions play out. To understand how individual or multiple, interdependent, infrastructure sectors perform over longer timescales, capacity/demand modelling is required. However, the outputs of such models are often a complex high-dimensionality result-set, and this complexity is further compounded when cross-sector evaluation is required. To maximise utility of such models, tools are required that can process and present key outputs. In this paper we describe the development of prototype tools for infrastructure performance evaluation in relation to different strategic decisions and the complex outputs generated from capacity and demand models of five infrastructure sectors (energy, water, waste water, solid waste, transport) investigated within the UK Infrastructure Transitions Research Consortium (ITRC). By constructing tools that expose various dimensions of the model outputs, a user is able to take greater control over the knowledge discovery process.

The authors would like to acknowledge funding from the Engineering and Physical Sciences Research Council (EPSRC) grant EP/I01344X/1 to the Infrastructure Transitions Research Consortium (ITRC), and the respective authors’ host institutions of Newcastle University, University of Oxford and Southampton University.

ASSESSING RISKS TO INFORM RESILIENCE: A CRITICALITY ASSESSMENT OF THE BRITISH RAILWAY NETWORK

Raghav Pant*, Simon Blainey*, Jim Hall and John Preston*

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*University of Southampton, UK

National infrastructures are at risk from extreme weather events and random shocks. For example, the vulnerability of Britain’s national-scale rail infrastructure has been highlighted during extreme floods, and it seems likely that such risks will increase in future years. Given the importance of rail infrastructure, there is need for an improved understanding of the risks it faces. This paper provides a methodology to meet this need, by analysing the systemic risk to Britain’s rail infrastructure from a range of disruptive events. It first considers the range of events and processes which have the potential to disrupt operation of the rail network. A procedure is developed for assessing the relative criticality of different nodes and edges on the network based on the passenger traffic they carry. Two case study risk types (floods and traction system failures) are used to demonstrate how criticality assessment can identify parts of the rail network most at risk of causing substantial disruption to rail traffic, and therefore are most critical to maintaining national mobility. The paper concludes by considering implications of this analysis for investment decisions and the potential for transferring this methodology to other spatial or economic contexts.
INTEGRATED RESOURCE PLANNING FOR A CHINESE URBAN DEVELOPMENT

Thomas Ravalde and James Keirstead
Imperial College London, UK

Urban areas manage vast quantities of energy, water and waste resources. In order to minimise the cost and environmental impact, optimisation modelling is often used in the design and operation of these systems. However, traditional modelling approaches only consider the energy, water and waste sectors in isolation. This approach neglects the synergies possible between these systems whereby outputs from one system form an input to another, and hence sets an upper bound on economic and environmental impact minimisation. We formulate a mixed integer linear programming (MILP) model which takes a ‘systems-of-infrastructure systems’ approach to show how resource consumption can be reduced. The model takes as inputs possible resource conversion and transportation infrastructure and resources, and resource demands, and returns the optimal infrastructure choice and layout. The model is called PRaQ because it models ‘processes, resources and qualities.’ We apply the model to the design of a new urban development in China for three scenarios of various levels of resource integration. Results are still to be obtained.

PORTFOLIO STRUCTURING MODEL FOR URBAN INFRASTRUCTURE INVESTMENTS

Francesca Medda, Francesco Caravelli, Athina Parayiotou and Eleni Rapti
QASAR, University College London, UK

The objective of this work is to propose a new methodology based on the concept of portfolio structuring for urban infrastructure investment. We argue that city investments need to be treated as an integrated and interdependent entity and from this perspective, the portfolio methodology is proposed in order to assess the non-financial impacts of infrastructure projects and then combine them in a portfolio of investments from a financial perspective. The methodology is applied for a set of project under the EIB JESSICA Initiative. The methodology shows that not only is it possible to develop a practical decision support system to assist stakeholders in assessing the performance of individual urban infrastructure projects, but also how it is possible to combine projects into a portfolio. The method exceeds the simple analysis of returns of individual investment schemes and capitalizes on effective and integrated management of projects/investment. And this is the key to devising a focused response which will enable therefore cities to be globally competitive, via innovative financial and business models.

AN AGENT BASED MODEL FOR THE SIMULATION OF TRANSPORT DEMAND AND LAND USE. APPLICATION TO A SYDNEY METROPOLITAN AREA.

Nam Huynh, Vu Lam Cao, Rohan Wickramasuriya, Matthew Berryman, Pascal Perez and Johan Barthelemy
SMART Infrastructure Facility, University of Wollongong, Australia

Agent based modelling has emerged as a promising tool to provide planners with insights on social behaviour and the interdependencies characterising urban system, particularly with respect to transport and infrastructure planning. This paper presents an agent based model for the simulation of land use and transport demand of an urban area of Sydney, Australia. Each individual in the model has a travel diary which comprises a sequence of trips the person makes in a representative day as well as trip attributes such as travel mode, trip purpose, and departure time. Individuals are associated with each other by their household relationship, which helps define the interdependencies of their travel diary and constrains their mode choice. This allows the model to not only realistically reproduce how the current population uses existing transport infrastructure but more importantly provide comprehensive insight into future transport demands. The router of the traffic micro-simulator TRANSIMS is incorporated in the model to inform the actual travel time of each trip and changes of traffic density on the road network. Simulation results show very good agreement with survey data in terms of the distribution of trips done by transport modes and by trip purposes, as well as the traffic density along the main road in the study area.
FINANCIAL TRANSMISSION RIGHTS (FTR) AS A CONGESTION MANAGEMENT SCHEME IN ELECTRICITY TRANSMISSION: STRATEGIC BEHAVIOUR IN A COUPLED FTR — ELECTRICITY MARKET MODEL

Sertac Oruc
TU Delft, Netherlands

With the emergence of liberalized markets, transmission line congestion has been a prominent technical constraint that has to be accounted for in designing the new markets. Transmission line congestion is a phenomenon in electricity markets that emerges more severely in time with ever increasing demand in electricity and resultant excessive loading of transmission lines. Various congestion management techniques such as market splitting, market coupling etc. are utilized currently in energy markets. However on the long run financial transmission rights (FTR), which is readily used by some US electricity market operators such as PJM, New York and New England operators, has potential to dominate other markets too. Modelling financial transmission rights to test some strategic hypotheses is imperative to be able to introduce suitable policies and regulations. In this paper we present a modelling approach for financial transmission rights and examine strategic use of hidden knowledge in a hypothetical electricity — FTR market.

REAL OPTIONS THEORY AND EU MEMBER STATES ENERGY INVESTMENT STRATEGIES

Tilemahos Efthimiadisa and Dimitrios Mavridisc
aEnergy Security, Systems and Markets Unit, Institute for Energy and Transport, Joint Research Centre, European Commission
bUniversity of Luxembourg

According to the European Commission’s latest energy and climate proposals (“Europe 2030”), Member States will be obliged to draft National Action Plans for competitive, secure and sustainable energy. In particular, these plans need to simultaneously address issues of achieving domestic objectives regarding renewable energy, energy savings, energy security, research and innovation, greenhouse gas emissions, nuclear energy, shale gas, carbon capture and storage, European Union level climate and energy objectives etc. Furthermore, coordination with neighbouring Member States as well as regional effects will also have to be taken into consideration.

TRANSMISSION CAPACITY AS A COMMON-POOL RESOURCE: THE CASE OF GAS INTERCONNECTOR CAPACITY

Reinier Verhoogg, Amineh Ghorbanib, Gerard Dijkemab and Zofia Lukszob
aEPFL, Switzerland
bTU Delft, Netherlands

to investigate the very real problem of congestion at gas interconnectors. Instead of suggesting further incremental change to the European regulation in force to remedy congestion problems, we took a step back and consider gas interconnectors as a Common-Pool Resource (CPR). We suggest to wait and see what institutions the shippers let emerge to govern and manage interconnector capacity.

To explore this idea, we developed a model to simulate the possible emergence of institutions that would coordinate the shippers and help overcome congestion. We simulate 40 shippers at the Dutch and Belgian interconnectors and allow them to autonomously book capacity. Agents can learn over time to improve their behaviour and coordinate with each other to collectively define a new institution in the system. The main simulator indicators are the observed booking behaviour, agent profits and emerging institutions. We present and discuss preliminary results from a set of simulation runs.
Panel Session: The need for adaptation
Day 1, Marschallzimmer 1, 17.00 — 18.00

PANELISTS

Anne O’Neil
INCOSE (International Council on Systems Engineering) Director of Industry Outreach and former founding Chief Systems Engineer, MTA New York City Transit

Jeremy Liu
Creative Ecology, Founding Principal and former Executive Director of the Asian Community Development Corporation, Boston, MA
(http://creativeecology.net)

Professor Neil Hoose
Transport Systems Catapult, and Visiting Professor, Centre for Transport Studies, Imperial College London
(https://ts.catapult.org.uk/)

Ceasar McDowell
Interaction Institute for Social Change, President and Professor of the Practice of Community Development at MIT
(http://interactioninstitute.org)

SESSION OVERVIEW
An undercurrent flows through this year’s ISNGI themes—namely, the need for adaptation. Each of the symposium themes highlights an opportunity or threat that requires infrastructure and its constituencies to adapt or else risk critical disruption by the rising tide of these changes. This adaptive pressure encompasses the way in which infrastructure is designed, financed, built and maintained as well as the evolving nature of infrastructure itself.

The most critical element of whether or not an infrastructure system will adapt is people—owners, managers, users, developers, designers and other stakeholders—and their capacity and willingness to recognize the need for and to manage adaptation. And just as infrastructure systems are highly complex, so too is the capability needed to successfully manage its adaptation. Our panel presents case studies and tools, operating at different scales and settings to advance the agenda of a human-centred approach to next generation infrastructure. We present two case studies of community adaptation, one in a neighbourhood setting addressing the changes wrought by the largest U.S. highway project of its time, the Boston Central Artery and Tunnel project, and the other, in an agency setting that birthed the systems engineering group at New York MTA NYC Transit agency. Our panel also presents two approaches to equipping people with the capabilities for managing adaption, one operating in an interagency and interdisciplinary setting, the Catapult for transport systems in the U.K., and the other supporting the interpersonal, the Interaction Institute for Social Change.
Infrastructure Interdependence — Part 1
Day 2, Marschallzimmer 1, 9.45 — 11.00

ESTABLISHING A COMMON LANGUAGE OF INFRASTRUCTURE INTERDEPENDENCY
Neil Carhart and Ges Rosenberg
University of Bristol, UK
Infrastructure systems can exist interdependently with one another either by design, necessity or evolution. There is evidence that interdependencies can be the source of emergent benefits and hazards, and therefore there is value in their identification and management. Achieving this requires collaboration and communication between infrastructure stakeholders across all relevant sectors.

Recognising, developing and sharing multiple understandings of infrastructure interdependency and dependency will facilitate a wide range of multi-disciplinary and cross-sectorial work and support productive stakeholder dialogues. This paper therefore aims to initiate discussion around the nature of infrastructure interdependency and dependency in order to establish the basis of a useful, coherent and complete conceptual taxonomy. It sets out an approach for locating this taxonomy and language within a framework of commonplace stakeholder viewpoints.

The paper looks at the potential structural arrangements of infrastructure interdependencies before exploring the qualitative ways in which the relationships can be characterised. This builds on the existing body of knowledge as well as experience through case studies in developing an Interdependency Planning and Management Framework for Infrastructure

INTEGRATED INFRASTRUCTURE MODELLING — MANAGING INTERDEPENDENCIES WITH A GENERIC APPROACH
Beate Dirks, Alexander Otto and Jim Hall
University of Oxford, UK
Infrastructure provision is a highly challenging task, especially when accounting for climate change mitigation and adaptation needs. Efforts of making infrastructure more efficient and flexible result in an increasing number of sensitive infrastructure interdependencies. This enforces an integrated infrastructure assessment for planning purposes, in contrast to the traditional independent infrastructure-sector modelling.

For the unification of the existing infrastructure-sector models, we propose the implementation of a generic communication interface, which allows the separate sector-models to communicate at the necessarily disaggregate level in order to account for interdependencies appropriately. This approach allows for infrastructure provision modelling under one unified umbrella in a minimally invasive way, while conserving crucial individualities of the separate models. This is achieved through a generic network description, in which we solve the resource allocation through a pragmatic network-flow algorithm that resembles market and consumer behaviour. The developed framework establishes the basis for fully integrated infrastructure evaluation and hence cross-sectorial infrastructure investment decision making — a crucial tool in times of tight governmental budgets.

ADAPTATION AND RESILIENCE OF INTERDEPENDENT INFRASTRUCTURE SYSTEMS: A COMPLEX SYSTEMS PERSPECTIVE
Liz Varga\textsuperscript{a} and Jim Harris\textsuperscript{b}
\textsuperscript{a}Complex Systems Research Centre, Cranfield University School of Management, UK
\textsuperscript{b}Environmental Science and Technology, Cranfield University, UK
The effects of disruption upon one or more components in interdependent infrastructure systems and the ability of the system to return to normal operations, are investigated in this paper. This addresses the notions of resilience, and examines the trade-off between redundancy and efficiency, as well as the adaptive ability of a system to respond to disruptions and continue to operate, albeit not necessarily as it did previously or initially.
IT’S THE LITTLE THINGS THAT COUNT…
Sara Adhitya and Nick Tyler
Universal Composition Laboratory, University College
London, UK

This paper will discuss the importance of detailed design decisions in the long term sustainability of any infrastructure system. It presents the concept of Universal Composition, first introduced by UCL’s new Universal Composition Laboratory (‘UCL-squared’) and emerging from the need to design in space and time for multiple senses towards the creation of more accessible, understandable and meaningful environments. It thus presents infrastructure design from the point of view of human perception, and argues the need to design for the senses in order to encourage sustainable behaviours concerning human mobility, transport and locational choice.

After first explaining people-environment interactions, it discusses how the design of our urban infrastructure systems and environments can help stimulate our senses and thus behavioural change. Through two examples concerning bus stops implemented in London, it will explain how the role of both low and high tech technologies can help enhance interaction, improve accessibility and encourage usage. Thus, this paper aims to show that seemingly small details have a big role to play in the creation of infrastructure systems which enable, rather than inhibit, long term sustainable development.

THE COHERENCE PROBLEM: MAPPING THE THEORY AND DELIVERY OF INFRASTRUCTURE RESILIENCE ACROSS CONCEPT, FORM, FUNCTION, AND EXPERIENCED VALUE
Paul Jeffrey and Heather Smith
Cranfield University, UK

In this contribution we explore the interface between the functional characteristics of infrastructures as artefacts and social need supplier. Specifically we are concerned with the ways in which infrastructure performance measures are articulated and assessed and whether there are incongruities between the technical and broader, social goals which infrastructure systems are intended to aspire to. Our analysis involves comparing and contrasting system design and performance metrics across the technical — social boundary, generating new insights for those tasked with the design and operation of networked infrastructures. The assessment delivered in the following sections is inherently interdisciplinary and cross-sectoral in nature, bringing thinking from the social and environmental sciences together with contributions from mathematics and engineering to offer a commentary which is relevant to all types of physical infrastructure.

CONSUMER AND COMMUNITY IN THE FUTURE ELECTRICITY NETWORK: AN INSIGHT FROM SMART GRID PROJECTS IN EUROPE
Anna Mengolini and Julija Vasiljevska
Institute for Energy and Transport, Joint Research Centre of the European Commission

Integration of growing shares of renewable energy sources into the electricity networks have resulted in the need for electricity network upgrade through pervasive deployment of information and communication technologies. Having power sources close to the consumer premises and exploiting the potential of smart metering infrastructure may lead to consumers’ empowerment and energy savings. Therefore, the consumer should be approached with clear engagement strategies in the early stages of the technological system development. The analysis of European smart grid projects points to an increasing interest in consumers and communities as focal players for the success of the future electricity system. This necessitates characterization of the consumer as well as the community from what concerns values, beliefs and goals that are culturally and geographically located. In this context, this contribution presents and discusses some EU smart grid projects with a focus on consumers and on their interactions within the community. The abstract also demonstrates successful consumers’ engagement strategies in large-scale deployment of smart metering systems at national level, highlighting the need to address social needs and concerns at an early stage of the technological system development.
PLANNED ADAPTATION IN DESIGN AND TESTING OF CRITICAL INFRASTRUCTURE: THE CASE OF FLOOD SAFETY IN THE NETHERLANDS

Arthur Petersen\(^a\) and Pieter Bloemen\(^b\)
\(^a\)STeAPP, University College London, UK
\(^b\)Staff Delta Commissioner, Netherlands

In the Netherlands, dikes and other primary water defence works are assets that are essential to keep the society and economy functioning, by protecting against flooding from sea and rivers due to extreme events. Given that 55% of the country is at risk of flooding, primary water defence works belong to its critical infrastructure. Many factors influence the risk and impact of flooding. Besides physical factors (e.g., landscape design, climate change) also socio-economic factors (e.g., population, assets) are important. Given that these factors change and feature complex and uncertain behaviour in past and future, the design and regulation of this critical infrastructure will have to be flexible enough to be able to deal with such changes. ‘Planned Adaptation’ refers to regulatory programmes that plan for future changes in knowledge by producing new knowledge and revising rules at regular intervals. This study describes the emergence of the next generation of Dutch primary water defence infrastructure, which through the stepwise implementation of Planned Adaptation for design and testing of primary water defence works in the mid-1990s has moved beyond the Delta Works approach of 1953 and subsequent unplanned adaptations. This has prepared the ground for the recent introduction of Adaptive Delta Management.

AN ANALYSIS OF THE VULNERABILITY OF POWER GRIDS TO EXTREME SPACE WEATHER USING COMPLEX NETWORK THEORY

Roberta Piccinelli and Elisabeth Krausmann
European Commission, Joint Research Centre, Institute for the Protection and the Security of the Citizen, Italy

Space weather can affect critical infrastructures, causing damage to systems and resulting in failures or service disruptions. Of particular concern is the long-distance high-voltage power grid due to its vulnerability to geomagnetic storms. The induction of Geomagnetically Induced Currents (GICs) in the power network can damage equipment, push high-voltage transformers into their non-linear saturation range, or trip protection systems due to harmonics. These effects can lead to grid collapse. Recently, several studies were commissioned in the U.S. to assess the power grid’s vulnerability to extreme space weather and to investigate the potential consequences of prolonged blackouts on society. These studies highlighted a potentially major impact on the North American transmission grid and its components.

This study aims at identifying the vulnerability of the European power transmission grid with respect to extreme space weather by using complex network theory. We try to understand the spatial distribution and magnitude of GIC loading and the impact on grid operations potentially incurred. In a later step, this study will continue to estimate the impact of extreme space weather on society in Europe via the interdependencies of critical infrastructures with the power grid.

SIMULATING IMPACTS OF EXTREME WEATHER EVENTS ON URBAN TRANSPORT INFRASTRUCTURE IN THE UK

Alistair Ford\(^a\), Katie Jenkins\(^b\), Richard Dawson\(^a\), Maria Pregnolato\(^a\), Stuart Barr\(^a\) and Jim Hall\(^b\)
\(^a\)Newcastle University, UK
\(^b\)University of Oxford, UK

This paper presents an approach for combining high-resolution climate models with GIS-based transport modelling to assess the impacts of extreme weather events (heat and rainfall) on transport networks in the UK. Using a simple threshold approach, disruptions to commuting journeys can be assessed and adaptation options tested.
A SYSTEMS-BASED APPROACH TO THE IDENTIFICATION OF ENTERPRISE/INFRASTRUCTURE INTERDEPENDENCIES AS A PRECURSOR TO IDENTIFYING OPPORTUNITIES TO IMPROVE INFRASTRUCTURE PROJECT VALUE/COST RATIOS

Christopher Bouch\textsuperscript{a}, Christopher Rogers\textsuperscript{a}, Richard Dawson\textsuperscript{b} and Christopher Baker\textsuperscript{a}

\textsuperscript{a}University of Birmingham, UK
\textsuperscript{b}Newcastle University, UK

The bulk of the investment needed for infrastructure renewal in the United Kingdom will have to come from private sector investors, who will require attractive value/cost ratios. Government recognises infrastructure interdependencies can help deliver these, but returns remain uncertain. New business models are required to overcome this problem, which take account of enterprise-centred infrastructure interdependencies (interdependencies between social and economic enterprises and the infrastructures they use). The complex and closely coupled nature of enterprise and infrastructure systems can stand in the way of identifying these interdependencies; however, model-based systems engineering techniques offer a framework for dealing with this complexity. This paper describes research that the iBUILD project is doing to develop a methodology for modelling the interdependencies between infrastructure and the enterprises that use it, as a precursor to identifying opportunities to improve infrastructure project value/cost ratios. The methodology involves: identifying the suite of policy, strategy and operational documents relating to the enterprise-of-interest; eliciting system data from the documents and integrating it to create an enterprise system model; and, generating N2 diagrams from the model to identify the interdependencies.

THE ROLE OF FUTURE PROOFING IN THE MANAGEMENT OF INFRASTRUCTURAL ASSETS

Tariq Masood, Duncan McFarlane, Jennifer Schooling, Ajith Parlikad and Phil Catton

University of Cambridge, UK

Ensuring long-term value from infrastructure is essential for a sustainable economy. In this context, future-proofing involves addressing two broad issues:

i. Ensuring the ability of infrastructure to be resilient to unexpected or uncontrollable events e.g. extreme weather events; and

ii. Ensuring the ability to adapt to required changes in structure and / or operations of the infrastructure in the future e.g. expansion of capacity, change in usage mode or volumes.

Increasingly, in their respective roles, infrastructure designers/builders and owners/operators are being required to develop strategies for future-proofing as part of the life cycle planning for key assets and systems that make up infrastructure.

In this paper, we report on a preliminary set of studies aimed at exploring the following issues related to infrastructure / infrastructure systems:

i. What is intended by the future-proofing of infrastructural assets?

ii. Why and when to future-proof critical infrastructure?

iii. How can infrastructure assets and systems be prepared for uncertain futures?

iv. How can future-proofing be incorporated into asset management practice?

In order to seek answers to the above questions, The Cambridge Centre for Smart Infrastructure and Construction has conducted two industrial workshops bringing together leading practitioners in the UK infrastructure and construction sectors, along with government policy makers. This paper provides an initial summary of the findings from the workshops, and proposes a simple framework for linking future-proofing into broader asset management considerations.
A SOCIO-TECHNICAL ANALYSIS OF INTERDEPENDENT INFRASTRUCTURES AMONG THE BUILT ENVIRONMENT, ENERGY, AND TRANSPORTATION SYSTEMS AT THE NAVY YARD AND THE PHILADELPHIA METROPOLITAN REGION, USA

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This paper reports on a research initiative that explores the interdependencies of the system of systems — the built environment, energy, and transportation — related to the redevelopment of The Navy Yard in Philadelphia and the Philadelphia Metropolitan Region. The overarching goal of the project is a clearer understanding of the dynamics of multi-scale interactions and interdependencies of systems of sociotechnical systems that will be useful to system practitioners. The understanding and the subsequent planning and design of sociotechnical systems are “wicked” problems and one characteristic is there is no definitive formulation. One of the main findings or lessons learned of the work reported for the understanding of interdependencies of infrastructure is the identification of what are the problems or challenges because for wicked problems “[t]he formulation of the problem is the problem!”

We find that systems practitioners have an overarching concern of a fragmented regional policy and decision making process. Four main themes of 1. Vulnerability of aging infrastructure, 2. Integration of emerging technology into existing infrastructure, 3. Lifestyle and value changes, and 4. Financial innovations were identified as challenges. Continuing research work explores three possible infrastructure projects for further study as well as the development of a high-level systems of systems model. The principle outcome is the initiation of a planning process so that the system practitioners will learn to better understand the connections among related sociotechnical systems and the constellation of problems they face not within their immediate scope of responsibility yet influences the operations of their systems.
STEPPING AWAY FROM TREND ANALYSES FOR REGIONAL INTEGRATED PLANNING AND MODELLING

Pascal Perez*, Rohan Wickramasuriya#, Nam Huynh* and Hedwig van Delden#
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Strategic regional plans aim to achieve aspirational objectives such as vibrant communities, affordable transport, productive economy and protected natural environments. But planners often lack decision support tools capable of tracking complex dynamic interactions between these various components. Many current regional planning models rely on feed-forward trend analyses. These trends are based on demographic or economic assumptions that lock-in regional growth into a unique pathway. The weaker the initial assumption is, the less plausible the evolution of other components of the regional development. In fact, useful regional planning models need to reproduce the co-evolution of land use, transport, economic and demographic dynamics. We have developed a dynamic model that includes five interconnected modules: (1) a cellular automata-based land use module, (2) a 4-step transport model with dynamic allocation of traffic, (3) a dynamic input/output economic model, (4) a synthetic population-driven demographic model, and (5) a utility module to capture the evolution of demand for energy and water as well as production of sewage and solid waste. We use a sophisticated simulation platform called GEONAMICA to build and integrate foregoing modules for the Illawarra region in New South Wales, Australia.

ALTERNATIVE ENERGY SOURCES AND ENERGY INFRASTRUCTURE FOR DUTCH GREENHOUSES-INVESTIGATING GROWERS’ PREFERENCES

Yashar Araghi and Gerard Dijkema
TU Delft, Netherlands

Presented by Andrew Bollinger, TU Delft, Netherlands

Today, Dutch greenhouse growers depend on natural gas and many use CHP technology. To secure their energy, reduce their CO2 footprint and increase the sustainability of their business, the sector has come to realize they must switch to other energy sources and technologies. However, the sunk investments in energy technology are huge and largely depend on regional energy infrastructure for gas, electricity, heat and CO2. Furthermore, growers are exposed to and must face gas, electricity and CO2 markets. Adopting alternative sources and technologies requires substantial investment and carries substantial risk.

In this study, we investigate growers’ preferences and opinions regarding three potential alternative energy sources and associated technologies: solar thermal energy, geothermal energy and biogas.

We use established methods from consumer behaviour theory and choice-modelling to elucidate how growers form an opinion and decide on the next technology to employ and grow their business.
SPATIALLY AND TEMPORALLY EXPLICIT ENERGY SYSTEM MODELLING TO SUPPORT THE TRANSITION TO A LOW CARBON ENERGY INFRASTRUCTURE. CASE STUDY FOR WIND ENERGY IN THE UK

Marianne Zeyringer, Hannah Daly, Fais Birgit, Ed Sharp and Neil Strachan, UCL Energy Institute, UK

Renewable energy sources and electricity demand vary with time and space and the energy system is constrained by the location of the current infrastructure in place. The transitioning to a low carbon energy society can be facilitated by combining long term planning of infrastructure with taking spatial and temporal characteristics of the energy system into account. There is a lack of studies addressing this systemic view. We soft-link two models in order to analyse long term investment decisions in generation, transmission and storage capacities and the effects of short-term fluctuation of renewable supply: The national energy system model UKTM (UK TIMES model) and a dispatch model. The modelling approach combines the benefits of two models: an energy system model to analyse decarbonisation pathways and a power dispatch model that can evaluate the technical feasibility of those pathways and the impact of intermittent renewable energy sources on the power market. Results give us the technical feasibility of the UKTM solution from 2010 until 2050. This allows us to determine lower bounds of flexible elements and feeding them back in an iterative process (e.g., storage, demand side control, balancing). We apply the methodology to study the long-term investments of wind infrastructure in the United Kingdom.

TOUR-BASED TRAVEL MODE CHOICE ESTIMATION BASED ON DATA MINING AND FUZZY TECHNIQUES

Nagesh Shukla, Jun Ma, Rohan Wickramasuriya, Nam Huynh and Pascal Perez, SMART Infrastructure Facility, University of Wollongong, Australia

This paper extends tour-based mode choice model, which mainly includes individual trip level interactions, to include linked travel modes of consecutive trips of an individual. Travel modes of consecutive trip made by an individual in a household have strong dependency or co-relation because individuals try to maintain their travel modes or use a few combinations of modes for current and subsequent trips. Traditionally, tour based mode choice models involved nested logit models derived from expert knowledge. There are limitations associated with this approach. Logit models assumes i) specific model structure (linear utility model) in advance; and, ii) it holds across an entire historical observations. These assumptions about the predefined model may be representative of reality, however these rules or heuristics for tour based mode choice should ideally be derived from the survey data rather than based on expert knowledge/ judgment. Therefore, in this paper, we propose a novel data-driven methodology to address the issues identified in tour based mode choice. The proposed methodology is tested using the Household Travel Survey (HTS) data of Sydney metropolitan area and its performances are compared with the state-of-the-art approaches in this area.
A GEOSOCIAL INTELLIGENCE FRAMEWORK FOR STUDYING & PROMOTING RESILIENCE TO SEASONAL FLOODING IN JAKARTA, INDONESIA

Etienne Turpin, Tomas Holderness and Rohan Wickramasuriya
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PetaJakarta.org is a web-based platform developed to harness the power of social media to gather, sort, and display information about flooding for Jakarta residents in real time. The platform runs on the open source software CogniCity—an FOSS platform developed by the SMART Infrastructure Facility, University of Wollongong—which allows data to be collected and disseminated by community members through their location-enabled mobile devices. The project uses a GeoSocial Intelligence Framework to approach the complexity of Jakarta’s entangled hydraulic, hydrological and meteorological systems and thereby converts the noise of social media into knowledge about urban infrastructure and situational conditions related to flooding and inundation. In this paper, PetaJakarta.org co-directors will discuss their GeoSocial Intelligence Framework as it applies to their preliminary findings from their 2014 Twitter #DataGrant, which has allowed them to develop a correlative analysis between historic social media information, the Jakarta government’s flood maps, and the infrastructure used to manage critical flood emergencies.

THE SPATIAL VULNERABILITY OF THE CHINESE INFRASTRUCTURE SYSTEM TO FLOODING AND DROUGHT RISKS

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Rapid urbanisation means that China has invested in numerous infrastructure assets, many of them built on natural hazard zones. This paper investigates how this system at a national scale is vulnerable to flooding and drought risks. Existing literature is restricted to city-scale analyses, while broader scale studies are usually focused on just one sector. Here, for the first time, we look at infrastructure vulnerability across five different sectors. With 10,561 nodes and 2,863 lines, we develop a methodology assigning customers to infrastructure assets at the local level and conduct hotspot analysis using the Kernel density estimator. Imposing this hotspot analysis on flooding and drought risk maps allows us to obtain a spatial understanding of China’s infrastructure vulnerability to these extreme events.

At a provincial level, we find that Hebei, Beijing, Henan, and Jiangsu are vulnerable to both flooding and drought risks. The average number of vulnerable customers to flooding for all five sectors is 206,003,786, and 6,279,536 for drought (electricity sector only). Our work demonstrates that broad-scale risk assessment in a country of this size is feasible and the results are useful for estimating the impacts of water-related extreme events, targeting infrastructure investment and informing policies for adaptation.

SYNTHETIC MUDSCAPES: HUMAN INTERVENTIONS IN DELTAIC LAND BUILDING

Elizabeth Anne Williams, Jeff Carney, Bradley Cantrell, and Matthew Seibert
Coastal Sustainability Studio, USA

In order to defend infrastructure, economy, and settlement in Southeast Louisiana, we must construct new land to mitigate increasing risk. Links between urban environments and economic drivers have constrained the dynamic delta landscape for generations, now threatening to undermine the ecological fitness of the entire region. Static methods of measuring, controlling, and valuing land fail in an environment that is constantly in flux; change and indeterminacy are denied by traditional inhabitation.

Multiple land building practices reintroduce deltaic fluctuation and strategic deposition of fertile material to form the foundations of a multi-layered defence strategy. Manufactured marshlands reduce exposure to storm surge further inland. Virtual monitoring and communication networks inform design decisions and land use becomes determined by its ecological health. Mudscapes at the threshold of land and water place new value on former wastelands. The social, economic, and ecological evolution of the region are defended by an expanded web of growing land.
CARBON CAPTURE CLUSTERING: THE CASE FOR COORDINATED APPROACHES TO ADDRESS FRESHWATER USE CONCERNS

Edward Byers, Jaime Amezaga and Jim Hall
University of Newcastle, UK
University of Oxford, UK

Carbon capture and storage (CCS) will be a key technology for reducing emissions from fossil-fuelled electricity generation. The UK is developing demonstration plants and UK Government strategy proposes the clustering of CCS facilities, having identified significant cost-savings from shared pipeline infrastructure. However, cooling water use from CCS power plants are almost double those of conventional plants. There are concerns about the volumes of freshwater used and vulnerability to low river flows, particularly in areas identified for CCS clusters. Two innovative approaches may reduce water use in CCS clusters by exploiting synergies with other infrastructures; district heating and municipal wastewater. Our analysis indicates that cooling water reductions from district heating may be feasible in the northwest, but less likely in Yorkshire. We also find that across the UK there are numerous, sufficiently large wastewater treatment plants capable of providing alternative cooling water sources for large power plants. Feasibility of these promising options will be highly contextual, require detailed analysis and may face economic and regulatory barriers. Historically, ad-hoc development of energy infrastructure has struggled to exploit such synergies, but may now be facilitated by the clustering of CCS facilities.

EVALUATING THE OPPORTUNITY OF A FLEXIBLE APPROACH IN DESIGNING THE INTEGRATION OF A GSHP SYSTEM IN A NEW BUILDING

Claudio Martani, Ying Jin, Kenichi Soga and Stefan Scholtes
CSIC, University of Cambridge, UK

Decision-making for effective infrastructure integration is challenging because the performances of long-lasting objects often depends on conditions which are either outside the control of the designer or difficult to foresee at the design stage. In this paper we examine a new approach to estimating the range of cost-effective solutions for integrating the construction/retrofit of two or more different types of infrastructure. Infrastructure integration has many perceived benefits, but also faces serious new challenges and doubts from practitioners, particularly in sectors with complex construction process, long asset lives, uncertain cost parameters, and slow and unwieldy decision-making, such as is common with civil engineering works. We test all main options in integrating a ground source heat pump (GSHP) system with the construction and retrofit of an archetypal, office building. A new simulation model is developed and parameterized using actual data in the UK. We incorporate unavoidable uncertainties and randomness in how the decisions are triggered, and test the effectiveness of proactive measures to embed future options. The model highlights how sensitive the range of cost-effective solutions is to the setting of renewable energy incentives, discount rates, technical performance and life-cycle asset management of interdependent infrastructure. This points to a clear need for establishing appropriate regulatory standards. We expect this model to find increasing applications in the planning and designing of integrated complexes of buildings, transport facilities, renewable energy supply, water supply and waste management in dense urban areas, which are an increasingly key part of sustainable urban development.

TOWARDS A CO-EVOLUTIONARY MODEL OF DEMOGRAPHICS AND INFRASTRUCTURE

Chengchao Zuo and Mark Birkin
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National infrastructure systems provide a foundation for economic prosperity and well-being. In addition to factors such as technological change and obsolescence, infrastructure systems need to respond to changing levels of demand, which is strongly driven by population growth. However demographic change is not independent of economic conditions, or the nature and quality of infrastructure. This research is concerned with the interrelationships between demographics, economy and infrastructure.

The paper therefore develops a novel approach to modelling the evolution of a national economy in the context of changing demographics and infrastructure provision. This approach is based in a model with coupled sub-systems which are spatially disaggregate with explicit temporal dynamics. A version of the model is calibrated using a demographic component which incorporates both natural change and migration, and an economic model which recognises both labour and capital as factors of production. Infrastructure is present as an influence on accessibility, geographical attractiveness and economic productivity.

The performance of the model is explored through a variety of scenarios which are offered as an initial proof of concept of the feasibility of implementing a co-evolutionary model of demographic and economic growth over a medium to long time horizon. These scenarios indicate the influence of government policies for international migration and infrastructure investment on regional development and performance.
EMERGENCE OF DISTRICT-HEATING NETWORKS; BARRIERS AND ENABLERS IN THE DEVELOPMENT PROCESS

Jonathan Busch, Catherine S.E. Bale, Christof Knoeri and Katy Roelich
University of Leeds, UK

Infrastructure provision business models that promise resource efficiencies and additional benefits, such as job creation, community cohesion and crime reduction exist at sub-national scales. These local business models, however, exist only as isolated cases of good practice and their expansion and wider adoption has been limited in the context of many centralised systems that are currently the norm. In this contribution, we present a conceptual agent based model for analysing the potential for different actors to implement local infrastructure provision business models. The model is based on agents’ ability to overcome barriers that occur throughout the development (i.e. feasibility, business case, procurement, and construction), and operation and maintenance of alternative business models. This presents a novel approach insofar as previous models have concentrated on the acceptance of alternative value provision models rather than the emergence of underlying business models. We implement the model for the case study of district heating networks in the UK, which have the potential to significantly contribute to carbon emission reductions, but remain under-developed compared with other European countries.

IMPROVING ENGINEERING GOVERNANCE FOR LARGE INFRASTRUCTURE PROJECTS

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The increased complexity of modern infrastructure projects together with the desire of governments to provide improved services to their citizens gives rise to the need for much better engineering governance capability and the ability to model system and user behaviour to ensure the desired increased level of service. Modelling all aspects of planned systems through the use of standardised architecture framework models that can be developed to provide the necessary insight across all aspects and levels of concern for the system(s) is an excellent approach for achieving this. For New South Wales (TfNSW) that will be used to ensure coordinated development activities between all divisions in the department, as well as with Planning NSW and the private sector providers for system design, implementation, maintenance and operation. The initial development described here particularly focuses on existing, current and future heavy rail projects, but continuing work is under way to extend and generalise the model so that it applies to all transport modes (rapid transit metro and light rail) and eventually to include all other TfNSW transport modes — buses, walkways, ferries, cycle ways, and roads. Furthermore, this paper details how the use of a metamodel for the architecture framework provides the rigour and abstraction necessary to allow this generalisation within the same model structure.

AN INTERDISCIPLINARY APPROACH FOR THE ASSESSMENT AND IMPLEMENTATION OF RESILIENT AND FLEXIBLE WATER SUPPLY INFRASTRUCTURE UNDER CHANGING OR INSTABLE CONDITIONS

Wolfgang K. Waltera and Wolfgang Günthertb

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In case of demographic changes or emergencies pipeline bound infrastructure like gas or water is specifically challenged. Then, the advantages of decentralized infrastructure should be considered: Minimization of asset bound funds; flexibility; resilience; response capacity. A research project at the Federal Armed Forces University together with the Brazilian utility company COPASA, the process engineering company Grünbeck and the ICT company Phönix focused on: A procedure for successful decentralized water infrastructure implementation; a new operation scheme; related pilot tests. To describe the local situation the Open System of Boundaries is created comprising 13 interdisciplinary groups and 68 subgroups. To describe water supply systems the Open System of Attributes is created comprising 15 groups and 64 subgroups. An Attributes Profile which fits into the Boundaries Profile makes a resilient decentralized application more likely. For Minas Gerais, Brazil, i.e. for instable conditions the Boundaries Profile and the Attributes Profile of a decentralized SCADA equipped water treatment plant are compiled. Results of on-site tests are discussed. Recommendations for decentralized water supply under instable conditions are given. The application of standardized SCADA equipped treatment plants is suggested with remote supervision from one control centre.
At the beginning of the 21st century, the global energy landscape is changing profoundly. Rapidly improving technologies for decentralized electricity generation are challenging the centralized topology and markets of the energy sectors — and not only in the Global North. They also provide new perspectives for access to modern energy in the Global South. In the World Energy Outlook 2011 the International Energy Agency presented a scenario for universal modern energy access by 2030. In this scenario 70% of rural areas are either connected with mini-grids or with small, stand-alone off-grid solutions. In countries of the global North, much academic research has been done to gain a better understanding about the conditions, dynamics and impacts of a transition towards more sustainable and flexible energy infrastructures for the post-industrial economies. Despite the United Nations announcement of the “Decade of Sustainable Energy for All” from 2014 to 2024 similar research for the developing world is still in its infancy.

This session brings together academics looking into different aspects of past and future energy infrastructures in Asia, Africa and South America with a focus on the dimension of centralization/decentralization. The session contributions cover aspects like the problematic legacy of centralized infrastructure systems, present concepts for decentralized bottom-up electrification by interconnecting stand-alone off-grid systems or analyse material flows associated with decentralized models for rural electrification.

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**LEGACIES OF A PAST MODERNISM — DISCOURSES OF DEVELOPMENT AND THE SHAPING OF CENTRALIZED ELECTRICITY INFRASTRUCTURES IN LATE- AND POSTCOLONIAL TANZANIA**

**Jonas van der Straeten**  
*Technische Universität Berlin, Germany*

As the UN has declared the years 2014-2024 the “Decade of Sustainable Energy for All”, countries in Sub-Saharan Africa struggle with the transition towards more sustainable and more inclusive energy infrastructures. In many rural areas, electrification rates remain as low as 1-2%. For many countries, one of the main barriers for rural electrification is the legacy of a model of top-down planning, large-scale power generation and a centralized topology of the electricity infrastructure. Nonetheless, historiography on electricity infrastructures in Africa is nearly non-existent. At the example of Tanzania this paper shows, that the centralized power models which dominate the continent today were shaped by modernization and development discourses during the late colonial and post-independence period. Because of its particular characteristics, electricity lent itself perfectly to the goal of making development measurable — a goal which was essential to a “high modernist” vision of development, advocated by new nation states as well as international funders. The paper illustrates how large hydropower projects proved successful in expanding generation capacities and urban electrification rates, but failed in providing electricity to rural areas and created path-dependencies which have led to dead ends in the last 20 years.
OFF-GRID ELECTRIFICATION AND ITS IMPACTS ON THE WASTE MANAGEMENT SYSTEM — THE CASE OF BANGLADESH

Alexander Batteiger
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By the end of 2010 more than 1.6 billion people lacked access to modern energy services. To overcome this situation the United Nations started the “sustainable energy for all initiative” with the objective to provide access to modern energy services for all until 2030. Especially for off-grid areas in the least developed countries decentralized systems based on renewable energies and in particular solar energy are seen as the most promising solution. Lack of access to modern energy services goes in general along with a lack of a proper waste management systems for the expected future waste electrical and electronic equipment (WEEE). By the end of 2013 in Bangladesh already 2.7 million Solar Home Systems were installed making it one of the most successful rural electrification programs. The main lessons learned from a waste management perspective, is that prequalification of the suppliers affects positively the complete battery industry. Local battery producers and recyclers and a working collection system are needed to guarantee that lead acid batteries are recycled properly.

A SYSTEM COMPLEXITY APPROACH TO SWARM ELECTRIFICATION

Sebastian Groh\textsuperscript{a} and Mathias Koepke\textsuperscript{b}
\textsuperscript{a}Research Focus Microenergy Systems, Technische Universität Berlin, Germany
\textsuperscript{b}Chair for Energy Management and Sustainability, Leipzig University, Germany

The study investigates a bottom-up concept for microgrids. Financial analysis is performed through a business model approach to test for viability when replacing a researched energy expenditure baseline in Bangladesh. A literature review compares the approach to current trends in microgrids. A case study of Bangladesh illustrates the potential for building on the existing infrastructure base of solar home systems. Opportunities are identified to improve access to reliable energy through a microgrid approach that aims at community-driven economic and infrastructure development by building on network effects generated through the inclusion of localized economies with strong producer-consumer linkages embedded within larger systems of trade and exchange. The analysed approach involves the linking together of individual stand-alone energy systems to form a microgrid that can eventually interconnect with present legacy infrastructure consisting of national or regional grids. The approach is likened to the concept of swarm intelligence, where each individual node brings independent input to create a conglomerate of value greater than the sum of its parts.
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