Institution:	University of Northumbria at Newcastle
Unit of Assessment:	15 - General Engineering
Title of case study:	Guiding the implementation of photovoltaic systems in the UK and Europe

1. Summary of the impact

Research into photovoltaic (PV) system performance carried out at the Unit has provided informed guidance and performance benchmarks used in:

- the Standard Assessment Procedure used by the Department for Energy and Climate Change for energy assessment in buildings;
- the UK Government's Microgeneration Feed-In Tariff scheme to support the development of the UK solar energy market;
- the development of the Microgeneration Certification Scheme for UK PV installers;
- the development of new European PV system monitoring guidelines and the updating of IEC monitoring standards.

2. Underpinning research

Rationale for Research Area

Solar energy has the highest global potential of all the renewable energy technologies, with PV being one of the most widely applicable options for harnessing solar energy. To maximise the contribution of this technology, it is necessary to understand system operation in the local climate, both initially and throughout its lifetime. PV research carried out within the Unit has focused on the development of PV devices and the study of PV system design and performance evaluation.

PV Performance Assessment

In 1994, Northumbria installed the UK's first PV façade, rated at 40 kW, on Northumbria University's city campus, under European and UK Government funding (SE/317/93/UK and S/P2/00171). This project had a dual commercial and research purpose and provided a wealth of performance data on the influence of system design, climate and shading on the electrical and thermal performance of PV modules in UK conditions. Between 2000 and 2007, Pearsall, Forbes and Hynes undertook a system performance assessment for the UK Domestic Photovoltaic Field Trials involving 370 individual domestic PV systems on 24 sites across the UK. The work was carried out within the UoA as part of a consortium led by the Building Research Establishment (BRE), under funding from the UK Department of Trade and Industry (DTI) New and Renewable Energy Programme (S/P2/00305 and S/P2/00409). This project remains the most comprehensive study of PV system performance in the UK. The study established typical annual system outputs, common loss mechanisms and the characteristics of export of power to the electricity grid, with the results being used to inform the UK Government's support policies for PV systems.

Performance Monitoring

In 2004, Pearsall was invited to join the European PV System Monitoring Working Group, convened by the DG Joint Research Centre Ispra, and then took charge of the PV system subproject in the EC FP6 Integrated Project PERFORMANCE (2006-2009, Ref. 019718). This work updated the European PV System Monitoring Guidelines, including assessment of fault and loss mechanisms in the field, failure probabilities and procedures for lifetime monitoring, building on the monitoring expertise developed at Northumbria since 1994.

Underpinning PV Materials and Device Research

The PV system research is underpinned by the development of new and sustainable materials for PV devices including the first UK work on the kesterite compound CZTS ($Cu_2ZnSnSe_4$) for which we achieved a world record device efficiency in 2009 (Forbes, Zoppi, EPSRC EP/F029624/1, Supergen "PV Materials for the 21st Century", 2008-2012). Forbes is a founder member of the

European Kesterite Network.
The group also carries out environmental impact assessment of PV manufacturing processes, in collaboration with European industry (FP7 PEPPER, 2010-2013, ENER/FP7EN/249782/PEPPER), which feeds directly into the development of new equipment for the market.

Staff positions and employment periods at Northumbria University

1. Hynes: Research Assistant, Senior Research Assistant, 1986 – 2007.
2. Forbes: Research Fellow, Senior Research Fellow and now Reader, 1994 – present.
3. Pearsall: Lecturer, Senior Lecturer, Reader and now Professor, 1994 – present.
4. Zoppi: Research Fellow and now Senior Lecturer, 2005 – present.

3. References to the research

1. Ramachandran, J., and Pearsall, N. M. (2004) 'Synthetic generation of solar radiation for different locations in the UK', *International Journal of Ambient Energy*, **25** (1), pp33-38. DOI:10.1080/01430750.2004.9674935
2. *****Brownsword, R., Fleming, P. D., Powell, J. C. and Pearsall, N. M. (2005) 'Sustainable cities - modelling urban energy supply and demand', *Applied Energy*, **82** (2), pp167-180. DOI:110.1016/j.apenergy.2004.10.005
3. Pearsall, N. M., Scholz, H., Zdanowicz, T., and Reise, C. (2006) 'PV system assessment in PERFORMANCE – towards maximum system output', Invited Plenary Paper, *Proc. of the 21st European Photovoltaic Solar Energy Conference*, Dresden, September, pp2574-2579
4. *****Zoppi, G., Forbes, I., Miles, R. W., Dale, P. J., Scragg, J. J., and Peter, L. M. (2009) '$Cu_2ZnSnSe_4$ thin film solar cells produced by selenisation of magnetron sputtered precursors', *Progress in Photovoltaics*, **17** (5), pp315-319. DOI: 10.1002/pip.886
5. Pearsall, N. M., Atanasiu, B., and Huld, T. (2009) European PV monitoring guidelines, December, hosted by EC-JRC on

   http://re.jrc.ec.europa.eu/monitoring/monitoring_main.php
6. *****Luckert, F., Hamilton, D. I., Yakushev, M. V., Karoti, A. V., Mudryi, A. V., Grossberg, M., Krustok, J., Beattie, N., Zoppi, G., Moynihan, M., Forbes, I. and Martin, R. W. (2011) 'Optical properties of high quality $Cu_2ZnSnSe_4$ thin films', *Applied Physics Letters*, **99**, art. 062104. DOI: 10.1063/1.3624827

***** denotes the references that best indicate the quality of the underpinning research

Major related grants:

1) Domestic PV Systems Field Trial, Management Contractor, UK Department of Trade and Industry, Contract Ref. S/P2/00305 and S/P2/00409, 2000-2007, lead organisation BRE, total award £450,000, Northumbria PI: Nicola Pearsall.
2) A science base on PV performance for increased market transparency and customer confidence: PERFORMANCE, EC FP6 Integrated Project, Contract Ref. 019718, January 2006-December 2009, co-ordinated by Fraunhofer Institute for Solar Energy Systems, Freiburg, Germany, total cost €11.8 million, EC contribution €7 million, Northumbria PI: Nicola Pearsall. *This project involved 28 partners from 13 countries, both academic and industrial. Northumbria's main role in this project was leading the sub-project in Performance Assessment and Evaluation of PV Systems, under which the new European monitoring guidelines were developed.*
3) "Photovoltaic Materials for the 21st Century (PV21)", EPSRC EP/F029624/1, April 2008 – March 2012, part of the second cycle of SUPERGEN grants following on from a previous project in which Northumbria also participated, project value of £6.3 million for the consortium, Northumbria's budget £1.04 million. Northumbria PI: Ian Forbes. *Academic partners: Bangor, Bath, Cranfield-Shrivenham, Durham* (*replaced by Liverpool when the PI relocated*)*, Edinburgh, Imperial College, London South Bank, Northumbria*

and Southampton, Northumbria's role: research into chalcogenide CuInSe2, CuInAlSe2 and In-free absorber materials (i.e. Cu2ZnSn(Se,S)4) Cu3Bi(SxSe(1-x))3, Cu3Sb(SxSe(1-x))3) and devices and development of internationally unique characterisation facilities.

4) Stability and Performance of Photovoltaics (STAPP), EPSRC Grant No. EP/H040331/1, India-UK Collaborative Research Initiative in Solar Energy, total grant value £1.06 million, led by Loughborough University. Northumbria PI: Nicola Pearsall.

5) Demonstration of high-performance processes and equipment for thin film silicon photovoltaic modules produced with lower environmental impact and reduced cost and material use: PEPPER, EC FP7, Contract Ref. ENER/FP7EN/249782/PEPPER, September 2010-August 2013, co-ordinated by Oerlikon Solar, Trubbach, Switzerland, total cost €16.7 million, EC contribution €9.3 million. Northumbria PI: Nicola Pearsall. *This project involves seven partners from four countries, both academic and industrial. Northumbria's main role in this project is leading the sub-project on environmental impact assessment of the developments in the manufacturing process.*

6) KESTCELLS, EU FP7 Marie Curie Initial Training Network (ITN), Contract Ref. PTN-GA-2012-316488, September 2012 – August 2016, led by IREC, Barcelona, 11 partner pan-European €3.7 million training network, that includes the leading European research groups in the field from eight countries. Northumbria PI: Ian Forbes. *Northumbria is conducting research into copper-zinc-tin sulphur-selenide (CZTS) solar cell materials following world-leading results from the SUPERGEN project in 2009.*

4. Details of the impact

The implementation of PV systems within Europe, in combination with other renewable energy sources, provides a route to the decarbonisation of our energy supply and an increase in our energy security. The research on PV system design and performance at Northumbria University has helped to promote the development of PV in the UK by providing essential benchmarks for expected performance that have informed Government policies for PV implementation.

The Microgeneration Feed-In Tariff Policy (Linked to PV Performance Assessment Research)

The UK installed capacity has increased from around 2 MW to around 2.5 GW in the period 2008-2013, with the most rapid growth occurring in the period since the introduction of the Microgeneration Tariff in April 2010. This provides a fixed amount for each kWh generated by the registered PV system, and a further payment is provided by the electricity supply company for the proportion of the generated electricity that is exported to the grid. For small domestic systems, there is a deemed 50% export for the purposes of calculating the export payment to be applied. The choice of this value was directly informed by the results of the Domestic Field Trial analysis carried out by Northumbria University, via PV experts on the development committee. The Field Trial is the only major UK study that has investigated the export percentage of typical domestic PV systems. By deeming the export amount, the costs of metering the export electricity are avoided for small systems. As of June 2013, over 420,000 small PV systems (of capacity up to 4kW) had been installed under the scheme (as given by DECC statistics, June 2013), giving an estimated saving in required metering of around £16 million.

Microgeneration Certification Scheme (Linked to PV Performance Assessment Research)

As part of the promotion of UK PV implementation via the Low Carbon Buildings Programme and the Microgeneration Feed-In Tariff, the Government required a certification scheme for installers to be established. The Microgeneration Certification Scheme was first developed by BRE Global and launched in 2006. Information from the analysis of the Domestic Field Trial data was used in the definition of requirements for high-quality installations under this scheme, based on the best practice guides produced in that project. The MCS continues to be operated for all PV installations claiming the Feed-In Tariff, where both products and installers must be MCS accredited.

Performance Monitoring (Linked to Performance Monitoring Research)

Although PV systems are low maintenance and easy to operate, it is important that suitable performance monitoring is carried out in order to minimise any loss of energy output due to operational issues. That monitoring should be appropriate for the size of system and the risk of energy loss. Given the range of system size and user type, including domestic systems, it is important to have sufficient assistance to make an informed decision. Northumbria has contributed to the promotion of lifetime monitoring for PV systems at an appropriate level for the application via the updated European PV system monitoring guidelines, which were published in 2009 and are freely available to both system providers and users on the EC Joint Research Centre's Institute for Energy website. The delivery system has also been designed for ease of update as the technology develops. At the end of 2009, the results were also provided as input to the relevant working group (TC82, WG3) of the International Electrotechnical Commission who are responsible for the international standards relating to PV components and systems The next edition of the PV system monitoring standard is due in 2014. It is difficult to quantify the economic effect of system monitoring, but the installed capacity of PV in the UK has the capability to provide over 1,700 GWh of electricity per year (on average), so even the prevention of a small percentage of losses in the system would have a substantial economic value.

Energy Output (Linked to Performance Monitoring Research)

Decisions on the balance of energy related measures to be taken in building design and the relative merits of these measures require a realistic estimate of the energy output of a PV system for typical UK conditions and in relation to system designs. The results of Northumbria's performance analysis for a range of installed UK systems was influential in the increase in assumed system output from 800 to 850 kWh/kWp for standard UK average generation in the Standard Assessment Procedure (SAP) currently used by Department of Energy and Climate Change (DECC) to assess and compare the energy and environmental performance of buildings.

5. Sources to corroborate the impact

Reports, reviews and web links or other documented sources in the public domain

Recommendations for Maintenance Revision of IEC 61724, Report 3.1.11, PERFORMANCE, EC FP6 Ref. 019718, December 2009. Available from Northumbria University on request.

M. Munzinger, F. Crick, E. J. Dayan, N. Pearsall and C. Martin, Domestic Photovoltaic Field Trials, Final Technical Report, ETSU S/P2/00305 and 00409, Department of Trade and Industry, 2006. Available at:
http://www.bre.co.uk/filelibrary/pdf/rpts/PVDFT_Final_Techn_Report.pdf

Individual users/beneficiaries who can be contacted to corroborate claims

Director of SolarBIPV Ltd., Co-Chair of the DECC Solar Strategy Group, Associate of the National Solar Centre and Solar Specialist Advisor to both the Renewable Energy Association and the Solar Trade Association has provided a statement to corroborate claims regarding the Microgeneration Tariff Policy/Energy Output.

Principal Consultant at BRE has provided a statement to corroborate claims regarding the Microgeneration Certification Scheme.

Technical Director of Sundog Energy and advisor to the UK Government on the implementation of PV in the UK has provided a statement to corroborate the impact of the research on performance monitoring. The corroborator is also the chair of the British Standards Committee GEL82 on photovoltaics and is the convenor of WG3 of the International Electrotechnical Commission TC 82 committee on photovoltaics.