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# Research@SMU: Sustainable Living

Singapore Management University

# RESEARCH@SMU:
# SUSTAINABLE LIVING

**SMU**
SINGAPORE MANAGEMENT UNIVERSITY

RESEARCH

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**Singapore Management University is a dynamic city University in the heart of Singapore. We are a specialised University focused on Management, Social Sciences and Technology, and their intersections. We adopt an integrated research-teaching-learning-practice approach that fosters innovative learning experiences and develops influential change agents and leaders. We create positive impact on business, government and society in Asia and beyond.**

# FOREWORD

From its early years as a trading settlement to its status today as a global financial hub, development has been at the heart of Singapore. It goes without saying that Singapore must continue to develop, but in recent years, it has become both apparent and imperative that we do so sustainably.

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. This definition comes from the seminal 1987 Brundtland report, known more commonly—and perhaps more aptly—as "Our Common Future". What stands out with this definition is the emphasis not just on the future, but also on the present.

This has always been of particular importance to Singapore, a country as defined just as much by its limited natural and human resources as by its dedication to research and development. We are reminded of this commitment daily through national plans such as the Singapore Green Plan 2030, the Singapore Food Agency's '30 by 30' goal and the Zero Waste Masterplan.

I am delighted to see that SMU is working towards addressing the country's sustainability challenges. Sustainable Living is one of the three key priorities of the SMU 2025 Strategy, and the University is committed to develop it into an area of cross-disciplinary strength. Additionally, the efforts of the Sustainability Taskforce, set up in 2021 and chaired by the President, have culminated in the University's Sustainability Blueprint.

On that note, SMU has produced a range of research on sustainability issues, from frameworks for sustainable finance to urban design and more. These efforts include collaborating with Imperial College Business School to establish the Singapore Green Finance Centre, Singapore's first research institute dedicated to green finance research and talent development.

At the same time, SMU's Centre for Research on Successful Ageing conducts multi-dimensional studies into sustainable ageing and wellness using data from the Singapore Life Panel®, one of the largest high-frequency surveys in the world. In another initiative, faculty from the College of Integrative Studies are co-leading the Cooling Singapore 2.0 project to tackle the challenge of urban heat islands with sustainable urban design techniques.

The articles in this booklet highlight these and other impactful sustainability research accomplishments at SMU, which spans five broad pillars: Sustainable Business Operations; Sustainable Finance and Impact Assessment; Sustainable Ageing and Wellness; Sustainable Urban Infrastructure; and Sustainable Agro-business and Food Consumption.

It is my hope that the insights from our research will contribute to Singapore's journey to becoming a sustainable nation.

I very much hope that you find the following articles insightful and inspiring to you.

**Professor Timothy Clark**
Provost
*Singapore Management University*

## Driving Sustainability Research with Impact

Our key differentiating factor in Sustainability research is the emphasis we place on research in management and social sciences. Our research initiatives go beyond the environmental aspects of sustainability to include communities and society while addressing policy and governance issues. To continue driving such impactful research, we aim to:



**Prioritise the development of high-quality sustainability research**



**Develop global and local research partnerships on sustainability agenda**



**Put sustainability ideas into practice on campus**

# STAYING SUSTAINABLE IN A CHANGING WORLD

The world is changing, and so too are businesses. From how you purchase your groceries to how food is shipped across continents, there are few aspects of modern life that have escaped untouched by the rapid upheaval brought on by the pandemic as well as trends like increasing digitalisation and urbanisation.

At the same time, the necessity for sustainable living also drives the need to rethink the way businesses and individuals operate to optimise available resources: to do more, more efficiently with less resources.

Here, work by SMU researchers are providing insights and best practices for businesses and industries to operate more sustainably. In this series of articles, read about some of the on-going research and findings in the realm of sustainable business operations.

In **Managing the Load on Loading Bays**, Professor Lau Hoong Chuin spotlights the potential value of synchronised logistics to reduce congestion at loading bays and thus boost the efficiency and sustainability of supply chains. He reveals how through better scheduling and coordination, congestion can be minimised and less resources wasted idling in queues, demonstrating that there are benefits to planning and adjusting delivery schedules in relation to others using these shared facilities.

In **Going the Last-mile**, Assistant Professor Aldy Gunawan builds upon the vehicle routing problem to identify the best combination of delivery and return routes in order to meet the growing demands of the logistics industry. Assistant Professor Gunawan's research focuses on the use of forward and reverse cross-docking practices and provides suggestions for service providers to consolidate goods and redistribute goods between fewer vehicles to minimise the resources expended in the supply chain.

Meanwhile, Associate Professor Onur Boyabatli tackles the process of decision-making in sustainable agriculture. While crop rotation can improve overall crop yields, these benefits are not immediately apparent to farmers who must consider a multitude of factors. Associate Professor Boyabatli shares his findings on this topic in **Feeding a Growing World** and provides a simple heuristic to help farmers make better crop allocation decisions in today's increasingly complex operating environment.

Finally, in **Pooling the Benefits of Sharing a Ride**, Associate Professor Wang Hai unravels the complex relationships between the factors and decisions involved in the emerging on-demand ride-pooling market. His research suggests that appropriate pricing strategies and a sufficient fleet size can make the provision of this service more tenable. By comparing ride-pooling and non-ride pooling markets, Associate Professor Wang's insights highlight the value of ride-pooling services and the factors required to make them feasible.

# MANAGING THE LOAD ON LOADING BAYS

**Research by Professor Lau Hoong Chuin shows how deconflicting delivery schedules at loading bays can reduce unsustainable bottlenecks and idle waiting time.**

Tucked away in obscure parts of shopping malls, loading bays are typically hidden out of sight and out of mind from the everyday patron. During certain times, however, one may be able to catch a glimpse of these loading bays—the snaking lines of delivery vehicles awaiting their turn to use the facility underscore the severity of these bottleneck situations.

Every minute spent waiting or queuing is a cost incurred by these logistics service providers (LSP). Apart from fuel and manpower costs, these providers may also face penalties if they fail to make their deliveries on time. Above all, there are also environmental costs to longer vehicle idling times.

To address these situations, Professor Lau Hoong Chuin from the School of Computing and Information Systems combines the use of artificial intelligence and operations research methods to improve coordination and alleviate scheduling problems in today's urban shared economy.

One way to reduce congestion in shared resources like loading bays is through careful planning and scheduling, typically managed through a central authority. However, this is not possible in reality where different LSPs work for their own interests and may not be willing to cooperate.

With self-seeking agents in mind, Professor Lau and his PhD student Joe Waldy developed a model which produces the best coordinated schedule to help minimise congestion in loading bays.

In the paper 'Coordinating Multi-Party Vehicle Routing with Location Congestion via Iterative Best Response', they modelled the problem as a game in which individual LSPs will make adjustments to their schedules as long as they benefit from the change.

The approach, which is grounded in game theory, derives the best coordinated schedule through iterative adjustments or best responses made by LSPs until a point where there are no longer incentives to change. Through the process, a new dataset was also developed so that other researchers presenting alternative solutions would be able to make objective comparisons against the presented model.

To showcase the value of coordination at the system level, Professor Lau also teamed up with researchers from Tsinghua University to identify the most robust delivery routes while taking into account congestion in shopping malls with limited docking capacity and uncertainty in travel times.

In the paper 'Coordinated Delivery to Shopping Malls with Limited Docking Capacity', Professor Lau and his

collaborators presented an approach based on Monte Carlo sampling from historical data which centrally generates coordinated vehicle delivery routes while simultaneously scheduling dock time slots at shopping malls. Compared against scenarios where individual LSPs do not coordinate their deliveries, their centralised approach on average had an approximately ten percent reduction in costs—showcasing the value of cooperation and collaboration between individual LSPs.

Beyond coordinated deliveries, other forms of collaboration that Professor Lau has developed include the use of marketplaces and formation of alliances among LSPs. In the paper 'Solving the Winner Determination Problem for Online B2B Transportation Matching Platforms', Professor Lau and his collaborators designed an auction mechanism to match shippers and transporters and thus improve B2B last-mile logistics. They also presented an algorithm that leverages machine learning to help SMEs share their resources and thus reduce delivery costs, improve efficiency and compete with larger players in the paper 'A Learning and Optimization Framework for Collaborative Urban Delivery Problems with Alliances'.

As urbanisation continues to take place and cities grow increasingly congested, particularly those in Asia, the constraints on resources such as loading docks and drivers will become increasingly salient. Professor Lau's research builds a case for the industry to foster closer cooperation and collaboration in order to optimise resource utilisation, paving the roadmap for a more sustainable supply chain.

# GOING THE LAST-MILE

**Assistant Professor Aldy Gunawan's catalogue of vehicle routing datasets paves the way towards more optimised and sustainable delivery and return routes.**

Until the advent of e-commerce, businesses did not generally have to worry about getting their goods to consumers past the checkout counter. In today's world however, things are changing: between 2018 and 2019 alone, global e-commerce sales jumped by 4 percent to US$26.7 trillion.

This shift from physical to online retail has fuelled the demand for last-mile delivery services, the final step in the journey of getting orders to consumers. Given the volume of online sales, companies have a strong incentive to make the right decisions that keep costs as low as possible, such as which routes and transportation options to use.

Interestingly, this vehicle routing problem (VRP) is not something new or unique to e-commerce deliveries. Apart from last-mile delivery, VRP is also relevant to garbage truck collection routes and the use of electronic vehicle fleets which have recharging downtime constraints. As such, VRP has been extensively studied for decades in different contexts where researchers try to develop algorithms to find the most cost-efficient solutions.

But for researchers to make more direct comparisons between their algorithms and methods, they need common databases with the same set of conditions. Over the course of VRP research history, the number of such benchmark datasets in different topics has grown extensively as well.

To facilitate easier access to these datasets and help researchers use them to make objective comparisons, operations research expert Assistant Professor Aldy Gunawan from SMU's School of Computing and Information Systems and his co-authors have published a research paper cataloguing the various VRP datasets available in 2020.

One extension of the VRP includes forward cross-docking, an intermediate activity within a supply chain network which enables a transhipment process. By coordinating the arrival and departures of several vehicles at the cross-dock, consolidated goods from different carts can be redistributed so that the total distance travelled and number of vehicles used are minimised.

At the same time, the opposite consideration, both forward and reverse cross-docking, is also becoming more important for VRP researchers. Because customers increasingly have to send faulty purchases back for returns, and as companies send unsold inventory back to suppliers, many companies have recently focused on reverse logistics. Here, the benefit of cross-docking with reverse logistics can be extended to facilitate the management of such return processes.

Despite already being commonly implemented in practice, little academic research has been done to consider the integration of forward and reverse product flows in a cross-docking network. To explore the untapped potential in this research space, Assistant Professor Gunawan and his co-authors developed a two-phase matheuristic algorithm which seeks to minimise operational and transportation costs of such a system.

For their model, the researchers shortlisted potential routes based on the destinations within a demarcated geographical neighbourhood. Based on the other constraints such as delivery time and number of vehicles available, the model was then able to find the best combination of routes from the shortlist, thus minimising operational and transportation costs.

When compared with other state-of-the-art algorithms, the experiments using benchmark datasets showed that the proposed algorithm outperformed most of the best-known solutions.

These findings are encouraging, considering the e-commerce boom in this region. As e-commerce continues to grow in Southeast Asia, with its over 25,000 islands and islets, the optimisation of supply chains and last-mile delivery routes will become increasingly relevant and essential for business viability and sustainability in this sector.

# FEEDING A GROWING WORLD

**Research by Associate Professor Onur Boyabatli has shown that comparing different farming decisions can improve sustainable agriculture outcomes.**

Agriculture is an ancient practice that can be traced back to the earliest human settlements. However, today's need for sustainability has pushed farms to produce more food for less resources. These pressures are particularly relevant amidst climate change and the growing global demand for food. Here, sustainable agriculture practices that enhance the quality of the natural resources and environment to increase crop output could offer a solution.

For example, rotating crops over the growing seasons according to their nutrient and water needs increases yield while making the most of soil nutrient cycles. However, implementing crop rotations requires a large amount of sophisticated decision-making from farmers at various points, such as selecting the type of crops to plant, as well as choosing how much farmland to allocate each crop while considering financial factors such as uncertain crop revenues and associated costs to purchase harvesting machinery and fertilisers.

To help farmers make better decisions in today's increasingly complex agricultural landscape, SMU Associate Professor Onur Boyabatli develops analytical models that analyse the impact and outcomes of different farming decisions. He also incorporates the use of industry data to calibrate the veracity of his analysis.

In a 2019 paper published in *Management Science*, Associate Professor Boyabatli and his colleagues Associate Professor Helen Zhou from SMU and Associate Professor Javad Nasiry from the Hong Kong University of Science and Technology examine crop planning decisions in sustainable agriculture.

In particular, the paper examines how a farmer, while facing uncertainty in crop revenues, should allocate his farmland across multiple crops in each growing season when the crops have rotation benefits across growing season. The paper proposes a recipe for the farmer to make crop allocation decisions to maximise profitability. In their model, Associate Professor Boyabatli and his colleagues identified different farmland allocation scenarios proposed by other researchers and compared the outcomes of these choices with their proposed policy.

The researchers found that monoculture, or planting only one type of crop in each season and changing the entire selection of crops in subsequent period, delivered the poorest profit outcome. According to Associate Professor Boyabatli, this discovery underscores the importance of allocating a mixture of crops on rotated land at any one period.

In comparison, profit is maximised when farmers use the "one-period lookahead policy", which involves making allocation decisions solely based on expected future cash flows from the subsequent period and a mixture of crops is allocated on rotated land.

In conducting such an analysis, Associate Professor Boyabatli and his colleagues have derived important managerial insights which could serve as a rule of thumb to help improve decision-making for more efficient and sustainable agriculture.

The researchers explained that while farmers may feel hesitant to make crop planning decisions on a long-term planning horizon due to the complexity of such a decision, their results serve as strong evidence that farmers do not have to do so.

"Our results demonstrate that making that allocation decisions by considering a short-term horizon does not lead to a significant loss in profit, and our analysis provides a recipe for making that decision," concluded the researchers.
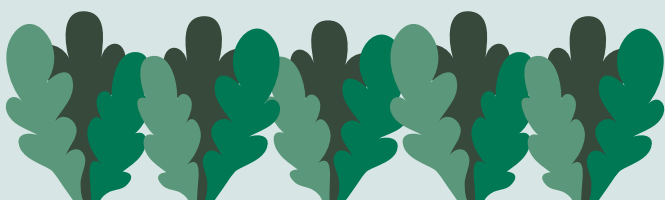
# POOLING THE BENEFITS OF SHARING A RIDE

**A mathematical model developed by Associate Professor Wang Hai might make sharing hired cars more efficient for passengers, companies and the environment.**

In terms of carbon emissions, not all public transport is created the same. According to a study from the US, taxis and on-demand private-hire vehicles tend to produce more carbon emissions per passenger compared to buses and trains, as cars ferry fewer people per trip. One way to reduce this disparity is ride-pooling: by pairing passengers with similar intended routes and encouraging them to share the same ride, more mileage can be reaped from a single journey's carbon emissions.

Many on-demand private-hire platforms have already introduced ride-pooling services on their mobile apps. But within such services, there are interdependent and dynamic relationships that need to be considered, such as those between passenger demand, fare discounts, added commute time, vehicle fleet size and the number of successful ride pairings. For example, bigger discounts attract more passengers and increase the odds of successful pairings, while setting an appropriate allowable detour time reduces the odds of passengers opting out of ride-pooling.

However, few mathematical studies have attempted to precisely understand these relationships and the impacts of this emerging service. While on-demand ride-pooling could reduce carbon emissions and traffic congestion, the service's success depends on a fine balance between its overall profitability to private hire platforms and its level of acceptance by consumers. Without a clearer understanding of the conditions needed for this service model to work, private-hire platforms may give up on their attempts at it before its potential societal and environmental benefits are reaped.

To tackle this challenge, Associate Professor Wang Hai of the SMU School of Computing and Information Systems and his colleagues from the US and China developed a mathematical model to clarify the complex relationships between the variables and decisions involved in a ride-pooling market. By comparing ride-pooling and non-ride-pooling markets, the team of operations research experts uncovered key insights to support the continued provision of these services.

In a paper titled 'Pricing and Equilibrium in On-demand Ride-pooling Markets', the team used their model to identify optimum combinations of trip fare, vehicle fleet size and allowable detour time under three different potential scenarios: a monopoly scenario, where the on-demand car hire platform aims for maximum profits; a social optimum scenario, which aims for maximum benefits to society; and a second-best scenario, which aims for both a certain level of guaranteed profit while maximising social welfare under that constraint.

The team found that in all three scenarios, optimum trip fares for ride-pooling markets were generally lower than non-ride-pooling ones, showing that consumers might ultimately stand to gain from services with ride-pooling options. Their results showed that optimal solutions always lay in a normal regime where prices respond to market demand, supporting the use of surge pricing mechanisms already present in today's for-hire vehicle market. They also found that decreasing the trip fare in ride-pooling markets attracts more passengers compared to non-pooling markets because it directly increases demand and also reduces actual detour time, which in turn indirectly increases ride-pooling demand.

Associate Professor Wang's work establishes a foundation for future studies on how ride-pooling services impact traffic congestion and reduce carbon emissions. More importantly, it shows that ride-pooling services can be a sustainable, viable and profitable business model for on-demand private hire platforms, which may incentivise the industry to pursue similar efforts in the journey towards a more sustainable future.

# RETHINKING SUSTAINABILITY IN THE NEW NORMAL

Running a sustainable venture is about a deft balance between the three P's: profit, people and planet. Essentially, sustainability is about creating long-term value without compromising on environmental, social and governance (ESG) issues.

This is all the more pertinent in a post-pandemic world. The COVID-19 pandemic brought tighter scrutiny not only on how businesses treated the environment, but the importance of having proper social and governance factors in place.

Meanwhile, corporate bodies seem optimistic: a 2020 McKinsey Global Survey found that 83 percent of C-suite executives and investment professionals believe ESG programs will generate more shareholder value in five years' time than they do today.

While the acceleration of the ESG agenda will undoubtedly lead to wide-ranging repercussions, questions abound as to the rules which govern the sustainability sphere. Frameworks can often be vague and fail to allay investor concerns of not only returns but genuine impact.

To tackle these problems, SMU researchers have drawn up cutting-edge solutions as well as radical ideas to not only push the discussion of sustainable investing forward but to ensure that investments truly make an impact.

We begin with the subject of conflicts of interest in the acquisition of ESG ratings by credit rating heavyweights Moody's and S&P in **When Going Green Becomes a Grey Area**. Here, Professor Zhang Liandong and his team outline signs of conflict and go on to flesh out the correlation between the rate of increase in ESG ratings and existing credit rating relationships.

In the next article in this series, **Making an Impact with Every Dollar**, Associate Professor Liang Hao calls for better approaches to gauge the success of impact investments, a trillion-dollar business. Measures include going beyond focusing on public equities to other asset classes.

Of course, no one can talk business without a discussion of the human resources that power corporations and firms. In **Building an Inclusive Singapore Starts at Home**, Professor Phang Sock Yong looks at how cities can narrow the inequality gap by considering Singapore's successful land and housing policies.

Finally, Professor Dave Fernandez lays out suggestions in **What Makes a Bond "Green"?**, to better frameworks that govern sustainable products such as green bonds. Green themed investments are here to stay, but a tighter and more up-to-date regulatory ecosystem is needed if sustainable finance is to make a dent, he proposes.

# WHEN GOING GREEN BECOMES A GREY AREA

**Credit ratings agencies that also give out ESG scores may represent a potential conflict of interest, says Professor Zhang Liandong of SMU's School of Accountancy.**

In 2019, credit ratings agencies Moody's and S&P muscled their way into the growing world of environmental, social and governance (ESG) performance ratings by acquiring Vigeo Eiries, a French ESG research and services firm, and RobecoSAM, a Swiss investment firm focused on sustainability investments.

But do these acquisitions create a conflict of interest, given that the primary service provided by Moody's and S&P is the provision of credit scores? Unsurprisingly, one of the risks flagged by the US Securities and Exchange Commission (SEC) for ratings agencies included failures to follow ratings methodologies and manage conflicts of interest.

The SEC's concerns are echoed by Professor Zhang Liandong of SMU's School of Accountancy. In 2022, Professor Zhang and his team found a positive correlation between ESG scores given to companies by Moody's and S&P and their status as paying clients of both agencies.

Together with researcher Li Xuanbo and Associate Professor of Accounting Lou Yun, Professor Zhang investigated the nexus between credit rating firms and ESG ratings in their paper titled 'Do Commercial Ties Influence ESG Ratings? Evidence from Moody's and S&P'.

In their study, Professor Zhang and his team stated that while these acquisitions may allow the financial services firms to leverage their financial and informational resources to produce better quality ESG ratings and data products, their multiple business lines can also provide a hotbed for potential conflicts of interest.

To test their hypothesis, the researchers analysed the ESG ratings issued by Vigeo Eiris and RobecoSAM before and after they were acquired by Moody's and S&P respectively, within a period from 2016 to 2020.

They found that companies that conducted credit ratings business with Moody's experienced a 1.287-point increase in ESG ratings after the acquisition—about 4 percent higher than the agency's average. Similarly, companies with existing credit rating dealings with S&P experienced a 1.997-point increase in ESG ratings after the acquisition—6.7 percent higher than the agency's average.

Professor Zhang's team further benchmarked Moody's and S&P's ESG scores against those issued by capital markets data provider Refinitiv to rule out the hypothesis that the scores of these companies improved because of inherent improvements in their ESG performance. As expected, they found a correlation between the rate of increase in ESG ratings and the existing credit ratings relationship between these agencies and the companies under their coverage. ESG scores also became more difficult to predict post-acquisition.

Factors that could contribute to conflict-of-interest situations, according to the authors, include ambiguity around ESG ratings where the quality of such scores is hard to judge due to the variance in categories, measurements and weights. Notably, the quality of ESG ratings is different from the quality of credit ratings, which are measurable and observable via the debt market. Furthermore, ESG ratings are still relatively new and unregulated, leaving more room for manipulation in the ESG space, they pointed out.

Professor Zhang and his colleagues believe that investors should be aware of potential conflicts of interest when they use ESG ratings to guide their investments. They also call on regulators to step up their game "to match the growing demand for ESG ratings with appropriate regulations to ensure the rating quality and reliability".

At the same time, Professor Zhang proposes using existing regulatory frameworks associated with credit rating agencies to increase supervision over any newly acquired ESG-rating businesses.

As for the financial services companies themselves, the researchers recommend that they tackle conflicts of interest by providing greater disclosure and assurance of the independence of their ESG ratings from other business lines.

# MAKING AN IMPACT WITH EVERY DOLLAR

**Changing the world for the better presents an investment opportunity, but how do we measure these outcomes? Associate Professor Liang Hao of SMU's Lee Kong Chian School of Business discusses.**

Trillions of dollars have gone into impact investing—US$2.3 trillion to be exact. This kind of investing, which mobilises capital towards projects that generate social and environmental impact along with financial returns, became popular during the pandemic due to increased awareness of climate change and social issues such as access to basic healthcare.

The International Finance Corporation found that the total value of impact investments recorded in 2020 accounted for about two percent of global assets under management. In this space, Southeast Asia is among the fastest-growing regions, with impact investing funds growing at an annual rate of 23 percent, according to a 2020 Global Impact Investment Network survey.

But despite the buzz surrounding impact investment, Associate Professor Liang Hao of SMU's Lee Kong Chian School of Business believes there is a concerning absence of standardisation and comparability across different frameworks, especially at a time when investors and businesses adopt environmental, social and governance (ESG) reporting.

"Many have missed that these standards are vague on how to be implemented at an organisational or activity level," Associate Professor Liang wrote in a chapter from the Handbook on the Business of Sustainability, published in 2021.

He identified some problems with current practices, including a heavy dependence on third-party ESG providers who only cater to public equities, and a lack of a robust framework to measure impact "that can be generalised across various business activities".

However, Associate Professor Liang also concedes that impact investing remains popular and holds great potential for investors, in addition to creating new knowledge from research that can better guide capital allocation for organisations and governments alike.

While previously existing within the domain of private equity due to the long-term focus and holding of significant stakes in businesses, the prevalence of frameworks such as the United Nations' Sustainable Development Goals (SDG) has helped to increase the accessibility of impact investing to different classes of investors.

"All kinds of capital providers—banks, development financial institutions, pension funds, family offices, endowments, foundations and corporations—now actively pursue impact investing," he wrote.

As a result of its rising popularity among investors, an important part of impact investing is now "active" impact measurement. "Investors in this space are usually concerned about how to report the social and environmental impact of their investments on the basis of transparency and accountability," he shared.

To ensure that impact is better measured, Associate Professor Liang proposes three solutions. First, he argues that research should go beyond simply analysing the challenges with current ESG rating practices to developing more robust approaches to navigate these challenges.

This means the research process should go beyond ESG measurement for public equities to other asset classes and not only measure them in percentile ranking or in their natural units such as tonnes or square meters, but also in monetary terms.

Second, he proposes that researchers and practitioners should adopt a more theory- and research-based approach by linking impact contributions to statistics and findings in leading policy databases, and academic research, citing the likes of the World Bank and ILOSTAT, a global reference for international labour statistics.

Associate Professor Liang argues that such an approach makes impact assessment and measurement more objective and generalisable, which in turn will help organisations better identify the right counterfactual reference scenarios and indirect impact, such as impact along the supply chain.

Third, he believes that scholars and practitioners need to collaborate with each other and further develop their impact measurement and assessment frameworks and improve the accuracy of its mapping to SDG targets.

"When evaluating how business activities, organisations, innovations or investments impact SDGs, one can better understand the opportunities and difficulties of implementing them," Associate Professor Liang said, adding that this understanding will facilitate the alignment of impact management with organisations and investors' pursuit of various SDG targets.
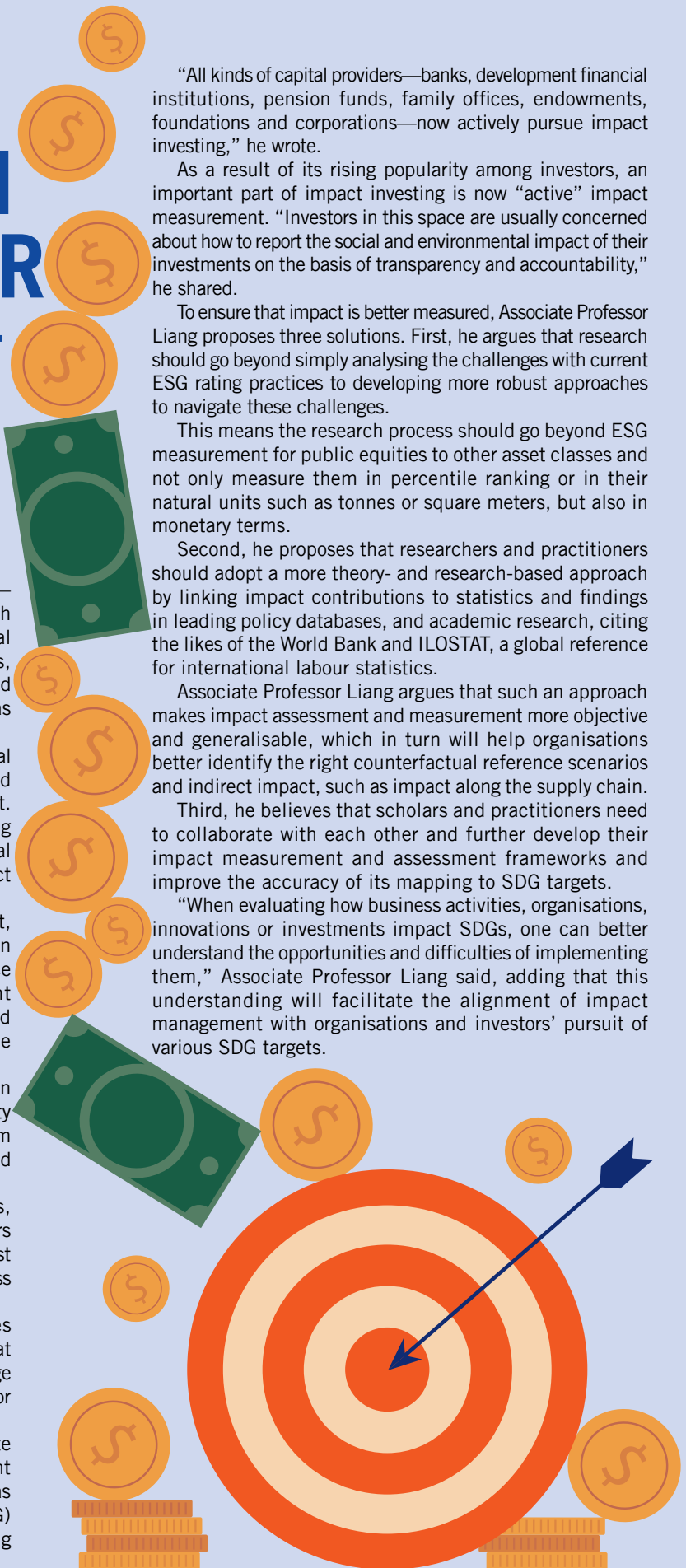
# BUILDING AN INCLUSIVE SINGAPORE STARTS AT HOME

**Singapore's housing policy has provided affordable and inclusive home ownership for the vast majority of its citizens, writes Professor Phang Sock Yong of SMU's School of Economics.**

If you've ever watched the 2018 romantic comedy-drama film *Crazy Rich Asians*, you might get the impression that Singapore is a nation of millionaires who, just like the movie's male protagonist Nick Young, live in similarly sprawling and opulent mansions.

Art does imitate life to a certain degree, it seems. Singapore indeed has the world's highest concentration of millionaires and one of the most expensive housing markets in Asia. But at the same time, it is also a place where a young family can afford to own a home of their own, thanks to the land and housing policies implemented by Singapore's Housing and Development Board (HDB).

According to Professor Phang Sock Yong of SMU's School of Economics, these policies "have produced some unusual outcomes compared to other cities in the world".

Professor Phang made the statement in a recent book chapter titled 'Building an equitable and inclusive city through housing policies: Singapore's experience'. In it, she argued that Singapore's success in designing and implementing an equitable housing policy can be a case study for narrowing inequality in other cities elsewhere.

"The biggest and most dynamic cities in a country also tend to have the highest housing prices, highest concentration of housing wealth, and the largest income and wealth inequality gaps," she noted.

Singapore is rather unique where land ownership is concerned: the densely populated city of 5.5 million people also happens to be a country where 90 percent of the land belongs to the government. Today, 78 percent of Singapore's resident households live in high-rise apartments originally built by government agencies.

Building an inclusive city has required deft policymaking on Singapore's part, meaning the country had to go significantly beyond relying on taxes, Professor Phang shared. She explained that Singapore uses a suite of inter-related policies which covers the entire spectrum–from land and housing legislation to housing market regulations, taxes and subsidies.

In her research, Professor Phang identified the policies that have helped Singapore close the housing inequality gap. These include, among others, setting stringent criteria to filter eligible buyers while ensuring the wealthy do not "crowd out" households with lesser means.

In addition to reducing wealth inequality, ensuring ethnic integration is another priority. While residential areas were originally segregated along racial lines and Chinese dialect groups in colonial Singapore, in the 1970s, HDB deliberately allocated new flats in a way that accounted for a diverse racial mix. In 1989, ethnic quotas were introduced to prevent races from "regrouping" through the HDB resale market.

The Singapore government also has the power to acquire land from private owners for economic development purposes, including for residential projects. Meanwhile, the government has put in place measures to reduce investment and speculative demand for land as well as housing.

Progressive property taxes have also helped move the needle towards more inclusive home ownership. For instance, the residential property tax regime rates for owner-occupied housing starts at 0 percent for annual values up to S$8,000 and will rise to 32 percent for annual values above S$100,000 by 2024.

Despite the advances made, Professor Phang noted that challenges still remain. Issues that require review include Singapore's ageing population, slowing social mobility and the integration of foreigners working in Singapore.

However, Professor Phang emphasised that these challenges should not detract from Singapore's significant achievements in making home ownership affordable and building an inclusive society for the vast majority of its resident population.

# WHAT MAKES A BOND "GREEN"?

**International standards will bring clarity to the green-bond market and prevent greenwashing practices, says Professor Dave Fernandez of SMU's Sim Kee Boon Institute for Financial Economics.**

Demand for sustainable finance products is booming among institutional and retail investors alike. Take green bonds, for example. According to the Climate Bonds Initiative, annual green bond issuance in 2021 broke the half-trillion mark for the first time at US$522.7 billion—a 75 percent increase from past year volumes. Green bonds also drew in 839 issuers during that year, with the average size of individual green bonds rising by more than 50 percent to US$250 million.

Sustainable finance is the practice of taking environmental, social, and governance (ESG) considerations into account when making investment decisions, explained Professor Dave Fernandez, Director of the SMU's Sim Kee Boon Institute for Financial Economics and Co-Director at the Singapore Green Finance Centre.

The blurring of lines between traditional profit-driven enterprises seeking financial gains and non-profit organisations seeking to achieve social or environmental good has given rise to "hybrid" organisations that combine profit-generating operations and a larger societal mission, he explained.

"Investing in such firms, or making so-called socially responsible investments (SRIs), is becoming increasingly common as impact investors proactively seek financial returns and positive social and environmental impact," he said.

Despite the growing investor interest in SRIs, there remains limited information regarding its societal impact, Professor Fernandez noted. He cited a Global Impact Investing Network 2020 report in which the investors surveyed viewed the inability to demonstrate impact results and compare impact results with peers as a key challenge to sustainable investing gaining widespread acceptance.

"Given the appetite for green-themed investments, it has become essential to determine whether securities, such as green bonds, qualify for green status or not, and how well investments have been allocated," he explained, adding that such detailed social and environmental performance data would be helpful to investors in incorporating non-financial information into their investment process.

"Many frameworks have been developed for organisations to report their ESG impact, but there is an absence of standardisation and comparability across different frameworks," Professor Fernandez said, highlighting greenwashing as a challenge this industry faces today.

Greenwashing, which occurs when an organisation makes false, unsupported or misleading statements or claims to raise money from investors, could "undermine green-bond usage and its relevance for a net-zero economy transition", he explained.

Another concern is the lack of consistent sustainability standards applied uniformly across the sector. "Numerous ESG metrics focus on public equity, mainly collecting data from large corporations. Since small- and medium-sized businesses form a critical part of the Asian economy, previous approaches have limitations," he said.

But there are some noteworthy improvements in sustainable investing, he added. For starters, regulators have been actively developing ways to inform issuers and investors, improve the quality of reporting, and prevent greenwashing practices.

One such development is the proposed EU Taxonomy and the Green Bond Principles and Standards, which seeks to create a European standard for the green-bond market that defines more clearly what is "green". The proposed EU Green Bond standard would remain voluntary, but its requirements will be stricter than existing market guidelines.

"These frameworks and regulations aim to improve information, reduce greenwashing and facilitate the development of high-quality green bond issuances in the global market," Professor Fernandez said. "We hope that by involving various stakeholders such as industry experts, banks and regulators openly in the framework development, we will be able to alleviate the challenges of measuring ESG performance."

# HELPING SINGAPORE AGE WITH GRACE

The world is rapidly ageing. The United Nations reports that by 2050, the planet will house close to half a billion people older than 80 years.

While this can be seen as a sign of overall progress— longer life expectancies often reflect advances in medicine and nutrition—it also poses unique challenges. Ageing seniors face more health problems, which can be further compounded by income instability brought about by retirement and dwindling job opportunities.

In aggregate, these challenges can bear down on the economy, which will need to provide long-term health and hospice care, social security and wellness services for an increasing proportion of the populace. Meanwhile, authorities and policymakers also must contend with a shrinking labour force, whose wellbeing and mental health are also being threatened by mounting workplace and societal pressures.

The situation is complex, urgent and uncharted—and SMU is rising to the challenge. In the articles that follow, researchers working under the University's Sustainable Ageing and Wellness pillar take stock of the current state of matters and pave the way forward, developing policy recommendations and innovative technologies that can help Singapore live and age with grace.

In **How Did Seniors Fare During the Circuit Breaker?**, researchers from SMU's Centre for Research on Successful Ageing (ROSA) illustrate how the COVID-19 pandemic exacerbated feelings of social isolation and loneliness among Singapore's seniors, in turn compromising their life satisfaction. The findings from their working paper and Singapore Life Panel (SLP) survey results could provide important pointers and guidelines for the country's decision-makers.

Alongside policy efforts, SMU is also working on technologies for ageing well. In **Sensing in Full One's Daily Schedule**, a team of researchers led by Professor Tan Ah Hwee, have developed an algorithm that can accurately recognise and monitor full daily routines, whereas other existing technologies can only track individual activities. Professor Tan's model opens the doors to fully integrated, smart and assistive homes for elderly adults.

The final article in this series, **Casting a Wi-Fi Safety Net for Stress and Depression**, looks at wellness on a much broader scale. SMU Associate Professor Rajesh Balan, with his colleagues, developed StressMon, a non-intrusive detection solution that leverages Wi-Fi networks to evaluate social and physical networks between people. By recognising changes in a person's movement and social interactions, StressMon enables a more holistic assessment of a person's stress levels and mental health risks.

# HOW DID SENIORS FARE DURING THE CIRCUIT BREAKER?

**Data from SMU's Singapore Life Panel reveals how the circuit breaker made seniors feel more isolated and less satisfied with life.**

As the dust settled from the initial chaos of the COVID-19 pandemic, psychologists and psychiatrists sounded the alarm about another public health emergency waiting to happen. Prolonged stay-at-home orders risked cutting people off from their social support networks, experts warned. This, combined with an overload of negative news surrounding the pandemic, could trigger a large-scale mental health crisis.

Older adults are more vulnerable not only to the virus' physical damage, but also to its psychological harms. But without a clear understanding of the specific ways older adults suffer mentally during the pandemic, targeted and effective solutions cannot be crafted for them—leaving them further behind as the world enters the new normal.

Seeking to rectify this is SMU's Centre for Research on Successful Ageing (ROSA), which has continuously examined the wellbeing of Singapore's senior citizens throughout the pandemic.

One of the earliest measures the Singapore government took to combat COVID-19 was to institute the circuit breaker in April 2020, a two-month partial lockdown that restricted outdoor movement only to the most essential activities.

While the circuit breaker was largely successful in keeping infections down, a recent working paper by ROSA researchers showed that the wellbeing of country's older adult population was at an all-time low during this time. These figures were drawn from the Centre's Singapore Life Panel (SLP), a monthly survey of more than 7,000 respondents aged between 55 to 75 years old who report on their wellbeing and recent life circumstances.

SLP data showed that life satisfaction was lowest during the circuit breaker and improved only starting June 2020, when the tight restrictions were lifted and Singapore entered its first phase of reopening. Life satisfaction plateaued a few months after and—as of June 2022—has still not returned to pre-pandemic levels, suggesting that older adults continue to face significant challenges to their wellbeing in the aftermath of the pandemic.

Seeking to identify factors that could explain this phenomenon, the interdisciplinary team at ROSA examined a range of factors known to have an impact on life satisfaction. They found that social isolation and feelings of loneliness were strong drivers of low life satisfaction. Seniors who lived alone and didn't participate in social activities were very dissatisfied with their lives. This effect was so strong that even at a time when many people were dissatisfied with their lives, socially active seniors reported better life satisfaction than those who were solitary.

On this note, ROSA's analysis revealed another important, but perhaps unexpected, facet of wellbeing in elderly adults: technology literacy.

Despite the lockdown, most Singaporeans were able to maintain their social networks to some degree online with technology. The matter isn't as simple for seniors, however, who may not be as comfortable with or knowledgeable about digital communication.

Further supporting this point is the SLP data that showed that in 2020, feelings of isolation and life dissatisfaction was consistently higher among older adults who used no more than one form of communication technology compared to those who used more.

These findings reveal a crucial opportunity for more pointed policy interventions that take into account the specific needs and capabilities of their target beneficiaries, say the researchers. For instance, policymakers could create programmes to boost technology literacy among seniors and encourage them to build and maintain digital networks with their friends and families.

The researchers add that interventions should also extend beyond the online realm as the country reopens. To combat loneliness and social isolation, local authorities could institute neighbourhood interest groups to build a healthy community of seniors.

Taken together, ROSA's research highlights the importance of making room for seniors in Singapore's new normal.

# SENSING IN FULL ONE'S DAILY SCHEDULE

**Professor Tan Ah Hwee has developed a computer model to encode and monitor daily routines, opening the doors for fully integrated smart homes that can look out for their residents' health and wellbeing.**

What does your daily routine look like? Do you bathe before breakfast? How often do you go out for errands? As mundane as these details may sound, knowing the intricacies of one's daily routine is very valuable from a health perspective, especially for older adults.

Collectively, the tasks in a person's day-to-day routine are called activities of daily living (ADLs). In seniors, even minor alterations in ADLs could be early signals of impending health problems. Taking longer to complete housework or difficulties getting dressed, for instance, could be warning signs of cognitive decline.

Researchers have long known the importance of monitoring individual ADLs in seniors, and several mathematical models, devices and sensors have already been developed for this purpose. However, methods of monitoring one's routine—

that is, the collective daily set and typical sequence of ADLs—remain relatively under-explored.

There is a good reason behind the lack of models and technologies for monitoring daily routines: complexity. The exact order and number of ADLs, their time allotment and the type of activities themselves often vary from day to day, depending on many different factors.

For instance, one might choose to delay or skip their daily exercise because it's raining outside. Meanwhile, a business or leisure trip could alter typical mealtimes or bedtime. Even individual human differences matter: some older adults are more spontaneous than others, and this would reflect in their more flexible daily routine.

Algorithms to learn and monitor daily ADL routines should therefore be able to tolerate and account for these variations. Though this may make development challenging, it would also more faithfully capture how an elderly person goes about their day—and would more reliably detect worrying signals of potential health problems.

Rising up to this challenge is Professor Tan Ah Hwee, Professor of Computer Science and the Associate Dean of Research of the School of Computing and Information Systems at SMU. To deal with the complexity of routines, Professor Tan and his team of researchers developed a self-organising neural network model called Spatial-Temporal ADL Adaptive Resonance Theory (STADLART), which uses three levels of data processing to learn patterns of an individual's ADLs.

STADLART's first layer primarily accepts basic input information from different wearable sensors, such as the type of ADLs, time, location and day. The second layer synthesises these data to build associations between the different ADLs and when and where they are performed.

In the third layer, the ADLs are laid out in sequence according to their spatiotemporal information, giving rise to the user's overall routine.

A computer model that can accurately learn someone's daily routines—and not just their individual activities—helps set the foundations for smart homes that not only maximise comfort and convenience, but can also be mindful of their residents' health.

Using STADLART, a network of Internet-connected devices and appliances could one day learn a person's daily habits and schedules as they live in the house. For instance, an algorithm could detect that on most days, the resident usually goes to the toilet early in the morning. Meanwhile, another routine pattern could show that the resident prepares meals at specific and regular intervals over the duration of the day, and that they usually like to bathe afterward.

As the algorithm becomes better acquainted with the resident, it might eventually also detect worrying deviations in their routine and flag the attention of healthcare professionals or the resident's family.

Such is Professor Tan's goal for STADLART moving forward. Further model iteration and development will make STADLART more accurate at identifying activities, patterns, routines and problematic abnormalities. Other points of improvement include automating the interpretation of the learned routines, as well as expanding the algorithm to accept even partial ADL inputs.

**25 Jun 2022**
25 mins
**26 Jun 2022**
28 mins

# CASTING A WI-FI SAFETY NET FOR STRESS AND DEPRESSION

**Using only a user's location data, Associate Professor Rajesh Balan has developed an accurate, highly practical Wi-Fi-based system to spot people at risk of severe stress and depression.**

The climate crisis. A global economic downturn. Rising geopolitical tensions. These are just some of our most pressing problems today, compounded even further by complications from the COVID-19 pandemic. It is no surprise that these issues can bear down heavily on our psyche and cause stress which, when left unchecked, can worsen into clinical depression.

While there is great incentive to prevent stress from progressing to depression, for those already suffering from the condition, early detection and intervention is crucial for recovery. To aid with timely detection, many groups have developed technologies that can monitor signs of depression.
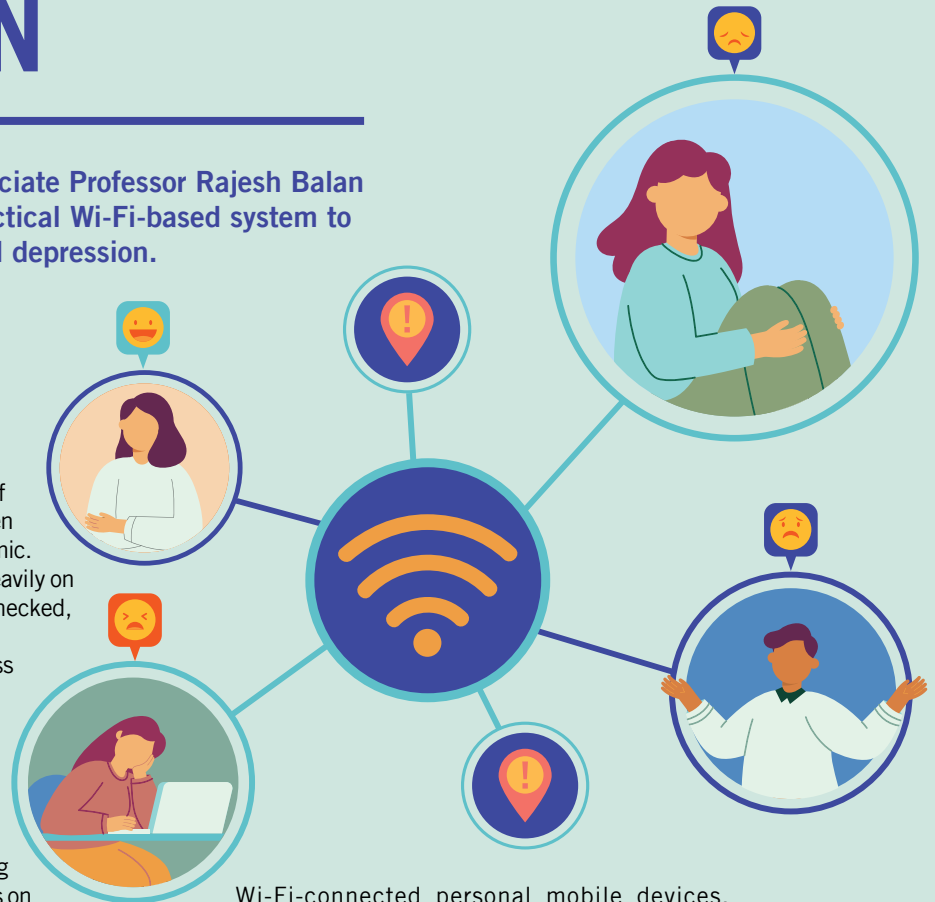
However, these solutions usually require users to install an app or wear unwieldy sensors, making scaling difficult. Existing solutions also tend to focus on individual factors such as sleep timing or speech patterns while overlooking social interactions, which are just as important in the assessment of stress and depression.

Rising to address this blind spot is a team of researchers led by Associate Professor Rajesh Balan of SMU's School of Computing and Information Systems. Their solution, called StressMon, is a passive sensing technology that connects to existing Wi-Fi networks to look out for individuals who may be under severe stress or at risk of depression.

Designed to be a network-wide "safety net," StressMon combines two prior technologies: a Wi-Fi-based indoor localisation method to track any connected device and a system to cluster devices together into logical groups based on location information. For easier deployment, the researchers tweaked these two methods to use only a single type of data input: user location.

While a singular focus can seem limiting, much can be gleaned from location data. After tracking changes in location, Associate Professor Balan's team employed machine learning methods to deduce users' typical daily routines and interactions. Such data allowed the researchers to spot worrisome changes in behaviour and flag them as potential signals of distress.

Furthermore, because StressMon non-invasively monitors stress and depression through a network of Wi-Fi-connected personal mobile devices, it doesn't require separate wearable sensors. Instead, StressMon draws location data from all Wi-Fi-connected devices in the vicinity and applies data processing and machine learning algorithms to identify stressed individuals at risk of depression.

This ease of use is StressMon's biggest selling point. "Users do not need install data collection apps or provide regular survey data," explained Associate Professor Balan. "Instead, the data is collected using sensors that are already installed such as Wi-Fi access points. Participants do not have to change their behaviour or install anything to participate."

But to be truly useful, StressMon must be more than just practical—it has to be accurate too. When tested on three separate cohorts of university students over two weeks, StressMon's true positive rate was better than 90 percent: it correctly identified a student under severe stress and depression in more than nine out of every ten cases.

"StressMon showed the viability of using Wi-Fi signals as a means of detecting stress and other mental health conditions," said Associate Professor Balan. Now, his team is looking to extend their findings to develop additional solutions that can detect other conditions such as social isolation or early onset of dementia in the elderly.

# BUILDINGS THAT WON'T COST THE EARTH

Sustainability relates to our ability to coexist harmoniously with the planet. In this vein, the built environment sector plays an important role in tackling complex issues and achieving goals under humanity's overarching global imperative to curb climate change.

A sustainable built environment is one that is circular in design; marrying elements of resiliency, adaptability, flexibility, longevity, reuse, and recoverability, while keeping future climate risks front of mind.

To create such environments, it is of paramount importance to advance sustainable building designs, as buildings— and their construction—are both significant energy consumers and key drivers of greenhouse gas emissions. The International Energy Agency (IEA) reports that the built environment sector accounts for almost one-third of the world's total final energy consumption and nearly 15 percent of its direct carbon dioxide emissions.

Yet in the short term, there will also be an inevitable need to build up urban infrastructure extensively, driven by factors such as improved access to energy and rapid growth of buildings, particularly in developing nations.

To accommodate these demands while limiting climate risk, it is essential to accelerate the shift towards healthy, sustainable built environments. In this section, we highlight the progress made by SMU researchers towards this sector of a more sustainable Singapore.

In **Keeping Singapore Cool in a Warming Climate**, Associate Professor Winston Chow spearheads the multidisciplinary Cooling Singapore 2.0 project to address urban heat, an issue increasingly challenging to the nation. The project will birth an island-wide Digital Urban Climate Twin (DUCT), a system designed to prioritise urban cooling strategies as previously assessed and established in research. To this end, DUCT has already shed light on the need for an integrated combination of strategies with the collaboration of various agencies and stakeholders as there is no "silver bullet" when it comes to battling urban heating.

"How do we create truly energy-efficient buildings that reduce power consumption while maintaining occupant comfort and productivity?" queries Professor Archan Misra. In **Applying AI to Make Future Buildings Greener**, Professor Misra's research team examines how camera- or Wi-Fi-based sensors might improve occupancy estimation techniques for fine-grained, energy-efficient smart buildings. They found that different devices suited different spaces, and while a combined solution would reduce errors significantly, a solution's associated cost and complexity might prevent wide-scale adoptions. While initially focused on lighting, the team plans to further apply their findings towards some of the most energy-intensive building operations in Singapore: ventilation and air conditioning.
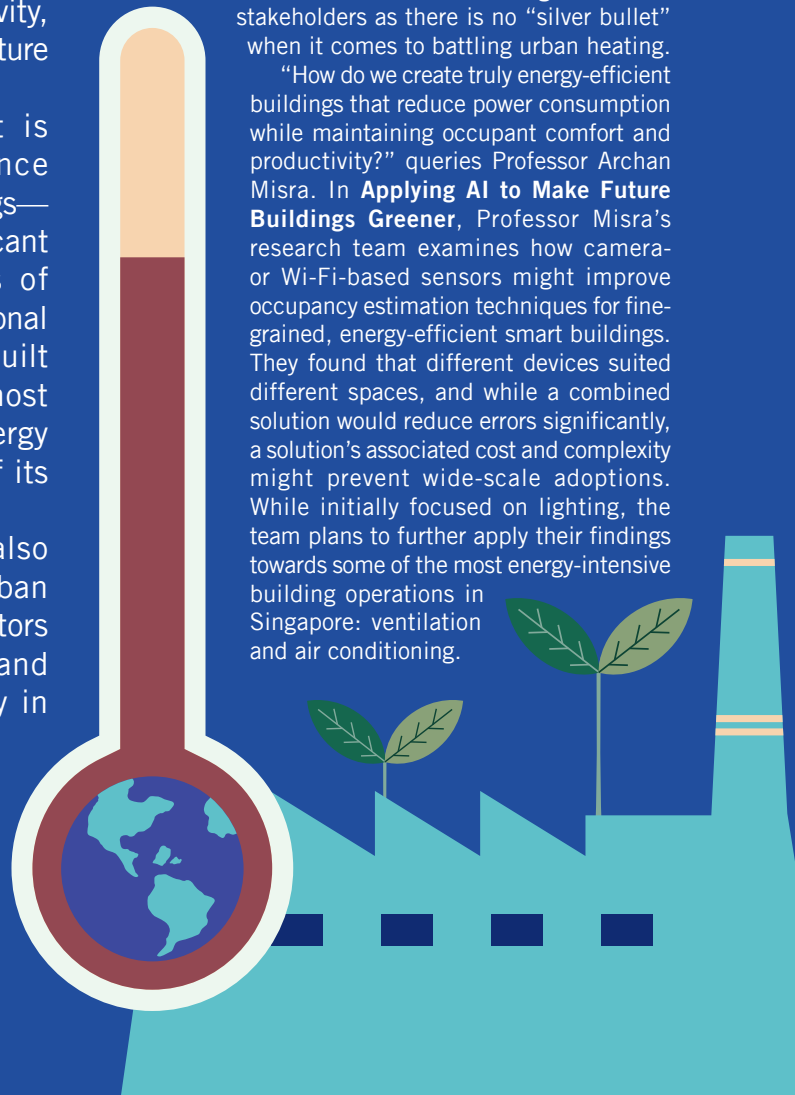
# KEEPING SINGAPORE COOL IN A WARMING CLIMATE

**SMU researchers lead the second phase of the Cooling Singapore project to identify practical, sustainable and scalable solutions to tackle the nation's growing urban heat challenges.**

Year-round heat and humidity—already unbearable for many—are some of the hallmarks of Singapore's climate. For a densely populated metropolis in the tropics, the slow but sure rise in ambient temperature is more than a quirk of the weather. Due to the repercussions of climate-induced urban heating, rising temperatures are expected to be detrimental to Singapore's population, economy and ecosystems.

Rising temperatures also perpetuate a viciously unsustainable cycle. More air-conditioning systems, which are still largely powered by non-renewable energy sources in Singapore, will be put on full blast to keep interior spaces cool. This not only pumps out more heat into the atmosphere, but also emits copious amounts of greenhouse gases that further exacerbate climate change. Coupled with the advent of hefty carbon taxes over the coming decade, the increased use of air conditioning will also place a heavier economic burden on the shoulders of both Singaporean businesses and consumers alike.

So while cooling techniques have been around for a long time, the challenge lies in formulating combinations that are truly effective in the long run—one that can combat the rise of urban heat and can be sustainably deployed on a large scale.

To fill these gaps, Winston Chow, Associate Professor of Urban Climate at SMU's College of Integrative Studies and his research team are part of the multi-institute Cooling Singapore project funded by Singapore's National Research Foundation.

The earlier phases of the project, Cooling Singapore 1.0 and 1.5, laid the foundation for the research team to assess climate-related impacts such as the urban heat island (UHI) effect and outdoor thermal comfort (OTC). The findings provided crucial tools and models to establish a catalogue of potential heat mitigation strategies.

Now, the Cooling Singapore 2.0 project builds on previous research to create an island-wide Digital Urban Climate Twin (DUCT)—a decision-support system helping to prioritise the preferred cooling strategies through environmental, economic and social performance scores.

"In Cooling Singapore 2.0, we first assess the combinations of heat reduction approaches using a variety of validated climate, energy, transport and building models that realistically represent changes in the ambient environment," said Associate Professor Chow. "We subsequently apply them in DUCT for stakeholders such as government agencies to ascertain the efficiency and effectiveness of such approaches before deciding on a policy for a given area."

According to Associate Professor Chow, DUCT overcomes the challenges in sustainable cooling by demonstrating that there is no "silver bullet" when it comes to shaping a policy or a solution to tackle rising temperatures in Singapore.

"Instead, our work has shown that an integrated combination of approaches—one that expands green (vegetation) and blue (water) spaces, facilitates smarter urban design and planning and commercialises energy-efficient technologies in the industrial, construction and transport sectors—is paramount to curbing the rise in temperatures," added Associate Professor Chow.

In terms of project progress, the research team is now testing and validating all the models in DUCT, planned to be finalised for stakeholders by the fourth quarter of 2023. Associate Professor Chow also revealed that the three-year Cooling Singapore 2.0 project will have a second stage which utilises DUCT to examine the heat risks on people and vegetation in Singapore in a warmer climate. The effort will be led by SMU, involving collaborations with colleagues from the National University of Singapore and Nanyang Technological University.

Associate Professor Chow emphasised that these integrative multi-agency and multi-stakeholder approaches are likely to give the most ideal outcomes to cool the country.

# APPLYING AI TO MAKE FUTURE BUILDINGS GREENER

**Research from Professor Archan Misra determines how sensor data from cameras and Wi-Fi networks can help Singapore's smart buildings estimate occupancy numbers and adjust energy usage.**

Imagine a city where residents can function optimally each day without any extensive use of the planet's resources. According to the International Energy Agency, buildings today consume more than a third of global energy use and energy-related carbon dioxide emissions. But to meet the targets set out in the landmark Paris Agreement, emissions from buildings must be 80 to 90 percent lower than they are today. Therefore, it is key to ensure that new and existing buildings are sustainable and energy-efficient.

Working in tandem towards this end are four main elements: decarbonisation, electrification, efficiency improvement and digitalisation. The latter two, when combined, are important enablers of energy efficiency but require buildings to dynamically adjust their operations in responses to changes in usage and occupancy patterns. For example, smart buildings can harness sensors, integrated control systems, data analytics and artificial intelligence (AI) to actively optimise energy use without degrading the comfort and functioning of building occupants.

However, several issues in occupancy estimation persist, which can affect the overall energy efficiency of smart buildings. Firstly, the technology must be fine-grained enough for high sensitivity. It should also ideally utilise existing building infrastructure such as Wi-Fi networks and cameras to minimise costs. Furthermore, the solutions should take advantage of commonly carried devices such as Wi-Fi-enabled smartphones and possess the flexibility to accommodate different forms of occupant movement behaviour, while maximising their comfort.

To address these issues, Professor Archan Misra at the SMU's School of Computing and Information Systems leads a research team that has investigated the effectiveness of using either Wi-Fi or cameras or a combination of both as sensors for occupancy estimation. By coupling such sensing with AI-based techniques to adjust lighting or cooling, the solutions can automatically learn from and adapt to both medium and short-term changes in building occupancy patterns.

Professor Misra and his team discovered that cameras are better suited for public spaces with poor Wi-Fi infrastructure, such as train stations or town halls, since such areas have non-regular occupants and therefore less privacy concerns.

"The issue about non-regular occupants, such as those passing through a train station, is important because Wi-Fi sensing counts the number of devices connected to a given network," said Professor Misra. "As these random visitors generally do not connect to public Wi-Fi, they will be excluded from the occupancy count, which lowers the overall accuracy of the solution."

On the other hand, Wi-Fi-based sensing works best in places with ample Wi-Fi access points, frequented by regular occupants who habitually connect to the network. Furthermore, since Wi-Fi signals are not blocked by objects, this technique also thrives in environments dominated by visual occlusion.

While a combination of both Wi-Fi and camera techniques is the most precise as it marries sensing data from both channels to reduce errors, Professor Misra believes that Wi-Fi may offer a more appealing, less expensive pathway for retrofitting a majority of buildings in Singapore to support occupancy estimation in the near term.

"While it may not be the most accurate solution, Wi-Fi is essentially ubiquitous in public or commercial spaces in Singapore, thus a Wi-Fi-based solution can be deployed widely and almost immediately," he explained. "In contrast, a combined solution would require deploying cameras if there aren't any existing ones, and carefully addressing potential privacy concerns in certain areas."

As testament to their techniques, the research team's smart lighting system deployed in the open-plan collaborative space of the SMU Connexion building has already been demonstrated to save up to 40 percent of the energy costs spent on lighting. This system applies AI algorithms on Wi-Fi and camera data to not just estimate occupancy, but also the brightness levels, of different tables in the space. These estimates are then used to automatically perform continuous microscopic adjustments to the brightness levels of the LED lights, saving energy without sacrificing the perceived brightness at any occupied tables. Professor Misra and his colleagues are in discussions with potential industry partners to adopt this technology.

Moving forward, the team also aims to apply and integrate their findings with artificial intelligence solutions to monitor and adjust additional indoor environmental parameters. A key priority is ventilation and air-conditioning in Singapore, which can typically cost a third of a building's energy budget.
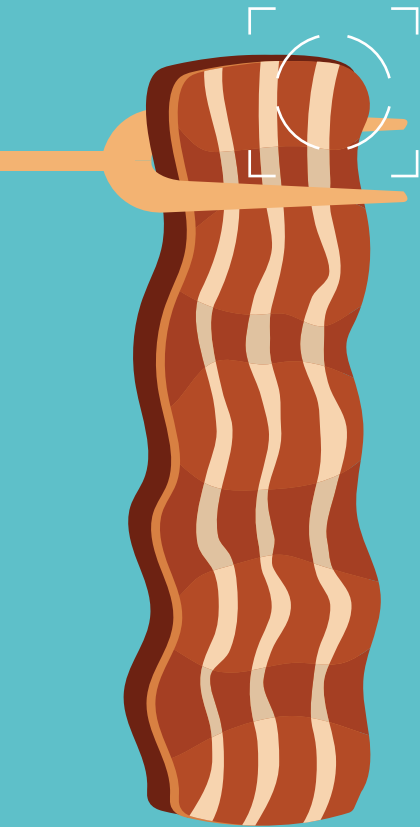
# A RECIPE FOR MORE SUSTAINABLE FOOD CONSUMPTION

Sustainable food consumption has been around since the time of our hunter-gatherer ancestors, who lived off what nature could provide. This lifestyle was a necessity for early humans, who lacked the scientific, economic and technological knowledge to produce food on an industrial scale.

Yet more than 10,000 years later, sustainable eating has been brought to the fore once again—this time as a strategy to combat both the toll on our health taken by the abundance of processed foods and the growing threat of climate change on food security.

Now, scholars across SMU are honing their expertise to understand and develop solutions to the myriad effects of modern lifestyles on our food systems. In the articles that follow, thought leaders from the Schools of Social Sciences, Computing and Information Systems and Business tackle the diverse topic by exploring the impact of external pressures on supply chains and the macroeconomics of food; technological tools to help consumers navigate their health; and public attitudes that could help or hinder the acceptance of alternate food sources.

Businesses are subject to constant external pressures ranging from consumer demands to ever-changing economic and political landscapes. In some cases, these pressures can be transformative. However, agribusinesses remain highly susceptible to the effects of natural disasters. In **Realising Resilience Through Diversity**, Associate Professor Forrest Zhang investigates how the economic transformation of rural Chinese communities is helping them cope with potentially devastating external threats.

At the other end of the supply chain, consumers are now faced with more food choices than ever before, with unhealthy options fuelling global epidemics of obesity and diabetes. One solution to traditionally high effort dietary interventions such as portion size measurement and food logging could be to automate these processes with multimedia analytics. In **Picking Apart Food Ingredients with AI**, Professor Ngo Chong Wah explores how artificial intelligence (AI) technologies can empower consumers to take charge of their health.

Scientific advances have also enabled the development of various innovations to combat food shortages with more nutritious alternatives to common crops, such as the advent of vitamin A-enriched Golden Rice, pest-resistant Bt rice and alternative proteins. However, stigma and lack of awareness among consumers can affect uptake of these innovations. In **Trailblazing a Path to Alternative Proteins Acceptance**, Associate Professor Mark Chong seeks to understand public attitudes to alternative proteins—a fast-growing symbol of sustainable food consumption in urban areas.

# REALISING RESILIENCE THROUGH DIVERSITY

**A study by Associate Professor Forrest Zhang finds that a diversified economic structure offers a rural Chinese community the resilience needed to buffer the early effects of the pandemic.**

The COVID-19 pandemic has left a mark on businesses the world over—some have shuttered their doors while others have dramatically scaled down personnel and production. These events are largely a consequence of the strict lockdowns and travel restrictions instated by governments in early 2020, measures that unwittingly halted global and local supply chains and sent shockwaves through businesses across urban and rural divides.

Associate Professor Forrest Zhang of SMU's School of Social Sciences, who has spent decades researching agricultural development in China, has recently been studying the effects of the pandemic on rural communities. In a 2019 video from SMU, he highlighted the need to rethink our perception of the rural community.

"It's no longer a homogeneous population," he said. "People are relying on different sources of income for their livelihood," he said.

As such, many villages across rural China can be classified as economic structures called diversified economic clusters, where members engage in a variety of livelihoods, employment types, and work across a range of distances. Researchers studying this issue theorise that these diverse communities should have high levels of resilience and flexibility in the face of external shocks like the pandemic.

On the back of this theory, Associate Professor Zhang and his colleagues sought to understand how households with different degrees of market integration in these clusters responded to the COVID-19 pandemic. To do this, the team interviewed households engaged in a range of employment types in Norwind village, a diversified economic community located in Shandong Province in Northern China, from the end of December 2019 to the end of April 2020 when recovery efforts began in the region.

The researchers found that the pandemic response—which included shutting down sections of highways leading into the region—had varied effects on businesses in Norwind. Those that were least integrated into markets, such as traditional family farms, fared the best, while businesses that catered to small scales of the community, like local restaurants, were hit hardest.

They also found evidence of the theorised benefits of diversified economic communities. Specifically, in Norwind, integrated businesses with long-distance operations who found their spatial connections disrupted by the lockdown were able to adapt to find new local markets.

For example, a business that normally supplied apples, long beans and cucumbers to a wholesale center located in the neighbouring county shifted to providing produce to local villagers in response to the growing need for fresh fruit and vegetables after the first week of lockdown.

The new venture was aided by "space-shrinking" technologies such as the messaging application WeChat, which enabled the owner to build a 300-person-large customer-base and implement cashless payment. The business' social standing in its community also allowed it to act as a distribution center for local vegetable growers who could no longer sell through their regular channels.

Ultimately, the impact of the pandemic on Norwind's economy was both modest and transient, with most businesses able to resume normal operations by the end of April 2020. However, while the team found clear evidence that the community's economic diversity helped it endure the first phase of the pandemic, they noted that this does not necessarily reflect an ability to remain resilient with further market decline.

"Short-term impacts and coping processes may differ significantly from long-lasting impacts and coping processes," the team wrote, adding that longer-term studies will be needed to examine changes in local responses to ongoing waves of the pandemic and thereafter.
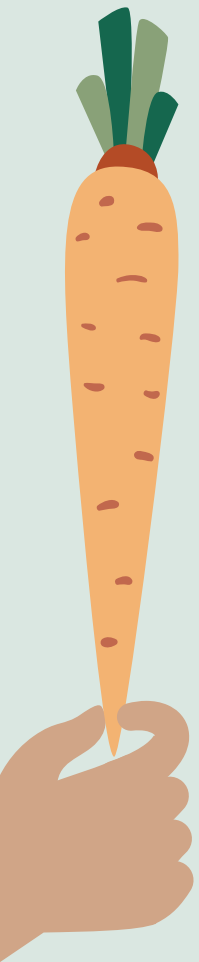
# PICKING APART FOOD INGREDIENTS WITH AI

**Professor Ngo Chong Wah's exploration of how neural networks recognise ingredients in digital photographs of food could enhance health and nutritional interventions.**

In restaurants today, one of the most common scenes you'll encounter is someone with a smartphone in hand, taking pictures of their food. For most people, these photographs simply serve as memories of the good meals they had. But what if pictures of our food could also have health-related applications, such as helping to combat increasingly prevalent diseases like obesity and diabetes?

Normally, individuals with these afflictions are encouraged to log their daily food intake in a food diary. Physicians can then use this information to assess their nutritional needs and recommend appropriate interventions. However, manually documenting the ingredients of each meal is cumbersome and unreliable, and often underestimates what the person actually consumed.

According to Professor Ngo Chong Wah of SMU's School of Computing and Information Systems, training a machine to automatically recognise ingredients in a photograph could offer more accurate and efficient results. However, while several artificial intelligence (AI) algorithms can successfully identify meals, doing so for individual ingredients has proved challenging.

Notably, ingredients can range in size, shape and colour depending on how they are cut and cooked. These variations are especially pronounced in Chinese dishes. "This domain is particularly tricky because dishes are often composed of a variety of ingredients being fuzzily mixed, rather than separated into different food containers or as non-overlapping food items as frequently seen in Japanese and Western dishes," Professor Ngo and his colleagues noted in a recent paper titled 'A Study of Multi-Task and Region-Wise Deep Learning for Food Ingredient Recognition'.

The answer to this problem could lie in more complex AI algorithms called neural networks, which mimic how the human brain processes information. In their study, Professor Ngo and his team compared the performance of two such models for identifying ingredients in Chinese food.

The first method, called multi-task learning, identifies the dish or food category and then leverages this information to recognise ingredients. In contrast, the second method, called region-wise recognition, identifies ingredients through the single task of analysing local patches of the image.

To conduct their comparisons, the team contributed a new dataset called Vero Food-251, which contains over 160,000 images of 251 popular Chinese food items, encompassing over 400 ingredients. For each food category, they randomly picked

60 percent of images on which to train each algorithm, used 10 percent for validation, and the remaining 30 percent for testing.

Based on metrics that measured the algorithms' precision and recall capabilities, the team found that the two models had unique advantages and disadvantages. Specifically, the multi-task learning method was more effective for recognising ingredients that were unique to few dishes, but tended to confuse those found in many different foods in the database.

The latter, the researchers noted, was a consequence of using food category information as input to help the model identify ingredients. A deeper dive also showed that poor recognition of ingredients was generally related to having fewer available examples on which to train the model.

Compared to multi-task learning, the region-wise recognition method was more effective for identifying small-sized ingredients and those with fewer training examples. Due to its local-acting nature, the algorithm could also be used to accurately pinpoint the location of individual ingredients in each image.

Although, intuitively, combining the two methods should enhance ingredient recognition, the team actually found the opposite. "The models' conflicting learning objectives caused performance to degrade. This suggested the need to develop more sophisticated networks that can adaptively combine the results of the two models in the future," said Professor Ngo.

# TRAILBLAZING A PATH TO ALTERNATIVE PROTEINS ACCEPTANCE

**Associate Professor Mark Chong finds that the cultural trait of "kiasuism," or the fear of being left behind, may be a major motivator driving Singapore's acceptance of lab-grown meat.**

Just a few years ago, names like Impossible Foods and Eat Just were known to only a handful of trend-seeking foodies. Fast forward to today and they are two of the most recognisable companies among hundreds offering alternative protein products. Rather than simply pushing a new fad, these businesses are manufacturing solutions to the dire multifactorial problem of food security—one our growing appetite for animal-based protein is helping to perpetuate.

With alternative proteins touted as both more sustainable and healthier than their animal-based counterparts, transitioning our diets toward these products could both ease pressure on global food systems and address the rise in diet-related diseases. However, consumers have historically been sceptical of new food technologies: genetically-modified organisms for example. One type of alternative protein known as lab-grown meat, so named because it is produced from animal cells in a laboratory, could be similarly contentious.

Understanding the motivations that drive people's food choices could help companies and governments better communicate the benefits of potentially controversial innovations like lab-grown meat. In a new study, Associate Professor Mark Chong of SMU's Lee Kong Chian School of Business marries his research interests in novel food technologies and communication to do just this.

Associate Professor Chong's research focused specifically on the contribution of social image motivations, or the need to convey a particular impression of ourselves to others. Similar to common drivers of food choice like taste and nutrition, these more implicit concerns can manifest in different ways in different cultures.

For example, in the US, which is considered a culturally "loose" nation, individuals may be more open to new food technologies as a way of standing out or a form of self-expression. Meanwhile, social image motivations for Singaporeans are likely related to a cultural trait known as "kiasuism," colloquially defined as the fear of losing out or being left behind.

Associate Professor Chong and his collaborators from SMU's School of Social Sciences, Professor Angela Leung and PhD student Verity Lua, studied differences in attitudes to lab-grown meat between the two nations by comparing survey data from over 750 American and 600 Singaporean participants with representative ethnic and gender characteristics of their respective populations.
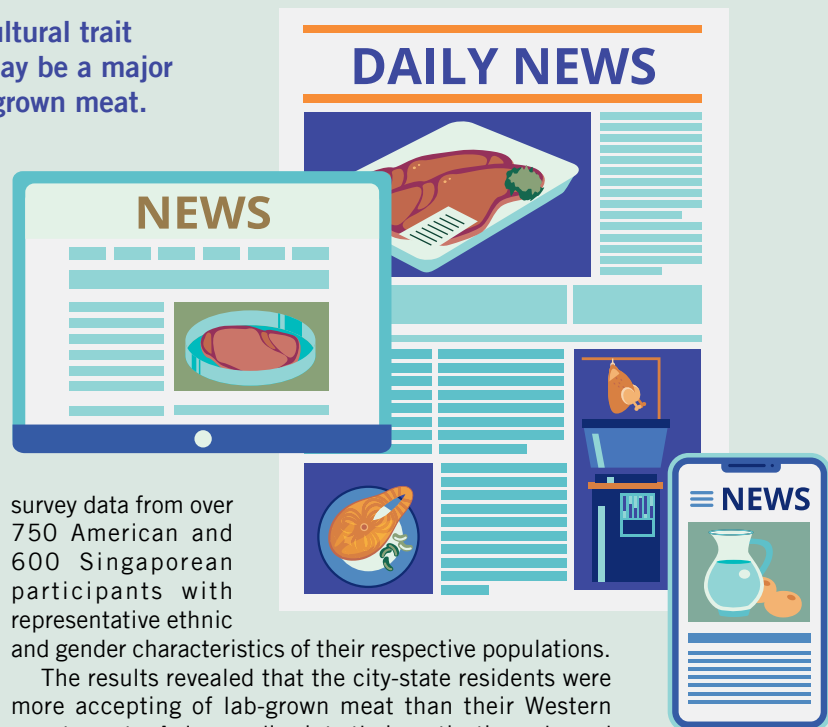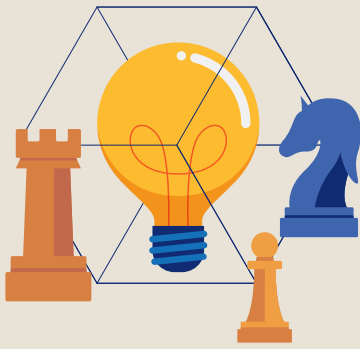
The results revealed that the city-state residents were more accepting of lab-grown meat than their Western counterparts. A deeper dive into their motivations showed that Singaporeans were more driven by social image concerns than Americans.

"Singaporeans are more motivated to present a favourable image of themselves to others through their actions, and these actions can include eating specific foods that put them in the position of being trailblazers," explained Associate Professor Chong on Channel NewsAsia in 2022.

The team also compared the influence of celebrities and experts on social media on these attitudes. Although, anecdotally, celebrity endorsements appear to have a powerful sway on product acceptance, the researchers found that there was no difference between that and the effect of expert influencers on consumer attitudes towards lab-grown meat.

Associate Professor Chong is mindful of the fact that the study did not examine the impact of social media influencers on consumer acceptance per se, but simply the influence of celebrities compared to experts.

"We suggest lab-grown meat companies and other players in the industry to boost their media coverage, and this includes social media coverage, of product-firsts," said Associate Professor Chong. He added that by promoting 'firsts' such as the first lab-grown chicken or beef in the world, companies could feed into Singaporean consumers' implicit desire to be trailblazers.
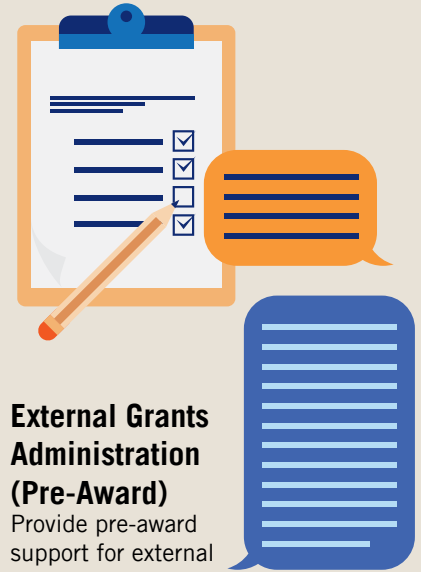
# ABOUT SMU
# RESEARCH OFFICE

SMU's institutional office overseeing and supporting a variety of research grant matters at the University level. Provides support to faculty across the research grants life cycle in these areas:

## Planning & Policy
Shape, narrate and implement University-wide research strategies and policies to create meaning research impact.

## Research Capacity Building
Strengthen SMU's capacity and capability to secure external research funding.

## External Grants Administration (Pre-Award)
Provide pre-award support for external research grants.

## Research Contracting
Review and negotiate research contract terms and conditions with external parties to align with SMU's interests.

## Research Administration Metrics
Use or derive metrics to support and improve research planning, administration and reporting.
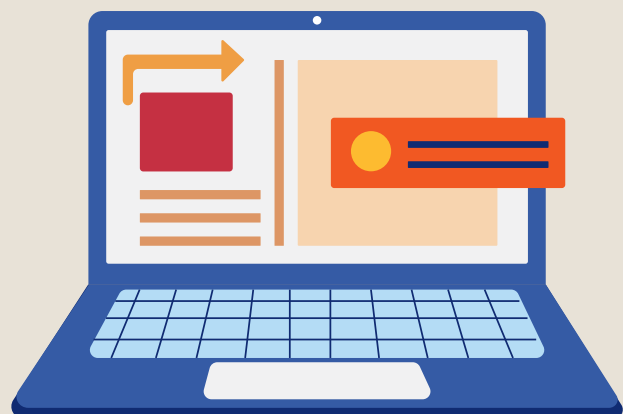
## Outreach & Engagement
Raise awareness of research conducted by SMU to seed both internal and external collaborations.

## Integrated Research Information System (IRIS)
Co-champion with IT department to develop and maintain a research grants management system.

## Sustainable Business Operations

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**Managing the Load on Loading Bays**
LAU Hoong Chuin
*Professor of Computer Science; Principal Scientist, Institute of High Performance Computing; (Joint Appointment with A\*STAR Research Entities)*

**Going the Last-Mile**
Aldy GUNAWAN
*Assistant Professor of Computer Science (Practice)*

**Feeding a Growing World**
Onur BOYABATLI
*Associate Professor of Operations Management*

**Pooling the Benefits of Sharing a Ride**
WANG Hai
*Associate Professor of Information Systems; Lee Kong Chian Fellow*

## Sustainable Finance and Impact Assessment

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**When Going Green Becomes a Grey Area**
ZHANG Liandong
*Lee Kong Chian Professor of Accounting; Associate Dean (Research)*

**Making an Impact with Every Dollar**
LIANG Hao
*Associate Professor of Finance; Co-Director, Singapore Green Finance Centre*

**Building an Inclusive Singapore Starts at Home**
PHANG Sock Yong
*Celia Moh Chair Professor of Economics*

**What Makes a Bond "Green"?**
Dave FERNANDEZ
*Professor of Finance (Practice); Director, Sim Kee Boon Institute for Financial Economics*

# Sustainable
# Ageing & Wellness

**How Did Seniors Fare During the Circuit Breaker?**
SMU's Centre for Research on Successful Ageing (ROSA)

**Sensing in Full One's Daily Schedule**
TAN Ah Hwee
*Professor of Computer Science;*
*Associate Dean (Research); Jubilee Technology Fellow*

**Casting a Wi-Fi Safety Net for Stress and Depression**
Rajesh BALAN
*Associate Professor of Computer Science*

# Sustainable
# Urban Infrastructure

**Keeping Singapore Cool in a Warming Climate**
Winston CHOW
*Associate Professor of Urban Climate;*
*Lee Kong Chian Fellow*

**Applying AI to Make Future Buildings Greener**
Archan MISRA
*Vice Provost (Research); Professor of Computer Science;*
*Co-Director, A\*STAR-SMU Joint Lab in Social & Human-*
*Centered Computing*
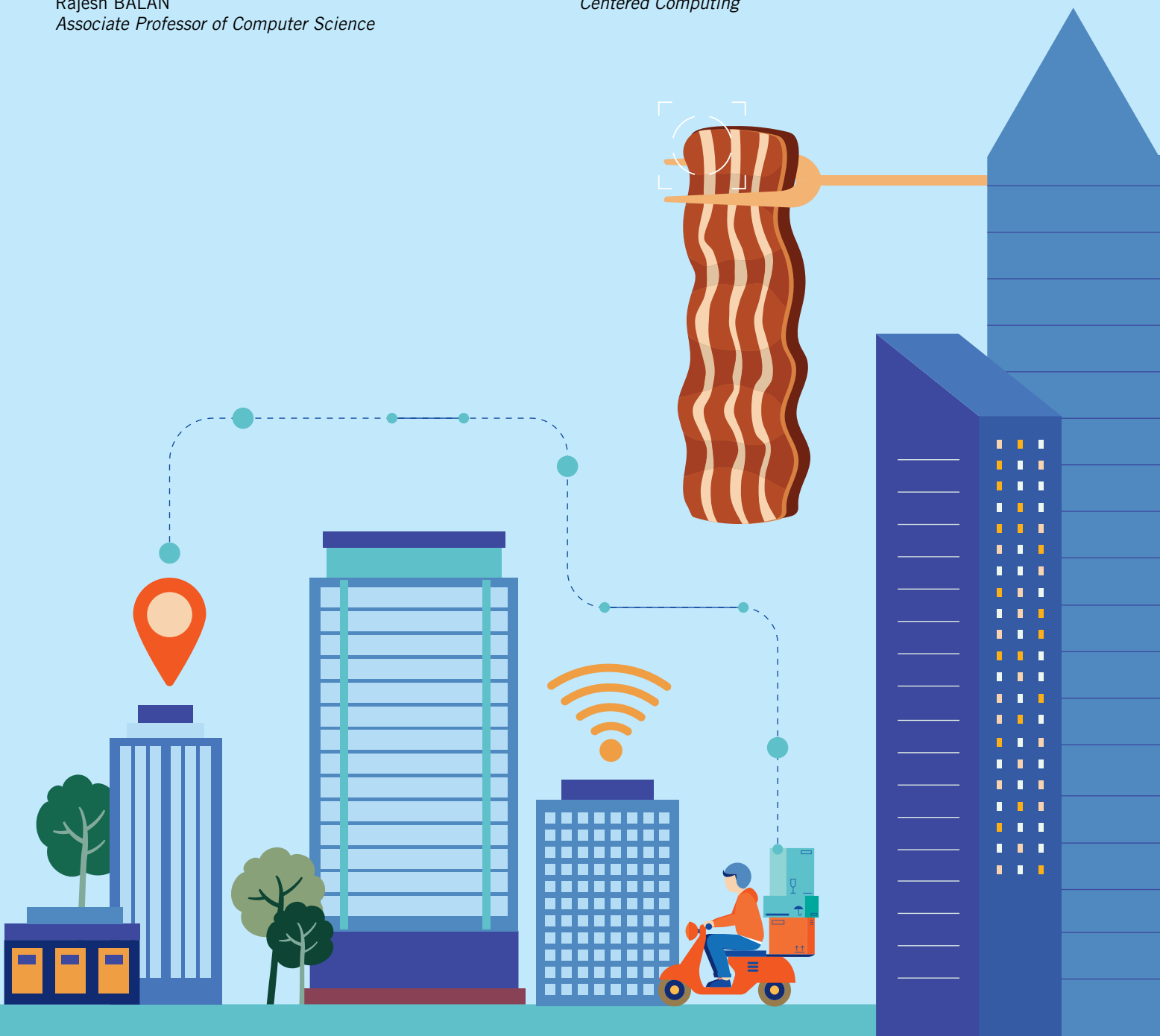
# Sustainable Agro-business and Food Consumption

**Realising Resilience Through Diversity**
Forrest ZHANG
*Associate Professor of Sociology;*
*Associate Dean (Research)*

**Picking Apart Food Ingredients with AI**
NGO Chong Wah
*Professor of Computer Science; Director,*
*Human-Machine Collaborative Systems Cluster*

**Trailblazing a Path to Alternative Proteins Acceptance**
Mark CHONG
*Associate Professor of Communication*
*Management (Practice); Area Coordinator,*
*Communication Management*

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# SMU

## SINGAPORE MANAGEMENT UNIVERSITY