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ABSTRACT

Australia leads the world in some areas of photovoltaic technology development, yet current innovation system limitations have seen local innovation overtaken by more rapid international development, or local product development moving offshore for commercialisation.

Innovation is traditionally viewed as a linear progression through phases of early research, demonstration, commercialisation and market uptake, and this traditional view strongly emphasises the importance of the early phases. The latest thinking on innovation suggests that technological learning occurs not only through R&D, but also through manufacturing and marketing activities and through the interactions of actors within networks. In this paradigm, technology diffusion, as well as invention and adoption, plays a role in determining the direction of technological change. Organisational change and institutional change, which are critical in determining which technologies become established, are considered to be as important as technical change.

This paper proposes the use of an innovation systems framework to assess the characteristics of the Australian PV innovation system, such as the type and number of actors, their linkages, and the resources available to them. Where much of the past support for the PV industry in Australia has been directed towards early research or market development, this research will provide information that could enable the design of policies that better facilitate innovation throughout the value chain and thus improve the impact of future policies on innovation.

Keywords: Photovoltaics, Industry development, Innovation, Policy, Australia.

MOTIVATION

In 1995, Australia was the 4th largest market in the world for photovoltaic (PV) modules (2 MW), behind Japan (12.2 MW), the US (9 MW) and Germany (5.3 MW), comprising about 13% of the total market in IEA countries (IEA PVPS, 2008). By 2007, Australia's market had decreased to 0.5% of the total market in IEA countries (*ibid.*). In 1998, Australia was the fourth largest manufacturer of PV cells, behind the US, Japan and France, producing 7% of the cells made in IEA countries (IEA PVPS Task 1, 1999). By 2007, Australian cell production was 1.5% of IEA country production (IEA PVPS, 2008) and 1.3% of global production (Hirshman *et al.*, 2007) and in 2009, BP solar, Australia's only remaining solar cell manufacturer, announced the closure of its Sydney factory.

While Australia retains leadership in some aspects of PV R&D and in off-grid applications, we have become less significant as manufacturers and exporters of photovoltaic products and have not played a major role in development of the new grid-connected markets. Developed countries usually access export markets and compete with imports on the basis of technological leadership, rather than low cost production, and Australia appears to be forfeiting a rare opportunity to develop such technological leadership in the PV industry; one that boasts rapidly growing global markets and large job creation potential, as well as the potential to address greenhouse emissions and energy security issues.

In order to capitalise on the advantages Australia currently has in the photovoltaics industry, the Australian PV Association (APVA) has identified the need for a coherent PV strategy for Australia (Watt *et al.*, 2008) and identifies eight aspects of the industry that need to be coordinated: R&D, manufacturing, grid-connected market, off-grid market, exports, regulations & standards, education & training, and public awareness and information. The purpose of this paper is to demonstrate that an innovation systems approach could be used to inform such a coherent strategy. As a starting point for a detailed study of Australia's PV innovation system, this paper will also identify areas where the innovation system appears to be working well or poorly and identify gaps in the current understanding of this innovation system that warrant exploration in such a study.

BACKGROUND: INNOVATION SYSTEMS

Innovation studies have traditionally focussed on the measurement of innovation via empirical indicators such as patent registration and R&D expenditure, but these types of studies have done little to explain how or why innovation occurs. The 'innovation systems' approach, despite being relatively new, has become the accepted theoretical basis for a more detailed understanding of innovation and has been used extensively by the OECD (1999, 2002).

The innovation systems approach emerged with the publication of works by Lundvall (1992) and Edquist (1997), who view innovations as 'new creations of economic significance', which may be of various kinds, including technological, organisational[1] or institutional.[2] It is a systems-based approach, where innovations emerge in an evolutionary and path-dependent manner from networks of actors.

Technological innovation occurs through R&D (learning by searching), but both technological and organisational innovation can also occur through manufacturing and deployment activities (learning by doing (Arrow, 1962)) and the interactions of actors within markets and networks (learning by interacting (Lundvall, 1992)). Institutional innovation can be economic, political and social and can influence market operation, connectivity and information flows, resource allocation and incentives to invest and innovate. In this paradigm, technology diffusion, as well as invention plays a role in determining the direction of technological change. Thus, organisational and institutional innovation, which are critical in determining which technologies are able to be established (Dosi, 1982), are considered to be as important as technological innovation.

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[1] Organisational innovations are non-technical improvements within a company, e.g. in the organisation of production, sales, after-sales service, inventory, investment, information collection etc.
[2] Institutions are defined as laws, rules and social or business norms which govern the behaviour of and relations between individuals or groups

The innovation systems approach has been used to examine innovation and compare the performance of national energy sectors (Jacobsson & Bergek, 2004; OECD, 2003). This approach has been found to be useful because policies, institutions and networks are often nationally based. However, a national view is too broad to understand innovation in a particular sector, since sectors often perform differently within a single country. A sectoral innovation systems approach has been applied to the photovoltaics or wind sectors in some Northern European countries (Jacobsson *et al.*, 2002). The UK government has sponsored the only detailed national study of innovation systems across a range of RE technologies. This study was commissioned to inform policy that would encourage innovation in the industry (Foxon *et al.*, 2005). In Australia, researchers have carried out seven sectoral studies of innovation systems, including a study relevant to PV (Balaguer & Marinova, 2006). However, this study was limited primarily to solar cell manufacture.

In order to identify the opportunities for innovation throughout the value chain, a more comprehensive study is required. The authors propose to carry out such a study, which would map out and assess the actors, networks and institutions, as well as their interactions, and so enable the identification of appropriate policy measures to capitalise on the potential of Australia's renewable energy industry. A parallel assessment of innovation systems in the other RE industries will also allow us to systematically compare RE industries and identify areas where Australia has competitive advantages.

ASSESSING THE PERFORMANCE OF INNOVATION SYSTEMS

Countries may have different goals that they hope to achieve through the development of a PV industry, such as job creation, export income, greenhouse gas reductions or energy security, and may therefore measure success in terms of their achievement. In Australia, goals include the creation of IP through R&D and development of specific market sectors (residential grid and off-grid) as part of wider greenhouse gas reduction policies. Nevertheless, activity throughout the value chain is required to fulfil many of the functions and in order for a national PV innovation system to be self-sustaining. Following the approach adopted by researchers from Chalmers University of Technology in Sweden (Andersson & Jacobsson, 2000; Edquist, 1997; Jacobsson & Bergek, 2004; Jacobsson & Lauber, 2006), the analysis in this paper will be organised around five functions of innovation systems that need to be working well for the technology to become established and the innovation system to grow:

- The creation of knowledge by actors and its exchange in networks
- The provision of investment opportunities and incentives to invest and improve
- The provision of resources to carry out production and innovation activities
- Guidance with respect to the potential of the technology and legitimisation.

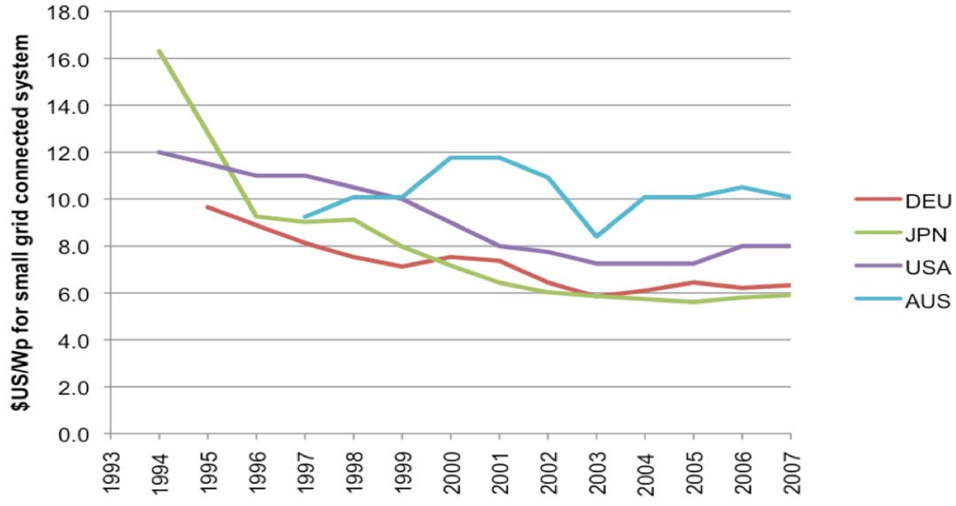
Knowledge Creation & Exchange in the PV Industry

Knowledge creation is the central role of innovation systems; it is the basis for competitive advantage and is therefore a measure of overall success. Knowledge is created in innovation systems as actors gain experience (learn by doing), conduct R&D (learn by searching) and through the interactions of actors (learn by interacting).

In the manufacture of PV cells and modules, the ability to compete on cost will be the major determinant of the ability of local industries to survive. Reduced ($/Wp) costs via either increased efficiency or reduced production costs are therefore the object of most efforts to improve cell and module manufacture and are a good measure of knowledge creation in the cell and module R&D and manufacturing sectors[3]. The decrease in the cost of production with accumulated experience can be empirically described by 'learning rates', which have produced fairly reliable predictions of cost reductions in the photovoltaics industry (Masini & Frankl, 2003; Schaeffer *et al.*, 2004; van der Zwaan & Rabl, 2003, 2004), with much of the learning in PV cell production attributed to factors such as scale effects, investments in R&D and interactions with other actors or industries (Nemet, 2006), which all build on previous experience.

Balance of system components (BOS) include all other inputs to PV systems excluding PV modules (i.e. electronics such as inverters and charge regulators, batteries, support structures, wiring, and in this paper will also refer to system integration and installation). Improvements in performance and reliability as well as cost have been a focus of the PV BOS manufacturing and system integration sectors, and have contributed to improved system performance (IEA PVPS Task 2, 2007). The emphasis in the PV industry worldwide has generally been on innovations and cost reduction in cell manufacture. However, in the German PV industry, the rate of price reduction from 1992-2002 for non-inverter PV Balance of Systems (BOS) components (i.e. array supports, cabling and installation) was greater than that for PV modules, which was in turn greater than that for inverters (Schaeffer et al., 2004). More cost reductions occurred via improved installation techniques and organisational learning such as improved business models than in product design and manufacturing.

System rather than module cost is therefore possibly a better measure to compare the extent to which knowledge has accrued in different countries[4]. Cost data would ideally be supplemented by performance ratio data that would capture differences in reliability and efficiency of systems, but there are few good datasets available for this purpose. Prices for small grid-connected systems decreased from 1992-2004 by 35% in Germany, 54% in Japan, 30% in the US and have not changed appreciably in Australia during that time (**Figure 1**).



Source: (IEA PVPS, 2008)

Figure 1: The evolution of prices for small grid-connected systems in Germany (DEU), Japan (JPN), the US (USA) and Australia (AUS)

[3] Price does not always follow costs, since there are other factors affecting price, such as marketing and distribution costs, profit margins, subsidies and tax concessions for manufacturers in different locations.
[4] Spillovers between national innovation systems will allow price reductions to be passed from one country to another, so not all of the price reductions can be attributed to improvements within the national technological system.

This is a fairly clear indication that learning has been more effective in Japan, Germany and the US than in Australia.[5] The next sections will attempt to explain these differences by comparing 'knowledge creation' in Australia with that of other countries. The following sections will then compare the operation of other functions of innovation systems, along the way identifying gaps in our current understanding of Australia's PV innovation system.

Learning by Doing and Scale Efficiencies in the PV Industry

The cost of delivering a product or service decreases as actors gain experience; 'learning by doing'. Larger markets and therefore greater activity throughout the value chain automatically leads to increased learning by doing and also provides opportunities for economies of scale. New PV cell manufacturing plants are now being built at the 500 MW (Koot, 2008) scale in order to be competitive. While the market for PV cells and modules is international and the size of local markets does not therefore have a significant impact on local learning, local markets do play a role in supporting manufacturing at this scale.

BOS component and system integration markets are more localised due to differences in local electricity networks and building industries, so BOS, system integration and business costs are the source of most of the differences in system prices between countries. Schaeffer *et al.* (2004) found that BOS prices were higher in European countries that had not yet entered large-scale PV diffusion than in countries that had more established markets. They concluded that, although the benefits of experience could spill over, giving late entrants a head start, BOS technology has some specific national attributes and adaptation is required to the local context. Learning by doing and scale are probably the best explanation of the differences observed in system prices between Australia and Germany, Japan and the US. Market expansion in Australia would therefore be likely to bring significant improvements in the cost and also the performance and quality of BOS components, efficient business models and PV systems.

Some questions that an innovation systems study could address in relation to learning by doing and scale include:

- What size would the market need to be to enable manufacture of PV cells or BOS components at a competitive scale in Australia?
- What opportunities do new thin film technologies offer?
- What are the sources of high system prices in Australia? Could different distribution and retail models and scale efficiencies have an impact?
- Have emerging business models such as bulk installations improved PV system prices in Australia?
- What is the quality of PV installations n Australia? Has it changed with market growth and novel business models?

Learning by Searching in the PV Industry

Nelson & Winter (1982) and Dosi (1988) have interpreted R&D activities as 'learning by searching', whereby enterprises look for new technological options, test them and generate new knowledge in particular directions. For PV cell manufacture, much of the R&D and most of the innovative technology was at least initially developed in publicly

[5] It should be noted that prices started from a lower base in Germany, reducing opportunities for price reductions and that in the last few years, module prices in Germany have increased, due to huge market growth and module shortages, which resulted in an artificially high price.

funded research institutes or universities (Surek, 2003), so linkages with these actors is expected to be of prime importance to manufacturers, especially to new entrants. Australia's world leading PV research groups are therefore likely to be an important factor in attracting investment in manufacturing to the country and in contributing to subsequent competitiveness, especially since access to this public R&D could favour locally based over foreign based companies.

Australia has not been able to utilise local R&D in local companies in recent decades. BP Solar's manufacturing plant did not use local R&D at all, while other IP developed at the University of NSW has gone overseas. In order to take advantage of government R&D spending, good interactions between R&D organisations and manufacturers are needed. University-industry network formation has been encouraged by tying funding to collaborations, as well as innovative arrangements for sharing public funding, facilities, and intellectual property in Germany, Japan and the US (Balaguer & Marinova, 2006). In Australia, conversely, the commercialisation of technology has occurred mainly through licensing, since government funding has been focused on university research. Commercialisation has been hampered by high transaction costs in IP transfers, concerns over the transparency of government funded research, and lack of funding for the development and commercialisation phases (Watt, 2003). An innovation system study could investigate what policies would best facilitate commercialisation of Australian IP.

As well as directly creating new knowledge in research institutes and universities, government R&D funding has the potential to promote private investment in R&D. Private investments in Japan (Watanabe et al., 2000) and the US (Surek, 2003) have been shown to mirror those of the government, especially when government support rapidly increased or decreased. Although Australia's R&D budget is smaller than those of the US, Japan or Germany, it could still be used to foster private sector investments in Australia, if suitable support structures are developed.

R&D support also tends to influence the direction of search. For instance, in Germany, private investments in amorphous silicon R&D followed government funding (Jacobsson *et al.*, 2002) and companies invested in BIPV R&D after a number of BIPV demonstrations. Public funding of PV device R&D is well established in Australia, but BOS and systems R&D tends to be undertaken on a small scale in the private sector. Given the number of industries involved at the applications end of the PV chain, public funding for applications based R&D could result in a significant increase in private sector R&D activity and hence to the development of IP and products suited to Australia locations, and to markets with similar characteristics. An innovation systems study could investigate the extent to which systems integrators and BOS manufacturers are investing in R&D and innovating, and what policies would best support further improvements.

Learning by Interacting in the PV Industry

Learning occurs when actors interact with other organisations, whether through market interactions with suppliers or customers, or through cooperation with other actors such as research institutes, industry associations or competitors. Interactive learning gives actors access to the technology possessed by others, and the sharing of technology provides opportunities for new knowledge creation, as existing knowledge is reinterpreted and combined in different ways. The entry of new actors in response to growing markets can therefore increase the opportunities for learning.

Networks between companies, customers and suppliers in close proximity (clusters) are likely to involve more frequent and face-to-face interactions, which enhance learning benefits and attract more actors. The US manufacturers ASE Americas, Evergreen Solar and Ascension Solar, for example are located in Boston, close to Massachusetts Institute of Technology. In Germany, many companies in the PV value chain (including equipment manufacturers) and the Fraunhofer Institute for Solar Energy are clustered around the central-east of the country where capital investment subsidies are provided. Suppliers of materials for making solar cells: silicon feedstock, ingots, wafers, metal pastes; modules: encapsulation materials, glass, metal frames; as well as equipment manufacturers have also emerged in Japan to supply cell manufacturers (Ikki et al., 2004). These clusters increase the potential for profitability, since transactions may be realised more quickly and at lower cost, while R&D cooperation and learning opportunities are also increased. Vertical integration can intensify interactions and reduce transaction costs between parts of the value chain. As PV costs decrease, more benefits can be gained by vertical integration, so the opportunities available in Australia are worth examining (Fath, 2009).

Learning by interacting can also occur via technological spillovers between different industries. Photovoltaics manufacture is closely related to microelectronics semiconductor technology. Much of the equipment, materials and many of the techniques used for standard silicon solar cell manufacturing are similar to those used in the microelectronics industry (Green, 2000), although as the photovoltaics industry matures, more technologies that are specific to the industry are being developed and the spillovers from that industry are becoming less important. The technological proximity of PV to the semiconductor industry has given Japan a technological advantage, enabled access to the supply chains of existing industries, and encouraged the government to see its strategic value in terms of inter-industry spillovers (Nagamatsu et al., 2006). Progress in other industries is also of relevance to the PV industry and spillovers may be obtained. For example, conductive metal pastes used for solar cells are also used for car rear windows. Lamination materials used in glass have formed the basis of the development of materials for PV module encapsulation. Countries with existing chemical, metals, semiconductor, glass and manufacturing industries are therefore likely to offer more opportunities for cell manufacturers to benefit from spillovers.

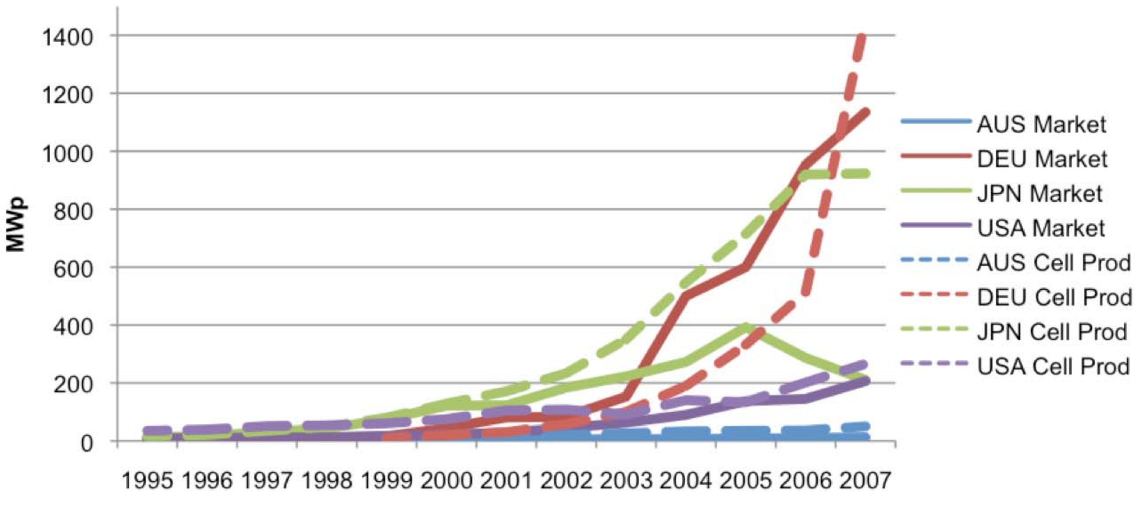
Australia has many of the key raw materials and expertise necessary, but lacks the advantages already gained in other countries through clusters of support industries. An innovation systems study for Australia would need to examine these issues and also to assess the potential advantages in establishing clusters based on the best new technologies, thus overtaking those countries locked into old and less efficient processes.

Learning may also occur through interactions with customers or downstream parts of the value chain. Manufacturers in Japan have standardised and mass-produced elements of residential grid-connected and BIPV systems via interactions with the construction industry (Balaguer & Marinova, 2006). In Germany, architects and project managers have also been involved in the development of BIPV products. In both countries, downstream interactions have enabled companies to access the marketing channels of existing industries. There has historically been much less effort to identify the importance of these types of interactions than those between research organisations and cell manufacturers. Non-technology spillovers from other sectors, such as deployment models and financing may also prove useful. Australia's current capabilities need to be examined in light of new PV products and markets, perhaps focussing on those aspects which differentiate the Australian market, and that of countries with similar infrastructure and climates, from those of Europe where much of the last innovation phase have occurred.

Investment Opportunities and Incentives in the PV Industry

Markets are the primary source of opportunities for enterprises to invest in production. Although markets for PV cells and modules are international, as are, to a lesser extent, markets for BOS, the existence of a local market, particularly if it is strongly supported by the government, is likely to influence investment decisions. Module manufacture follows markets, since it is commonly carried out close to market in order to avoid transportation costs, while long term government support signals a commitment to the industry and increases investor confidence in other parts of the value chain.

As noted in the introduction to this paper, Australia's market growth has not kept pace with developments in the leading countries. **Figure 2** compares the annual cell production with the annual PV sales in Australia, Germany, Japan and the USA. It is clear that market size is strongly correlated with investment in production. In countries such as the USA and Australia, which have not been able to grow local markets strongly and consistently, the development of the PV cell manufacturing industry has been stifled, even while there have been successful R&D activities. In general, measures that do not have long-term political certainty are less likely to encourage local investment. PV companies will instead take up short-term market opportunities, such as importing. The Japanese experience so far indicates that once the manufacturing industry is established, it no longer depends on local markets. Export industries can be accessed instead.



Sources: (IEA PVPS, 2006, 2007a, b, 2008; Maycock, 2006; Mints, 2006a; Schmela, 2005, 2006; Stryi-Hipp, 2006)

Figure 2: Cell Production and Market Size (MW/year) 1995-2005 in Australia (AUS), Germany (DEU), Japan (JPN) and the US (USA)

Although a local market is a necessary condition for a production industry to become established, the existence of a local market does not guarantee growth of a local manufacturing industry. For instance, quota and competitive tender approaches limit the size of the market, whereas the German feed in tariff and Japanese subsidy models do not, and may therefore provide more incentive for manufacturers to make the large and long-term investments required. Australia's proposed new PV market programs support the 1.5 kW residential rooftop market via the proposed Solar Credit or REC multiplier and the very large (up to 250 MW) Solar Flagship projects. Neither program is long term or continuing and no support is available for the mid range 30-250 kWp market which has been the mainstay of the German and US markets.

Some market development programs explicitly favour locally owned companies. Local content rules employed in Germany, for example, have mandated a certain percentage of locally manufactured content in PV projects. Companies that wish to sell their product in such a market must transfer some of their manufacturing to the country. Other financial inducements to locate manufacturing in a particular place have included direct assistance for new capacity, tax concessions, R&D funding, finance for commercialisation, export assistance, import tariffs and local content rules. In East German economic development zones, state governments offer investment incentives of up to 50% of capital expenditure for new manufacturing facilities. Japan's government has provided direct subsidies for the establishment of manufacturing, bringing production costs and system prices down (Mints, 2006b).

BOS manufacturers, and particularly system integrators are well placed to serve local markets. Opportunities for further development of Australian stand-alone BOS and system expertise and development of local and export markets should be examined. Research could focus on the size of markets required to encourage BOS and systems manufacture, the manufacturing incentives Australia should employ, and whether they are different from those needed for cell and module manufacture.

Innovation systems, primarily through markets, must also provide incentives for both technological and institutional improvements in all phases of technology generation, production, diffusion and after-sales service if technologies and local industries are to become and remain competitive. Porter (1998) believes that as a driver of technological change, the size of domestic demand is less important than its character, since buyers that are sophisticated will pressure companies into innovation. Some market development policies will also be more effective at inducing companies to invest in innovation. Policies that reward electricity production, rather than investment in capacity may encourage good system performance. Since the introduction of feed in tariffs in some countries, as an alternative to capital grants, systems have been better maintained (IEA PVPS Task 2, 2007). Standards also regulate markets, while the information gained through monitoring can also be used to incentivise improvements.

Resources for the PV Industry

The availability of resources, such as an appropriately skilled labour force, finance and low cost inputs to production are also likely to impact competitiveness and influence a company's decision to locate manufacturing in a particular country. 1GW_p cell manufacturing plants are expected by 2010, at a cost of around US$1 million per MW_p (Lüdemann, 2005; Solarbuzz, 2007). In order to operate at a competitive scale, new manufacturers will therefore need to raise significant finance to invest in such a facility. There is a shortage of personnel with industry specific technical expertise in the PV industry as the it rapidly expands. Australia has good education and training systems in place. High labour costs are likely to be a barrier to manufacture in Australia, but can be outweighed by the benefits of skilled personnel.

The cost of importing solar cell production equipment and materials into Australia, is estimated by Fath (2009) to add 2-3% to manufacturing costs. An innovation system study should consider whether the development of any supply industries is feasible for Australia in light of the impact on plant maintenance costs and yields of using imported production equipment. The main infrastructure requirement for PV manufacture is large amounts of cheap electricity, especially for silicon feedstock production. Although Australia can currently supply cheap coal generated electricity, carbon prices may increase the price of electricity in Australia in the long term, which should be taken into consideration in any assessment.

Legitimisation & the Establishment of Self-Sustaining Innovation Systems

Policies and institutions are likely to favour existing technologies, because of the path dependence of institutional change and the influence of vested interests in those entrenched technologies. Political acceptance or legitimisation of PV as a suitable or significant technology may be necessary to achieve suitable institutional arrangements to facilitate the growth of markets and to work to ensure the availability of resources required by the industry.

Countries that have had success in this respect include Japan and Germany. The Japanese government has driven the legitimisation process for PV, recognising its strategic importance in the context of its energy policy, particularly in relation to energy security, economic efficiency and harmony with the environment (Jäger-Waldau, 2006). The PV industry is also valued as an emerging industry to replace the shrinking heavy machinery industry and as a 'key industry' because of its interdisciplinary nature and the potential for spillovers with other technologies. In Germany, legitimisation occurred through political pressure from green groups, some of which were integrated into the political structure, and community support for renewable energy deployment (Jacobsson *et al.*, 2002). Both countries have limited indigenous energy resources.

In the US, despite large R&D investments and one of the largest markets in the world for many years, the technology had, until recently not been accepted politically as a viable future option, but the US is now emerging as a major player in the renewable energy industry with the Obama government's support for green jobs as part of the US's economic stimulus package, combined with a renewed attempt at reducing US dependence on imported energy. In Australia, one of the pioneer countries in the use of photovoltaic technology, and the home of one of the world's leading research organisations, photovoltaics has also struggled for acceptance. In both these countries, the public conversation has been one of climate change denial and emphasis on the importance of keeping energy costs low. The low cost of electricity from fossil fuels in Australia and most US states, and the strong political support for economically powerful fossil fuel industries has also hampered the perception of the renewable energy industries. Neither country has been able to build the confidence of manufacturers to invest heavily in the past decade, since market support has been piecemeal, inadequate and uncertain, and without an observable political commitment to long term renewable energy development.

In Germany and Japan the market expansion facilitated learning by doing in manufacture, investment in upstream and downstream parts of the value chain and learning by interacting. A 'virtuous circle' of learning was observed, as market growth encouraged learning investments independently of publicly funded R&D, further bringing down costs and expanding markets. New entrants were also encouraged by the market growth, bringing further knowledge, resources and links to new market segments, such as BIPV. As the number of entrants has grown, the legitimisation of the technology and political pressure has further increased. The actors and their networks, and the virtuous economic circles, work for the survival of the innovation system, and the government support it depends on.

Learning occurs not only in manufacturing, but also by strengthening the supporting infrastructure, networks and institutions. More information about the technology is disseminated and the technology is legitimised. Standards and testing facilities establish the quality and reliability of the product and build consumer confidence, since customers can differentiate between good and poor quality products. Customers also benefit from increasing returns to adoption, such as better system maintenance as more people use PV, potentially increasing the price people may be willing to pay. Banks in Germany, for example now readily offer finance for PV investments, since the return on the investment is predictable.

CONCLUSIONS FROM THE SCOPING STUDY & GAPS IN THE KNOWLEDGE

The literature reviewed in this paper provides an industry-wide view of sources of innovations and cost reductions, and indicates some of the national-level factors that influence the success of PV companies within countries. Most of the data available on innovation pertains to the cell manufacturing industry. A greater understanding of the other industry sectors, such as BOS manufacture, distribution and installation are necessary in order to develop a national PV comprehensive strategy.

Australia has not managed to maintain its early lead in PV manufacture and deployment. However, the PV industry is young, developing fast and offers opportunities for innovation at various levels. A more detailed study of the Australian PV and RE innovation system is suggested which can be used to identify and capitalise on Australia’s strategic advantages in the PV innovation system and to suggest appropriate institutional changes and where resources should be invested in order to create an innovative and therefore competitive and sustainable photovoltaics industry. Local innovation would also allow local enterprises to take advantage of specific local market opportunities and solve local problems.

REFERENCES

Andersson, B.A. and Jacobsson, S. (2000), *Monitoring and assessing technology choice: the case of solar cells*, Energy Policy, 28 (14), p 1037.

Arrow, K. (1962), *The economic implications of learning by doing*, The Review of Economic Studies, 29 (3), pp 155-173.

Balaguer, A. and Marinova, D. (2006), *Sectoral Transformation in the Photovoltaics Industry in Australia, Germany and Japan: Contrasting the Co-evolution of Actors, Knowledge, Institutions and Markets*, Prometheus, 24 (3).

Dosi, G. (1982), *Technological paradigms and technological trajectories : A suggested interpretation of the determinants and directions of technical change*, Research Policy, 11 (3), pp 147-162.

Dosi, G. (1988), *Sources, procedures and microeconomic effects of innovation*, Journal of Economic Literature, 26 (3), pp 1120-1171.

Edquist, C. (1997), *Systems of innovation : technologies, institutions, and organizations*, Pinter, London ; Washington.

Fath, P. (2009), *Potential for High Volume PV Manufacture in Australia*, Seminar on High Volume PV Manufacture in Australia, UNSW, Sydney, May 21st 2009.

Foxon, T.J., Gross, R., Chase, A., Howes, J., Arnall, A. and Anderson, D. (2005), *UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures*, Energy Policy, 33 (16), pp 2123-2137.

Green, M.A. (2000), *Photovoltaics: technology overview*, Energy Policy, 28 (14), pp 989-998.

Hirshman, W.P., Hering, G. and Schmela, M. (2007), *Gigawatts - the measure of things to come: Market survey on global solar cell and module production in 2006*, Photon International (March 2007), pp 136-166.

IEA PVPS (2006), *IEA Photovoltaic Power Systems Programme International Statistics*.

IEA PVPS (2007a), *Australia Country Information*.

IEA PVPS (2007b), *Germany Country Information*.

IEA PVPS (2008), *Trends in photovoltaic applications. Survey report of selected IEA countries between 1992 and 2007, Report IEA-PVPS T1-17:2008*, International Energy Agency PVPS Task 1.

IEA PVPS Task 1 (1999), *IEA survey of trends in photovoltaic power applications 1992-1998, Report IEA-PVPS 1-07:1999*, International energy Agency Photovoltaic Power Systems Programme.

IEA PVPS Task 2 (2007), *Cost and Performance Trends in Grid-Connected Photovoltaic Systems and Case Studies, IEA-PVPS T2-06:2007*, International Energy Agency Photovoltaic Power Systems Programme.

Ikki, O., Ohigashi, T., Kaizuka, I. and Matsukawa, H. (2004), *Overview of PV Activities in Japan: Current status and future prospects*, 19th European Photovoltaic Solar Energy Conference, Paris, France, 7-11 June 2004.

Jacobsson, S., Andersson, B.A. and Bångens, L. (2002), *Transforming the energy system - the evolution of the German technological system for solar cells, SPRU Electronic Working Paper Series Paper No 84*, Science and Technology Research, University of Sussex, Brighton, U.K.

Jacobsson, S. and Bergek, A. (2004), *Transforming the energy sector: the evolution of technological systems in renewable energy technology*, Ind Corp Change, 13 (5), pp 815-849.

Jacobsson, S. and Lauber, V. (2006), *The politics and policy of energy system transformation--explaining the German diffusion of renewable energy technology*, Energy Policy, 34 (3), pp 256-276.

Jäger-Waldau, A. (2006), *Research, Solar Cell Production and Market Implementation of Photovoltaics, PV Status Report*, European Commission.

Koot, E. (2008), *The Global PV Market: fasten your seatbelts. Analyses of market demand to 2010*, Solar Plaza.com.

Lüdemann, R. (2005), *Experience and Expectation of Silicon Solar Cell Mass Production - Requirements for Next Generation Equipment*, 1st International Advanced Photovoltaic Manufacturing Technology Conference, Munich, Germany, April 13th.

Lundvall, B. (1992), *National systems of innovation : towards a theory of innovation and interactive learning*, Pinter Publishers; St. Martin's Press, London, New York.

Masini, A. and Frankl, P. (2003), *Forecasting the diffusion of photovoltaic systems in southern Europe: A learning curve approach*, Technological Forecasting and Social Change, 70 (1), p 39.

Maycock, P.D. (2006), *PV cell production data*, PV News (March).

Mints, P. (2006a), *PV - The story so far*, Refocus, November/December 2006, pp 32-36.

Mints, P. (2006b), *PV in the US: Where is the market going and how will it get there?*, Renewable Energy World (September 2006).

Nagamatsu, A., Watanabe, C. and Shum, K.L. (2006), *Diffusion trajectory of self-propagating innovations interacting with institutions--incorporation of multi-factors learning function to model PV diffusion in Japan*, Energy Policy, 34 (4), pp 411-421.

Nelson, R.R. and Winter, S. (1982), *An Evolutionary Theory of Economic Change*, Harvard University Press, Cambridge, U.S.A.

Nemet, G.F. (2006), *Beyond the learning curve: factors influencing cost reductions in photovoltaics*, Energy Policy, In Press, Corrected Proof.

OECD (1999), *Managing National Innovation Systems*, OECD, Paris.

OECD (2002), *Dynamising National Innovation Systems*, OECD, Paris.

OECD (2003), *Innovation in Energy Technology: Comparing National Innovation Systems at the Sectoral Level*, OECD.

Schaeffer, G.J., Alsema, E., Seebregts, A., Beurskens, L., de Moor, H., van Sark, W., Durstewitz, M., Perrin, M., Boulanger, P., Laukamp, H. and Zuccaro, C. (2004), *Learning from the Sun Analysis of the use of experience curves for energy policy purposes: The case of photovoltaic power, Final report of the Photex project: Report ECN-C-04-035*, ECN Renewable Energy in the Built Environment.

Schmela, M. (2005), *Super Sonic Solar Market - Worldwide Market Survey - cell & module production*, Photon International (March 2005), pp 66-82.

Schmela, M. (2006), *Silicon Shortage - so what! Market survey on cell & module production 2005*, Photon International (March 2006), pp 100-124.

Solarbuzz (2007), *Solar Cell Manufacturing Plants*.

Stryi-Hipp, G. (2006), *Photovoltaics in Germany: Market and Industry Development*, German Special Renewable Energy Day, Solar Power 2006, San José, California / U.S.A, 17 October 2006.

Surek, T. (2003), *Progress in U.S. photovoltaics: looking back 30 years and looking ahead 20*, pp 2507-2512 Vol.2503.

van der Zwaan, B. and Rabl, A. (2003), *Prospects for PV: a learning curve analysis*, Solar Energy, 74 (1), p 19.

van der Zwaan, B. and Rabl, A. (2004), *The learning potential of photovoltaics: implications for energy policy*, Energy Policy, 32 (13), p 1545.

Watanabe, C., Wakabayashi, K. and Miyazawa, T. (2000), *Industrial dynamism and the creation of a "virtuous cycle" between R&D, market growth and price reduction: The case of photovoltaic power generation (PV) development in Japan*, Technovation, 20 (6), p 299.

Watt, M. (2003), *The Commercialisation of Photovoltaics Research in Australia, A report for Science and Innovation Mapping*, Department of Education Science and Training, Canberra, Australia.

Watt, M., Passey, R. and Watt, G. (2008), *Designing a Coherent PV Strategy for Australia*, ISES-AP - 3rd International Solar Energy Society Conference – Asia Pacific Region (ISES-AP-08), Sydney, Australia, 25-28 November 2008.

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