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What Can be Done to Encourage More Vertical Farming in Australia?

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Abstract

Vertical Farming may provide part of the solution to feeding a growing world population. However, evidence on what drives its adoption in particular countries is relatively sparse. Despite potential advantages in Australia, there are equally many obstacles and the concept has struggled to gain traction with investors. As a result there are still few Australian vertical farms. Qualitative research based on interviews with market participants indicates that the solution is to change policy settings that are not conducive to investment.

***Keywords*:** Vertical Farming; Australia; land prices; financial analysis, consumer acceptance

Introduction

Feeding a rising global population is a major challenge. Estimates suggest that global population will reach 9.7 billion by 2050 and 11 billion by 2100 (United Nations Population Division, 2022). Population growth has and will continue to demand increased urbanisation, eating into available farmland. Yet decreased soil productivity, depleted soil nutrient reserves, limited water availability, climate change and diminishing returns to genetic engineering are already resulting in decreasing yield growth (Maja & Ayano, 2021, p. 272; Mir et al., 2022, p. 1175). At the same time, consumers worldwide are exhibiting increased concern over food quality, both in terms of nutrition and environmental impact. This poses a further problem for food production (Kumar et al., 2023, p. 291). Solutions to all these problems are needed.

One widely advocated way forward is Vertical Farming (VF), an important type of indoor urban and peri-urban agriculture. It has been suggested that VFs can contribute to Sustainable Development Goal 9, to build resilient infrastructure, promote sustainable industrialisation and foster innovation, and also to Sustainable Development Goal 12, to ensure responsible consumption and production patterns (Lombardi & Lombardi Jr, 2022, p. 4)**.** VF has been adopted worldwide in a number of jurisdictions, notably in Europe. However although Australia is a very significant agricultural producer, with a 2.6 per cent share of agriculture in GDP in 2023 (World Bank, 2024), and is the third largest global agricultural exporter (FAO, 2024), there are very few Australian VFs. One study included just one Australian case out of 68 in a global total (Parkes et al., 2022, p. 8). Another included no Australian VF in a list of examples of successful growers nor of technology providers (Van Gerrewey et al., 2022, p. 3). This disparity between Australia's status as a very significant agricultural producer and exporter, yet a

relative laggard with respect to VF, is surely worthy of note. The objective of this paper is therefore to identify how, given its potential benefits, VF might be further and more rapidly developed in Australia. This necessarily involves identifying and analysing the current obstacles in its way.

Background to VF

VF entails growing crops either on horizontal layers or on a vertical surface (Beacham et al., 2019, p. 277). VF employs soilless cultivation techniques such as hydroponics, aeroponics or aquaponics (Avgoustaki & Xydis, 2020, p. 20). Its potential cornucopia of benefits include: reduced water consumption (Saad et al., 2021, p. 29), lower pesticide and fertiliser use, shortening of food chains, reduced growing cycles (Harris & Kountouris, 2020, p. 3), potentially increased all year round production, reduced contamination risk (Eaves & Eaves, 2018, p. 53), soil degradation, deforestation, and water eutrophication, new uses for urban areas – It has been suggested that the primary goal of VF is to maximise crop output in a small amount of space (Kumar et al., 2023, p. 292) – reuse of urban waste (energy and materials), new job opportunities (Benke & Tomkins, 2017, p. 15), education, visual amenities, and social well-being (Mina et al., 2023; van Delden et al., 2021, p. 953) and the potential reduction of transport and marketing costs achieved by the potential propinquity of VFs and consumers (Mir et al., 2022, p. 1179).

However, there are also disadvantages. These include high start-up, training and operating costs, (van Delden et al., 2021, p. 953) including more expensive labour (Kumar et al., 2023, p. 302), high energy consumption (Lubna et al., 2022, p. 2), lower production volumes, and the need — given the well-established importance of pest control for VFs (Roberts et al., 2020) — for an integrated pest management (IPM) programme (Lubna et al., 2022, p. 4). Currently too there are a limited number of crop types that are grown on VFs (Benke & Tomkins, 2017, p. 19; Mina et al., 2023 para.3), although VF can potentially produce a much wider range, including lettuce, kale, chard & collard greens, chives and mint, basil (sweet, lemon, cinnamon, etc), oregano, parsley, tomatoes, strawberries, thyme, radish, iceberg, spinach, and other seasonal vegetables (Barui et al., 2022, p. 226).

The value of the VF global market was estimated to be $US5.6bn in 2024. While statistics on the number of VFs by country are not yet available, countries where VF has made significant inroads include relatively highly developed East and Southeast Asian countries, such as China, Japan, and Singapore. The United States, Canada and European countries, notably the Netherlands but also Belgium, France, Sweden, Norway, and the United Kingdom, have also seen significant VF investment, with the United States in the lead (MarketsandMarkets, 2024). In less developed countries, however, VFs remain as yet almost completely unknown (Oh & Lu, 2023, p. 134).

Research Question: how to improve Australian VF

Although Australian agriculture is currently internationally competitive, it may eventually be threatened by disruptive new technologies, including intensive urban farming such as VF (Benke & Tomkins, 2017, p. 13). Moreover, several indicators point to Australia as a potentially fertile location for investment in VF. If there is a need for a 'hybrid renewable energy system' (HRES) for VFs (Udovichenko et al., 2021), then Australia leads in renewable energy and rapidly reducing renewable energy lifecycle costs (Pourasl et al., 2023). Moreover, less energy is required to grow crops in Australian VFs than for example in much of Europe, as its climate is more similar to Spain than Sweden (Kobayashi et al., 2022).

Australia also has a comparative advantage in income and education, although this should not be overstated. The average age of the population is a negative indicator, whilst empirical research into consumer attitudes raised concerns over isolated rural communities and product quality (Jaeger et al.,

2023; Kalantari et al., 2018). Land prices and rents exhibit a particular characteristic favourable to VFs. They are very high indeed in city centres, and there are former industrial sites suitable for conversion, as in the United States (Benke and Tomkins, 2017). But they then fall rapidly beyond the outskirts of Australian cities, where there is ample land supply (Rossini, 2020; Yiu & Cheung, 2023), suitable in principle for VF systems at scale, especially if the use of existing buildings can reduce capital cost (Beacham et al., 2019). Additionally, both rail and road transport networks are sophisticated, easily able to cope with the limited volume of food produced by a typical VF. Finally, the planning system is reliable, if generally regarded as slow (Phelps et al., 2023). Yet despite all these apparent advantages, VF in Australia lags behind comparably developed jurisdictions.

This apparent paradox leads to the Research Question of this paper: What could be done to improve the relatively low growth rate of VF in Australia? This question necessarily involves investigating what drives this low growth rate by comparison to other jurisdictions, in order to derive an initial hypothesis about the causes of the present problems of the industry in Australia and how to solve them.

Literature Review: Explaining the Rate of Growth of VF

Despite the alleged economic advantages of VF, research has been largely focused on technical and design aspects of VF, such as the impact on sustainability at city level (Gómez-Villarino & Ruiz-Garcia, 2021; Khalil & Wahhab, 2020) or comparative CO_2 emissions (Vatistas et al., 2022), rather than its economics (Moghimi & Asiabanpour, 2023, p. 1839). In terms of actual explanation for adoption in practice, although their success depends on (net) economic benefits (Csordás & Füzesi, 2023, p. 13) there is little research available on the economics of VF, such as project lifecycle costs, and even less on its financial feasibility, specifically the widely-used techniques of Net Present Value (NPV) and Internal Rate of Return (IRR). In the absence of sufficient empirical evidence, both the alleged advantages and disadvantages outlined above remain largely conjectural.

Evidence suggests that if the economics can be made to work, consumers are largely receptive. Research in OECD countries indicates that younger consumers, those with higher incomes and higher education have more positive attitudes to new farm technology (Mina et al., 2023, p. 5). This has largely revolved around perceptions of sustainability, as a study of German consumers indicated (Jürkenbeck et al., 2019, p. 13). Equally, however, keenness on sustainability also means that they can be more sceptical. Surveys conducted in Nordic countries, for example, suggested that relatively low levels of acceptance were driven by VFs' perceived lack of sustainability, in particular their use of artificial LED light and enriched supplements of nutrient solutions (Perambalam et al., 2021, p. 10). It is therefore encouraging to know that the empirical evidence suggests that 'most participants responded favourably once the technology was described to them' (Jaeger, 2024, p. 3).

By comparison, evidence suggests that the primary reasons for the current unprofitability of VFs globally are capital cost, land, buildings and technical fitting (Sarkar & Majumder, 2019, p. 1087). Profitability flows from a combination of at least semi-rural locations, a focus on the re-use of existing buildings and on potential economies of scale from their widespread installation (Abdullah et al., 2021). This may result in disparities between the economic and financial feasibility of different types of VF, such as plant factories, container farms, in-store farms, and appliance farms (Kabir et al., 2023, p. 4). However, these may not be the only obstacles. Canadian experience suggests that harsher heating seasons and higher energy costs can pose a problem for the development of all types of indoor farms (Udovichenko et al., 2021). Comparisons with greenhouses have highlighted variables such as the higher electricity needs of VFs, with their adverse sustainability implications (Martin et al., 2023). The critical importance of comparative lighting efficiency (Jin et al., 2023; Wong et al., 2020) and the role of reducing energy costs (Despommier, 2019, p. 72) have also been recognised as drivers of the future economic efficiency of VFs.

As a result, at the current stage of their development, VFs are largely introduced for research, or other objectives that are either wholly or partially unconnected with commercial objectives. Research has suggested that where VF has made comparatively greater strides than in most other countries worldwide, it has been public policy and the availability of subsidies that has driven investment in the sector (Abdullah et al., 2021), for example in the Netherlands (Farhangi et al., 2020, p. 13). This view was complemented by the conclusion that the role and impact of change agents on both micro and meso levels has been crucial in the development of Dutch 'green city' policies more widely (Stobbelaar et al., 2022, p. 10).

Research Hypothesis

What hypothesis for ways to improve the take-up of VF in Australia does the literature suggest? Considering the evidence overall, even in jurisdictions where there has been both positive reception by consumers and significant uptake and growth in the industry, success has depended on favourable policy settings driven by a combination of sustainability and food security concerns. The research hypothesis that the literature indicates is that the industry should be focused on policy initiatives that lead to a reduction in capital or operating costs, which would be expected to be key to unlocking investment in the sector.

Research Method

The choice of qualitative analysis to test this hypothesis was dictated primarily by data considerations. There is a lack of published data on VF financial performance in Australia, partly due to the limited number of VFs that might provide such data. Even if data were plentiful, however, the research questions matched the capacity of qualitative analysis 'to investigate the 'what', 'how' or 'why' of a phenomenon rather than 'how many' or 'how much', which are answered by quantitative methods' (McCusker & Gunaydin, 2015, p. 537). The need was to understand the reasons underlying the behaviour that the organisations in which interview subjects have been working, their attitudes, opinions, and role in the organisations. The method adopted therefore employed in-depth, semi-structured interviews as the data collection method, in order to gain detailed information and insights into entrepreneurial behaviour. Similar methods have been used in other research, such as on factors influencing the implementation of new construction technologies in Western Australia (Correia et al., 2020), and opportunities and barriers to upscaling city farming (Hardman et al., 2022).

As is typical for the semi-structured approach, a list of themes and key questions to be covered was assembled (although the approach allows for variation in questions between interviews and the order in which questions are asked (Saunders et al., 2019, p. 391)). The questions posed to respondents (listed below) followed a sequence familiar from other such qualitative studies, both in agriculture, for example on food security (Brownhill & Hickey, 2012; Thow et al., 2018) and agricultural adaption technologies (Mertz et al., 2009) as well as in other fields such as health studies (Waring et al., 2022). The questions were aimed at securing agreement on the subject matter, understanding the respondent's own position in the industry, and then proceeding through a series of analytical questions aimed at drawing out respondents' perceptions of the current state of the VF industry in Australia, its problems and prospects. Finally, the interview was concluded by asking the important final direct question about how policy settings could be altered to improve the prospects of VF in Australia.

- How would you define vertical farming?
- Could you say something about how your own organisation has been involved in vertical farming?
- What do you see as the main advantages of vertical farming?
- What about potential disadvantages?

- What is your overall understanding of vertical farming in Australia?
- What vertical farms are you aware of in Australia?
- What funding of vertical farms in Australia are you aware of?
- Who is prepared to fund them and who not?
- Do you think there are particular obstacles facing vertical farming businesses and projects in Australia? If so, what do you believe they are?
- What about quality and price issues?
- What do you see as the future of vertical farming in Australia?
- How do you see vertical farming in Australia by comparison to other jurisdictions you know?
- What policy measures by government /other actions by other interested parties could or should be taken to improve the deal flow and overall future of vertical farming in Australia, and by whom?

As the intention was to gain the perspective of the industry itself, the criterion for selection of interviewees was that they should be active participants in the industry either as directors or managers of VFs. Interviews were conducted between March and May 2024 with twelve representatives of the VF industry in Australia and one long-term observer of the industry. Four additional comprehensive written responses to the questions from industry representatives were also received. First and second stage qualitative analysis coding was undertaken using NVivo software, an already familiar process from other studies of vertical farming, for example in Oman (Khan et al., 2024).

Constraints on the Development of VF in Australia

Potential advantages

Where is Australian VF in terms of industry progression? Most VFs themselves believe that the industry 'is still in its' infancy' (Respondents 11,17), but that it is 'growing quite rapidly' (Respondent 14). Others make distinctions between the outset, 'The very early history of the sector was more akin to a cottage industry producing crops for niche markets, while there remain examples of this within Australia the sector is rapidly changing' (Respondent 16). There was also agreement that the future of VFs in Australia may well depend on its ability to address issues like water scarcity, land limitations, and climate variability (Respondent 4). Supermarket and other major organisational supply chains may be increasingly threatened by more extreme weather events such as floods in the Hawkesbury plains which potentially play to the advantage of VFs (Respondents 2,13). These in turn result in 'a lot more conversations within society about supply chains being a bit more resilient' (Respondent 14) and that therefore 'they're thinking about VF' (Respondent 11).

Respondents also cited technical advances. Increased yield was the first advantage mentioned by all respondents - orders of magnitude increases were achievable (Respondents 4,14) 'without compromising the plant's actual growing space to ensure they are full and healthy' (Respondent 1). And at the same time, VFs produce less CO_2 (Respondent 1) and use (and dispose of) far less fertiliser, pesticide and herbicide as well as up to 90 per cent less water (Respondents 3,4,8,12,16,17). The second set of advantages mentioned by all respondents was reliability and stability of long-term supply for products like basil (Respondent 12) at constant prices. This was especially the case in the face of inclement weather such as cyclones or tornados to which even a greenhouse may not stand up (Respondent 11). If scale production can be achieved, control over the exacting quality parameters imposed by supermarkets such as size and colour therefore would give VFs a potential competitive edge. This would include a more precise and predictable outcome (Respondent 17). It would also be possible to obtain a higher quality product than conventional farming, including those with health benefits such as organic produce with specific characteristics such as guaranteed nutritional content (Respondents 1,7,13,16,17).

The ability to grow in much less space in urban areas (Respondent 13), whether 'basements, car parks, underground, poor yielding space' (Respondent 11) and the resultant reduction in supply chain length was another frequently cited advantage, according with the existing literature (Kumar et al., 2023; Singh et al., 2023). The more optimistic amongst respondents argued that over time, VFs would, as a result of design, components and the overall engineered solutions, become more economical to build and operate. These would become the norm as the industry matures (Respondent 1). Integration along the supply chain will bring opportunities for large fringe city industrial sites (Respondent 5). This would also reduce the need for packaging (Respondent 6). This would increase price competitiveness (Respondent 6). Because 'The competitive nature of the wholesale markets is where innovation is driven from' (Respondent 1), and 'cost and prices drive the adoption of new technology' (Respondent 8), this would also drive innovation in the Australian VF market. At the same time, respondents hoped that the demands of food security planning in the face of climate change would themselves reinforce positive attitudes towards VF in Australia, at least as a supplement to conventional agriculture (Respondent 2,8,16). Concerns about price would eventually be shouldered aside in favour of 'a new technologically sustainable way to grow that will change their world' (Respondent 5).

Given all these apparent advantages, what then did respondents identify as the causes for the slow growth of the industry? Respondents were neither unaware nor unwilling to discuss the obstacles to the success of VFs in Australia and the risks they posed: 'The challenge we face is stabilising the industry for long enough for this to take place' (Respondent 16).

The boundary issue

It is evidently hard to craft a policy for an industry if it cannot adequately define itself, which is the first problem to be overcome. The combination of the absence of an agreed definition for VFs (Respondent 1) and that 'Everyone has a different model' (Respondent 5) was one problem identified. The principal difference that emerged, however, was between those aiming to sell VF technology and those engaged in actual VF itself, whether purely as farmers or both farming and selling services. (Respondents 6, 9,11). But there are also very significant differences between those with who have adopted the business model of 'building and operating VFs' (Respondent 1), notably between those operators that are still edging towards verticality or co-locating with conventional farms or greenhouses, and those offering 'farming as a service' (Respondent 11), or less sympathetically as 'selling a farming system with a little bit of farming on the side' (Respondent 13). The threefold distinction drawn between 'selling produce, VFs companies that are selling their technology, and then technology companies selling to VFs' (Respondent 10) therefore appears a very appropriate characterisation of the segmentation of the VF industry.

The second most important difference that emerged is between a macro and micro approach. The macro hub-and-spoke approach involves very significant capital expenditure to create a VF factory with packaging and a fully-fledged distribution network, mainly to wholesalers (Respondents 11,16,17). One such company for example has an operational production farm capable of producing 400 tonnes of lettuce a year and is in the process of building a second farm six times the size. The micro approach by contrast minimises packaging and aims at locating as close as possible to its customer base. The micro approach envisages delivering the capability to turn unused urban space into functional farms (Respondent 4), including the capability to install 'plug and play' VFs that can be installed and moved within days into hotels and residences where 'people can pick plants whilst still living' (Respondent 5). Other VFs commenced at the micro level, using containers to understand VF technologies and business practices, before gradually expanding the scale of their operations.

At a still greater level of granularity, some VFs sell to the wholesale market, others directly to restaurants. Very few have direct offtake agreements with the twin supermarket majors, Coles and

Woolworths. The evident issue with the latter is the severe constraint it places on business expansion (Respondent 6). Respondents unanimously expressed the hope that the most well-known and largest firms in the VF industry in Australia would succeed and generate a 'halo effect' (Respondent 17).

Limited employment benefits

Facing high employment costs, Respondent VFs can also automate as a response to labour shortages (Respondents 3,15), maximising production quality, reducing wastage, and achieving an efficiency of production which humans simply cannot (Respondent 16). This would certainly reduce the job prospects that have been claimed for VFs (Benke & Tomkins, 2017) and in turn their appeal to government as a priority policy area. The most that can perhaps be said is that those jobs that they can and do create will be safe and inclusive jobs, creating prosperity and business opportunities wherever they are needed. These are important commercial rather than environmental or even strategic benefits (Respondent 11).

Retail concentration

Another set of issues concerns food retail industry concentration, which is exceptionally high in Australia. The VF industry believes that because of the supermarket duopoly of fruit and vegetable supply 'the Australian consumer doesn't really know what good quality is' (Respondent 3). If presented with superior quality, whether from VFs or from overseas, consumers will pay, but this is rare. So, although 'vertical farming is capable of producing a much higher quality product' (Respondent 16), quality and consistency is something you can guarantee (Respondent 11). Current lack of adoption 'comes down to the cost of the produce' (Respondents 8,11,15) as the supermarkets are 'the price makers' (Respondent 8). The result is that 'competition for VFs is not from other vertical farmers, it is from other farmers' (Respondent 6). There may also have been predatory pricing in competition with VFs (Respondent 12). Comparative costs are not merely operational. VFs necessarily involve capital expenditure (capex), which is incorporated in VC returns. By comparison the sunk costs of land prices for conventional farming are rarely computed by farmers in calculating their own returns (Respondent 8).

Energy and capital costs

Energy costs to run artificial lighting (Respondent 17) and heating/cooling systems were unanimously identified as the main obstacle to the further development of the industry. Renewables are still not yet universally ready to replace conventional energy provision for VFs (Respondent 5). Respondents also recognised that VFs are 'hugely capital intensive' (Respondent 6). They require investment in infrastructure, technology, and energy-efficient systems, including even high-quality growing trays. Finding the right space, the building of the facilities and sourcing the correct equipment is therefore often one of the biggest hurdles (Respondents 3,7). This hurdle is a barrier to entry for macro-scale VFs (Respondent 12), especially when accompanied by high carbon emissions from VF facilities (Respondents 8,17). Respondents also suggested that because of VF complexity and machinery requirements, 'workflow is probably the biggest stumbling block that most indoor farmers face' (Respondent 5).

Rent, materials and labour costs, the latter given the requirement for expertise in managing controlled environments (Respondent 4), were also a constant challenge. Moreover, costs such as wages, materials, equipment, energy and farm builds were subject to the inflation of recent years, yet were poorly aligned with product prices and therefore sales revenues (Respondent 1). Regulatory challenges across agriculture, food safety and environmental standards were identified as a source of cost and delays (Respondent 4). Likewise, the requirement to reliably source organically certified nutrients

(Respondent 12). Finally, logistical challenges to create macro-scale VF supply chains are complex and the operations are tightly coupled (Respondent 16), presenting particular obstacles to scaling up VFs (Respondent 5).

The issue of distance

Perhaps Australia could adopt the recommendation of protagonists for VF, a hyper-localised mode of consumption in which citizens would buy and consume produce from their own buildings (Despommier, 2019). But in Australia which has many geographical and economic advantages but a relatively small, widely distributed population, VF faces relatively high transport costs that make it uneconomical (Respondent 2,3,4,6.8 16), a point on which literature concerned with other jurisdictions such as Singapore and Hong Kong where problems of insufficiency and cost mainly concerned space (Mir et al., 2022) Equally importantly, the climate and the size of the country means that the optimum source of the seed, intensity of the light, and level of pH are all very separate and configurable for local conditions (Respondent 5), posing a challenge for the dispersion of the technology itself.

Reputational concerns

VF in Australia has had and still has an image problem. The Australian media is saturated with examples of two extremes of vertical farming, cottage industries and science-fantasies that are commercially unviable. At the same time the perception persists that crops grown in vertical farms are not organic or 'are in some way manmade, artificial' (Respondent 16), an observation that chimes with the evidence of surveys, notably in Europe (Perambalam et al., 2021). Hotels, restaurants and supermarkets are set in their ways and tend to prefer dealing with incumbent suppliers (Respondent 5). Market acceptance therefore requires educating customers and gaining market acceptance for vertically farmed produce, as well as competing with traditional farming methods (Respondent 4). Moreover, 'to realise the full advantages of the industry you have to excel at every single facet. When done well, the method of production can be superior, but it can be unforgiving if you do not, and the value can be quickly lost' (Respondent 16). As a result of all these factors, Australia is and will remain a tough market, both for operations and funding (Respondents 6,14, 15). This has had consequences for the development of the industry.

Limited range of produce

As a result of these operating conditions, especially costs, the VF produce range in Australia remains limited. Currently, the industry is primarily focused on leafy greens and herbs such as lettuce, spinach and coriander. These products can go very short distances directly to the consumer (Respondent 6) and which experience high demand in Australia (Respondents 15,16). They are easy and quick to grow and are eminently suited to VF production systems. But their market is relatively small, even arguably saturated, so that returns have been driven down (Respondent 16). Australian VFs themselves would very much like to broaden their range of produce, to move from the outside to the centre of the plate (Respondent 8) 'because it feels like we're not making enough of an impact' (Respondent 14). Strawberries, pot plants, medicinals and the mass scale production of crops for animal consumption were all mentioned as future possibilities (Respondents 3,5,6,9). But VFs admit that cost considerations continue to conspire against them. Widening the produce range as in other countries may not be feasible (Respondent 6). Respondents also opined that in the Australian context, greenhouses presented a better alternative requiring much less infrastructure investment (Respondents 6,9,11). They also benefitted from less stringent regulations than in some other jurisdictions, for example regarding how water is disposed of after use (Respondent 6).

Current and prospective funding

The call for 'more funding needed' (Respondent 4) was frequently heard from respondents in different forms. Governments have lacked interest (Respondent 1), with even previously existing agricultural funding now becoming harder to access (Respondent 2) and VFs reliant on technology funding (Respondent 3). The grant application process was protracted, and start-ups in particular have found it difficult to navigate (Respondent 3). Respondents recognised that this suite of problems was not specific to VF, nor even to agriculture (Respondent 8).

That leaves the private sector. Debt was very difficult to obtain as banks were unable to see reliable future cashflows (Respondent 6). This also constrained private equity investment as in Australia 'agriculture specific private equity tends to focus more on traditional agriculture' (Respondent 17). This resulted in VFs relying on venture capital (VC), but the investor landscape is pretty small, relatively, compared to the United States or other countries. Moreover, as in the United States, investor money rushed into the VF space without a huge amount of due diligence and based on over-optimistic forecasts, both for revenues and costs (Respondent 6). After the end of the pandemic even that fell away with the failure of VC-funded VFs overseas that have 'tainted the space' (Respondent 17). This may tentatively be said to have reversed, with venture capitalists returning to the industry after having recognised that technology has advanced and there could be significant returns for early investment (Respondent 16).

But there are now identifiable differences in approach. Respondents from both VFs and their funders argued that in the past VCs sought out VFs for their technology (Respondents 15,16). The result was that 'a lot of these vertical farms were funded as a tech startup, when in reality, they're selling a very low cost, salad green to a supermarket chain that can price them out of the market' (Respondent 3). VCs also often preferred capital-light firms, which VFs are certainly not (Respondent 17). It is understandable therefore that some companies have expressed a wish to move away from VC funding. They expressed a familiar refrain that it imposes unrealistic expectations on the industry and is therefore partly to blame for early failures (Respondent 16). Yet different technologies are still competing in the VF space in Australia, for example actual vertical towers vs. stacked trays (Respondent 12). Some operators continue to try and in some cases succeed in raising capital to build a proprietary and patented technology solution and implement it on a VF themselves (Respondent 17). This has however proved challenging in the current Australian funding environment. Australian VFs themselves, unlike in the United States, were never the subject of over-enthusiastic investment hype. Because 'the potential of the industry was initially underestimated' (Respondent 16), VFs were largely forced to grow organically. They might for example begin with an old warehouse and gradually expand thereafter (Respondent 12). Some VFs may be satisfied with remaining at a small scale (Respondent 6). By contrast, the largest VF operator has raised over $100m in two approximately equally sized major funding rounds. It is backed by international venture capital, and national funding sources from the food industry have all been involved in funding the company. By comparison, a smaller company has raised $7m from similar sources.

However, a large proportion of VF operators were of the view that VF technology development was now on a flattening curve. The trend for VFs in Australia was 'back to basics' (Respondent 6). The distinction was made between 'VF 1.0', where there was a strong focus on equipment and scale, and 'VF 2.0', a business model that would allow for integration across cities (Respondent 5). VF 2.0 was held to bring other advantages.

The time for projected very high returns akin to tech start-ups is therefore over. In future value will be created in the crop not the technology (Respondent 3) so being able to pick optimum machinery and technology off-the-shelf very much played to their advantage. This imposed choices. As one

respondent advised, 'Be technology or be a farmer. Don't try and do both' (Respondent 11). The logic of this advice has been reinforced by the perception that Australia is safe, albeit lacking competitiveness on the global stage, 'one of the reasons that investment in technological innovation here has lagged behind' (Respondent 16). VC funding at scale has therefore been into operators with technology, rather than pure technology plays. For their part, funders argued that 'perception is key - is that innovation arises from the alignment of technology (invention), funding (money) and opportunity (need/acceptance)' (Respondent 16). So long as the Australian market remains reluctant to accept the advantages VF has to offer in respect of quality, respondents believed that investors would continue to be cautious. This despite the many potential locations and land ownership models that render the relationship between land and capital unique for VFs even amongst controlled agriculture more widely, suggesting the accuracy of the importance of this factor for VF success (Sarkar & Majumder, 2019). VFs themselves demonstrate the kind of reciprocal caution often associated with investees, treading the 'fine balance between holding the shares in the company, and expanding too slowly to be competitive' (Respondent 1).

But amidst the widespread perception of the limits on the development of the industry imposed by funding, the significance of the decision by a leading VC in 2023 to fund a VF cannot be underestimated. The future may also open out more funding opportunities for VF based on environmental, social and governance (ESG) principles, including offtake agreements with supermarkets and other major purchasers such as catering and mining companies (Respondents 3,8). Some VFs have already succeeded in raising finance on a smaller scale from high-net-worth individuals, family offices, and impact groups (Respondents 8,16). So too 'The ability to build rapidly growing networks of farms utilising stable technology will attract infrastructure investment more commonly used to build data centres. This may bring consequences for the structure of the industry' (Respondent 16). It was not surprising therefore to hear the view expressed that 'There is likely a time in the future, when only the largest farming operators can afford to operate' (Respondent 1). Another described the imminent future of the VF industry as 'the year of the cockroach' when the fittest would survive (Respondent 6). For the industry to expand, however, policy settings would need to be changed.

Solutions: Policy Recommendations

As a result of these obstacles, the VF industry in Australia appears to be stalling. The industry is however not short of suggestions for ways in which government could help to develop VF in Australia.

Clear, unequivocal definitions to improve the ease of funding, planning and standards for VF

One of the most clearly expressed policy recommendations was the need for changes in planning regulations. Respondents wanted future real estate projects in urban areas to be built with vertical farming in mind, even integrated into new developments alongside renewables (Respondents 3,6). They wanted to see government engaging with commercial real estate and trying to incentivise them to incorporate VF in their developments and existing buildings (Respondent 14). But for this to happen, there would clearly have to be changes in zoning and planning permission regulations. This would have two aspects. One is to streamline processes and reduce costs (Respondent 13). The other would be to offer incentives, for example for building owners to convert dead space into VFs, including reductions in land tax (Respondent 5) given the high cost of land acts as a deterrent for Australian VFs (Respondent 17). As yet however, unlike aquaponics, VF and indoor farming is not explicitly recognised in the Australian planning system in respect of zoning for technology and food production (Respondent 11). Currently to install VFs in Australian cities involved 'way too many hurdles' (Respondent 13), a fact rather at odds, respondents suggested, with the green visions advanced in city strategies. The problem is accentuated by the fact that planning regulations with respect to VF vary between different

Australian states (Jayamurthi & Griffith, 2024, p. 31), so changes would have to occur in parallel across multiple jurisdictions.

An industry peak body

Respondents believed that there was a need to organise for change in planning regulations and the fact that there is no one established regulatory body focusing specifically on VF technologies (Jayamurthi & Griffith, 2024, p. 30) was one reason for the frequently expressed suggestion that the Australian VF industry would benefit significantly from a 'focus group of SMEs' (Respondent 1) or 'some sort of advisory body' (Respondent 14). This would presumably be a 'peak organisation', analogous to the Property Council of Australia and indeed working closely with it, especially with regard to planning matters (Respondent 13). The current AgTech Association focused on fundraising, which whilst of evident importance, was seen as only part of the potential mission of a VF peak body; AgTech is also much broader than just VF (Australian Agtech Association, 2025). By contrast the proposed peak body would also take on responsibilities for promoting the interests of the sector, including advocating for support, training of existing and potential employees, and generating education content aimed at greater market acceptance, revolving around 'how much better the product is compared to normal produce' (Respondent 6).

The development of a VF ecosystem

Respondents also called more broadly for the creation of what some called an 'ecosystem' for VF in Australia, akin to that which already exists in Israel, European countries such as the Netherlands (increasingly also the United Kingdom) and the United States, to nurture the technology. In the United States, Agritecture, which aims to bring controlled agriculture producers together to 'treat food safety as a pre-competitive issue' (Agritecture, 2024) and the New York City Agriculture Collective, which describes itself as 'An Urban Agriculture Nonprofit Driving AgTech Policy, Education, and Opportunities for the Future of NYC' (NYCAgCollective, 2024) seek to build confidence and indirectly, encourage potential investors. Respondents wanted the 'ecosystem' to be funded by government and nationally backed by organisations such as CSIRO and to perform similar functions in Australia: to draw investors, universities, government and VFs together, with the objective of creating partnerships across the dimensions of research, development, education and technology implementation (Respondents 2,4). Longer term, it would become possible for more firms to become VF systems exporters (Respondents 1,4,6). This would enable Australia to compete with existing jurisdictions that currently monopolise this space, the Netherlands in particular (Respondents 1,6) instead of being 'forced to purchase all that technology from overseas' (Respondent 8). Funding from the public sector would therefore constitute one element of the ecosystem, for example for the evaluation of VF technology (Respondent 8). The 'city deal' created by the Federal Government (AHURI, 2017) was suggested as a prototype for how proposals advanced by VFs could be better supported by Federal, State and City agencies in alignment (Respondent 13). Respondents also recognised that VF would be best placed as part of wider sustainability initiatives, to include other technologies such as bioengineering and renewable energy, but 'basically having the infrastructure and thinking about eco-parks or even communities with circular economies where we can do smarter things' (Respondent 11). The Peel Precinct in Western Australia was mentioned as an example of how this might work in practice, although problems with required capex remain (Respondents 6,11).

Another potential contribution would be the inclusion of VF (and the creation of offtake agreements) in the sustainability initiatives by public sector organisations, for example the Australian Defence Force (Respondent 8) or by private sector real estate operators such as data centres (Respondent 13). Given the industry's need for expertise, an interrelated objective would be to raise awareness and increase education. This would have a triple benefit. It would help to supply the high-quality workforce essential

for the development of the industry in Australia. At the same time it would positively affect consumer acceptance and therefore willingness to pay. The creation of an effective ecosystem and a VF peak body would also serve an educational purpose, as it was suggested that many potential investors have not even now thought about the underlying drivers of VF economics or what kinds of interventions, such as automation or business model design are required to get a value proposition to the customer (Respondent 16).

More accessible State and Federal financial support

Lowering electricity costs remain a policy priority for the VF industry. Energy was just 'so, so expensive' (Respondent 12), it was 'the biggest operational cost' (Respondent 6). Respondents were clear that a level playing field with broadacre farming would not suffice: 'we're not going to see broad adoption of the technology until we can get the costs down' (Respondent 8). Small steps were already being taken, for example to use surplus renewable energy for VFs (Respondent 6). But sunlight variability demanded switchable energy supplies (Respondent 6). Respondents suggested that the privatisation of energy in Australia (except WA) has made radical policy steps in this direction virtually impossible (Respondent 8). There have been a few exceptions, such as the low tariffs in a dedicated power purchase agreement that the WA State Government has made possible in the Peel Precinct. The benefit to the VF industry for other States and Territories (as well as the Federal Government) in following the lead of New South Wales in making Controlled Environment Agriculture and therefore VFs one of the key methods for decarbonising the State was also highlighted (Respondent 17).

More rigorous Australian standards for the products in which VF has a potential advantage

There is currently no standardised way of measuring or comparing quality across different VFs in Australia. Nor is there organic certification of VFs as exists in the United States. Enhanced product standards, possibly along the lines of the AU/NZ Standards (Respondent 1) would ensure that every farm is producing the same quantity (Respondent 13) and quality of produce (Respondent 16). It could then be extended, for example to identifying parameters that quantify and measure how much CO_2 a VF could save through growing particular crops (Respondent 1).

Carbon pricing as a first step to wider environmental pricing

Respondents also favoured the inclusion of the social price of carbon into agricultural costings. Initially even tracking its use would be advantageous in 'helping people rethink supply chains' (Respondent 1). But the price has been estimated to have risen substantially over the past decade, from US$9/t of CO_2 to US$40/t of CO_2 for a high discount rate and from US$122/t of CO_2 to US$525/t of CO_2 for a low discount rate (Tol, 2023, p. 532). Factoring it in would therefore dramatically increase the competitiveness of VF. Later, such pricing could be extended to other environmentally negative farming practices, such as 'the costs of some of the chemicals that we put into the soil, which then leach into the ground' (Respondent 8).

Conclusion

Australian VF needs capital if it is to increase its current rate of growth: respondents identified funding as the leading constraint on the growth of the VF industry in Australia to date. The industry believes that a series of policy measures are now required in order to unlock that capital. There would however have to be a significant change in institutional thinking for some or all of these policy recommendations to transpire, perhaps any of them. Despite the potential importance of VF for Australian food security in the future, conventional agriculture understandably continues to dominate policy debate. CSIRO's *2050 Blueprint for AgScenarios*, for example, makes no direct mention of VF, suggesting only that

'Investing in disruptive production methods decoupled from land use could address challenges in traditional agriculture' (CSIRO, 2024, p. 16). Yet in the absence of these policy measures, the likelihood is that the industry will evolve only extremely slowly. As other countries take the lead, this may be a collective decision that unless it is reversed within the next decade Australia will come to regret in the future.

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