Summary of iiESI Workshop on ESI Research Challenges in London

March 30th and 31st

Imperial College London

The workshop brought together an experienced group of international research active people with a diverse range of expertise (see list of attendees below). The workshop was open and vibrant, (see agenda and briefing documents below) and while **the focus of the workshop was on identifying the research challenges in Energy Systems Integration (ESI),** the discussion was much broader as the group grappled with the extremely complex environment within which the research questions have meaning and impact. There were some particularly salient ideas that defined the diversity and richness of the research challenges ahead of us. For example, “the difference between electricity and heat for an engineer is as profound as the difference between a consumer and a citizen for a social scientist”. This underscored one of the most significant outcomes of the workshop: **the need to combine economic, social, and political perspectives with the engineering knowledge** that better connects the behaviour of end use customers with how energy is produced and delivered. Such an approach is essential to produce ESI solutions that are both technically sound and desirable to users, thus enhancing the chances of real deployment and impact.

The value of ESI itself was questioned in a constructive manner. This led to a consensus that **ESI and its boundaries need to be precisely defined.** The word “optimal“ was used liberally during the discussions, however there was a consensus that a pragmatic definition of the term was elusive. Ambiguity around the concept of optimisation is driven by the need for considerations for “consumer’s” needs and technology acceptance (also in need of a clear definition indicating a range from individuals to industries to cities) and their “optimal” behaviour as they derive value from energy services (i.e. light, heat, cooling, communications, etc.), as distinct from using energy (kWh)—again, highlighting the importance of the social science/ engineering interaction. Indeed, if an “optimal” system is to achieve maximum benefits at least cost with greatest efficiency, researchers will need to better understand economic and social factors which may not be easily quantified, but which are of paramount importance in fully accounting for costs and benefits in energy systems. **A set of robust metrics spanning the engineering and social sciences (e.g. financial impacts, emissions costs, resiliency, public health considerations, social utility etc.) to measure and highlight the benefits is highly desirable**.

Any set of definitions, metrics, examples etc. will have to be flexible enough to accommodate a wide range of circumstances. Every system will approach ESI from a different starting point (e.g. contrast an urban area in the developed world with a rural area in the developing world). The relevance of ESI will be different in different systems. For example, renewable integration is the driving force of ESI in many regions but not all. Different incentives, decision-making processes and access to capital will result in much different energy system e.g. a government can invest in high voltage transmission while individuals will not. **Therefore, the research challenges will be system specific.** The research challenges are also subject to disruptive, unforeseen developments such as the revolution in shale gas and longer term trends. For example, many of the opportunities in ESI exist because of inefficiencies but, as efficiency increases, these opportunities decline e.g. combined heat and power opportunities decline with more energy efficiency. Therefore the research challenges are strategic with a longer term focus or more opportunistic with an emphasis on the short term. The latter links better with the political reality that strategic decisions have to be justified in a relatively short term.

Despite the complexities described above and recognising the incompleteness of the exercise the following areas where research challenges exist were identified following the workshop and a careful reading of the extensive notes taken by the many of the participants.

<u>Virtual storage</u>

It was generally accepted that cheap and ubiquitous electricity storage would be a game changer (some argued it would negate the need for ESI). This is particularly true of systems that are pursing very high penetrations of variable renewables (i.e. wind and solar photovoltaics), but the costs and/or efficiencies of dedicated electricity storage are still significantly above where mass deployment might occur, at least in the short term. Research into the basic sciences to develop cheap, dedicated electricity storage is potentially important but this is not an ESI research challenge. The possibility exists to capitalize on **"virtual storage" where the flexibility in other systems, integrated with the electricity system, can be used in a similar manner to electricity storage is an ESI research challenge of significance**. Virtual storage can be significantly cheaper than dedicated storage as it does not require large capital investment but it does require a better integrated energy system. Demand management (controlling heating and cooling loads) that is currently being deployed and developed is in part leveraging this virtual storage but here we are proposing it at a grand scale where gas, fuel, heat and water systems will be systematically planned, designed and operated as flexible "virtual storage" resource for the electricity grid (and vice versa). For example, the potential in some regions for thermal grids was raised but questions remain as to how big they should be, how best to integrate them into the electricity grid and importantly how will the consumer requirements be ensured and will the "consumer" accept them. There is also the potential to use the natural gas fuel grid as a way to create virtual energy storage throught he concept of "power-to-gas".

Studies and analysis

While the flexibility in the electricity system is well understood and is starting to be quantified the understanding and quantification of other systems flexibility (e.g. gas, fuels, heat, water etc.) is not as well understood or quantified. A first step in realising large scale virtual storage solutions will require a deep understanding of these systems and will **require analytical studies which were identified in general as being important in ESI**. The studies can be used to identify and quantify ESI opportunities and to quantify (e.g. metrics above) the benefits. A set of sample questions that these studies could focus on include:

- What is the best size and level of integration? i.e. understand the trade-offs between centralised versus decentralised energy systems
- How does "customer" behaviour impact planning and operations of an integrated energy system?
- What is the value of smart gas grids?
- What is the value of technology developments in e.g. hybrid gas/electricity heat systems?
- What is the role of electricity in a well integrated energy system? Is it the central role player?

Some "best in class" campus, city, regional, developing world examples of ESI would be useful to develop and would allow e.g. policy makers/regulators to gain insights into what is possible.

Modelling

The research studies described above **will need better models** in particular they will need models that capture "consumer" behaviour and co-simulate the energy domains at proper scales. Not only do the models have to consider the "consumer" but other diverse aspect of the context that will make the modelling results more realistic and actionable e.g. the risk profiles of ESI solutions. Better and more granular models in order to identify system inefficiencies and lead to actionable steps to reduce these inefficiencies (it was accepted that a certain amount of inefficiency is unavoidable) are also needed. All these models will need data for verification but how much and of what quality needs to be justified in terms of the benefits.

Regulatory and market

Much of the technology to capture the benefits of a more integrated energy system exist and to be deployed just need to overcome regulatory and market barriers and business model breakthroughs, that respect the laws of physics, may be more important than technology breakthroughs. Centralised planning of an integrated energy system to an engineering definition of "optimal" is instructive but the "consumer" and the market/regulatory framework will determine what actually happens. Therefore the **design of this regulatory and market framework is critical to capturing the benefits** and requires amongst other things, better long term signals, experimental economics approaches with the "consumer" and better policy coordination.

<u>Control, optimisation and data tools</u>

The development of new technologies can dramatically alter the energy system. For example underground electricity transmission is incremental – are there game changing technologies that would be more acceptable and feasible than overhead transmission? In the shorter term there is an increase use of power electronics in electricity grids that is leading to some profound changes that require better and more active controls to maintain system stability. The stochastic nature of the increasing variable renewables is also a challenging the existing planning and operational methods need to account for this increased stochasticity. The architecture of the increasingly decentralised and complex energy system with active consumers is also evolving and producing vast amounts of potentially useful data and cyber threats. **Together these changes require more advanced controls, better stochastic methods, more robust cyber security, and are a rich source of potential "big data" applications.**

<u>Dissemination and education</u>

Dissemination and education were discussed at length mainly in the context of ensuring policy makers and regulators are given robust evidence to underpin their decisions and are sufficiently prepared to grasp the importance and impact of their decisions. The **research community needs to adapt and change in particular existing professionals in one domain may have to become knowledgeable about the other domains**. The importance of dissemination within the research community was questioned i.e. do we reward impactful dissemination properly? In addition to communicating with peers, new and better dissemination methods should be developed e.g. visualisation methods. Commonality between systems/regions needs to be leveraged and systems/regions need to learn from the mistakes and successes of others but all the time being aware that the best solutions are all system specific. Finally there is a dearth of ESI expertise that needs to be addressed through better educational offerings in the Universities.

A draft white paper that expands in detail on this summary with the intention of clearly defining the idea of ESI and identifying research challenges will now be produced which will be circulated to the attendees and to other interested parties for comment before publication.

April 29th 2015

Key Research Challenges of Energy Systems Integration (ESI)
Imperial College London 30th - 31st March 2015

Attendees

Name	Organization
Ben Kroposki	National Renewable Energy Laboratory, USA
Chongqing Kang	Tsinghua University, China
Chris Dent	Durham University, UK
David Hill	Hong Kong University & Australia National University
Efstathios Peteves	Joint Research Centre, Petten, The Netherlands
Geertje Shuitema	University College Dublin, Ireland
Gert Jan Kramer	Shell and Leiden University
Goran Andersson	ETH Zurich, Switzerland
Jacob Klimstra	Consultant, The Netherlands
Janusz Bialek	Skoltech Center for Energy Systems, Russia
Jim McCalley	Iowa State University, USA
John Holmes	Oxford University, UK
Juha Kiviluoma	VTT, Finland
Klaus Willnow	Siemens, Germany
Marc Bettzuege	University Köln, Germany
Mark Howells	KTH, Sweden
Mark O'Malley	University College Dublin, Ireland
Mattias Andersson	EERA Secretariat & DTU, Denmark
Michael Goldstein	Durham University, UK

Neil Strachan	University College London, UK
Nick Jenkins	University of Cardiff, UK
Nilay Shah	Imperial College London, UK
Nils-Henrik von der Fehr	University of Oslo, Norway
Paul Denholm	National Renewable Energy Laboratory, USA
Pierluigi Mancarella	University of Manchester, UK
Roch Drozdowski	GRDF, France
Sarah Darby	Oxford University, UK
Simon Hogg	University of Durham
Trevor Gaunt	University of Capetown, South Africa
Wanda Reder	S&C Electric & IEE PES, USA
William D'haeseleer	KU Leuven, Belgium
Marta Lopes	University of Coimbra, Portugal
Goran Strbac	Imperial College London, UK
Tim Green	Imperial College London, UK
Johanette van der Merwe	University of Cape Town, South Africa
Sarah LaMonaca	University College Dublin, Ireland

“Key Research Challenges of Energy Systems Integration (ESI)”
Imperial College London 30th - 31st March 2015
Room 170 Queen’s Gate (building 24 on map attached)

AGENDA

Day 1

8.30 – 9.00	Registration, Tea & Coffee
9.00 – 9.15	Introduction and workshop objectives – Mark O’Malley, UCD

The morning discussion will centre on the five questions posed in the workshop briefing document (attached). Each session will last 30 minutes, will be led by a chairperson and involve all workshop attendees.

9.15 – 9.45	“What mix of energy fuels and technologies will yield an optimally integrated energy system?” Goran Strbac, Imperial
9.45 – 10.30	“Which practical/economic hurdles exist in ESI that could be informed or solved by scientific breakthrough?” Chair: Goran Andersson, ETH
10.30 – 11.00	“What is the role and impact of the consumer in an integrated energy system?” Chair: Sarah Darby, Oxford University
11.00 – 11.30	Coffee Break
11.30 – 12.00	“What regulatory and market framework best supports an integrated energy system?” Chair: Marc O. Bettzuege, University of Collogne
12.00 – 12.30	“What degree of system flexibility is both possible and economical?” Chair: Nils-Henrik M von der Fehr, University of Oslo
12.30 – 14.00	Lunch

The afternoon sessions will comprise of cross-cutting multidisciplinary discussions on application domains of ESI. Workshop attendees will opt to take part in one discussion with the aim of having a balance of expertise within each session. Each breakout session will have a designated chairperson.

14.00 – 16.30	Breakout Session # 1: "Opportunities for Energy Systems Integration in the developing world" Chair: Trevor Gaunt, UCT
14.00 – 16.30	Breakout Session # 2: "Delivering truly integrated energy systems for cities" Chair: Nilay Shah, Imperial
14.00 – 16.30	Breakout Session # 3: "Challenges associated with energy systems integration in a regional environment" Chair: Jim McCalley, ISU
19.00	Dinner hosted by Imperial College – 58 Prince's Gate – building 23 in map attached

Day 2

The second morning will begin with a readout from the chairs of the breakout sessions from the afternoon session on Day 1. This is followed immediately by a panel discussion focussing on different sectorial perspectives on the issues surrounding Energy Systems Integration, giving each sector the opportunity to reflect on the discussions of Day 1.

9.00 – 9.30	Readout from breakout sessions on Day 1. Trevor Gaunt, Nilay Shah & Jim McCalley
9.30 – 11.00	Sectorial Panel Discussion. A representative from each of three sectors, Government (Efstathios Peteves, JRC), Industry (Gertjan Kramer, Shell) and Academia (Janus Bialek, Skoltech) will give a short presentation on challenges in ESI from their perspective. This will be followed by a discussion to identify the differences and synergies in these perspectives. Chair: Ben Kroposki, NREL
11.00 – 11.30	Coffee Break
11.30 – 12.30	The final group discussion will involve all attendees and will be centred on the written output of the workshop. Tangible to address the identified research challenges will be discussed e.g. ESI research centre? The discussion will also focus on next steps and how to engage interested parties who could not attend. Chair: Mark O'Malley, UCD
12.30 – 12.45	Workshop closing remarks - Ben Kroposki, NREL.

DRAFT Workshop Briefing Document

"Key Research Challenges of Energy Systems Integration"

Imperial College London 30th - 31st March 2015

Workshop Focus: The aim of the iiESI London Workshop will be to identify a core set of research challenges in the area of Energy Systems Integration (ESI). The meeting will be attended by high-level academic and industry-based participants from a range of countries and research disciplines, and will result in a white paper to be circulated among key stakeholders to assist the research community in defining a focused, prioritised research agenda.

Topic Summary: Energy systems have evolved over decades from individual energy devices and small, disparate sub-systems into a complex set of regulatory and economic regimes governing diverse physical systems, including electricity grids, gas networks, generation assets, etc. These systems are becoming increasingly integrated physically, institutionally, and financially, a trend which has been accelerated by ubiquitous cheap communications and control infrastructure, as well as shifts in the political and economic landscape. Increased integration of energy systems also takes place against the backdrop of similar and overlapping trends in other large-scale infrastructures including data, transport, and water. Research in ESI, a multidisciplinary area ranging from science, engineering, and technology to policy, economics, regulation, and human behaviour, is essential to informing effective analysis, design, and operation of the global energy system

The considerations that govern ESI are numerous and complex, and outcomes can be difficult to define. Indeed, a major theme or goal of ESI is system optimization, however, optimization can be measured by any number of interrelated—and in some cases, contradictory—indicators. A number of specific issues are driving efforts at system optimization in both the developed world and in emerging economies. Around the world, rapidly growing penetration of clean energy technologies, particularly wind and solar photovoltaics (PV), requires flexible energy systems that can accommodate and optimize variable and distributed generation. Uncertainty due to geopolitical dynamics can rapidly affect energy supply and global markets, with potentially dramatic impacts on energy systems. New and existing energy infrastructure requires adaptation and investment in order to be suitably flexible, reliable, and resilient. These changes must also be accompanied by timely, complementary adjustments in regulation, market structures, and consumer/end use interactions. The purpose of this workshop is to identify the most relevant research questions in the ESI field, and to articulate those questions in a manner that will elicit a constructive, robust response from the academic community **By focusing on optimization of energy systems, we can better understand and capture potential benefits that increase reliability and performance, and minimise cost and environmental impacts**.

Research Challenges

Below are five research challenges that can serve as starting points for the workshop discussion.

What mix of energy fuels and technologies will yield an optimally integrated energy system?

This question, which will require significant modelling capability, will challenge researchers to design a future energy system that is technically and economically optimized based on a range of to-be-defined technical, geophysical, and financial constraints. For example, respondents would need to consider how/whether to quantify the costs and impacts of climate change, what balance of domestic and imported resources is secure and economic, what system configuration operates most reliably, most cleanly, at lowest cost, etc.

Which practical/economic hurdles exist in ESI that could be informed or solved by scientific breakthroughs?

This question acknowledges that some economic or policy challenges in ESI require technical solutions or advancements. The question should challenge researchers to identify scientific questions which, if answered, could yield solutions that would allow more efficient operation of the integrated energy system. Battery and storage technologies are a possible example in relation to electrified transportation and its impact on the grid.

What is the role and impact of the consumer in an integrated energy system?

Increased accessibility of energy data, as well as commercialization of energy management services (e.g. Opower) allows consumers to better understand and engage with their energy use. This question should examine potential impacts of informed, empowered energy users, and consider how systems should be designed to facilitate or mitigate those impacts. For example, if consumers are given access to their energy use data, or a control mechanism for adjusting their energy use, a. will they use it b. how will their use/lack of use impact overall system optimization and c. how should system participants (operators, suppliers, policymakers, etc.) respond?

What regulatory and market framework best supports an integrated energy system?

This question should identify which characteristics should be reflected in regulatory frameworks and market designs to ensure reliability and effective operation, as well as appropriate pricing and proper long-term investment.

What degree of system flexibility is both possible and economical?

Investments in system flexibility can be costly, but are necessary to deal with variability and uncertainty. This question explores the interplay between technical improvements that can be achieved (forecasting, controls, plant/network characteristics, etc.) and their associated costs/savings.

Resources

For those interested, workshop organizers offer the following selection of publications as relevant resources in advance of the discussion:

Cochran, J., Bird, L., Heeter, J. and Arent, D. A. (2012) '*Integrating Variable Renewable Energy in Electric Power Markets: Best Practices from International Experience*', National Renewable Energy Laboratory (NREL), Golden. Available at: http://www.nrel.gov/docs/fy12osti/53732.pdf

De Jonghe, C., Hobbs, B. F. and Belmans, R. (2012) 'Optimal generation mix with short-term demand response and wind penetration', *IEEE Transactions on Power Systems*, 27(2), pp. 830–839.

EC (2010) '*Energy 2020 A strategy for competitive, sustainable and secure energy*', COM 639, Brussels. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0639:FIN:En:PDF

EC (2012) '*Study on synergies between electricity and gas balancing markets*', Brussels. Available at: https://ec.europa.eu/energy/sites/ener/files/documents/20121220_ebegs_final_report.pdf

KPMG (2014) '*Future State 2030: The global megatrends shaping governments*', Available at: http://www.kpmg.com/Global/en/IssuesAndInsights/ArticlesPublications/future-state-government/Documents/future-state-2030-v3.pdf

EPRI (2014) '*The Integrated Grid: Realizing the Full Value of Central and Distributed Energy Resources*'. Available at: http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002002733

EPSRC (2014) '*Engineering Grand Challenges*'. Available at: http://www.epsrc.ac.uk/newsevents/pubs/engineering-grand-challenges/

ETSAP (2011) '*Final Report of Annex XI (2008-2010) Joint Studies for New and Mitigated Energy Systems October 2011*'. Available at www.iea-etsap.org/web/FinReport/ETSAP-Annex-XI-final-report-final%20version-June-2012-v03.pdf

Pöyry (2014) '*Revealing the value of flexibility*', Oxford. Available at: http://www.poyry.com/sites/default/files/imce/files/revealing_the_value_of_flexibility_public_report_v1_0.pdf