Exploring Future Skills Shortage in the Transition to Localised and Low-Carbon Energy Systems

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***Abstract*—As the climate change pressures mount, the need to transition to clean (non-fossil fuel based) energy systems becomes ever more apparent. Such a transition requires availability of trained workers to install and control the new energy systems, as well as skilled governance and regulation to guide such a major societal change. This paper takes the first steps to explore the issues related to said skills and training provision, using group discussions with the UK's energy researchers and practitioners. It reports on the areas of currently perceived skills gaps, and argues for the need to research on the future skills shortage prediction and training provision. This work aims to prevent such shortages from arising in order to facilitate a successful transition to clean energy systems.**

***Index Terms*—energy systems transition; skills gap; skills shortage, skills training, low-carbon energy system.**

I. Introduction

Global energy demand has grown steadily at around 2.4% per year since 1850, nearly all of which has been obtained from fossil fuels. Unsurprisingly, energy generation and distribution is one of the highest greenhouse gas emitting sectors in the developed countries (e.g., 3rd in the UK, after industry and transport). Faced with the problems of climate change, most countries have set targets to decarbonise their energy systems [1], [2]. Realisation of such plans will require substitution of fossil fuel-based energy sources with renewable alternatives. Yet, the energy system underpins and is tightly intertwined with all other sectors of economy and areas of social life: from high-tech industrial production processes to agriculture; from home heating to transportation. Changing energy systems implies changing the very core of the modern societal life [3].

The transition to low-carbon and localised energy systems is already under way. The relevant technologies[1] have been developed and continue to be improved; government initiatives provide funding to research and support the transition [4], [5]; and several groups have led the way with successful decentralised and community energy projects. One such example is Robin Hood Energy set up by Nottingham council in 2015 to supply energy from mainly renewable sources [6]. Robin Hood Energy has saved at least £200 a year for over 100,000 customers and has also seen successes in supplying energy outside of Nottingham through partnering with local brands, such as Angelic Energy in Islington. Other examples of successful local energy communities include the Bethesda hydro-powered project in Wales [7], the Orkney island's energy self-sufficiency in Scotland [8], or the PV for Schools programme that supplies solar energy generation to UK schools [9], saving energy bills, carbon emissions, and promoting environment-related education in schools.

Yet, all these are relatively small, disconnected projects. In order for the transition to be adopted on a national scale, resources must be in place that provide the necessary skills, knowledge and most importantly, the societal will to implement this change. Transition to a nation-wide low-carbon energy system is not simply about installing some PV or wind generation, but it is about the whole-scale change of the energy generation, distribution, and use practices: integration of all renewable sources (to address their generally intermittent availability i.e. there is no solar generation during the nights); ability to regulate demand (e.g. switching off non-critical appliances when generation is low, and scheduling energy use tasks when generation is high, e.g., [10]); willingness to regulate and set policies that foster engagement of all user groups with the energy generation and consumption issues; enabling and mandating the transition of the incumbent large energy companies to new business models centred around clean energy sources, etc. *All of this requires new kinds of skills from the employees, new kinds of jobs from the employers, and new kinds of education and training for all.*

With appropriate methods, the journey to a more sustainable future can have great potential for the job market. Although it is critical that the appropriate training of skills is in place in order to avoid long lead times and a widening gap between the demand and supply of the necessary labour.

This paper explores the skills shortages that the transition to a clean-energy society is likely to face. Section II reviews insight from existing literature concerning the causes of a skills shortage, how they arise and how they can be tackled. These

[1] To name a few: PV panels, wind turbines, tidal and wave energy stations, anaerobic digestion systems and bore holes for heat storage, batteries and hydro turbines, electric vehicles and peer-to-peer energy trading platforms, smart controllable appliances for demand response, etc.

issues will be addressed in terms of what they mean for the energy market, the labour market as well as for policy and social change. To relate the findings from the literature to the current state of practice, we carried out several small group-based discussions which are outlined in Section III. Here we present the emerging topics from these group discussions between interdisciplinary experts on energy systems. Section IV concludes this paper with a summary of our findings and a plan of how they will be used in deriving a skills training curriculum and skills shortage assessment model.

II. Background

In this section we review literature relating to the definition of skill shortages and how they can be tackled from three viewpoints:

1) energy systems;
2) labour market;
3) policy and social change.

It is relevant to consider this issue from a top-down, economic approach (labour market) as well as bottom-up, industry-specific angle (the energy system). Furthermore, since our lives are centred around energy, we conclude this section with a discussion of the societal impacts of a skill shortage in the transition to a low-carbon economy.

Background from the Energy Sector

The lack of required skills has been reported as the biggest challenge facing the global renewable energy sector [11]. The demand for necessary skills and further training is applicable for new graduates of non-specialised STEM courses, those with relevant skills from other sectors as well as those already working in renewable energy in the case that their organisation develops through digitisation or updated technology. Therefore, it can be said that the onus to fill the skills gap is as much on employers as it is on external education and training institutions.

A suggested solution for educators would be to create tailored courses. However, there is less need for specialist education programmes in renewable energy. Existing STEM subjects provide the necessary foundation for professional work in this sector [12]. It would be more favourable to have several low-carbon related modules within a higher education course to provide students with the awareness and insight of the benefits of alternative, cleaner energy systems.

The most recent Global Talent Index Report (GETI) [13] carried out by 17,000 respondents from 162 countries has shown that although there is an obvious skills shortage, the most worrying issue for the renewable energy sector is, in fact, the political landscape. A lack of subsidies is of huge concern to the renewable industry, significantly more so than to the conventional and better established non-renewable sectors. However, the skills shortage is a looming crisis that many are also worried about: 60% of respondents believe there is only 5 years to act before it hits. So what talent is lacking? The discipline of Engineering was reported to be in highest need (50%) and project leadership following with 25%. The latter reinforced by the lack of understanding of the system as a whole: how multiple energy generation methods can work together and complement each other, the role of legal experts and policy makers in steering the path to change, the implementation of effective and relevant training and education programmes and how all of these factors come together. The key risks to the sector, as a result of talent shortages, include decreased efficiency, loss of business and reduced productivity. These consequences will trigger a negative feedback loop since it is likely that there will be less incentive to work in the renewable energy industry if it is a failing one. The top three methods to attract the right talent, agreed amongst hiring managers and professionals, include better training, clearer career progression and increased remuneration and benefits packages. However, remuneration was one of the least common reasons for choosing to work in this sector. A possible explanation could be that the majority of the workforce in the renewable industry are between the ages of 25-34. The concern for the climate is more apparent among the younger employees who may enter the sector as they wish to take action against global warming rather than for gaining "job perks".

A novel solution to deal with skills shortages has been implemented by Business in the Community through the Ban the Box campaign [14]. By engaging with employers on specific programmes, the 20% of the UK workforce with criminal convictions can be given the support and training to close the skills gap.

Over the past decade we have seen a rise in automation which can be argued to have a positive effect on decreasing the skills shortage. Whilst it is true that automation has put many out of work, with the right systems in place, automation can allow members of the workforce to engage in less repetitive tasks and transfer their talent to more technical areas of their company.

In summary, factors that should be taken into account in the skills shortage assessment model to be developed include the view of consumers, employees, employers and educators on the areas where training is necessary, including both technical skills training and policy-related education. This knowledge will help in preparing for the changing technological landscape, as well as in directing the action of policy makers in requesting funding or regulation in specific areas. Contributions to a *skills training curriculum* aimed at preventing the looming skills shortages for energy systems transitions, should include both general and tailored STEM courses and project leadership for the proliferation of the low-carbon and localised energy systems.

Background from the Labour Market

In economic theory, a skills gap is regarded as a disequilibrium phenomena between the skills available by workers and those demanded of them by employers. Such a gap is a common cause of structural unemployment. The Oxford dictionary of Economics [15] defines structural unemployment as unemployment due to a lack among unemployed workers of necessary skills which can occur as a result of changes in demand leading to the decline of industries which previously provided jobs. Furthermore, structural unemployment cannot be cured by simply increasing demand or cutting wages but rather, it requires major investment in education and training or subsidies to support the migration of jobs to depressed areas. In other words, there must be a boost in the supply of labour. It is important to note that structural unemployment focuses on those who are unemployed and are out of work as a result of a shift in the economy and it relates less so to those who have the relevant skills but are employed by other institutions. Therefore, its application is not a perfect match to our case since, under the traditional interpretation of structural unemployment, people who have suitable skills to be employed in the low-carbon energy sector may simply be working in other industries. Nevertheless, this area of labour economics provides a starting point for our analysis of skills gap understanding and modelling.

An example of structural unemployment was seen in the coal mining industry when employment fell by nearly 80% between 1980 and 1990 as a result of a change in governmental policy along with the growing unrest in the industry. The scale of the coal mining industry decay is shown in Figure 1. Many of the miners did not have the skills or experience that would transfer to other sectors. Given that the majority of the population of mining towns were inevitably miners, the changes put excessive pressure on the unemployed miners to relocate geographically as well as occupationally to find work.

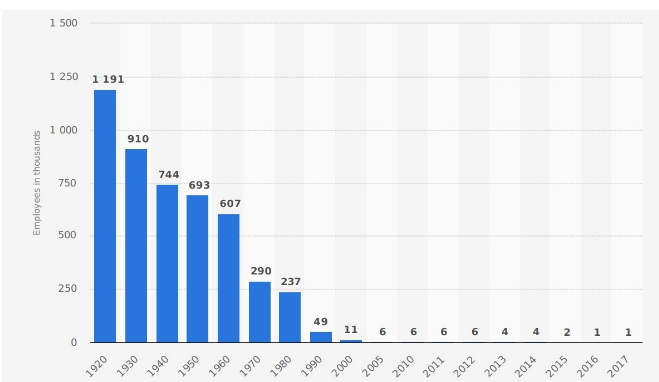

Fig. 1. Number of people employed in the coal mining industry in the United Kingdom from 1920 to 2017 (in 1,000s). Figure obtained from [16].

The solutions introduced by the UK government to regenerate the areas of ex-coal mining industries included funding to support upcoming small businesses, investments from large automotive and technology companies who built sites in the affected areas and provision of higher education courses with strong connections to manufacturing and IT industries [17].

Structural unemployment is typically long-term unemployment as a result of 'shocks' that the economy needs to take time to adjust to. We expect that in our transitional scenario, structural unemployment is both about decarbonisation and the decline of the fossil fuel industry as well as the adoption and development of low-carbon and decentralised energy options. This results in workers becoming displaced since their occupations cease to exist as well as new jobs being introduced causing a shortage of workers with appropriate skill sets and to some extent, an overlap between the two.

The shocks in economic activity that can lead to structural unemployment in the area of low-carbon and localised energy systems can arise from three main drivers:

- Firstly, as industries become more energy efficient and less polluting, the demand for occupations such as drilling engineers decreases whereas there is an increase in the demand for others, such as solar panel technicians. In some cases the occupations are relatively transferable. For example, an individual working on oil or gas drilling sites will be able to transition to the geothermal industry which relies on similar methods for heat extraction. The change in market behaviour can also be encouraged by consumer habits, for instance, through mass pressure for greener energy which in turn causes the industry to adapt in order to meet the demands of their customer base.
- Secondly, entirely new occupations can emerge as a result of developments in technology. Occupations are also limited by this factor since a technology may not be available in a certain country or relocation to an area where the occupation is vacant may not be a feasible option.
- Thirdly, the introduction of regulation and environmental policy can force the industry to alter its structure. For example, policies may be put in place that ban certain materials or processes with negative environmental impacts [18]. All of these factors are geographically specific and will be taken into account when developing a model for assessing a skills shortage with the constraint of localisation.

Over time, the labour market adjusts to equilibrium commonly through increasing wages to attract skilled workers from other firms or from unemployment. Alternatively, training can be provided to increase the supply of skilled workers, yet the length of a training course may cause long lead times and it is also necessary to incentivise individuals into enrolling in the training programmes in the first place. One way to speed up this process is for companies to offer apprenticeships and teach workers the skills or training 'on-the-job'.

Furthermore, a transparent labour market with available information to technological innovators, firms and educators is a fundamental criterion of an efficient market. This transparency will minimise the time taken for information to flow about new opportunities from firms to the educators who will provide future workers with the suitable skills [19]. According to the GETI [20], when asking hiring managers in the renewable energy industry how employers can overcome the skills gap, 45% believed this could be done through partnering with colleges and education boards. Yet, it is worth noting that this part of the GETI survey was a closed set of answers and although multiple answers could be selected, the options did not include a choice of closing the skills gap via is input from policy makers, which, as noted before is a key influence area to be considered.

From bans on harmful products to the introduction of a carbon tax, the government has an extraordinarily influential power in promoting a smooth transition to low carbon and more localised energy systems through legislative prohibitions as well as by providing both incentives and disincentives. This is clearly shown in Figure 2 that illustrates the success of encouraging installations of solar panels through the introduction of the Feed-in Tariff in 2010. The growth in the number of installations post April 2016 could partly reflect the rush to set up projects before further reductions in subsidies take effect. Nonetheless, this example of a positive incentive for participation in cleaner production methods should be learnt from to support the transition.

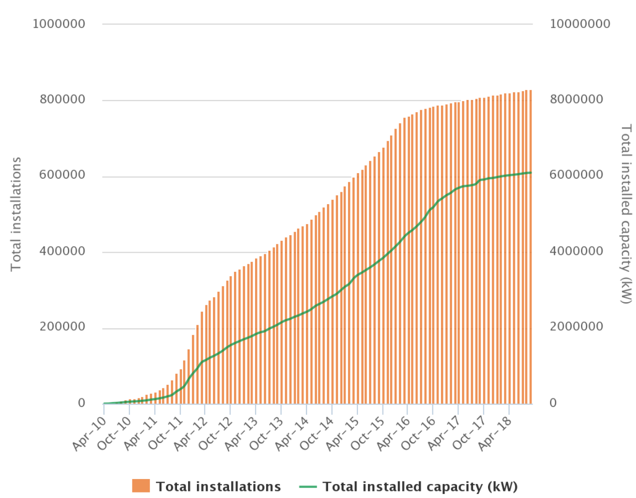

Fig. 2. Quarterly breakdown of number of installations and total installed capacity accredited under the Feed-in Tariff. Figure obtained from [21]

The background research into the effects of an energy transition for the labour market demonstrates that we can learn from previous periods of structural unemployment in developing models for skills shortages prediction and prevention. For example, the measurement of how many skills are transferable from jobs in industries that are declining could provide an indication of how investment should be injected back into geographically affected areas, i.e. which companies should be encouraged to open their doors to those affected by structural unemployment, and which should invest into development of new business opportunities. Furthermore, to make the labour market more transparent, the firms creating technologies should be motivated to state the occupations and skills that will be required to maintain and operate the new products and services. In this way a relevant skills training curriculum can be devised and kept up to date with emerging technologies.

Background from Policy and Social Movements

The transition to low-carbon and localised energy systems is as much a change in the way we use our energy as it is the way we think about it. We consider the 'mindset transition' to be a skill shortage in the green energy industry in the same way that there is a shortage of engineering skills in this sector. Whilst it is crucial that the right policies are put in place to secure enough investment in skills development, the attitudes towards the benefits of low-carbon energy alternatives need to be addressed: firstly to ensure people are willing to work in the industry, secondly, that they are willing to accept relevant policy and regulations, and finally, to encourage participation of end users (including end user companies) both as consumers, investors and producers (where possible) in one's local energy system. The investment in skills training and the attitude of the society towards low-carbon energy go hand in hand. For instance, according to the Solar Energy Society of Canada, one of the reasons why solar thermal got a bad reputation there was due to unqualified workers installing systems that did not work properly [22], as skills in that sector were amiss and available installation engineers did not want to or could not afford to invest in training.

Societal change is often brought about by leaders who believe that they can influence policy. Activism of this kind can take the form of strikes, protests or civil disobedience. One movement, Extinction Rebellion, urges policy-makers to take climate change more seriously by causing non-violent disruptions such as blocking bridges [23]. Participants include academics and scientists from across the globe and they have been successful in making their voices heard and raising awareness for the lack of governmental action through gaining media attention. However, policies to aid decarbonisation can also create disruption and unrest, as recently seen with the 'gilets jaunes' in France. When president, Emmanuel Macron proposed a rise in the tax of diesel and petrol without any subsidies for the alternative cleaner, electric vehicles, protesters took to the streets in violent clashes with the police [24]. This is comparable to a disregard of a just transition that must be avoided in the journey to a greener society. Just as workers employed in the non-renewable sectors must be given the opportunity to learn new skills, consumers need to be provided with alternatives before enforcing change.

Other leaders who can encourage the mindset transition are the large corporations such as Google, Apple and Facebook who are all in a race to operate on 100% renewable energy in their worldwide facilities [25]. Industry, being the biggest contributor of greenhouse gases, has to pay the price for these emissions. As well as operating in a low-carbon manner, businesses that benefit from high profits should invest in education programmes that will in turn reward their reputation and help to provide an adequately skilled workforce within their companies and in the wider industry.

The inclusion of the 'mindset transition' into the skills assessment model is a real challenge. One way to address this is through input from surveys carried out by energy consumers. Questions in such a survey could enquire what drives or deters consumers from using low-carbon energy methods. Once the reasons behind the lack of willingness to transition are discovered, these reasons (where relevant) could also be addressed through the skills training curriculum, or information sharing campaigns and/or regulations. Informational and educational resources could also be made available to consumers through their energy providers.

III. Pilot Study

As part of the UK Engineering and Science Council funded project (EnergyREV), 34 researchers and practitioners of interdisciplinary topics within energy systems were invited to take part in small group discussions to help us understand the current state of the skills gap with regards to the localised renewables-based energy systems in the UK. Five groups, consisting of 4 to 7 persons were formed (through random allocation of the participants). The groups were set 3 questions to address:

In the transition to localised and low-carbon energy systems,

1) What examples of skills shortages have you come across?
2) What factors do you think cause these skills shortages?
3) How can we measure such skills shortages?

The groups recorded their answers as they discussed the questions, and the resulting findings were collated after the workshop. These are presented in Table I and discussed in the remainder of this section.

Discussions of Preliminary Findings

Although the groups worked independently from each other, several ideas overlapped and there was a clear emphasis on the need for a combination of top-down and bottom-up solutions.

Firstly, there was a noted **shortage of multi-vector energy systems and interoperable technology**. As many renewable generation methods are intermittent by relying on natural cycles, it is necessary to complement methods of generation with others to provide a secure energy supply. The integration of systems will be specific to different regions since not all localities will have access to every form of energy generation and some forms are more efficient than others in certain areas. Most importantly, different forms of generation must be compatible when combined in the same system. Interoperability can appear in a number of ways:

- Consumer interoperability - difficulty in switching energy service providers,
- Data interoperability - data sharing and combined analysis of data from different platforms,
- Device interoperability - compatibility of equipment bought to monitor or manage energy usage,

Contributing factors that relate to these issues include a lack of standards, a lack of appreciation of the commercial value of tackling the skills shortage as well as silo training and thinking. A standardised set of requirements to ensure interoperability would be an effective solution if enforced as a regulation. Additionally, a standard in education and training programmes would provide a bigger systems understanding rather than focusing on individual topics. This would also aid in reducing silo approaches to the industry.

In a similar vain to the shortage of system integration, a **shortage of skills in conducting whole systems retrofitting** was reported. Adapting existing buildings or systems is a challenging task and ever more difficult to achieve whilst simultaneously constructing efficient and low carbon new builds. The lack of action in this area is partly down to little investment or available funds since retrofitting is a large and expensive venture. Furthermore, there is low value awarded to refurbishing a perfectly functional building when the will to decarbonise is not a priority and the capital to complete such a project is not readily available. Other factors that contribute to this shortage are a traditional vision about buildings and a lack of understanding about the relationship between all parts of the energy system.

One suggested metric to measure the shortage of skills in this context is by comparing the gap between sales and certificates. With this information it is possible to to determine approximately how many installations are associated with each certified worker. Consequently, one can assess whether the output per worker is a realistic quantity or if it is likely that installers are working overtime to compensate for the lack of skills in this area. We must also bear in mind the possibility that non-certified individuals are carrying out part of this workload.

Another shortage mentioned in the workshop was that of **whole systems understanding, the architects to design them and analysts to assess their performance**. Analytic skills on carbon saving and efficiency is something we are seeing more of in smart systems which provide the resulting information on carbon savings and efficiency to end-users. However, the performance of buildings in terms of their efficiency calculated through measures such as BREEAM analysis could be useful in clarifying whether a building operates on the level it claims to or was designed to. Cross-certification in this respect can imply whether there is a high enough quality of skills to provide the low-carbon solutions that are aimed to be achieved.

It is evident that there is a **shortage of policy makers and legal experts with specific knowledge of low-carbon and localised energy systems**. The lack of government action could be due to the lack of conclusive data which provides the evidence that the supply of energy will be secure when generated on smaller scales or by alternative methods off the trusted National Grid. Although some successes have been reported by several energy communities and projects, they are viewed as piece meal, often reported in non-comparable ways. Aggregating and integrating the data required for demonstration of such successes across many projects is a key part of the research carried out by members of the EnergyRev Consortium. The factors contributing to the shortage of legal experts could again be due to a lack of whole-systems understanding as well as a low will and acknowledgement of the urgency of working to support the transition. A suggested way to measure skills gap in this area is by looking at the vacancy rates of related jobs; how long the positions are vacant for as well as how many vacancies there are as a ratio of total legal experts for example.

TABLE I
COLLATED INPUT FROM DISCUSSION-BASED WORKSHOP.

Skills Shortage Examples	Contributing Factors	Measurement Methods
• Multi-vector qualified installers • Minimum standards for installers • Interoperable technology	• Lack of accreditation • Lack of standards • Lack of tripadvisor-style ratings • Current lack of demand for local energy • Lack of appreciation of commercial value in tackling the skill shortage • Lack of trusted advice • Lack of expertise about wider benefits (ecological and social)	• Number of qualified installers compared with the size of the market or compared with the number of businesses offering the service
• Local energy system architects • Communication liaison • Energy focused ICT/ cyber • Whole systems understanding • Installation, operations & maintenance • Multi-vector systems	• Lack of training infrastructure • Lack of thought about what is needed • Lack of investment • Lack of systems thinking in education • Diversity of systems • Lack of appropriate/static regulation • No clear local energy project owner (not BAU) • Poor incentives (low salaries and attractiveness) • Unclear career path • Broken apprenticeship schemes	• Number of people trained in specific programs • Number of installations etc. • Number of school children engaged in related activities
• Certified installation skills • Energy efficient buildings • System performance skills (analytics of efficiency or carbon saving) • Whole building retrofit of skills based on outcome measures not models	• Employer-driven certification/ skills • Regulation change	• Cross certification of existing data • Gap between sales and certificates • Shift in installations and projections • Job guidance • Job roles
• Transferable skills • Apprenticeships • Retrofit • QA • Further education • Professional development • System integration • Lack of legal skills	• Policy driven peaks and troughs in market due to funding stopping and starting • Lack of awareness of the benefits of renewable energy when choosing career • Visibility • Size of job market • Traditional vision of building refurbishment • Need to be multi-skilled or be knowledgeable about whole building retrofit • Job perks - salary • Lack of willingness to change	• Job satisfaction • Job adverts/ job skill surveys (ONS) - single and multi skill • Salaries in sectors • Educational courses • Post course surveys • Professional membership figures • Installation rates
• Evaluating social phenomenon • Interdisciplinary technical skills e.g. energy & digital • System integration • Diversity • Local government • Geography • Engagement • Management	• Not valued • Silo training/thinking • Cost of training • Responsibility • Prejudice • Traditional mindset • Incumbency	

Final key shortages learned from the workshop were the **lack of individuals with transferable and interdisciplinary skills as well as appropriate further education**, namely in STEM subjects, project management or more specific courses. Financial, IT, cyber and installation skills were amongst the highlighted skills in shortage. Reported factors contributing to their low supply include poor incentives, such as remuneration or other job perks, expensive courses to gain the qualification and a lack of investment in education. Metrics to quantify this include the number of people out of the entire workforce with the required qualifications, enrolled in relevant training programmes as well as the aforementioned length of vacancy advertisements.

The preliminary workshop raised interesting points from a range of backgrounds. Several issues that were voiced had not been learnt from the review of existing literature such as the lack of skills relating to whole system retrofitting and the lack of accreditation of relevant skills. These findings, along with those from the previously presented literature review, will be incorporated into our ongoing research on developing a skills assessment model. These findings include, for instance, cross certification and skill surveys to be completed by employers (which skills are difficult to source in job vacancies) and graduates (perceptions of working in low-carbon and localised industry and reasons for and against). Furthermore, it is important to have an understanding of the economic and social impacts resulting from a given skill shortage as well as those factors driving the shortage. Since there is no single measure that can fully represent a skills imbalance, a selection of metrics should be used as well as including indicators relating to the given area where the shortage exists and their specific economic or social impacts. Geographically-dependent factors, such as local regulations and availability of resources, provide useful information in assessing a lack of skills and the potential causes for a given locality.

Additionally, as a skills training curriculum is to be developed to support prevention of skills shortages from arising, we used the workshop results to identify preliminary areas to be covered by this curriculum, which are training provision for the legal and regulatory expertise, whole-systems understanding, systems integration and interdisciplinary skills.

IV. Conclusions and Future Work

This paper acts as the premise for our ongoing work on a more detailed study to produce a reference map of knowledge areas for the Energy Systems domain along with the skills mapped against each knowledge area, a methodology for skills gap assessment at various scales (i.e. local, regional, and national) and opportunities and gaps in the skills training provision nationally and internationally.

As part of our ongoing work, a skills assessment model is to be designed in such a way that it will point to the key factors that are responsible for the lack of skills. The employees, regulators, and educational and training providers will then be able to directly deal with these "guilty causes". The output of this work, when completed, will be shared with educational, training and policy making bodies who can be advised on the best avenues support the unfolding "energy revolution" of transitioning to a localised, renewable-based, secure energy systems.

The consolidated body of knowledge on energy systems, along with the respective skills, is intended to serve as an evolving and living schema against which the educational and training provisions within the UK and internationally will be assessed, akin to that of the SWEBOK [26] for Software Engineering, or CyBoK [27] for Cybersecurity professionals.

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References

[1] House of Commons, "2020 renewable heat and transport targets," House of Commons, 2016, second Report of Session 2016–17, together with formal minutes relating to the report.

[2] BEIS and Ofgem, "Upgrading our energy system smart systems and flexibility plan: Progress update," Department for Business, Energy and Industrial Strategy, 2017, the National Archives, London.

[3] W. Young and L. Middlemiss, "A rethink of how policy and social science approach changing individuals' actions on greenhouse gas emissions," *Energy Policy*, vol. 41, pp. 742 – 747, 2012. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0301421511009177

[4] Inovate UK and UK Research and Innovation, "£102 million to make uk prosper from the energy revolution," 2018. [Online]. Available: https://www.gov.uk/government/news/102-million-to-make-uk-prosper-from-the-energy-revolution

[5] Ofgem, "Non-domestic rhi," 2011. [Online]. Available: https://www.ofgem.gov.uk/environmental-programmes/non-domestic-rhi/about-non-domestic-rhi

[6] D. Hellier, "Robin hood energy: Nottingham launches not-for-profit power firm," 2015. [Online]. Available: https://www.theguardian.com/environment/2015/sep/07/robin-hood-energy-nottingham-council-launches-not-for-profit-energy-company

[7] E. Local, "Cyd ynni," 2016. [Online]. Available: http://www.energylocal.co.uk/cyd-ynni/

[8] "Orkney renewable energy forum," 2000. [Online]. Available: http://www.oref.co.uk/orkneys-energy/

[9] D. of Energy and C. Change, "'power to the pupils': Solar pv for schools – the benefits," DECC, 2014. [Online]. Available: https://www.gov.uk/government/publications/power-to-the-pupils-solar-pv-for-schools

[10] R. Chitchyan, P. Shah, and C. Bird, "Eliciting requirements for demand response service design to households: A pilot study," in *Proceedings of the Evaluation and Assessment on Software Engineering, EASE 2019, Copenhagen, Denmark, April 15-17, 2019*, 2019, pp. 299–304.

[11] Airswift and Energy Jobline, "The Global Energy Talent Index Report 2018," 2018.

[12] International Labour Office, "Skills and Occupational Needs in Renewable Energy," ILO Skills and Employability Department, Geneva, 2011.

[13] Airswift and Energy Jobline, "The Global Energy Talent Index Report 2019," 2019.

[14] S. Howard, "'Ban the Box' campaign asks employers to give ex-offenders a chance," 2013. [Online]. Available: https://www.theguardian.com/sustainable-business/ex-offenders-unemployment-businesses

[15] J. Black, N. Hashimzade, and G. Myles, *A Dictionary of Economics*, 5th ed. Oxford University Press, 2017.

[16] UK Department for Business, Energy and Industrial Strategy, 2019. [Online]. Available: https://www.statista.com/statistics/371069/employment-in-coal-mining-industry-in-the-united-kingdom-uk/

[17] T. Merrill and L. Kitson, "The End of Coal Mining in South Wales: Lessons learned from industrial transformation: GSI REPORT," The International Institute for Sustainable Development, 2017.

[18] O. Striestska-Ilina, C. Hofmann, D. H. Mercedes, and J. Shinyoung, "Skills for Green Jobs: A Global View: Synthesis Report Based on 21 Country Studies," *International Labour Organization*, 2011.

[19] C. Shah and G. Burke, "Skills shortages: Concepts. measurement and policy responses," *Australian Bulletin of Labour*, vol. 31, 2005.

[20] Airswift and Energy Jobline, "The Global Energy Talent Index Report 2017," 2017.

[21] Ofgem, "FIT quarterly breakdown," 2018. [Online]. Available: https://www.ofgem.gov.uk/environmental-programmes/fit/contacts-guidance-and-resources/public-reports-and-data-fit/feed-tariffs-quarterly-statistics#thumbchart-c4831688853446394-n91793

[22] O. Strietska-Ilina, C. Hofmann, M. Durán Haro, and S. Jeon, "Skills for green jobs: a global view: synthesis report based on 21 country studies," International Labour Office, Geneva, 2011.

[23] J. Watts, "Extinction rebellion goes global in run-up to week of international civil disobedience," *The Guardian*, 2018. [Online]. Available: https://www.theguardian.com/world/2018/dec/10/extinction-rebellion-goes-global-international-civil-disobedience-climate-talks-poland

[24] A. France-Presse, "Extinction rebellion goes global in run-up to week of international civil disobedience," *The Guardian*, 2018. [Online]. Available: https://www.theguardian.com/world/2018/dec/30/paris-police-fire-tear-gas-yellow-vest-gilet-jaunes-protesters

[25] A. Moodie, "Google, apple, facebook race towards 100% renewable energy target," *The Guardian*, 2016. [Online]. Available: https://www.theguardian.com/sustainable-business/2016/dec/06/google-renewable-energy-target-solar-wind-power

[26] IEEE Computer Society, "Swebok." [Online]. Available: https://www.computer.org/web/swebok

[27] "The Cyber Security Body of Knowledge." [Online]. Available: https://www.cybok.org/