sustainability

MDPI

Article

Ireland's Transition towards a Low Carbon Society: The Leadership Role of Higher Education Institutions in Solar Photovoltaic Niche Development

William Horan *, Rachel Shawe and Bernadette O'Regan

Centre for Environmental Research, Department of Chemical Sciences, School of Natural Sciences, Faculty of Science & Engineering, University of Limerick, V94 T9PX Limerick, Ireland; rachel.shawe@ul.ie (R.S.); bernadette.oregan@ul.ie (B.O.)

* Correspondence: william.horan@ul.ie; Tel.: +353-(0)61-203101

Received: 28 November 2018; Accepted: 15 January 2019; Published: 22 January 2019

check for updates

Abstract: Ireland is currently considered a laggard within Europe in relation to decarbonisation of its society, with future projections estimating increases in greenhouse gas emissions up to and beyond 2030. To accelerate Ireland's transition towards a low-carbon society, there is a need for leadership in deployment and experimentation of low carbon technologies. As Higher Education Institutions (HEI) currently play a major role in generation of human capital and the associated impact on societal development, HEIs are ideal locations to focus resources in terms of deployment and experimentation of decarbonisation technologies to demonstrate best practice for further replication within wider society. To guide Irish HEIs in this regard, a novel integrated approach titled 'Higher Education Accelerating Development for Sustainability' (HEADS) has been developed and applied to the sector. The HEADS approach utilises the perspectives of quantitative systems analysis, sociotechnical analysis, and living lab learning to inform HEIs of their potential roles within national sustainability transitions. Applied to solar photovoltaic transitions in Ireland, the HEADS approach has identified HEIs as vital locations to deploy low-carbon technologies due to their amplification effect in signalling to wider society the attractiveness of these technologies.

Keywords: integrated approach; quantitative system analysis; sociotechnical analysis; living lab perspective; photovoltaics

1. Introduction

Ireland is projected to exceed its carbon reduction targets in 2020 and 2030 by a substantial margin, with emissions projected to remain relatively stable over this period [1]. In comparison to European counterparts Ireland has been considered a laggard in relation to decarbonisation of its society [2], and without urgent action Ireland's projected greenhouse gas emissions will drift further from a pathway consistent with a low-carbon society [3]. While agricultural emissions accounted for the largest sectorial share of greenhouse gas emissions in Ireland at 33%, energy-related greenhouse gas emissions accounted for the largest share of greenhouse gas emissions across sectors accounting for 64% of all emissions [4]. Electricity generation from energy industries currently accounts for 32% of Ireland's total energy related emissions [4] and is forecast to grow due to increased electrification of heating and transportation [5,6].

The importance of tackling climate change in Ireland has received increased attention from a national policy context in recent years. The Irish government outlined its National Policy Position on Climate Change in 2014, which stated that there is a need for an aggregate reduction in carbon dioxide (CO_2) emissions of at least 80% by 2050 compared to 1990 levels in the electricity generation, built environment, and transport sectors [7]. The Department of Communications, Energy and Natural Resources published its energy white paper in 2015, titled 'Irelands Transition to a Low Carbon Future', outlining how Ireland will transform its energy system to reduce 2050 greenhouse gas emissions by between 80% and 95%, compared to 1990 levels. The white paper states that, to decarbonise the energy system, there is a need to transition from an energy system that is almost exclusively government and utility led, to one where citizens and communities will increasingly be participants in renewable energy generation, distribution, and energy efficiency [8]. Ireland's National Development Plan (NDP) 2018–2027 [9] has allocated €22 billion for mitigation and adaption to climate change with high ambition targets relating to electric vehicle and renewable energy deployment nationally. However, the NDP does not make explicit how implementation of national targets may be achieved at a local scale.

From the international literature, Higher Education Institutions (HEIs) campuses have been identified as ideal testbeds (also called living labs) for pilot demonstration projects to evaluate and adapt decarbonisation technologies and methods to facilitate mainstreaming by wider society [10–12]. Although the NDP has allocated €2.2 billion exchequer funding to the HEI sector for campus infrastructure construction and upgrades, the plan does not stipulate that HEIs should incorporate sustainability into existing and planned developments beyond energy efficiency. As part of the NDP, HEIs are eligible to collaborate with enterprises on projects for the Disruptive Technologies Innovation Fund, with decarbonising the energy system and sustainable living considered priority areas. Currently there is a gap in the academic literature and government policy in Ireland relating to how HEIs may best facilitate a national transition towards a low carbon society by capitalising on synergies between government policy, private sector commercialisation, and HEI living lab resources. This paper outlines the development of a novel integrated approach, titled 'Higher Education Advancing Development for Sustainability' (HEADS), to guide policy makers in how HEIs may act as a leader in facilitating decarbonisation of Ireland's energy system. The approach was applied to HEIs' role in facilitating niche development of solar photovoltaics in Ireland to illustrate the usefulness of the approach.

2. Materials and Methods

2.1. Integrated Approaches Surrounding Sustainability Transitions at HEIs

To evaluate sustainability transition pathways, it is argued that no single perspective or discipline will be adequate due to the multi-dimensional nature of sustainability transitions that requires integration of multiple theories and approaches to generate useful knowledge [13–17]. To gain a broader perspective of sustainability transitions, integrated approaches and linkages between individual forms of analysis have been proposed [16–18]. There are a number of integrated approaches that look at HEI sustainability transitions [14,19–21], but these studies assess individual campus sustainability only, and a literature search found no relevant studies in relation to the HEI sector.

Turnheim et al. [16] proposed an integrated approach to improve international, national, and sectorial sustainable transition pathway projections by bridging the perspectives of quantitative systems analysis, sociotechnical analysis, and initiative-based learning. This study utilises the three perspectives proposed in reference [16] but adapts them to the objective of this study, which is to conceptualise and evaluate the HEI sector's role in facilitating national sustainability transitions. Therefore, the approach developed is not designed to improve national or sectorial projections but rather to inform the HEI sector's role in national sustainability transitions. The adaptation of the integrated approach to study the HEI sector's role in national sustainability transitions required a critical review of the three perspectives utilised, to establish the most appropriate configuration of the integrated approach.

2.1.1. Quantitative Systems Analysis

In projecting future quantitative scenarios, what is technologically and behaviourally possible can be estimated. According to reference [22] there are three classes of quantitative scenarios, namely, what will happen based on current trends (trend extrapolations, business as usual), what could happen (forecasting, foresighting, strategic scenarios), and what should happen (normative scenarios such as backcasting). Factors that may impact scenario development include assumptions surrounding current growth rate of the sector, penetration rates of renewables into the grid, efficiencies of technologies, learning rates or installation rates associated with renewable technology rollout, energy, and cost payback times, and the time cost of money. However, due to the complexity involved in projecting future scenarios, only a limited number of these factors are accounted for in projections.

Quantitative systems analysis has been applied to Irish national projections in the following areas: electricity grid energy sources [5,6], national greenhouse gas emissions [4], and renewable energy sources in relation to renewable electricity, heat and transport [5,23], and electric vehicle roll-out [5,24]. As the focus of this research is on how HEIs may facilitate national sustainability transitions, the quantitative systems modelling aspect of the integrated approach analyses Irish national level sustainability projections to identify areas where HEIs may take action to catalyse these transitions. Higher Education Institution sectorial projections relating to deployment of sustainability technologies have not been carried out in Ireland but may be used to outline the potential for HEIs to facilitate national sustainability transitions.

2.1.2. Sociotechnical Analysis

Sociotechnical analysis is a perspective that looks at how technology and social systems co-evolve over time. Sociotechnical systems consist of dynamically interconnected components that include technologies, infrastructure, organisations, markets, regulations, and user preferences that are responsible for the delivery of societal functions [25]. Transitions at the societal level involve a change from one sociotechnical system to another, and this is referred to as systems innovation [26]. The two most common research frameworks that have been applied to sociotechnical transitions are the Multi-Phase Concept (MPC) of transitions and the Multi-Level Perspective (MLP) of society [27].

According to the MPC of transitions, the ideal pattern that represents a transition process can be represented by an S-shaped curve that includes the four phases of pre-development, take-off, breakthrough, and stabilisation (Figure 1). According to references [28,29], each phase is characterised as follows:

1. Predevelopment phase: there is very little visible change on the societal level but experimentation is occurring.
2. Take-off phase: the process of change commences, and the state of the system begins to shift.
3. Acceleration phase: structural changes take place in a visible way through an accumulation of socio-cultural, economic, ecological, and institutional changes that interact with one another during this phase; there are collective-learning, diffusion, and embedding processes.
4. Stabilisation phase: the speed of societal change decreases, and a new dynamic equilibrium is reached.

The MPC is used here to conceptualise the role HEIs play in each of these phases through research, experimentation, deployment, and up-scaling of sustainability solutions.

The MLP is a framework for understanding sustainability transitions that provides an overall view of the multi-dimensional complexity of changes in sociotechnical systems [30]. The MLP offers a heuristic to analyse the development and entrenchment of technology and technological systems within society [31] and to analyse interactions between industries, technology, markets, policy, culture, and civic society [32]. The MLP views transitions as non-linear processes that result from the interplay of developments on three analytical levels: niches or micro level (protective space for path-breaking innovations), sociotechnical regimes or meso level (established practices and associated rules that stabilise existing systems), and an exogenous sociotechnical landscape or macro level that encompasses broader social and physical factors (political and cultural norms, economic and demographic trends) [25,33,34]. Within this framework, acceleration of sociotechnical transitions or regime change involves the three mutually reinforcing processes of increasing momentum of niche innovation, weakening of existing systems, and strengthening of exogenous pressures which can create windows of opportunity for niche innovations (Figure 2) [25].

Previous studies that have used sociotechnical analysis to study HEI sustainability transitions have included transitions in HEI governance [35], and food production at HEIs [36]. These analysed how the current dominant systems or regimes within HEIs might be transformed to sustainable alternatives by niche actors within the HEI community. Here we propose a novel framing of HEI, within the MLP, as niche actors in catalysing national sustainability transitions of sociotechnical systems. From this perspective, HEIs are viewed as niche actors in that they facilitate niche development through research and development of innovative and disruptive technologies, whereas HEI campuses provide locations where sustainability innovations can be experimented with and deployed. Such activities facilitate niche development through learning by doing, and establishing or mainstreaming the sustainability solution or technology for further replication. Higher Education Institutions also have a role to play in shaping sociotechnical landscape change, as they have an important role to play in socialisation of individuals at a national level and may facilitate shifts in cultural and political norms (for example, teach the leaders of tomorrow that tackling climate change is important, and showcasing what is technologically possible by demonstration of sustainability solutions on campus). By shaping sociotechnical landscape change HEIs can facilitate landscape pressure on current sociotechnical regimes which leads to windows of opportunity for niche innovations. Higher Education Institutions, as niche actors, can also engage with current sociotechnical regime actors to incorporate niche innovations into the current regime to improve environmental efficiency. By applying this novel perspective to previous sociotechnical transitions, potential actions for the HEI sector in Ireland were identified.

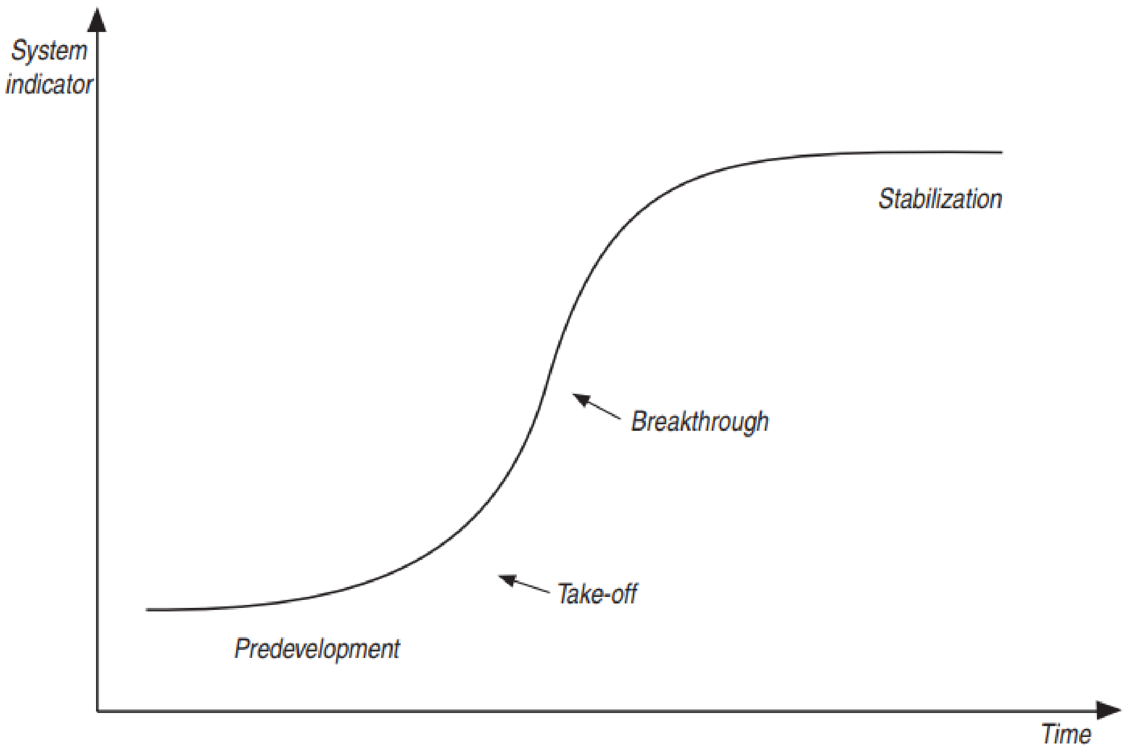

Figure 1. Four phases of a transition [29].

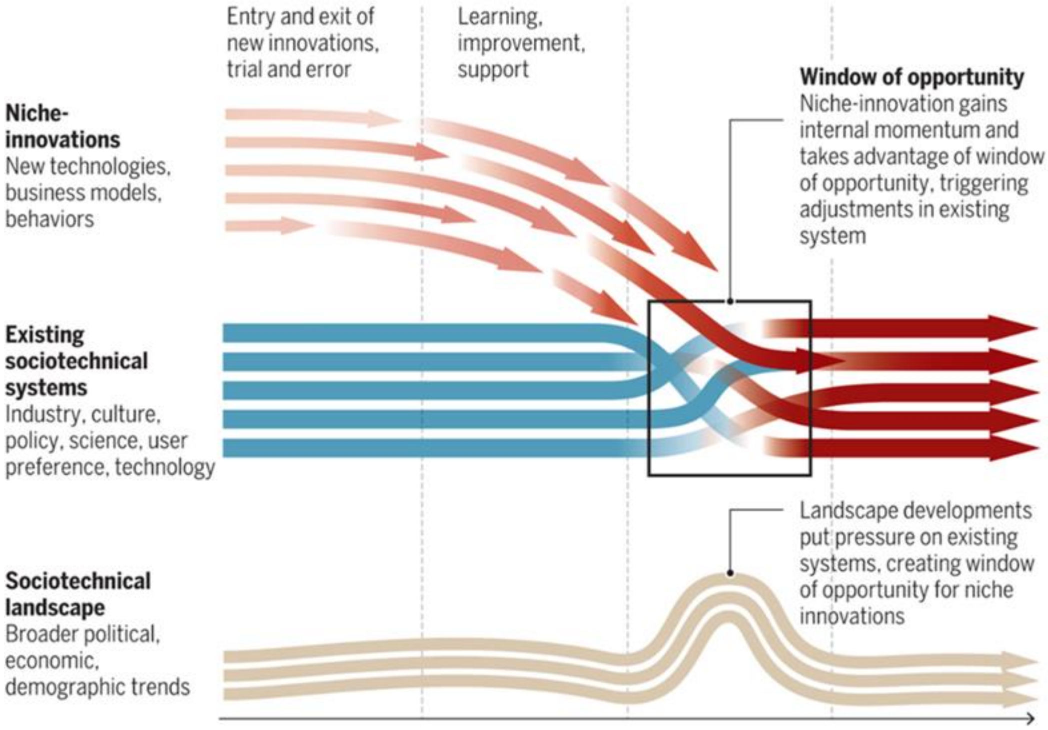

Figure 2. Summary of Multi-Level Perspective (MLP) on sociotechnical transitions [25].

2.1.3. Living Lab Perspective

Initiative-based learning is focused on developing sustainability innovations and generating new knowledge by experimenting and demonstrating sustainability solutions in a real-world context. In the initiative-based learning literature, the living lab concept is becoming an increasingly popular model through which universities and cities are engaging with each other to generate practical solutions to sustainability challenges [37–39]. The living lab perspective is utilised by a number of organisations including HEIs as "platforms for experimentation to develop and market approaches to sustainability" [40]. Living labs have also been defined as "geographically or institutionally bounded space, they conduct intentional experiments that make social and material alterations and incorporate an explicit element of iterative learning" [39].

The overall aim of living labs is to learn and experiment by integrating the processes of research and innovation [10,41,42]. The innovation aspect refers to the development of new products and to the discovery of innovative solutions to existing problems, whereas the learning and experimenting aspect refers to the generation and dissemination of knowledge among participants [42]. The emphasis on formalised knowledge production, that is, lessons that are formulated and can be disseminated, is what sets living labs apart from other policy experiments and niches of innovation [40]. One vital aspect of the living lab is that the output created does not stay in the academic community but is disseminated to wider society [40] with the hoped-for impact being refinement and dissemination of new methodologies and technologies.

2.1.4. Configuration of HEADS Approach

Based on a critical review of each perspective, a configuration of the approach was developed to guide the HEIs role in national sustainability transitions. It was decided that the quantitative systems analysis perspective was to be applied to national-level sustainability transitions projections to identify arenas where HEIs might take actions to best act as leaders in societal sustainability transitions. Quantitative estimations relating to the Irish HEI sector's potential deployment capacity may also be estimated using novel techniques and proxies to identify their contribution to niche development. The sociotechnical analysis perspective entailed using a multi-phase concept of transitions (the ideal pattern that represents a transition process following an S-shaped curve through the phases of pre-development, take off, acceleration, and stabilisation) and a novel framing of HEIs as niche actors using the multi-level perspective of society (niche, regime, and landscape levels of structuration). The initiative-based learning aspect entailed utilising a living lab perspective to identify experimentation and demonstration of sustainability solutions currently taking place on the ground at HEI and how lessons learned may be replicated by other HEIs and up-scaled to wider society. Each of these perspectives was integrated into an approach that was specifically adapted to guide HEI actions in facilitating national sustainability transitions. The linkages between the perspectives are shown in Figure 3.

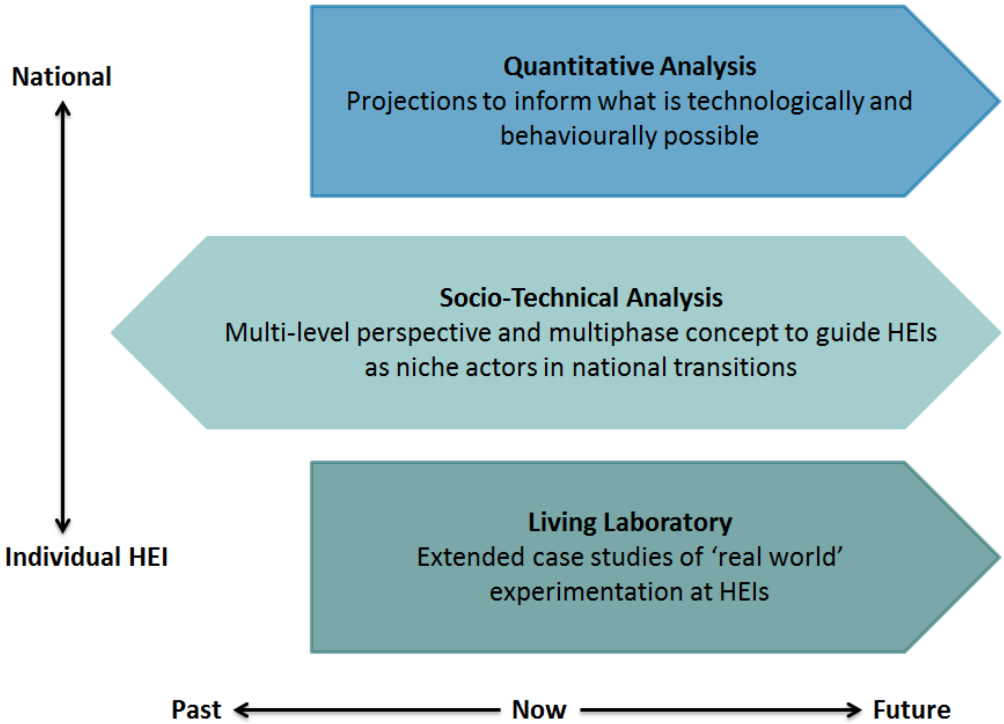

Figure 3. Higher Education Advancing Development for Sustainability (HEADS) approach.

The HEADS approach links projections of sustainability transitions at the national level to experimentation and demonstration of sustainability solutions at the local level by HEIs. The multilevel perspective of the sociotechnical analysis perspective serves as a link along the spatial dimension between HEIs' leadership role in contributing to national-level focused projections and on-the-ground experimentation and demonstration. This link is achieved by conceptualising HEIs as niche actors interacting with national sociotechnical systems and regimes. Along the temporal dimension, the quantitative systems analysis and living laboratory perspectives both focus on informing future trends, whereas the sociotechnical perspective looks to the past to identify the role HEIs have played in previous national transitions, utilising the multiphase concept and the multilevel perspective (niche, sociotechnical systems, and landscape actors), which is then used to guide future HEI actions in sustainability transitions.

By bridging the perspectives of national quantitative analysis, sociotechnical analysis and living laboratory analysis, the HEADS approach provides a comprehensive integrated approach to guide HEIs' leadership role in facilitating national sustainability transitions. The main limitation of this approach is that it focuses on what is technologically feasible with little regard to economic viability, which may be overcome by replacing one of the perspectives with a socio-economic perspective.

3. Results and Discussion

3.1. Case Study—Transition towards Solar Photovoltaic Electricity Generation

Application of the HEADS approach to guide the HEI sector's role in Ireland's national transition towards PV electricity generation is described below using desk-based research and site visits to Birkenfeld Umwelt, Germany and Galway Mayo Institute of Technology, Ireland.

3.1.1. Quantitative Systems Analysis—PV

Compared to European counterparts, Ireland may be considered a laggard; in terms of installed PV capacity per capita, it was placed second last of the EU 27 [43]. Projections relating to Ireland's national transition towards solar PV are shown in Table 1. As of 2016, the installed capacity of PV connected to the grid was 15 MW which accounts for less than half a percent of installed renewable electricity capacity in Ireland [6]. According to the studies highlighted in Table 1, by 2030 the projected installed capacity will range from 100 MW to 5.1 GW. These national projections assume major increases in installed capacity from a low baseline.

Table 1. Irish national PV projections.

Source	Document	Projections
Eirgrid [6]	Tomorrow's Energy Scenarios 2017	200-2500 MW by 2030
PwC [44]	Transitioning to a Low Carbon Energy System	2GW by 2050
KPMG [45]	A Brighter Future: The Potential Benefits of Solar PV in Ireland	100 MW-5.1 GW by 2030
Deane et al. [46]	Low Carbon Energy Roadmap for Ireland	4 GW by 2050

The technological feasibility of PV for the Irish HEI sector was also estimated to assess the HEI sector's potential contribution towards meeting national PV installation targets. The official online maps of each Irish HEI were utilised to identify buildings and open carparks under their control. In total, 635 buildings were identified, assuming that all terraced or physically linked buildings were counted as one building. The number of open carparks for HEIs in Ireland was found to be 153. Google Earth's polygon tool was then utilised to estimate roof area and open carpark area of the HEI sector in Ireland. Total roof area for the sector in Ireland was estimated at 1,027,556 m^2, whereas open carpark area was estimated at 461,472 m^2. Coupled with assumptions of 0.4 utilisation factor (100 m^2 of roof area corresponds to 40 m^2 suitable roof areas for building integrated PV due to solar and architectural constraints) for roof area [47], installation potential of 0.1 kW/m^2 [48], the potential installed PV capacity on Irish HEI roofs was estimated at 41 MW. To estimate PV potential of Irish HEI carparks a 0.5 utilisation factor was used (half the carpark area is suitable for PV due to solar and architectural constraints), with 0.16 kW/m^2 for open carpark area [49], which resulted in a potential installed capacity of 35MW. Total on-campus installed capacity of up to 76 MW was estimated for the sector in Ireland which would allow considerable progress towards national targets.

Additionally HEI campuses may be viewed as a microcosm of society or cities due to their large size, diverse population, and the numerous complex activities and operations which occur on their campuses and the resulting direct and indirect environmental impacts [14,50]. Experimentation and deployment of PV systems at HEIs may offer major potential to showcase best practice for replication among commercial, public sector, and residential communities due to similar characteristics. Commercial, public sector, and residential communities accounted for 58% of electricity total final consumption (TFC) in 2016 [51]; therefore, it is pertinent that HEIs accelerate learning rates associated with PV in an Irish context to expedite deployment in other sectors.

3.1.2. Sociotechnical Analysis—PV

The United Kingdom's PV installed capacity was 11,847 MW by December 2016 [52]. Based on World Bank [53] population figures for 2016, installed capacity per million citizens in the UK was

180 MW per million citizens. In Ireland, installed capacity was 3 MW per million citizens. As the UK has similar climatic and planning conditions to Ireland, it serves as a useful case study to inform how Ireland may facilitate national niche development by deployment of PV on-campus. National incentives that have facilitated PV installations in the UK include PV Feed-In Tariffs (FITs), Renewable Obligation Certificates (ROCs), and Contracts for Difference (CfDs), which are currently lacking in Ireland. From the perspective of the UK HEI sector, it consumed 6GWh from onsite PV in 2015/16 [54]. Photovoltaic installation size at each UK HEI was derived by dividing the total on-site PV energy generated by the average output of 1kW PV installation for the UK in a year, i.e., 960 kWh/kWp [55]. This resulted in an installed PV capacity of 7 MW for the HEI sector in the UK. With a full-time student equivalent (FTE) of 1,710,135, the installed PV capacity was 4 kW per 1,000 students. Based on desk research, installed PV capacity at Irish HEIs was 170kW in 2016. If this same level of ambition in terms of PV installations was replicated at Irish HEIs as at UK HEIs, installed capacity would be 690 kW for the sector with a student FTE of 172,687. Photovoltaic installation size associated with replicating UK HEIs results in installations that are less than 1% of what is deemed technologically feasible in this study. This highlights the limitations of relying solely on quantitative analysis to inform the sector's ambition, as social and economic considerations are not taken into account. By employing a sociotechnical perspective and learning from case studies where niche development is more advanced then in Ireland, more realistic expectations may be set relating to HEIs' role in such transitions.

3.1.3. Living Lab—PV

The living lab perspective looks at how PV installations have been implemented on the ground at HEIs in order to inform replication. Mechanisms for operation were identified from on-campus deployment of PV installations and include testing different PV systems onsite, different finance mechanisms such as Power Purchaser Agreements (PPAs), loans from a Green Revolving Fund (GRF), and university/staff/student-led funded projects as highlighted in Table 2. The initiatives highlighted offer lessons to Irish HEIs in implantation of solar PV on-campus which will contribute to further niche development at a national level. Lessons from UK HEIs are most valuable to Irish HEIs due to the similar planning and climatic conditions of both countries compared to lessons from Asian countries such as Singapore, with major differences in climatic conditions (PV electricity output potentials). From an Irish HEI perspective, with scarce economic resources, the potential for self-funded PV projects is limited. Two more promising funding mechanisms to facilitate PV deployment at Irish HEIs include GRFs and PPAs. Green Revolving Funds provide capital (loans or government funds) for campus-related green projects that generate operational savings which in turn pay back the GRF with additional savings reinvested in further projects [56]. Successful examples include the SALIX Finance Ltd revolving fund promoting energy efficiency for the UK public sector, which include HEIs such as Cranfield University, and the US Sustainable Endowments Institute's initiative, comprising 79 revolving funds for renewable energy and energy efficiency at HEIs [57]. The attraction of a GRF to facilitate Irish HEI PV deployment is that financial savings beyond payback of the loan may be reinvested in further PV installations at no cost to the HEI. Power Purchaser Agreements are also attractive financial mechanisms to stimulate PV deployment on Irish HEI campuses, as they allow campuses to receive financial savings associated with PV energy generation without the upfront costs associated with taking on ownership of the PV system. Power Purchaser Agreements entail HEIs leasing out their roof area to project developers who take on the costs associated with installation, operation, and maintenance of the PV system while offering discounted electricity prices to the HEI [58]. Case studies from HEIs in the UK, USA and Switzerland (Table 2) offer potential models for replication at Irish HEIs.

Table 2. Living lab PV examples.

	Size of Installation	HEI	Mechanism for Operation
1	510 kW roof mounted	Birkenfeld Umwelt, Germany (Site Visit)	Testing different PV panels on-site
2	1 MW ground mounted	Cranfield University, England [59]	Funded by revolving green fund for HEI sector
3	2.1 MW roof mounted	École Polytechnique Fédérale de Lausanne, Switzerland [60]	Power purchase agreement
4	865 kW roof mounted	University of Sussex, England [61]	Power purchase agreement
5	5 MW Rooftop mounted	Nanyang Technological University, Singapore [62]	Funded by university
6	>100 MW roof mounted	61 United States of America Universities [58]	Power purchase agreement
7	29.6 kW roof mounted	School of Oriental and African Studies, Singapore [63]	Student led initiative
8	6 kW roof mounted	Galway Mayo Institute of Technology, Ireland (Site Visit)	Testing different PV panels on-site

4. Conclusions

A novel integrated approach called HEADS was developed to conceptualise and evaluate the Irish HEI sector's leadership role in national sustainability transitions. Conceptualisation is needed to provide a rationale for governments and government agencies to recognise and exploit opportunities within this sector for policies and actions which may be expected to aid in meeting national and international commitments. Evaluation of the sector's performance relative to countries with more advanced niche development in particular sustainability transitions informs the Irish HEI sector of best international practice and mechanisms for replication. Applied to Irish HEIs' role in Ireland's transition towards PV, the HEADS approach has identified that national projections have projected major increases in installed PV capacity by 2030 with no guidance or targets relating to HEIs' role in this transition. Although this report has identified the potential PV installations that are technologically feasible at Irish HEIs, utilisation of a sociotechnical perspective to study countries with more advanced PV niche development (UK) has suggested that HEIs have a role to play in national sustainability transitions, but replication of their level of ambition would result in installations that are 1% (690 kW) of what is technologically feasible at Irish HEIs. The living lab perspective has identified examples of how HEIs have deployed PV on-campus internationally with lessons relating to testing performance of PV systems to funding mechanisms such as GRFs, PPAs and university-funded installations. The HEADS approach suggests that capitalising on synergies between government policy, private sector commercialisation, and HEI living lab resources may expedite renewable technology deployment to meet national decarbonisation targets, due to the HEI sector's amplification effect in signalling to commercial, public sector, and residential communities the attractiveness and utility of solar PV.

Author Contributions: W.H. conceived and designed the approach and wrote the original draft of the paper; R.S. and B.O. reviewed and edited the paper.

Funding: This study was funded by the Sustainability Pillar of the Environmental Protection Agency (EPA) Research Programme 2014-2020 (2015-SE-MS-3).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. EPA. *Ireland's Greenhouse Gas Emission Projections 2016–2035*; Environmental Protection Agency: Wexford, Ireland, 2018.
2. CAN. *Ranking of EU Countries' Ambition and Progress in Fighting Climate Change*; Climate Action Network Europe: Brussels, Belgium, 2018.
3. CCAC. *Annual Review 2018*; Climate Change Advisory Council: Dublin, Ireland, 2018.
4. EPA. *Ireland's Final Greenhouse Gas Emissions*; Environmental Protection Agency: Wexford, Ireland, 2018.
5. Davies, G.; Madden, C. *Ireland's Low Carbon Future-Dimensions of a Solution*; ESB: Dublin, Ireland, 2017.
6. EirGrid Plc. *Tomorrow's Energy Scenarios 2017 Planning our Energy Future*; Eirgrid Plc: Dublin, Ireland, 2017.
7. Department of Communications, Climate Action and Environment. *National Mitigation Plan*; Department of Communications, Climate Action and Environment: Dublin, Ireland, 2018.
8. Department of Communications, Climate Action and Environment. *Ireland's Transition to a Low Carbon Energy Future 2015–2050*; Department of Communications, Climate Action and Environment: Dublin, Ireland, 2015.

9. Department of Public Expenditure and Reform. *National Development Plan 2018–2027*; Department of Public Expenditure and Reform: Dublin, Ireland, 2018.
10. Streiff, L.G.; Ramanathan, V. Under 2 °C living laboratories. *Urban Clim.* **2017**, *21*, 195–217. [CrossRef]
11. Meier, A.; Davis, S.J.; Victor, D.G.; Brown, K.; McNeilly, L.; Modera, M.; Pass, R.Z.; Sager, J.; Weil, D.; Auston, D.; et al. *University of California Strategies for Decarbonization: Replacing Natural Gas*; UC TomKat Carbon Neutrality Project; University of California: Santa Barbara, CA, USA, 2018.
12. Victor, D.G.; Abdulla, A.; Austin, D.; Brase, W.; Brouwer, J.; Brown, K.; Davis, S.J.; Kappel, C.V.; Meier, A.; Modera, M.; et al. TomKat Natural Gas Exit Strategies Working Group. Turning Paris into reality at the University of California. *Nat. Clim. Chang.* **2018**, *8*, 183–185. [CrossRef]
13. Parker, P.; Letycher, R.; Jakeman, A. The Potential for Integrated assessment and Modeling to solve Environmental Problems: Vision Capacity and Direction. In *Understanding and Solving Environmental Problems in the 21st Century*; Costanza, R., Jorgensen, S.E., Eds.; Elsevier Science Ltd.: Oxford, UK, 2002; pp. 19–39.
14. Alshuwaikhat, H.M.; Abubakar, I. An integrated approach to achieving campus sustainability: Assessment of the current campus environmental management practices. *J. Clean. Prod.* **2008**, *16*, 1777–1785. [CrossRef]
15. Ostrom, E. A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science* **2009**, *325*, 419–422. [CrossRef] [PubMed]
16. Turnheim, B.; Berkhout, F.; Geels, F.W.; Hof, A.; McMeekin, A.; Nykvist, B.; van Vuuren, D.P. Evaluating Sustainability transition pathways: Bridging analytical approaches to address governance challenges. *Glob. Environ. Chang.* **2015**, *35*, 239–253. [CrossRef]
17. Cherp, A.; Vinichenko, V.; Jewell, J.; Brutschin, E.; Sovacool, B. Integrating techno-economic, socio-technical and political perspectives on national energy transitions: A meta-theoretical framework. *Energy Res. Soc. Sci.* **2018**, *37*, 175–190. [CrossRef]
18. Papachristos, G. System dynamics modelling and simulation for sociotechnical transitions research. *Environ. Innov. Soc. Trans.* **2018**. [CrossRef]
19. Baker-Shelly, A.; van Zeijl-Rozema, A.; Martens, P. A conceptual synthesis of organisational transformation: How to diagnose and navigate, pathways for sustainability at univeristies? *J. Clean. Prod.* **2017**, *145*, 262–276. [CrossRef]
20. Disterheft, A.; Caeiro, S.S.; Leal Filho, W.; Azeiteiro, U.M. The INDICARE-model-measuring and caring about participation in higher education's sustainability assessment. *Ecol. Indic.* **2015**, *63*, 172–186. [CrossRef]
21. Velazquez, L.; Munguia, N.; Platt, A.; Taddei, J. Sustainable university: What can be the matter? *J. Clean. Prod.* **2006**, *14*, 810–819. [CrossRef]
22. Vergragt, P.J.; Quist, J. Backcasting for sustainability: Introduction to the special issue. *Technol. Forecast. Soc. Chang.* **2011**, *78*, 747–775. [CrossRef]
23. SEAI. *Ireland's Energy Projections: Progress to Targets, Challenges and Impacts*; Sustainable Energy Authority of Ireland: Dublin, Ireland, 2017.
24. SEAI. *Electric Vehicles Roadmap*; Sustainable Energy Authority of Ireland: Dublin, Ireland, 2011.
25. Geels, F.W.; Sovacool, B.K.; Schwanen, T.; Sorrell, S. Sociotechnical transitions for deep decarbonization. *Science* **2017**, *357*, 1242–1244. [CrossRef]
26. Elzen, B.; Geels, F.W.; Green, K. *System Innovation and the Transition to Sustainability: Theory, Evidence and Policy*; Edwards Elgar: Cheltenham, UK, 2004; pp. 1–19.
27. Chang, R.; Zou, J.; Zhao, Z.; Soebarto, V.; Zillante, G.; Gan, X. Approaches for transitions towards sustainable development: Status quo and challenges. *Sustain. Dev.* **2017**, *25*, 359–371. [CrossRef]
28. Rotmans, J.; Kemp, R.; van Asselt, M. More evolution than revolution: Transition management in public policy. *Foresight* **2001**, *3*, 15–31. [CrossRef]
29. Loorback, D. *Transition Management: New Mode of Governance for Sustainable Development*; International Books: Utrecht, The Netherlands, 2007; p. 19.
30. Geels, F.W. Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. *Res. Policy* **2010**, *39*, 495–510. [CrossRef]
31. Geels, F.W. Technological transitions as evolutionary reconfigurations process: A multi-level perspective and a case study. *Res. Policy* **2002**, *31*, 1257–1274. [CrossRef]
32. Geels, F.W. The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environ. Innov. Soc. Trans.* **2011**, *1*, 24–40. [CrossRef]

33. Verbong, G.P.J.; Geels, F.W. Exploring sustainability transitions in the electricity sector with socio-technical pathways. *Technol. Forecast. Soc. Chang.* **2010**, *77*, 1214–1221. [CrossRef]
34. Smith, A.; Stirling, A. The Politics of Social-ecological Resilience and Sustainable Sociotechnical Transitions, Ecology and Society. *Ecol. Soc.* **2010**, *15*, 11. [CrossRef]
35. Stephens, J.C.; Graham, A.C. Toward an empirical research agenda for sustainability in higher education: Exploring the transition management framework. *J. Clean. Prod.* **2010**, *18*, 611–618. [CrossRef]
36. Eatmon, T.D.; Krill, H.E.; Rynes, J.J. Food production as a niche innovation in higher education. In *The Contribution of Social Sciences to Sustainable Development at Universities*; Leal Filho, W., Zint, M., Eds.; Springer: London, UK, 2016; pp. 145–160.
37. König, A.; Evans, J. Introduction: Experimenting for Sustainable Development? Living Laboratories, Social Learning and the Role of the University. In *Regenerative Sustainable Development of Universities and Cities: The Role of Living Laboratories*; König, A., Ed.; Edward Elgar Publishing Limited: Cheltenham, UK, 2013; pp. 1–26.
38. Liedtke, C.; Welfens, M.J.; Rohn, H.; Nordmann, J. Living lab: User-driven innovation for sustainability. *Int. J. Sustain. High. Educ.* **2012**, *13*, 106–118. [CrossRef]
39. Evans, J.; Jones, R.; Karvonen, A.; Millard, L.; Wendler, J. Living labs and co-production: University campuses as platforms for sustainability science. *Curr. Opin. Environ. Sustain.* **2016**, *16*, 1–6. [CrossRef]
40. Schliwa, S.; Evans, J.; McCormick, K.; Voytenko, Y. Living labs and sustainability transitions—Assessing the impact of urban experimentation. In Proceedings of the INOGOV Workshop: Climate Change Policy and Governance: Initiation, Experimentation, Evaluation, Helsinki, Finland, 12–13 March 2015.
41. Schuurman, D.; De Marez, L.; Ballon, P. The impact of living lab methodology on open innovation contributions and outcomes. *Technol. Innov. Manag. Rev.* **2016**, *6*, 7–16. [CrossRef]
42. Steen, K.; van Bueren, E. The defining characteristics of urban living labs. *Technol. Innov. Manag. Rev.* **2017**, *7*, 21–33. [CrossRef]
43. EurObserv'ER. *Photovoltaic Barometer 2016*; EurObserv'ER: Paris, France, 2017.
44. PwC. *Transitioning to a Low Carbon Energy System*; PricewaterhouseCoopers LLP: Dublin Ireland, 2017.
45. KPMG. *A Brighter Futurel: The Potential Benefits of Solar PV in Ireland*; KPMG: Dublin, Ireland, 2015.
46. Deane, P.; Curtis, J.; Chiodi, A.; Gargiulo, M.; Rogan, F.; Dineen, D.; Glynn, J. *Low Carbon Energy Roadmap for Ireland*; Department of Environment, Community and Local Government: Dublin, Ireland, 2013.
47. IEA. *Potential for Building Integrated Photovoltaics*; International Energy Agency: Zurich, Switzerland, 2002.
48. Kingspan. *Energy Solution Specification Guide*; Kingspan Ltd.: Flintshire, UK, 2018.
49. Alghamdi, A.S.; Bahaj, A.S.; Wu, Y. Assessment of Large Scale Photovoltaic Power Generation from Carport Canopies. *Energies* **2017**, *10*, 686. [CrossRef]
50. Jain, S.; Agarwal, A.; Jani, V.; Sinhal, S.; Sharma, P.; Jalan, R. Assessment of carbon neutrality and sustainability in educational campus (CaNSEC): A general framework. *Ecol. Indic.* **2017**, *76*, 131–143. [CrossRef]
51. SEAI. *Ireland's Energy Balance for 2016*; Sustainable Energy Authority of Ireland: Dublin, Ireland, 2017.
52. DBEIS. *Solar Photovoltaics Deployment*; Department of Business, Energy and Industrial Strategy: London, UK, 2018.
53. Worldbank.org. Available online: https://data.worldbank.org/indicator/SP.POP.TOTL (accessed on 1 May 2018).
54. HESA. *Estates Management 2015/2016*; Higher Education Statistics Agency: Cheltenham, UK, 2017.
55. Mason, N.B. Solar PV yield and electricity generation in the UK. *IET Renew. Power Gener.* **2016**, *10*, 456–459. [CrossRef]
56. IEN. *Investing in Clean Energy: Campuses and Endowments*; International Endowments Network: Andover, MA, USA, 2016.
57. Gouldson, A.; Kerr, N.; Millward-Hopkins, J.; Freeman, M.C.; Topi, C. Innovative financing models for low carbon transitions: Exploring the case for revolving funds for domestic energy efficiency programmes. *Energy Policy* **2015**, *86*, 739–748. [CrossRef]
58. NREL. *Using Power Purchase Agreements for Solar Deployment at Universities*; National Renewable Energy Laboratory: Golden, CO, USA, 2016.
59. Cranfield University. Available online: https://www.cranfield.ac.uk/events/events-2018/solar-farm-open-day (accessed on 13 October 2018).

60. École Polytechnique Fédérale de Lausanne. Available online: https://developpement-durable.epfl.ch/management/energy/solar-park/ (accessed on 12 October 2018).
61. University of Sussex. Available online: http://www.sussex.ac.uk/broadcast/read/42115 (accessed on 13 October 2018).
62. Nanyang Technological University. Available online: http://www.ntu.edu.sg/AboutNTU/UniversityPublications/Documents/NTU%20Sustainability%20Report%20FY16.pdf (accessed on 15 March 2018).
63. SOAS. Available online: http://www.uni-solar.org/solarsoas/ (accessed on 13 October 2018).