CREDENCE

(Collaborative REsearch of Decentralization, ElectricifcatioN, Communications and Economics)

FREEDM SYSTEMS CENTER

MaREI Energy · Climate · Marine

QUEEN'S UNIVERSITY BELFAST

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Section 1: Introduction

How can we accelerate the transition to a low carbon future, while also increasing our energy security by reducing our dependence on imported fossil fuels?

CREDENCE (**C**ollaborative **RE**search of **D**ecentralization, **E**lectrificatio**N**, **C**ommunications and **E**conomics) was the first funded US-Ireland Centre to Centre research project focusing on the energy transition. CREDENCE explored two key dimensions of the shift to a low carbon energy system over the period January 2017 – June 2021, namely to what extent will energy systems be:

- electrified (exploring how much of our future heat and transport energy needs will be met with electricity as opposed to other options, i.e. fossil or renewable fuelled heat and transport)
- decentralized (i.e. decentralized system operation), and what are the optimal levels of decentralisation for future energy systems?

By exploring and understanding these relationships, the CREDENCE partnership provided government and industry with key insights into how to accelerate the transitions towards electrification and decentralisation.

The project also investigated how communication technologies and socio-economics can enable the energy transition towards optimum levels. CREDENCE generated excellent research and used this to achieve significant impacts in informing policy, supporting industry and empowering society.

CREDENCE achieved a number of key research **breakthroughs** and impactful **outcomes**, including:

- produced the first 100% renewable energy scenarios by 2050 for Ireland using a least-cost whole energy systems approach. The paper was co-authored with US partners, published in the journal Energy, and selected as 'Editor's Choice' by Energy journal editor – Least cost energy system pathways towards 100% renewable energy in Ireland by 2050.
- developed a unique system of systems approach to electrification and decentralisation, spanning time horizons from micro-seconds to decades, and different systems (ranging from electrical devices, electricity users, the distribution power system, the transmission system all the way to the entire energy system and the wider economy).
- generated new insights into public acceptance of renewable electricity generation and transmission network developments.
- informed US energy policy deliberations at the International Energy Workshop 2017 in Maryland, leading discussions on the challenges of addressing short term power system operational challenges (due to variable non-synchronous renewable electricity) while simultaneously also deciding on long term energy system evolution.
- informed Ireland's policy shift towards increased mitigation and renewable electricity targets articulated in Ireland's Climate Action Plan 2019.
- underpinned rural energy transition on the Dingle Peninsula, focusing on quantifying energy use and energy-related emissions on the Dingle peninsula and developing scenarios for future energy demand and supply, drawing on the outcomes of parish consultation meetings.
- supported industry partners, in particular, ESB Network, by working collaboratively with EPRI on new advances in integrating low voltage and medium voltage power systems analysis and supporting EPRI in establishing and launching their European HQ in Dublin.

Section 2: Project Overview

Project Partners

The project was a collaboration between three partners from the three jurisdictions of the United States, Ireland and Northern Ireland. Each of the three project partners brought a significantly unique perspective to the problem at hand. The perspectives of each centre, combined with the regional differences of the three, provided the opportunity for major transformations in the nature of the energy marketplace.

- **MaREI** provided experience in central control of large-scale intermittent renewable resources, long-term energy systems modelling and in socio-economic aspects of the energy system transformation through collaboration with the Economic Social Research Institute (ESRI).

- **FREEDM**, headquartered at North Carolina State University, provided wide-area, distributed control of small-scale distributed intermittent renewable resources.

- **EPIC** in QUB provided expertise in wider scale issues of communications and the interactions between various fuel marketplaces.

Faculty Research Teams at the project partners

Each of the three brought significant partnerships, enabling ready integration of market information and data while rapidly deploying new information, allowing for widespread change in thought across the industry. A more detailed overview of each project partner is included as follows:

MAREI (IRE)

MaREI is the SFI Research Centre for Energy, Climate and Marine research and innovation, coordinated by the Environmental Research Institute (ERI) at University College Cork. The Centre comprises over 230 researchers working in 12 third level and research institutes with over 80 industry partners, focusing on defined global challenges such as the Energy Transition, Climate Action and the Blue Economy. Prof. Brian Ó Gallachóir serves as the Lead ROI Principal Investigator, supported by Dr. John Curtis and Dr. Barry Hayes, focusing on optimal levels of electrification, associated power system impacts, and consumer behaviour and socio-economic evaluation.

FREEDM (US)

The NSF Future Renewable Electric Energy Delivery and Management (FREEDM) Systems Engineering Research Center was established in 2008 and is headquartered in the Keystone Science Center at North Carolina State University. At the FREEDM Center, universities from the United States have joined forces with industry partners to develop a more secure, sustainable, environmentally friendly grid. FREEDM develops technologies to manage the flow and storage of energy on the utility grid, with a specific focus on micro-grids and decentralisation. Prof. Joe de Carolis serves as the Lead US Principal Investigator and is the Associate Professor in the Department of Civil, Construction, and Environmental Engineering at North Carolina State University.

EPIC (NI)

The Energy, Power and Intelligent Control (EPIC) cluster is based at QUB and was formed in 2012. It has established itself as a world leader in the development of controls and intelligence related to the power system. EPIC is a member of the UK's IET Power Networks Research Academy and several UK EPSRC SUPERGEN consortia. Energy-related activities take place across four groups in the Faculty of Engineering and Physical Sciences at QUB: 1) Clean Energies Research Cluster, 2) Energy Power and Intelligent Control (EPIC) cluster 3) Centre for Secure Information Technologies (CSIT) and 4) QUESTOR.

Work Packages

CREDENCE comprised four distinct Work Packages spread across each of the project partners. The specific outcomes of each of these Work Packages are outlined as follows

David Laverty (QUB)

Work Package 1 (Telecommunications)

The focus of WP1 has been the development of novel load identification and modelling tools in order to determine the population and electrical network connection point of distributed energy resources, particularly electric vehicles and photovoltaic systems. Non-invasive load modelling (NILM) has been the preferred approach. The WP1 team has contributed to knowledge in the form of new machine learning and neural network methods that reliably identify EV and PV locations from 'bulk data' collected at neighbourhood level. These methods are further improved with precision time-synchronised measurements obtained using OpenPMU type sensors.

In parallel, WP1 has considered the telecommunications aspects needed to deliver the new methods developed throughout the CREDENCE work packages. Special consideration has been made to cyber-security considerations and the protection of critical national infrastructure (CNI). Novel approaches to electrical utility operation data security were developed using Software Defined Networking (SDN), such that the surface area for a cyberattack is significantly reduced and the impact of network intrusion is mitigated.

WP 1 contributed to 6 Co-authored papers in peer-reviewed journals, 10 papers presented at international conferences, and open-source software research tools.

Aoife Foley (QUB)

Work Package 2 (Optimal Levels of Decentralisation)

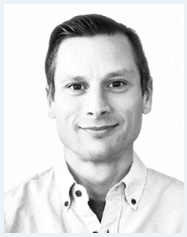
The goals and objectives of WP2 were to investigate the impacts of varying levels of decentralisation, compared against additional interconnection from a cost perspective, and the power system impacts of decentralisation. Investigations also included the development of new methods needed to control the widely distributed generation resources.

WP 2 contributed to 15 Co-authored papers in peer-reviewed journals and 3 papers at international conferences.

Brian Ó Gallachóir (MaREI)

Work Package 3 (Optimal Levels of Electrification)

The critical focus of WP3 has been the development and use of energy systems modelling tools to explore the implications of different levels of electrification, provide insights into the transition to a low carbon future, study comparisons between electrification with alternative technological options for carbon reduction, and explore different penetration levels of renewable energy. How electrification of heat and transport affects energy prices was also investigated.



Joe DeCarolis (FREEDM)

The CREDENCE team published papers on pathways to 100% Renewable Energy Systems, to investigate the impact of different levels of minimum inertia constraints in Europe, and to test a computationally efficient energy systems model that could support seasonal planning. For more information on these papers, see Work Package 3 Publications.

WP 3 contributed to 12 Co-authored papers in peer-reviewed journals, underpinned energy and climate policy decisions, and supported the Dingle Peninsula 2030 rural energy transition initiative, capturing learning and insights through a series of innovative learning briefs.

John Curtis (MaREI/ESRI)

Work Package 4 (Socio-Economic Evaluation)

This work package has focused on four elements related to consumer preferences and behaviours within the electricity system.

- The first examines electricity customers' attitudes towards future electricity supply contracts that may include appliance curtailment clauses.
- The second project examines residential appliance loads, specifically during the evening peak.
- The third project examines the public's acceptance of new electricity system infrastructure, specifically wind electricity generation and transmission lines.
- The fourth project examines the scale deployment of hydrogen electrolysers within the power system and the potential use of hydrogen for residential heating.

WP 4 contributed to 11 Co-authored papers in peer-reviewed journals.

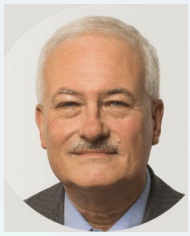
Section 3: Collaborative Activities

Industry Advisory Committee

The CREDENCE Industry Advisory Committee was established early in the project, has met six times, and involves participation from key staff at EPRI, ESB Networks, EirGrid, Smart Grid Ireland, Ervia, CRU, Siemens, Glen Dimplex, Schneider, and Power Analytics. Below are some of the reflections from our Industry Advisory Board, where they discussed the impact of working with the CREDENCE team and the project's successes.

Mark McGranaghan
EPRI Fellow at EPRI Europe

"The findings here are really reflective of what we're finding in the industry overall, mainly that we can't look at the electric system in isolation anymore. Everything is about energy system analysis, and it involves complex systems and systems of systems... government policies, technology development and the interactions between all these systems are really bringing new challenges around data and modelling to our research needs, and I think CREDENCE started to tackle some of these challenges and set the stage for ongoing work in those areas."



Bob Hanna
Chair, Smart Grid Ireland

"This project is a unique celebration of what can be done when you get people together in the same project with encouragement from industry to get things done... Many other processes have provided an end result, but not the pathway. In bringing together the disciplines of researchers and focused on decentralisation of energy systems and electrification of heat and transport, you have, between [the three jurisdictions], results which are valid and real. And this pathway means something. The outputs will help energy system planning. They will help electricity system design, and they will help electricity system operation in the near term, as well as in the long term."

Aoife MacEvilly
Chairperson at Commission for Regulation of Utilities (CRU)

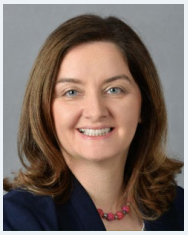
"It's just fascinating and also incredibly relevant to what we're trying to do in Ireland. So the focus on electrification of heating and transport, along with decentralisation, is hugely aligned with the work that Ireland is undertaking on the Climate Action Plan... I found also hugely interesting was the insight that we got into other jurisdictions, particularly the American crossover [which] added huge value to the project."

Clare Duffy
Network Development and Electrification Manager at ESB Network

"For us, the focus of CREDENCE on key dimensions of the low carbon energy transition are really well aligned with what ESB networks innovation strategies. For us, our interests were clearly around the move by future customers to electrify their heat and transport, and we're interested to understand how that might happen in Ireland and what we might need to do to future proof our network."

Kevin Meagher
Principal at Energy One Solutions International

"I think the collaborative nature of the project is extremely useful in particular because I perceive Ireland as a gateway to the EU, so there is significant value both in terms as an industry partner and the access to other markets that we are already a participant in."



Maeve Cowley
Vice President, Engineering & Green Economy, IDA Ireland

"CREDENCE is a very exciting project for us. The depth of knowledge that exists within the broad agreement of CREDENCE and the talent that is being deployed to meet many of the challenges is tremendous. It also has a great international focus and is a level of collaborations across national boundaries and in different organisations of different sizes."

Power of Collaboration

The project held five annual meetings from 2017 to 2021, hosted by each of the partners. Participation included team members and members of the CREDENCE Industry Advisory Board which was established early in the project, has met six times and involves participation from key staff at EPRI, ESB Networks, EirGrid, Ervia, CRU, Siemens, Glen Dimplex, Schneider, and Power Analytics.

The fifth and final event titled the CREDENCE Showcase Event took place on Tuesday, June 29th, 2021, via Zoom, hosted by MaREI. The purpose of the event was to share some of the research, insights, impacts and outcomes of CREDENCE and celebrate the project's success as it comes to an end.

- Session 1 consisted of five presentations from the CREDENCE leaders where they discussed the success and results of the research carried out.
- Session 2 (titled Reflections) involved insights and testimonies from senior public officials from the US, Ireland and Northern Ireland.

Section 4: Reflections

Dan Mulhall
Ambassador of Ireland to the United States

"Collaborative research has a key role to play. We've seen that in the response to the pandemic in the development of vaccines which is essentially a collaborative venture that involved Europeans and Americans working together.

The CREDENCE project demonstrates how the power of scientific research can be used to underpin decisions on emissions reductions in energy systems. And we must look to your project to have an important impact, informing policy deliberations in the United States, Ireland, and Northern Ireland, supporting industry partners that are the frontiers of energy transition, empowering citizens and communities to realise their ambitions positively engage with climate action.

The CREDENCE project is funded by the US research and development partnership that was developed over several years, and it's a vibrant partnership between the United States, Northern Ireland and Ireland. It is an excellent example of science and diplomacy, working together in a unique bilateral partnership."

Ruth Freeman
Director of Science for Society, Science Foundation Ireland

"I'm really delighted that the CREDENCE project chose the Dingle Peninsula as a real-life case study, and as part of this project, they're supporting the community there to realise their own ambitions to achieve this rural energy transition to a low carbon future...

I think we need more of these kinds of dialogues in all research. New technologies and science are going to impact on different people in different places in different ways, so it's only right that end users are given opportunities to participate in their development."

Roxanne Nikolaus
Office of the Director National Science Foundation

"NSF considers our partnerships with SFI and Department for the Economy in Northern Ireland to be a great success. We see it as a win for our research communities for our countries and even beyond that... these co-operations are tackling real-world challenges and are informing decisions, and that's really what it's all about."

Stephen McGonagle
Head of Energy Intelligence, Department for the Economy NI

"This CREDENCE project and Dr Foley's outputs are actually helping with the energy transition inputs and the future energy scenario development, and the wider departmental Northern Ireland research agenda. So we very much welcome the addition of this CREDENCE research project, the evidence base, and the contribution that it will make to the support, policy development, connected with the energy strategy in Northern Ireland."

Angelina LaRose
Assistant Administrator for Energy Analysis Energy Information Administration

"One of the key benefits that I also see in the CREEDENCE collaborative project is it adopts a system of systems approach with aspects focusing on a very granular level such as the control and telecommunication associated with individual devices, but then layer on different modelling resolutions, time horizons, and ultimately linking the economy with the wider society."

Brian Carroll
Assistant Secretary General Dept. of Environment, Climate & Communications

"In terms of the work we're doing with the US via the CREDENCE program, the outputs the results and outcomes couldn't be more timely in terms of informing those decisions. Within the department here, we've greatly benefited from the energy systems modelling that's at the heart of the CREDENCE project, and not just in terms of developing national policy but also in responding to proposals that come out at EU level and Ireland's contribution to enhanced EU ambition.

It's really important to us as policymakers to have a very good understanding of the least cost energy systems pathways to achieve different levels of emissions reduction or increased levels of renewable energy when we're making our decisions.

We need to be able to answer questions such as how far can we go with emissions reduction? What's the marginal cost of additional abatement? What are the energy system costs? What's the appropriate choice of carbon budgets? And what's the appropriate sectoral division of those budgets? The outputs of the energy systems modelling are currently being used both by the departments and the development of the Climate Action Plan, and I know with the Climate Change Advisory Council in terms of examining the carbon budgets they're planning to propose."

Annex 1 Publications

Work Package 1

Co-authored papers in Peer-Reviewed Journals.

- Andres F. Moreno Jaramillo, David M. Laverty,D. John Morrow,Jesús Martinez del Rincon,Aoife M. Foley. (2021). ***Load modelling and non-intrusive load monitoring to integrate distributed energy resources in low and medium voltage networks***. Renewable Energy Vol 179, Pages 445-466 https://doi.org/10.1016/j.renene.2021.07.056
- D.M. Laverty, J. Hastings, D.J. Morrow. (2021) ***"Islanding Detection by Phase Difference Method using a Low Cost Quasi-PMU"*** in IET Generation, Transmission & Distribution, July 2021 https://doi.org/10.1049/gtd2.12261
- A. Jahic, J. Hastings, D.J. Morrow, D. Laverty. (2021) ***"Hardware-in-the-Loop Demonstration of Automated Demand Response for Distribution Networks using PMU and MQTT***," in IET Smart Grids, vol. 4.1, pp. 107-120, Feb 2021 https://doi.org/10.1049/stg2.12009
- L. Meegahapola, D. Laverty and M. Jacobsen (2018) **"Synchronous islanded operation of an inverter interfaced renewable rich microgrid using synchrophasors"** in IET Renewable Power Generation, vol. 12, no. 4, pp. 407-414, 19 3 2018, doi: 10.1049/iet-rpg.2017.0406.
- Hastings, J.C., Laverty, D.M., Morrow, D.J. (2018) ***"A Converged Approach to Physical-Layer Communications in Supporting Domestic-Level Automated Demand-Response Systems utilizing"*** ISO/IEC 20922. IEEE/PES General Meeting, Portland, Oregon, USA, 5th -10th August. DOI: 10.1109/PESGM.2018.8585914
- X. Zhao; D. M. Laverty; A. McKernan; D. J. Morrow; K. McLaughlin; S. Sezer, (2017) "***GPS-Disciplined Analog-to-Digital Converter for Phasor Measurement Applications"***, in IEEE Transactions on Instrumentation and Measurement Vol. 66, pp. 2349 – 2357 DOI: 10.1109/TIM.2017.2700158

Conference Publications

- A. F. Moreno Jaramillo, A.A. Raouf Mohamed, D.M. Laverty, J.M. del-Rincon, A.M. Foley, **"Photovoltaic Power Disaggregation using a Non-Intrusive Load Monitoring Regression Model"** in IEEE ISGT-Europe, 2021, in press
- A.F Moreno-Jaramillo, J. Lopez-Lorente, D.M. Laverty, J.M. del-Rincon A. Foley, ***"Load Identification of Distributed Energy Resources in Low Voltage Distribution Networks"*** in IEEE ISGT-Europe, 2021, in press
- A. F. Moreno Jaramillo, D. M. Laverty, J. M. Del Rincón, P. Brogan and D. J. Morrow, ***"Non-Intrusive Load Monitoring Algorithm for PV Identification in the Residential Sector"*** 2020 31st Irish Signals and Systems Conference (ISSC), Letterkenny, Ireland, 2020, pp. 1-6, doi: 10.1109/ISSC49989.2020.9180192.
- A. F. Moreno Jaramillo, D. M. Laverty, J. M. del Rincón, J. Hastings and D. J. Morrow***, "Supervised Non-Intrusive Load Monitoring Algorithm for Electric Vehicle Identification"*** 2020 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), Dubrovnik, Croatia, 2020, pp. 1-6, doi: 10.1109/I2MTC43012.2020.9128529.

- A. F. Moreno Jaramillo, D. M. Laverty, J. M. del Rincón, J. Hastings and D. J. Morrow, ***"Supervised Non-Intrusive Load Monitoring Algorithm for Electric Vehicle Identification***," 2020 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), Dubrovnik, Croatia, 2020, pp. 1-6, doi: 10.1109/I2MTC43012.2020.9128529.
- A.F. Moreno Jaramillo, D.M. Laverty, D.J. Morrow, A. Foley, ***"Review of non-intrusive load monitoring methods in distribution networks to optimise renewable energy integration,"*** *14th Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES) 2019*, Dubrovnik, Croatia, 2019
- J. O'Raw, D. M. Laverty and D. J. Morrow, ***"Reliable Data Communications Device Configuration Using IEC61850***," *2019 IEEE Milan PowerTech*, Milan, Italy, 2019, pp. 1-5, doi: 10.1109/PTC.2019.8810903.
- J. C. Hastings, D. M. Laverty and D. J. Morrow, ***"A Converged Approach to Physical-Layer Communications in Supporting Domestic-Level Automated Demand-Response Systems utilizing ISO/IEC 20922,"*** *2018 IEEE Power & Energy Society General Meeting (PESGM)*, Portland, OR, 2018, pp. 1-5, doi: 10.1109/PESGM.2018.8585914.
- D. M. Laverty, J. Hastings, D. J. Morrow, R. Khan, K. Mclaughlin and S. Sezer, ***"A modular phasor measurement unit design featuring open data exchange methods,"*** *2017 IEEE Power & Energy Society General Meeting*, Chicago, IL, 2017, pp. 1-5, doi: 10.1109/PESGM.2017.8273986.
- J. O'Raw, D. M. Laverty and D. J. Morrow, ***"IEC 61850 substation configuration language as a basis for automated security and SDN configuration,"*** *2017 IEEE Power & Energy Society General Meeting*, Chicago, IL, 2017, pp. 1-5, doi: 10.1109/PESGM.2017.8274265.
- J. C. Hastings and D. M. Laverty, ***"Modernizing wide-area grid communications for distributed energy resource applications using MQTT publish-subscribe protocol,"*** *2017 IEEE Power & Energy Society General Meeting*, Chicago, IL, 2017, pp. 1-5, doi: 10.1109/PESGM.2017.8274486.

Work Package 2

Co-authored papers in Peer-Reviewed Journals.

- Andres Moreno Jaramillo, Javier Lopez Lorente, David Laverty, Jesus Martinez-del-Rincon, D John Morrow, Aoife Foley (2022) Effective identification of distributed energy resources using smart meters net-demand data IET Smart Grid https://doi.org/10.1049/stg2.12056
- • Andres F Moreno Jaramillo, David M Laverty, D John Morrow, Jesús Martinez del Rincon, Aoife M Foley (2021) **Load modelling and non-intrusive load monitoring to integrate distributed energy resources in low and medium voltage networks** Renewable Energy. Vol 179, 445-466 https://doi.org/10.1016/j.renene.2021.07.056
- Phuong H Hoang, Gokhan Ozkan, Payam R Badr, Behnaz Papari, Christopher S Edrington, Mustafa Alparslan Zehir, Barry Hayes, Laura Mehigan, Dlzar Al Kez, Aoife M Foley. (2022) **A Dual Distributed Optimal Energy Management Method for Distribution Grids With Electric Vehicles.** IEEE Transactions on Intelligent Transportation Systems. doi:10.1109/TITS.2021.3126543
- Dlzar Al Kez, Aoife M Foley, Faraedoon W Ahmed, Mark O'Malley, SM Muyeen. (2021) **Potential of data centers for fast frequency response services in synchronously isolated power systems** Renewable and Sustainable Energy Reviews. Vol 151, 111547 https://doi.org/10.1016/j.rser.2021.111547

- Mehigan L., Dlzar A.K., Collins S., Foley A., Ó Gallachóir B., Deane P. (2020) ***Renewables in the European power system and the impact on system rotational inertia.*** Energy. Volume 203, 15 July 2020, 117776 https://doi.org/10.1016/j.energy.2020.117776
- B. Hayes, S. Thakur, J. Breslin. (2019) **"*Co-simulation of electricity distribution networks and peer to peer energy trading platforms*"**. International Journal of Electrical Power & Energy Systems, vol. 115, July 2019 https://doi.org/10.1016/j.ijepes.2019.105419
- M. A. Devlin and B. P. Hayes. (2019) **"*Non-Intrusive Load Monitoring and Classification of Activities of Daily Living Using Residential Smart Meter Data*,"** in IEEE Transactions on Consumer Electronics, vol. 65, no. 3, pp. 339-348, Aug. 2019 DOI: 10.1109/TCE.2019.2918922
- B. Papari, C. S. Edrington, and D. Gonsoulin, (2019) "***Optimal energy-emission management in hybrid AC-DC microgrids with vehicle-2-grid technology"***. Journal of Renewable and Sustainable Energy, 10(1), pp. 1- 21 https://doi.org/10.1063/1.5041492
- Mehigan L., Deane, J. P., Ó Gallachóir, B. P., Bertsch V. (2018) ***The role of Distributed Generation (DG) in Future Electricity Systems.*** Energy 163 pp 822-836 https://doi.org/10.1016/j.energy.2018.08.022
- Mousa Marzband, Mohammad Hossein Fouladfar, Mudathir Funsho Akorede, Gordon Lightbody and Edris Pouresmaeil (2018) ***"Framework for Smart Transactive Energy in Home-Microgrids Considering Coalition Formation and Demand Side Management".*** Sustainable Cities and Society 40, 136-154 https://doi.org/10.1016/j.scs.2018.04.010
- Mousa Marzband, Fatemeh Azarinejadian, Edris Pouresmaeil, Mehdi Savaghebi, Josep M. Guerrero and Gordon Lightbody. (2018) ***"Smart Transactive Energy Framework in Grid-connected Multiple Home Microgrids under Independent and Coalition Operations"***. Renewable Energy 126, 95-106. https://doi.org/10.1016/j.renene.2018.03.021
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- Brinkerink, M., Deane, P., Collins, S., Ó Gallachóir B., 2018. ***Developing a global interconnected power system model.*** Global Energy Interconnection 1-4 330-343. https://doi.org/10.14171/j.2096-5117.gei.2018.03.004
- Mousa Marzband, Masoumeh Javadi, S. Ali Pourmousavi, and Gordon Lightbody. (2018) ***"An Advanced Retail Electricity Market for Active Distribution Systems and Home Microgrid Interoperability Based on Game Theory"***. Electrical Power System Research, Vol. 157, pp. 187-199, April 2018. (IF 3.289) https://doi.org/10.1016/j.epsr.2017.12.024
- Papari, C. S. Edrington, (2017), "***Effective Energy Management of Hybrid AC-DC Microgrids with Storage Devices"***, IEEE Transactions on Smart Grid, (IEEE Early Access) DOI: 10.1109/TSG.2017.2736789

Conference Publications

- D. Al Kez, A. Foley, D.J. Morrow (2020) ***"A Comparative Assessment of Battery Energy Storage Location in Power Systems with High Wind Power Penetrations",*** target: Power Systems Computational Conference (PSCC), Porto, Portugal, 29th June to 3rd July, 2020
- M.A. Zehir, B.P. Hayes, S.Z. Djokic, ***"Real-time Grouped Management of Electric Vehicle Battery Chargers (EVBCs) for Voltage Profile Improvement in Radial Distribution Networks",*** IEEE PES Innovative Smart Grid Technologies Europe 2019, Oct. 2019
- M.A. Devlin, B.P. Hayes**,** ***"Non-Intrusive Load Monitoring using Electricity Smart Meter Data: A Deep Learning Approach"***, in Proceedings of IEEE Power and Energy Society General Meeting 2019

- D. Al Kez, A. Foley, N. McIlwane, D.J. Morrow "A review of the dynamic impacts of renewable generation, distributed generation and emerging smart loads on the power system", 14th Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES), Dubrovnik, Croatia, 1st October to 6th October 2019
- M. Khan, B.P. Hayes, "Three Phase State Estimation in Power Distribution Networks by Integrating IEEE-1588 with Smart Meters", International Conference on Smart Grid Synchronized Measurements, May 2019
- B. Papari, N. Deb, G. Ozkhan, P. Hoang, C. S. Edrington, and R. Cox (2019). "Enhancement of Energy Management in the Shipboard Power Systems Based on Recursive Distributed Load Shedding Model", IEEE Electric Ship Technology Symposium
- Shahab Dehghan, Meysam Khojasteh, Mousa Marzband, Gordon Lightbody, "Optimal Energy Providing Strategy of Micro-grid's Operator based on a Game Theoretical Approach". 5th International Conference on Control, Decision and Information Technologies, Greece, 2018
- B. Papari, C. S. Edrington, and T. Vu, (2017), "A Heuristic Method for Optimal Energy Management of DC Microgrid, In IEEE 2nd International Conference on DC Microgrids", Nurnberg, Germany
- B. Papari, C. S. Edrington, and T. Vu, (2017), "Stochastic Operation of Interconnected Microgrids", In IEEE Power and Energy Society General Meeting, Chicago, IL

Work Package 3

Co-authored papers in Peer-Reviewed Journals.

- Connor McGookin, Brian Ó Gallachóir, Edmond Byrne. (2021) Participatory methods in energy system modelling and planning–A review Renewable and Sustainable Energy Reviews. Volume 151, 111504. https://doi.org/10.1016/j.rser.2021.111504
- Connor McGookin, Brian Ó Gallachóir, Edmond Byrne. (2021) An innovative approach for estimating energy demand and supply to inform local energy transitions. Energy. Volume 229, 120731. https://doi.org/10.1016/j.energy.2021.120731
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- Curtis, J. ***"White goods appliances: electricity loads and residential curtailment contracts"*** - ESRI-UCC-MaREI energy research: climate action conference 17 May 2019, Dublin
- Curtis, J. ***"White goods appliances: electricity loads and residential curtailment contracts"*** – ESB Networks 3 September 2019, Dublin
- Curtis, J**.** ***"White goods appliances: electricity loads and residential curtailment contracts"*** – Commission for Regulation of Utilities, 17 September 2019, Dublin