Institution: Leeds Beckett University		
Unit of Assessment: UoA 11 (Computer Science and Informatics)		
Title of case study: Smart and Pervasive Technologies for Environmental Sustainability: Changing Policy and Practice, Improving Performance and Promoting Sustainability across a Number of Sectors		
Period when the underpinning research was undertaken: August 2013 - present		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Dr. Ah-Lian Kor	**Reader in Sustainable and Intelligent Computing**	**Aug 2005-present**
Dr. Giuseppe Colantuono	**Senior Research Fellow**	**Dec 2015 – present**
Period when the claimed impact occurred: **Data Centre Energy Efficiency (2015-now); PERCCOM and GENIAL (2012-2019; 2019 – 2025); RED WoLF (Jan 2019 – 2023)**		
Is this case study continued from a case study submitted in 2014? N **Smart and Pervasive Technologies for Environmental Sustainability: Data Centre (N) with ENEA(N); Education (PERCCOM and GENIAL)(N); Renewable Energy Storage in RED WoLF(N)**		

1. Summary of the impact (indicative maximum 100 words)

Leeds Beckett sustainability research has contributed to impact in three areas. The first area relates to change in data centre thermal and energy management-related operations and best practice in ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development) that results in 7-15% energy savings (and its associated carbon emissions) due to better managed cooling system. The underpinning research includes AI driven data centre management, thermal characteristics analysis, and data centre energy efficiency metrics. The second area involves 'green IT' skills training for 88 IT engineers and industry professionals (from 39 different countries in the world) through EU funded PERCCOM EMJMD programme and underlying research is green IT research. The third area involves the installation of low carbon technologies in 90 social homes (in the UK, Ireland, and France) to reduce carbon emissions by 215 tonnes/year. This contributes to social housing policy impact that aims to enhance quality of life and green strategy (i.e. Neolia, France; Carbery Housing Association, Ireland; Oldham City Council, First Choice Homes, Wakefield District Housing Association, UK). The underlying research is Photovoltaic Array combined with multiple hybrid energy storage system.

2. Underpinning research (indicative maximum 500 words)

According to the Smarter2030 report (by GeSI), smart and pervasive technologies is a central pillar in the response to climate change. The key targets for EU 2030 are at least: 40% cuts in greenhouse gas emissions (from 1990 levels); 32% share of renewable energy; 32.5% improvement in energy efficiency. The European Green Deal is a climate action that aims to reduce greenhouse gas emissions through research and innovation so that by 2050, the EU could attain climate-neutrality. Leeds Beckett Sustainable IT research team is active in the following research to support the EU/UK Green Deal initiative: data centre, ICT infrastructure and devices energy monitoring and energy efficiency (Dr. Ah-Lian Kor in collaboration with PERCCOM consortium partners: ENEA, Italy; University of Lorraine, France; Lulea University of Technology, Sweden; University of Chittagong, Bangladesh); renewable energy storage and smart energy management system (Dr. Giuseppe Colantuono).

Data Centre Energy Efficiency

The research on data centre energy efficiency is first supported by the project entitled '*Measuring Data Centre Efficiency*' funded through JISC Greening ICT initiative (2010) (See **G1**). This research encompasses deployment of varying levels of granularity for the measurement of energy use for individual and aggregated devices in a physical data centre. It also provides real experimental data for the calculation of Power Usage Effectiveness (PUE), trends and comparative analysis of the data centre energy efficiency. Further analysis has been conducted on the collated real experimental data set using Artificial Intelligence technique (i.e. BRB, belief rule-based expert system) to predict the PUE of the use case data centre (**R2**; funded PERCCOM research and collaborators are Lulea University

of Technology and University of Chittagong). This technique is further enhanced through the incorporation of a novel learning mechanism to improve the accuracy of PUE prediction using real-world data collected from Facebook data centre in Lulea, Sweden (**R5, G2**; funded PERCCOM research and collaborators are Lulea University of Technology and University of Chittagong). Emerging data centre energy efficiency metrics are employed for the analysis of energy consumption of computer systems at ENEA-DC HPC Clusters (**R4, G2**; funded PERCCOM research and collaborators are ENEA and University of Lorraine). This research involves rigorous analysis using productivity metrics and energy waste ratio metric to provide valuable insight into energy consumption of actual data centre parallel queues for running applications followed by exploring the impact of job scheduling on data centre energy efficiency. This is followed by transformation of attained results to sustainability metrics, i.e. Carbon Usage Effectiveness (CUE) of the use case data centre. Research in **R3, G2** (funded PERCCOM research and collaborators are ENEA and University of Lorraine) involves thermal characteristic analysis of a data centre facility using real thermal monitoring data. It also encompasses the employment of an unsupervised machine learning technique to identify persistent hotspots due to weaknesses of the data centre directed air cooling system. The findings of **R3** and **R4** feed into the formulation of energy efficiency as well as thermal management strategies and compute system-related operational policies for data centre operators and end-users of the facilities.

Grid Integrated PV-Battery Energy System

Grid integrated PV-battery energy related research conducted at LBU encompasses the modelling of combined PV arrays and multiple storage solutions (i.e. battery and hydrogen reservoir with electrolyser-fuel cells) (**R1**) and hybrid energy storage system (i.e. battery, thermal storage heaters, and water cylinder) (**R6, G4**; funded RED WoLF research). Modelling includes the grid feature where energy drawn from the grid is stored in the energy storage devices when demand, price and carbon intensity of grid electricity is low. Applied research for grid integrated PV-battery energy is conducted for the RED WoLF system (**R6, G4**). This applied research involves the development of a smart energy control and management system (based on machine learning) that is firstly tested in simulations (for 4 seasons with varying battery sizes and PV arrays) followed by pilot tests in 90 homes across UK, Ireland, and France.

3. References to the research (indicative maximum of six references)

R1. Colantuono, G., Kor, A. L., Pattinson, C., and Gorse, C. (2018). PV with multiple storage as function of geolocation, Elsevier Solar Energy, Vol. 165, pp. 217-232, doi: https://doi.org/10.1016/j.solener.2018.03.020

R2. Hossain, M. S., Raiful, S., Kor, A. L., Andersson, K., and Pattinson, C. (2017). A Belief Rule Based Expert System for Datacenter PUE Prediction under Uncertainty, IEEE Transactions on Sustainable Computing, April-June 2017, Vol. 2(2), pp.140-153, E-ISSN 2377-3782, DOI: https://doi.org/10.1109/TSUSC.2017.2697768

R3. Grishina, A., Chinnici, M., Kor, A. L., Rondeau, E., and Georges, J. P. (2020). A Machine Learning Solution for Data Center Thermal Characteristics Analysis, Energies, Vol. 13(7), 4378 doi: https://doi.org/10.3390/en13174378

R4. Grishina, A., Chinnici, M., De Chaira, D., Rondeau, E., and Kor, A. L. (2019). Energy-oriented analysis of HPC Cluster Queues: Emerging Metrics for Sustainable Data Center, in: Ntalianis K., Vachtsevanos G., Borne P., Croitoru A. (eds) Applied Physics, System Science and Computers III. APSAC 2018. Lecture Notes in Electrical Engineering, vol 574. Springer, Cham, https://doi.org/10.1007/978-3-030-21507-1_41 .

R5. Islam, R. U., Ruci, X., Hossain, M. S., Andersson, K., and Kor, A. L. (2019). Capacity Management of Hyperscale Data Centers Using Predictive Modelling, Energies 2019, 12(18), 3438, doi: https://doi.org/10.3390/en12183438 .

R6. Shukhobodskiy, A., Colantuono, G. (2020). RED WoLF: Combining a battery and thermal energy reservoirs as a hybrid storage system, Applied Energy, Volume 274, doi: https://doi.org/10.1016/j.apenergy.2020.115209

G1. 2011-2012: JISC, Measuring Data Centre's Efficiency; £50K (PI: Professor Colin Pattinson).

G2. 2012-2019: EU EMJMD PERCCOM – 532450-1-FR-2012-1-ERA MUNDUS-EMMC - Your Erasmus Mundus Action 1 Application: PERCCOM (Professor Colin Pattinson and Dr. Ah-Lian Kor); ≈ €80K

G3. 2019 – 2025: EU EMJMD GENIAL - 610619-EPP-1-2019-1-FR-EPPKA1-JMD-MOB led by University of Lorraine, Leeds Beckett Team (PI: Dr. Ah-Lian Kor) Total: €4.46m; LBU: €0.5m.

G4. 2019 – 2023: INTERREG VB NWE Application: RED WoLF - Rethink Electricity Distribution Without Load Following (PI: Dr. Giuseppe Colantuono; WP2 Pilots Leader: Dr. Ah-Lian Kor, Leeds Beckett University (Total, € 6.3m; ERDF Funding € 3.46m; LBU – €1.2m)

3. Details of the impact (indicative maximum 750 words)

The three groups of beneficiaries of Leeds Beckett Sustainable IT research are: public body (e.g. ENEA, Italy); IT professionals and engineers (trained through PERCCOM (**G2**) followed by GENIAL (**G3**)); local authorities and housing associations in three European countries namely: UK, Ireland and France.

Impact on Public Bodies

Data centre energy efficiency research work conducted with ENEA through PERCCOM (**G2**) results in the impact of changes in job scheduling for processing applications at the operational level policy (note: See **Evidence 1**). The change to the job allocation algorithm is that the first available compute node selection is switched to best suitable thermally cooler node selection facilitated through thermal characterisation and clustering of compute nodes. The result is an even thermal distribution within the data centre facility to avoid hotspots and coldspots. Action plan for future practice is thermal-related parameters monitoring (i.e. temperatures of each component in compute nodes, nodes' inlet and exhaust air temperatures, CPU as well as memory temperatures, and cooling fan speeds). The impact of the job scheduler algorithm has effected an estimated 7-15% energy savings (due to a better managed and efficient cooling system with 25% of the cooling machines being shut down) for the use case data centre. A conclusion that could be drawn is a corresponding reduction of 7-15% on carbon emissions.

Impact on IT Professionals and Engineers

Transnational education provision through PERCCOM (**G2**) effects knowledge transfer through sharing of technology amongst 13 universities from 10 different countries, 6 industrial partners, and 2 NGOs. The impact of PERCCOM is the acquisition of cutting edge green IT and digital skills (in pervasive computing and communication) by 5 PERCCOM cohorts to meet market demands (see PERCCOM mission[1]). Various sources of evidence reveal the following: a face-to-face interview with 7 PERCCOM students/alumni (**Evidence 2**) reveals changed lives (social, cultural outlook, sustainability and green IT awareness, and technological skills) and this is further supported by this published YouTube video entitled "PERCCOM Master Program"[2] created by PERCCOM Cohort 1 (2014, 800 views) and an article on "Green revolution through IT"[3]. A total of 88 students from 39 different countries across the globe have been trained in pervasive computing and communication with embedded green IT skills (see here[4]). A survey conducted on PERCCOM Alumni (Cohorts 1-4; n=58; see **Evidence 3**), reveals that more than 75% of them have acknowledged the importance of Green ICT in the industry, 44% are in academia (including PhD study), 40% in specialist IT jobs, and 16% in non-IT jobs .Additionally, about 43% of Cohorts 1-4 PERCCOM alumni are either directly or indirectly involved in Green IT jobs. These findings are found in this published paper (pp. 109-116)[5]. GENIAL[6] is PERCCOM's successor and its main focus is also Green IT and through this project, we are expected to train 100 IT professionals or engineers from 2020-2025).

Impact on Local Authorities and Housing Associations

(i) Home Related Low Carbon Technologies/Innovation Impact

In the RED WoLF Project (**G4**), low carbon technologies include grid Integrated PV array and Hybrid Energy Storage System (chemical battery, storage heaters, and water cylinder). They have already been implemented in 24 homes (in the North Western European region comprising UK, Ireland, and France; note the target is 90 homes by year 2021, See **Evidence 4** for Official Website with Newsletter on Pilots Update). RED WoLF smart home technologies installation will reduce carbon emissions by 215 tonnes/year. Partners are: France - edf[7], edf-Neolia (14 social homes in Montbeliard[8]), edf-

[1] http://perccom.univ-lorraine.fr/perccom/employment/
[2] https://www.youtube.com/watch?v=W5K8wValelk
[3] http://perccom.univ-lorraine.fr/la-revolution-verte-passe-par-linformatique/
[4] http://perccom.univ-lorraine.fr/main-results/
[5] http://confcats-uploads.s3.amazonaws.com/ACE19.pdf
[6] http://genial.univ-lorraine.fr
[7] https://www.edf.fr/groupe-edf/qui-sommes-nous/activites/recherche-et-developpement/projet-red-wolf-rethink-electricity-distribution-without-load-following
[8] http://www.neolia.fr/fr/neolia/leurope-notre-partenaire.html

Campus de L'espace (6 properties); Ireland – Cork City Council (10 Cork City Council Homes/Social Houses[9]), Carbery Housing Association (22 Social Homes)[10]; UK – Oldham City Council (19 council homes managed by housing associations)[11], First Choice Homes (10 Social Homes), Wakefield District Housing Association (18 properties)[12]. On the 1st December, 2020, EDF has organised an international virtual event entitled "Electric Days 2020", opening address by EDF CEO and French President Emmanuel Macron[13], lined with very high profile speakers[14] and the number of registered attendees is more than 80,000 around the globe. The smart energy management system for the RED WoLF project has been showcased as one of the 71 innovative projects for efficiency and smart use of electricity (see **Evidence 5**). A long-term RED WoLF 10-year strategy aims to deploy 15,000 PVHs fitted with RED WoLF Hybrid Storage System (HSS) in 15,000 homes within the North Western Europe region.

(ii) Social Policy/Strategy Impact

Providing housing with affordable renewal energy with smart home technologies (through RED WoLF Project, **G4**) has social policy impact on the society because it addresses the fuel poverty problem in deprived areas in Ireland, France and the UK. Outputs from RED WoLF informs social housing association policies and strategies in Ireland). The long term RED WoLF Strategy is rolled out as: Neolia's (France) strategy on "Reducing energy consumption in Social Housing" (**Evidence 7**); Carbery Housing Association's policy on fuel poverty elimination (**Evidence 6**); Oldham City Council's housing strategy aims to provide support to improve people's lives by improving the condition of homes and making them affordable to heat through RED WoLF[15]; First Choice Homes prioritises sustainability quality homes (**Evidence 8**); Wakefield District Housing Association aims to tackle fuel poverty through RED WoLF smart technologies (**Evidence 10**).

iii. Green Strategy Impact

RED WoLF (**G4**) smart technologies contributes to Oldham Council's Climate Change Strategy to reduce carbon emissions from domestic homes (see Green Scheme[16]) and aims to be carbon neutral as an organisation by 2025 and leading the borough to carbon neutrality by 2030[17]. RED WoLF is part of the 5-year environmental plan - Zero Carbon Cities (YEP) for Greater Manchester through Oldham City Council[18]. The Oldham City Council has developed the 'Oldham Code' for new build homes, to achieve a higher standard of energy efficiency and carbon performance. RED WoLF is an integral part of the work to contribute to the 'Oldham Code' (**Evidence 9**) for new council homes where land's price is negotiated with developers in exchange to stricter CO_2 standards. RED WoLF's technologies (HSS) constitute part of Oldham Code standards for storage and compatibility with the Grid and this strategy will flow into the "Greater Manchester (GM) Spatial Framework" joint plan, regulating development in GM to meet the GM zero-carbon targets (Greater Manchester plans to be carbon neutral by 2038). RED WoLF is also part of Wakefield District Housing Association's commitment to Sustainability (**Evidence 10**) and to support its transition to low carbon economy.

4. Sources to corroborate the impact (indicative maximum of 10 references)

Evidence 1: ENEA – Email from ENEA Project Manager with attachment and annual report (Private and Provided on request: email with attachment https://leedsbeckett-my.sharepoint.com/:u:/g/personal/a_kor_leedsbeckett_ac_uk/EU3xLu2Da4FCim-pTcOllgABKh8SEJ7ZiEUG5RqK8D95DA?e=ctI8Po; **attachment** https://leedsbeckett-my.sharepoint.com/:w:/g/personal/a_kor_leedsbeckett_ac_uk/ERafys3r71xIibKkZsz_4ocBp9dEjULw57B25pgAtiQiYA?e=agsgCe); **accompanied with annual report** (https://leedsbeckett-my.sharepoint.com/:w:/g/personal/a_kor_leedsbeckett_ac_uk/ERDgm9YXr9NMpY51DBMa-GQBFIGFmcEAVEbviVGZxXsw9g?e=RarGmM)

[9] https://www.corkcity.ie/en/council-services/news-room/latest-news/blog-cork-city-council-homes-benefit-from-interreg-red-wolf-project.html
[10] https://www.southernstar.ie/news/more-families-are-saved-from-eviction-by-cha-4202463
[11] https://aboutmanchester.co.uk/oldham-council-plans-to-purchase-19-homes-for-affordable-rent-and-all-of-which-will-be-fitted-with-state-of-the-art-renewable-energy-equipment/
[12] https://www.wdh.co.uk/AboutUs/OurCommitmentTo/Sustainability/REDWoLF/
[13] https://ens-paris-saclay.fr/agenda/electric-days-2020
[14] https://www.electricdays.fr/en/speakers
[15] https://aboutmanchester.co.uk/oldham-council-plans-to-purchase-19-homes-for-affordable-rent-and-all-of-which-will-be-fitted-with-state-of-the-art-renewable-energy-equipment/
[16] https://www.oldham.gov.uk/homepage/790/green_schemes
[17] https://aboutmanchester.co.uk/oldham-council-plans-to-purchase-19-homes-for-affordable-rent-and-all-of-which-will-be-fitted-with-state-of-the-art-renewable-energy-equipment/
[18] https://democracy.greatermanchester-ca.gov.uk/documents/s2710/Five%20Year%20Environment%20Plan%20Forum%206f.pdf

Evidence 2: PERCCOM - Interview Videos accompanied with Transcripts (Private and Provided on request: Videos https://leedsbeckett-my.sharepoint.com/:f:/g/personal/a_kor_leedsbeckett_ac_uk/EjmnvYS2QVFGql89G69kd5wBgTC4JKaVUHIP66ShP8fKGQ?e=t9kagf **accompanied with Transcript** https://leedsbeckett-my.sharepoint.com/:w:/g/personal/a_kor_leedsbeckett_ac_uk/EeJbqWpy7BdAtsutTKLTHfAB71dwNgBeMu39FWPZVWOUiw?e=QrQHny)

Evidence 3: PERCCOM – Survey 2019 for Cohorts 1-4 (Private and Provided on Request https://leedsbeckett-my.sharepoint.com/:x:/g/personal/a_kor_leedsbeckett_ac_uk/ETjVVT_kdC9HkQs9rmqhJ2oBqvx0IOaMLpVTpc7S-a1K0w?e=fYAQUv)

Evidence 4: RED WoLF (Official website with Newsletter) - https://www.nweurope.eu/projects/project-search/red-wolf-rethink-electricity-distribution-without-load-following/#tab-4 and Newsletter on updates of Pilots https://www.nweurope.eu/projects/project-search/red-wolf-rethink-electricity-distribution-without-load-following/news/red-wolf-newsletter-2-an-update-on-our-pilots/

Evidence 5: RED WoLF – Showcased in EDF organised international virtual event (entitled "Electric Days 2020") as one of the 71 innovative projects for efficiency and smart use of electricity in https://www.electricdays.fr/en/innovations/red-wolf

Evidence 6: RED WoLF (Ireland) – Carbery Housing Association, News Release https://www.southernstar.ie/news/more-families-are-saved-from-eviction-by-cha-4202463

Evidence 7: RED WoLF (France) – Neolia Website http://www.neolia.fr/redwolf-linnovation-verte/

Evidence 8: RED WoLF (UK) – First Choice Homes in Oldham, Piloting smart green energy storage Video and News Release https://www.fcho.co.uk/news/customers-in-failsworth-set-for-greener-smarter-future/

Evidence 9: RED WoLF (UK) – Oldham City Council, Oldham Code https://www.nweurope.eu/projects/project-search/red-wolf-rethink-electricity-distribution-without-load-following/news/oldham-housing-strategy-the-oldham-code-as-key-for-a-higher-standard-of-energy-efficiency-and-carbon-performance-of-new-homes/

Evidence 10: RED WoLF (UK) – Wakefield District Housing Association, Commitment to Sustainability Plan https://www.wdh.co.uk/AboutUs/OurCommitmentTo/Sustainability/