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Factors influencing Australian sugarcane irrigators' adoption of solar photovoltaic systems for water pumping

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ABSTRACT

Sugarcane farmers have several options to manage their energy costs of irrigation. One option these farmers are yet to widely adopt is solar photovoltaic (PV) systems for energy generation. The objective of the study was to understand the potential rate and peak level of adoption by Australian sugarcane irrigators of solar PV energy systems for water pumping and the key factors influencing adoption. This study used the ADOPT framework to examine farmers' adoption behaviour regarding solar PV systems. An industry survey and expert focus group findings were used to apply the ADOPT framework, and sensitivity testing was performed. The study found that after 10 years, 50% of sugarcane farmers were estimated to adopt solar PV systems for irrigation. Farmers' adoption decisions were predicted to be influenced by several factors including economic and environmental benefits, ease of use, existing knowledge, business risk, and the farmer's current financial position. Sensitivity testing revealed that improving the profitability from installing solar PV systems could markedly increase the level of adoption. Grid connection policies and government renewable energy subsidies that increased income or reduced capital costs and thereby increased economic returns for sugarcane irrigators could improve peak adoption levels by up to 40%. Government policies had a greater impact on adoption than environmental benefits generated by the PV systems. From the results we infer that the historically changing relative advantage of the technology has resulted in some farmers exercising the option to hold off investing until they feel the relative advantage has peaked. This is the first study using the ADOPT framework to consider solar technology in Australia.

1. Introduction

Energy is one of the fastest growing costs for irrigated sugarcane growers, with electricity and, to a lesser extent, diesel accounting for a significant portion of total farm input costs.

Innovative energy technology applications could reduce pumping costs and improve irrigated sugarcane farm productivity in Australia. Pumping costs form eight to 30 percent of variable costs in irrigated sugar cane gross margins (Welsh and Powell, 2017). Powell et al. (2019) found solar photovoltaic (PV) to be the most cost-effective technology for this purpose when tested among a range of components, including wind turbines, diesel gensets, and battery storage. Renewable energy also offsets emissions from fossil fuel-based energy, resulting in reduced greenhouse gases under each scenario analysed by Powell et al. (2019). Although solar PV is a mature technology, the number of PV installations for irrigation pumping in Australian sugarcane production remains low.

This study investigates the barriers to adoption of PV systems to target subsequent research, development and extension that can enhance future adoption of these systems on irrigated sugarcane farms in Australia. In this study we specifically aim to understand adoption rate and the peak adoption potential for solar PV using the Adoption and Diffusion Outcome Prediction Tool (ADOPT). By applying ADOPT we also discover the importance of policy incentives in increasing sugarcane farmers' investments in PV systems. Findings will also contribute to knowledge of solar PV technology adoption in other broadacre irrigated industries such as grain, cotton, and horticulture crops.

The potential of renewable energy in agriculture as a cheap and prevalent source of alternative fuel and preferred technology was recognised over 40 years ago. The first such work by Katzman and Matlin

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(1978) investigated the potential of solar PV systems and battery storage in broadacre crop irrigation. Under the assumption of high utilisation rates of renewables and a seven-year payback period, the authors estimated that solar PV systems should see “widespread adoption” on irrigation farms by the year 2000, some 22 years later. Yet, in 2020, solar PV has not been widely adopted, so we look to the literature to understand why.

Price risk can affect the attractiveness of a PV investment. Price risk usually refers to downside risk, such as the risk of receiving lower output prices or facing higher input prices and consequently experiencing lower incomes, when deciding an investment. Surprisingly, in the study by Beckman and Xiarchos (2012), the price of grid-sourced electricity bore no impact on installation of solar PV system size on farms. Similarly, a study of cotton growers in Pakistan found well-educated farmers were more likely to adopt technologies on their farms due to being more capable of understanding and effectively applying new information (Zulfiqar et al., 2016). In developed agricultural economies, Borchers et al. (2014) examined nationwide adoption of renewables on US farms and found incentives that reduced capital costs were only effective when implemented in combination with net metering. This finding is consistent with that of Powell et al. (2019) who examined grid connection policies (net metering and feed-in-tariffs (FiT)) in Australia. Powell et al. (2019) found these policies principally affected the attractiveness of PV systems for Australian sugarcane irrigators who heavily relied on grid power for water pumping. Powell et al.’s findings illustrate how government policies can influence the uptake of new technologies. For example, renewable energy that contributes to national goals of emission reduction has been targeted specifically through the Australian government’s Renewable Energy Target (RET).

Governments can consider behavioural science to increase the effectiveness of policy. In the USA, where agricultural productivity is being pressured by high electricity prices (Davis, 2018) and water available for irrigation, the government-supported Social and Behavioural Sciences Team (SBST) was formed to improve implementation of Federal policies and programs. Regarding renewable energy, SBST aimed to facilitate informed decision-making to improve adoption.

The adaptation of any new technology to local needs and restrictions can greatly affect the adoption of technology. This is particularly the case with solar PV systems integrated into water pumping infrastructure, because the failure of such technology under a standardised solution can adversely affect crop growth, income and livelihoods. In a study of adoption of solar PV systems and water pumping in traditional communities, Fedrizzi et al. (2009) found that knowledge of the receiving communities’ social and cultural dynamics facilitated the achievement of high adoption rates. Of similar importance is the availability of trusted communication channels that ensure decisions and knowledge can be shared and technology limitations are revealed up-front, to avoid frustration once a decision to invest has been made.

Quality of information and delivery is also an important element of successful adoption of farm technologies (Abdullah and Samah, 2013). A meta-analysis of agricultural best-management practices by Baumgart-Getz et al. (2012) in the USA found access and quality of information had the largest impact on agricultural adoption. If communication channels inside a family farming business were poor, then this led to investment indecision and lower adoption rates. For example, Suess-Reyes and Fuetsch (2016) found a lack of connectivity between farming family members made scientific discourse on available technologies difficult. Applying systems theory, Arist von and Hermann (2013) found that effective communication between the family, regarding the farm system, affected farm innovation and consequently, adoption of innovations. Further to this, irrigator surveys in the Murray Darling Basin by Wheeler et al. (2013) found those farms who had identified a successor were positively associated with more innovative and environmentally conscious management decisions.

At an enterprise level, recent analyses on adoption of renewable energy in Australian broadacre irrigation have narrowed attention to a few key areas. A study by Cotton Australia (2018), covering four regions in New South Wales and Queensland, found barriers and challenges of adopting solar PV can categorised as technical (engineering-based understanding), economic (investment uncertainty) and quality of information limitations (expert advice, connection information and lack of trust in farm-specific advice). These authors deuced the main barrier to adoption to be the significant lack of grower engineering expertise that prevented effective engagement with networks and PV suppliers/installers during early stages of a solar PV installation. In a survey across various commodities and involving 1000 farmers, sugarcane growers named energy pricing as having the largest impact (54%) on their businesses (Agri Insights, 2018), yet adoption of energy technologies in cane growing remained low. A survey of 116 irrigated sugarcane growers (Welsh and Powell, 2017) found a low uptake of solar PV, despite it being a mature technology. The study identified irrigators’ lack of knowledge around energy and investment feasibility to be the main limiting factors preventing investment in new energy technologies. Within the survey farmers recorded their own ‘energy’ knowledge score at an average of 4.8 out of 10 (1 = low, 10 = high). A lack of cash flow was also identified as a limitation to investment, consistent with other global studies, referencing the importance of national policy incentives to reduce the investment’s capital requirements to encourage adoption. Other limiting factors noted included a lack of area suitable or large enough for solar PV installations, policy uncertainty and the fast-moving pace of energy technology – should farmers wait for the silver bullet? To a lesser degree, irrigators were concerned that a long-term solar PV installation would be superseded by something new soon after, devaluing their investment.

This review confirms the adoption of solar PV energy technology for sugarcane irrigation is a complex issue. It involves many factors including relative advantages, risks and trade-offs for sugarcane farmers, the learnability of the advantage, and short-term constraints such as financial position.

The next sections outline this study’s method and results. The results aim to provide further insight into why the adoption rate of the mature solar PV technology has been slow for the application of irrigation, compared to the prediction of Katzman and Matlin (1978).

2. Method

There is a long and rich tradition of empirical research that seeks to explain farmers’ adoption of agricultural innovations. In a review of methods used to estimate adoption of conservation farming by Knowler and Bradshaw (2007), the authors found differences in sample sizes, methods and statistical outcomes reflect differences in quality among the analyses.

In this study we use the ADOPT framework, chosen for its simplicity, relevance to real-world decision making and practical management. In a similar way to other adoption methods assessing technology, a mix of qualitative and quantitative questions are structured around four categories of influence: characteristics of the innovation, characteristics or the target population, relative advantage of using the innovation and learning of the relative advantage of the innovation (CSIRO, 2019a). The framework uses a step by step process to evaluate a technology and population to predict the likely level of adoption (G. Kuehne et al., 2017).

ADOPT has been applied in R&D and innovation analysis and has over 1000 registered users across 43 countries (CSIRO, 2019b). Geoff Kuehne et al. (2012) used the ADOPT tool to measure expected benefits, adoption and diffusion issues relating to mixed farming R&D programs. The tool was also used to analyse uptake and predicted peak level of adoption of seasonal forecasting among Australian farmers across various industries such as grains, livestock and rice (Pearl, 2018). It has also been the chosen method of analysis for other recent agricultural adoption studies such as (Dhehibi et al., 2018) predicting date palm farmers willingness to adopt liquid pollination in Oman and (Andrew et al., 2019) who investigated the adoption of chicken strains in Tanzania. Unlike other tools and methods used to analyse adoption, the ADOPT tool allows evaluation and prediction of the likely level of adoption of the technology, by making adoptability knowledge and considerations more transparent and understandable.

The ADOPT framework is based on a set of 22 input questions about the population of potential adopters and the new technology or "innovation". Answers to the questions are multiple choice with four answer categories which are essentially low to high. These groupings are designed to give adoption estimates using broad classifications, without the need for statistical analysis or extensive data sets (G. Kuehne et al., 2017). Table 1 outlines the 22 questions, the consensus answers and reasoning. The consensus answers indicate the answers to ADOPT's multiple-choice questions that were chosen by the expert group. The schematic in Fig. 1 illustrates the ADOPT framework, highlighting the inter-relating factors affecting farmer adoption.

ADOPT has more commonly been used to assess emerging technologies. In this case, solar PV is a mature technology, so the questions were answered considering the technology, population and advantage of the innovation for the present day. Answers to the 22 input questions were collected via a two-part process that included, firstly, a survey completed by a group from the target population *Australian sugarcane irrigators*, and secondly a detailed discussion with a carefully selected focus group of experts. The aim of the survey was to provide input into the discussions of the expert group, which used that information together with their own knowledge to make decisions about the responses to the 22 questions in ADOPT. The six focus group members were selected due to their wide knowledge of the population of producers and consisted of industry extension specialists, researchers, engineers and a solar PV retailer. The group discussed each question giving consideration to the survey responses, particularly those where consensus seemed to be lacking. Questions that did not have a consensus answer from the focus group were identified and sensitivity testing was applied to gauge how the different possible responses might affect adoption outcomes. Given this process, it was not important for the survey of sugarcane producers to be representative of the whole industry. Rather the aim was to provide a variety of perspectives from producers. For that reason, a relatively small number of survey responses (24) was considered sufficient for the study. The discussions within this analysis aim to improve the conceptional understanding of the adoption process for renewable technologies in Australian agriculture, using the specific example of applying solar PV to irrigation systems on Australian sugarcane farms.

3. Results

Application of the inputs outlined in Table 1 in the ADOPT framework generated the following results.

3.1. Peak adoption

Peak adoption has two elements. First is the maximum proportion of the target population who will adopt the innovation. Second is the number of years from now before that maximum proportion is reached. The ADOPT framework predicted the peak level of adoption for solar PV is estimated to be 52% of the target population, Australian sugarcane irrigators. Welsh and Powell (2017)estimated that 175,000 MW of grid power is used annually to irrigate sugarcane, costing the industry an estimated $47 million, and emitting approximately 165,000 t/CO$_2$e per annum. An adoption level of 52% would result in significant economic and environmental benefits across the sugarcane industry. The estimated time to near-peak adoption using ADOPT is 12 years from 2019 (when the survey was conducted).

Table 1
ADOPT framework questions and consensus answer.

ADOPT question	Consensus answer	Reasoning
1. What proportion of Australian (irrigated) sugarcane growers have maximising profit as a strong motivation?	Almost all have maximising profit as a strong motivation	Require profitability for longevity of a business
2. What proportion of Australian (irrigated) sugarcane growers has protecting the natural environment as a strong motivation?	About half have protection of the environment as a strong motivation	All consider the environment, usually profit is ranked above environment
3. What proportion of Australian (irrigated) sugarcane growers has risk minimisation as a strong motivation?	About half have risk minimisation as a strong motivation	Risk management is a higher level business skill
4. On what proportion of Australian (irrigated) sugarcane farms is there a major enterprise that could benefit from the irrigation?	A majority of the target farms have a major enterprise that could benefit	Most farms have an irrigation site with an electric motor under 80 kW
5. What proportion of Australian (irrigated) sugarcane growers have a long-term (greater than 10 years) management horizon for their farm?	A minority have a long-term management horizon	Sugarcane farmers are an aging population. Most prioritise short term issues over long term planning
6. What proportion of Australian (irrigated) sugarcane growers are under conditions of severe short-term financial constraints?	About half currently have a severe short-term financial constraint	(ABARES, 2015). Sugarcane farmers hold large assets, but often have limited cash flow
7. How easily can the innovation (or significant components of it) be trialed on a limited basis before a decision is made to adopt it on a larger scale?	Not trialable at all	Not trialable. Could install on one site only
8. Does the complexity of the innovation allow the effects of its use to be easily evaluated when it is used?	Not at all difficult to evaluate effects of use due to complexity	Easy to calculate using comparable electricity bills
9. To what extent would the innovation be observable to farmers who are yet to adopt it when it is used in their district?	Easily observable	Solar PV installations are visible, the effect (cost savings) are not visible
10. What proportion of the target population uses paid advisors capable of providing advice relevant to the project?	Almost none use a relevant advisor	Not many independent advisors with renewable skills. Distrust for sales people
11. What proportion of Australian (irrigated) sugarcane growers participate in farmer-based groups that discuss farming?	About half are involved with a group that discusses farming	Involved = attend. Milling groups, advisor groups, extension groups (SRA, prod services, cane growers)
12. What proportion of the target population will need to develop substantial new skills and knowledge to use the innovation?	A minority will need new skills and knowledge	Minimal skills required to operate, however farmers are unlikely to buy something they don't understand. Most have limited understanding of solar PV
13. What proportion of Australian (irrigated) sugarcane growers would be aware of the use or	A majority are aware that it has been used or trialed in their district	Innovators and early adopters have had solar PV installations for irrigation for up to 5 years

(*continued on next page*)

Table 1 (*continued*)

ADOPT question	Consensus answer	Reasoning
trialing of solar energy in their district?		
14. What is the size of the up-front cost of the investment relative to the potential annual benefit from using the innovation?	Large initial investment	Low in terms of additional capital, high in terms of proportionate cash flow
15. To what extent is the adoption of the innovation able to be reversed?	Moderately difficult to reverse	Physically reversible however would lose capital invested
16. To what extent is the use of the innovation likely to affect the profitability of the farm business in the years that it is used?	Moderate profit advantage in years that it is used	Highest benefit is from offsetting grid electricity demand. (Powell et al., 2019)
17. To what extent is the use of the innovation likely to have additional effects on the future profitability of the farm business?	Small profit advantage in the future	Potential benefit from a FiT depending on connection policies.
18. How long after the innovation is first adopted would it take for effects on future profitability to be realised?	Immediately	Where a FiT is received, the benefits are realised when the sun is shining
19. To what extent would the use of the innovation have net environmental benefits or costs?	Moderate environmental advantage	Average 500 kg CO^{2}e p.a (G. Kuehne et al., 2017)
20. How long after the innovation is first adopted would it take for the expected environmental benefits or costs to be realised?	Immediately	Where a FiT is received, the benefits are realised whenever the sun is shining
21. To what extent would the use of the innovation affect the net exposure of the farm business to risk?	No increase in risk	Reduces price risk exposure for grid electricity, increases financial risk if increased debt is required
22. To what extent would the use of the innovation affect the ease and convenience of the management of the farm in the years that it is used?	Small decrease in ease and convenience	An extra element introduced to the farm, requires some cleaning, monitoring etc.

3.2. Adoption rate and time to adoption

The ADOPT framework assumes that adoption of a new technology will proceed over time according to a sigmoidal response. Adoption would be slow at the start, gaining momentum and then slow at the end (Fig. 2). Solar PV is a mature technology, with minimal adoption by sugarcane farmers, so the ADOPT questions were answered relative to the current situation – which would be considered year 0.

By year 5, the adoption level predicted by ADOPT for solar PV is around 25% of irrigated sugarcane farmers, and by year 10 adoption on 50% of farms is predicted. Considering the current minimal adoption of the technology to date, the next section discusses the sensitivity of the predictions for level and rate of adoption.

4. Discussion and sensitivity of adoption

Sensitivity tests help assess the effect of changes in key variables in the analysis on the robustness of the results (Sinden and Thampapillai, 1995). Adoption is influenced by many factors. Fig. 2 illustrates different adoption responses. The predicted level of peak adoption has a wide range: from 25% to 75% under different scenarios to aid (step up) or reduce adoption (step down).

Information from relevant sensitivity analyses can usefully inform governments and industry of the key opportunities to drive the rate and level of adoption.

4.1. Sensitivity of PEAK level adoption

The ADOPT framework (Fig. 1) includes input questions likely to affect the peak adoption level. The level is most sensitive to the relative advantage of the technology in terms of the population and the innovation. The relative advantage to the population considers their orientation regarding profits, the environment, risk, the enterprise scale and management horizon. Individually, a step change in an answer to these questions can change the peak level of adoption by up to 27%.

The results show the most sensitive question to the level of peak adoption is question 16, "to what extent is the use of the innovation likely to affect the profitability of the farm business in the years that is used?". The consensus answer was a moderate profit advantage. Depending on irrigation method (i.e. furrow, centre pivot, high pressure overhead), the cost of energy for sugar irrigation represents between approximately 8 to 33% of variable crop expenditure (Welsh and Powell, 2017). Solar PV was found to effectively reduce the cost of energy for irrigation of Australian sugarcane by up to 25% (Powell et al., 2019). The authors also identified the key influences on the profitability of solar PV for irrigation as; cost of installation and eligibility for a FiT. The falling market price of solar PV, together with government subsidies through the RET and Clean Energy Finance, has reduced the cost of solar PV, effectively increasing the relative advantage of the investment for all potential consumers. Conversely, sites with a total rated inverter capacity over 30 kW are not eligible for the Queensland Government's regional FiT. The seasonal nature of irrigation results in long periods of energy being generated in excess of site requirements. Where this energy can be sold back to the grid, the investment is favourable. If the site is not eligible for a FiT, the investment in solar PV is usually not economically feasible. An increase in the system size eligible for a FiT would increase the economic benefit of a solar PV installation and could result in a step increase in adoption of 27%.

Profit motivation (question 1) is linked to question 16 and is also a key influence on adoption. For this study, the strongest motivation – *almost all have maximising profit as a strong motivation* – was selected. However, while sugarcane farmers are motivated by profits, some of the population may have a perception that solar PV technology is not profitable due to earlier assessments of the technology; or growers are unaware of instances when it is (Welsh and Powell, 2017).

The peak level of adoption results are also particularly sensitive to questions relating to change in risk, the proportion of farms that could benefit, and environmental benefits. The framework indicates sensitivity to a change in exposure to risk (question 21). An investment in solar PV could increase financial risk for a business with marginal cash flow that requires an increase in debt to purchase the technology. However, a solar PV installation reduces the demand for grid energy and thus the exposure to input price risk. These factors result in a net zero change in risk. The target audience risk orientation (question 3) is also linked. A change in risk profile could reduce the peak level of adoption by 18%.

The proportion of farms with a major enterprise that could benefit from the irrigation was considered in question 4 "majority of the target farms (irrigated sugarcane farms) have a major enterprise that could benefit". The government could influence this factor by increasing the rated size of the solar PV system eligible for the regional FiT. Not only would this increase the economic benefit of the investment, it would also increase the number of farms that would benefit. A higher category of response to question 4 improves the peak level of adoption by 16%. Alternatively, an increase in grid energy prices and/or a decrease in the

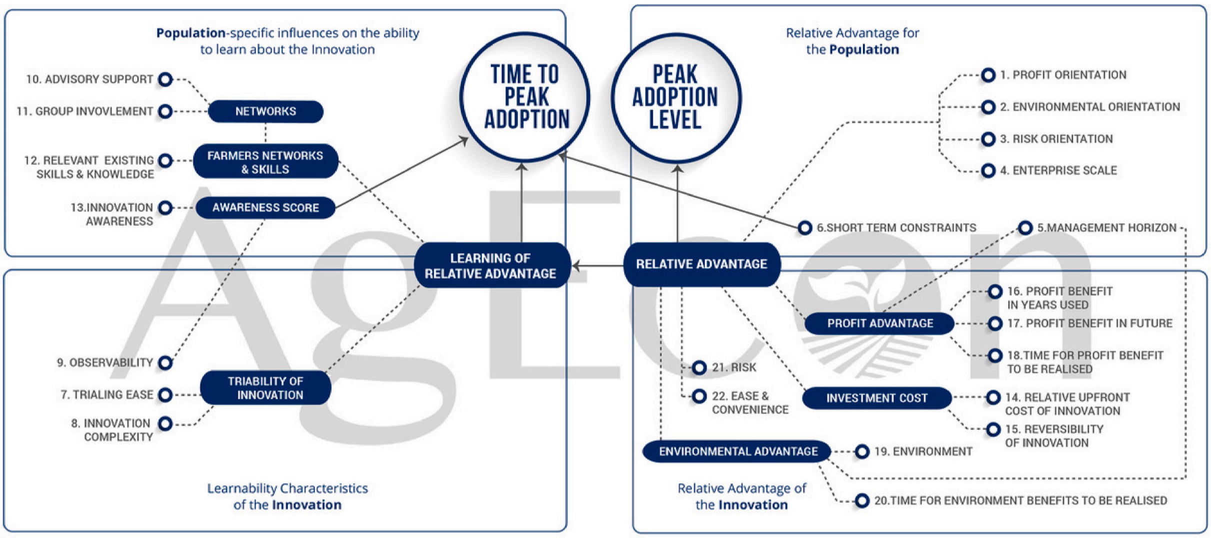

Fig. 1. Adopt framework.

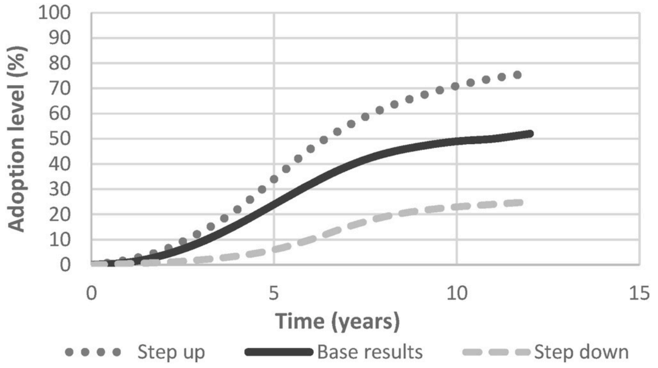

Fig. 2. Adoption curves from ADOPT generated using sensitivity analysis under the original level of resourcing (solid line), a step up in resourcing (dotted line) or a step down in resourcing (dashed line).

cost of solar PV, through either market forces or government incentives, would increase the number of farms that benefit and also trigger a step increase in the peak level of adoption by 16%.

The environmental benefit of solar PV for irrigated sugarcane is also a sensitive factor for adoption (question 19). Powell et al. (2019) identified the potential emission abatement from a solar PV system installed on a standard grid-connected irrigation pump as approximately 500 kg CO_2e per annum. The ADOPT framework also considers environmental protection (see question 2). The consensus answer was *About half have protection of the environment as a strong motivation*. The focus group identified there could be a big difference between motivation and practice. In many cases, the environment is less important than the profitability of the crop. A step change in environmental motivation changes the peak level of adoption by up to 5%.

Results indicate that the peak level of adoption is most sensitive to the profit advantage of the solar PC technology. The RET is an example of a successfully implemented policy that improves the profit advantage and thus peak level of adoption for renewable technology broadly within Australia. This study's results also suggest that widening the eligibility of the Queensland Government's regional FiT could make a significant improvement to the peak level of adoption by up to 40%, by increasing both the economic benefit of the technology and the number of farms that would benefit. These results were consistent with those of Borchers et al. (2014) who identified a major benefit in creating policy incentives that increase the profitability of solar PV.

4.2. *Sensitivity of time to adoption*

The two key factors influencing the time (or rate) of adoption are the ability for a population to learn about the relative advantage of the technology and the current financial conditions of the population. Learnability can be broken into the characteristics of the population's ability to learn and the technology.

Population-specific influences include advisory support, farmer group participation, existing skills, and knowledge and innovation awareness. The most sensitive question in this study that impacted time to peak adoption level was question 12 "What proportion of the target population will need to develop skills and knowledge to use the innovation?" Once the technology is installed by a certified installer, there is very little operational skill required; hence the consensus answer was *A minority will need new skills and knowledge*. However, farmers are practical people who like to understand the equipment on their farm. This is supported by Welsh and Powell (2017) who identified lack of skills and knowledge as a barrier to adoption. The focus group concluded that farmers have a distrust for solar providers due to the fact the farmers do not understand solar PV equipment and do not have the skills to identify good quality equipment. These findings suggest that building skills in renewable technologies would aid the rate of adoption. Each step change in the answer to this question for a higher proportion of sugarcane farmers requiring new skills or knowledge increased the time to adoption by over 1.5 years.

Learnability characteristics of the innovation include observability, trialing ease, and complexity. The trialability (question 7) and complexity (question 8) influence the time to peak adoption of solar PV for sugarcane irrigation. A step change in either of these factors changes the rate of adoption by over one year. As a technology, solar PV needs to be purchased and installed to gain the benefits. While the technology is not trialable, it can be scaled (e.g install a solar PV array on one site, identify the benefits then roll out to other sites). Once installed, the benefits of solar PV are immediately realised (question 18), observable (question 9) and easily evaluated (question 8). The benefit is the reduction in energy bills, although there may be some variation of energy requirements depending on the season, it is relatively simple for a farmer to see if their total expenditure on energy has been reduced.

The time to peak adoption of solar PV in irrigated sugarcane is also influenced by the current financial situation of the population and capital outlay.

Sugarcane growers have on average an 85% equity position (ABARES, 2015). Their equity has been improved by the rapid increase in coastal land values and the growing competition for agricultural land in some sugarcane growing regions from tree crops such as macadamias. Conversely, low sugar prices and poor yields have resulted in lower gross margins for sugarcane, and these reduced cash flows influence the consensus response to question 6 as *About half currently have a severe short-term financial constraint*. A step increase or decrease in financial conditions will affect the time to adoption by approximately one year.

Sensitivity testing indicates that a step change in the relative upfront cost of the innovation (question 14) can change the time to peak adoption by one year. The upfront cost of a solar PV system (under 100 kW) is currently subsidised by the Australian Government's RET. The capital outlay depends on the size of the system; however, considering common pump sizes, the outlay is likely to be between $40,000 and $70,000. Relative to the variable cost of crop expenditure, a solar PV investment is a large initial investment. An increase to the cost (e.g. solar PV becomes more expensive due to the removal of RET) would increase the time to peak adoption by a year. The resulting change in rate of adoption is minimal. However, a removal of the RET would also reduce the relative economic benefit of an investment in solar PV and result in a large reduction in the peak level of adoption. A potential reduction in the size of the relative investment (e.g. sugarcane margins increase due to a sustained increase in the sugar price) would result in a decrease in the time to peak adoption by one year.

In this study, the strongest driver for the rate of adoption was the requirement for skills and knowledge. While the ADOPT survey suggests these skills are to operate the technology, the focus group also identified the need for skills to understand the technology and assess the relative advantage of solar PV for sugarcane irrigation. These results are consistent with other PV studies abroad such as Zulfiqar et al. (2016) and Zhou et al. (2017) and more recent Australian studies by Cotton Australia (2018). In the case of the rapidly advancing solar PV technology, farmers may not be motivated to develop these skills if they have previously assessed and found solar PV to be an unviable investment. Educating the population that the relative advantage of the technology is improving is important. Within agriculture, industry technical extension and support services for irrigators seeking clarity on renewable energy information can assist in bridging gaps in capacity.

Alternatively, some farmers, having observed the improving advantage, may be exercising the option to wait until such a time they feel the advantage has peaked. The changing relative advantage can be accounted for in ADOPT through sensitivity testing of the potential peak level of adoption. The segment of the population waiting for the relative advantage of the technology to peak, affects the rate of adoption. Those farmers unwilling to reassess the technology or waiting for the relative advantage to peak could partly explain the slow rate of solar PV adoption to date in sugarcane irrigation.

This study highlights that government policy can influence both the peak level and rate of adoption of solar PV technology. Policy can increase the peak level of adoption by up to 40% and increase the time to peak adoption by a year. Policy incentives that increase the peak level of adoption of solar PV also thereby reduce emissions. In addition, by reducing the energy cost of irrigation, investment in technologies that improve water use efficiency is also aided.

Co-benefits of improved sustainability metrics (CO_2e per unit output) also have flow-on effects for irrigators seeking to meet expectations of more environmentally aware consumers and gain access to premium agricultural export markets.

5. Conclusion

Decisions about adopting energy technology, such as incorporating solar PV systems into irrigation pump sites, are influenced by a complex set of factors.

Factors influencing the level of adoption are focused around the relative advantage of the technology. In this study the greatest influence was how the technology affects farm profit, particularly grid and connection policies that affect profitability. Also influencing the level of adoption was the number of farms that could benefit, how the technology impacted farm business risk, its ease of use, and environmental benefit.

Applying the ADOPT framework to assess farmers' adoption of solar PV systems for irrigation pumping revealed that the estimated peak level of adoption is around 50%, occurring after ten years.

The immediate economic benefits generated by the PV systems was the main rationale for their adoption. All factors that contribute to increasing revenue and reducing costs have an impact on profitability and therefore the level of adoption. The up-front capital cost of the systems and the ongoing revenue they generate from energy export via a FiT were major drivers of the financial model, as most sugarcane irrigation pumps were connected to grid power. Government incentives provided by the RET and CEFC to lower the cost of the technology and connection policies influencing FiT eligibility, both increased the profitability of the technology and potentially increased the number of sites that could benefit. Together these incentives could potentially lift the level of adoption from 50% to 90%.

The factors influencing the rate of adoption were focused around the ability for a population to learn about the relative advantage of the technology, and the current financial conditions of the population. The most sensitive factors around the learnability of the technology were the requirement for new skills by the population. While farmers did not require new skills to operate a solar PV installation, the lack of knowledge around the technology was likely to influence adoption. Increased industry communication around instances where and when the technology was most profitable, and demonstration of improved profitability could decrease the time to peak adoption by 1.5 years. The study's results indicate a larger change could be in made in the potential level rather than rate of adoption.

Existing adoption of solar PV technology for irrigation has been slow, this is likely to be influenced by the changing relative advantage of the technology. Some farmers who previously assessed the technology may be unaware the advantage has improved and those that understood the improving relative advantage may be waiting to invest when they feel the relative advantage has peaked. Both factors affect the rate and level of adoption.

Using the ADOPT framework in this study of solar PV technology uptake and investment provides richer interpretations, relevant inferences and reveals information that can be applied widely to further improve farm business profitability and sustainability.

The results obtained from the application of ADOPT also can help policy makers assess likely impacts on farmers' adoption choices of changes in government policy and practice. The findings from this study can aid future extension strategies in irrigated industries, and potentially influence Australian or international government energy and industry policy design to ensure industry economic and sustainability goals are achieved. Increased adoption of solar energy directly improves farm productivity, lowers emissions and may indirectly improve farm water use efficiency through increased investment in the more energy intensive technologies that improve water use efficiency.

Co-benefits of improved sustainability metrics (CO_2e per unit output) also have flow-on effects for irrigators seeking to meet expectations of more environmentally aware consumers and gain access to premium agricultural export markets.

Further research would be useful around the uncertainty in the factors influencing the relative advantage of solar PV and investment in an uncertain environment.

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