

Sustainability Adaptation to Climate Change: Evidence from the Wine Industries in China

Iat Meng Chan

City University of Macau, Macau, China

The study considers sustainability adaptation measures within China's wine industry in the wake of the increasing threat to climate change and the mutual influence exerted by climate variation on viticulture. Returning to the increasingly dominant Chinese wine sector, the study investigates how wineries implement adaptive measures against environmental volatility. Through a qualitative interpretive study approach with semi-structured interviews with key stakeholders within the Ningxia region, the research identifies possible sustainable practices, addresses constraints to their adoption, and considers what conditions enable potential opportunities. Early indications show investments currently being made into precision agriculture, renewable energy, and organic management, with increasing consumer awareness around sustainable packaging. On the other hand, several challenges remain, including high costs of upfront investment, lack of on-the-ground technical know-how, and inconsistent policy support framework. This study provides insight into practical adaptation strategies and structural constraints, with recommendations for industry actors and policymakers in China appropriate to context; hence, lessons for other wine-producing regions facing similar climate stressors are available.

Keywords: climate change, sustainability, wine industry, China, adaptation

Introduction

Climate change represents a crucial and growing threat to world viticulture, really affecting important things of temperature increases and meteorological variability: wine quality, sugar levels, and alcoholic strength (Pahr, Grunow, & Amorim, 2024). It has been emphasized how severely this threat is posed by 2023 being confirmed by NASA to be the warmest year on record, and the direct need for all agricultural sectors to have climate resilience stands endorsed (Bardan, 2024). Such extreme weather events caused them to miss harvests increasingly and heavily affected the financial performance of winemakers globally (Mutascu, Lessoua, & Murgea, 2024).

Table 1 indicated that China has rapidly risen as a major wine-producing country in this global environment. However, despite the growing international presence, Chinese wineries face grave struggles from environmental volatility. Climate change, in practice, bringing undesirable effects through temperature increments, changing precipitation patterns, and drought hazards on wine-producing regions, threatens the long-term sustainability of major areas (Wheeler & Marning, 2019). Hence, a comprehension must be developed to see how the industry in China is responding to these threats through sustainability.

Iat Meng Chan, Doctor of Business Administration, Faculty of Business, City University of Macau, Macau, China.

Correspondence concerning this article should be addressed to Iat Meng Chan, Unit 1701, 17/F, Wai Fung Plaza, 664 Nathan Road, Mongkok, Hong Kong.

Table 1

Statistics of Wine Production Countries

	2024 vineyard surface area	World ranking
Spain	930,495 hectares	1st
France	783,049 hectares	2nd
China	752,065 hectares	3rd
Italy	728,255 hectares	4th

Note. Source: <https://www.oiv.int/what-we-do/country-report?oiv>.

The literature sets and initial studies, including this one, suggest that there is a wide spectrum of technologies and environmental measures taken by Chinese wineries. Many have focused on long-term adaptation technologies, such as precision agriculture tools including crop-diagnostics, and weather-dependent forecasting service to enable data management of resources and to cushion extreme weather events (Wang, He, Yu, & Li, 2024). A small number of different vineyards are trying alternative cultivars and irrigation methods to save water and to build resilience towards their changing climate (Aijaz et al., 2025). Again, research on the adoption of renewable energy sources with solar energy and wind power being the most favourable comes into the picture as an effort to reduce carbon footprints, while at the same time, organic modes of agricultural management are evolving, to lessen the effects of chemicals and improve ecosystem services (Volanti et al., 2021). Consumer preference for sustainable options seems to have also contributed towards the adoption of eco-friendly wine packaging (Orlowski, Lefebvre, & Back, 2022), which indicates that from the standpoint of marketing, sustainability offers a competitive advantage.

Nevertheless, the world must somehow find ways for these practices to be accepted on a wide scale. Many small wineries and family vineyards consider advanced technologies out of their rather meagre reach due to heavy upfront investment costs (Latessa, Hanley, & Tao, 2023). A universal lack of technical knowledge and irregular access to pertinent training opportunities, primarily for rural producers, generates an asymmetry in their synergy realization. Secondly, given the absence of a policy that supports the sector in a stable manner and the consequent regulatory inconsistencies created by regions, certain levels of uncertainties can present themselves, thus obstructing any long-term planning of sustainability (Mura, Vicentini, Botti, & Chiriaco, 2022). To address this research gap, the present study aims to analyze these adaptations, barriers, and enablers within the Chinese wine industry comprehensively. This would allow the provision of context-sensitive recommendations aimed towards a more robust sector.

Hence, climate change is a great and growing threat to global viticulture. Some adaptive measures are in the process of being tried on, but still, huge obstacles from costs to inconsistent policy support halt their dissemination. Thereby, it is essential to understand how the Chinese wine industry is responding to threats from sustainability.

Research Objectives

This research, in all its entirety, is to be done as a complete study of sustainability adaptation strategies opted for by the Chinese wine industry under threats of climate change.

- (1) To research sustainable practices that wineries have adapted to combat climate associated challenges.
- (2) To assess the barriers and enablers to adopt sustainability measures in the wine industry.
- (3) To recommend concrete suggestions for industry actors and policymakers to enhance the resilience of the sector.

Methodology

Table 2

Characteristics of Interviewed Vineyard Managers in Ningxia

Participant ID	Position	Winery size (hectares)	Years of experience	Key area of focus
P1	Vineyard manager	Less than 5	5	Technical knowledge
P2	Vineyard manager	Less than 5	10	Technical knowledge
P3	Vineyard manager	Around 10	11	Cost-efficiency
P4	Vineyard manager	Around 20	10	Water management
P5	Vineyard manager	Around 20	8	Water management
P6	Vineyard manager	Over 50	11	Alternative grape varieties
Total	6 vineyard managers			

Table 2 showed that, the research methodology of this qualitative and interpretive study identifies key stakeholders of which the China-based wine industry has experiences perceiving their sustainability implications impacting the climate challenges in response to climate variability by interviewing stakeholders about their motivations and behaviors of sustainability practices. In Ningxia, semi-structured interviews of six vineyard managers are conducted. These regions are selected both for their significance in China's development of modern viticulture, and for their different exposure to climatic stressors. Interviews explore participants' use of adaptation strategies, technology adoption, regulatory frameworks, and sustainability awareness. Thematic analysis is used to allow for the voice of participants to organically shine through each theme that recurs. This fosters internal exposure to local practices, institutional opportunity, and innovation. Through situating the findings in a wider sustainability context, the research seeks to highlight the stark realities of adaptation in practice and what conditions could shape more sustained complex interactions between climate and ecological systems.

Results

The semi-structured interviews with important stakeholders of the wine-producing region in Ningxia unfold a multiplicity of approaches and challenges to the sustainability adaptation to climate change. From this series of interviews, three main themes arose.

Table 3

Sustainable Practices Being Adopted by Chinese Wineries

Practice category	Specific practice	Description/benefit
Resource management	Precision agriculture	Actively practiced for efficient resource use and countering climate vagaries, including crop diagnostics and weather-dependent forecasting systems.
Energy	Renewable energy (solar & wind)	Utilized to keep the carbon footprint low.
Agricultural methods	Organic management	Employed to nurture soil health and biodiversity.
Packaging	Sustainable packaging	Gaining momentum due to increasing consumer environmental consciousness, including lightweight glass bottles and biodegradable alternatives.
Agricultural methods	Alternative cultivars (implied in intro)	Mentioned in the introduction as being tried by a small number of vineyards to build resilience towards changing climate.
Resource management	Water-saving irrigation methods (implied)	Mentioned in the introduction as being tried by a small number of vineyards to save water and build resilience towards changing climate.

Table 3 showed that the wineries are actively practicing precision agriculture for efficient resource use and countering the vagaries of climate. Weather-dependent forecasting systems and diagnosis of crops are some

such systems. Renewable energy, from solar to wind, is being channelled to keep the carbon footprint low besides employing organic methods to nurture soil health and biodiversity. Sustainable packaging, be it lightweight glass bottles from the source or any biodegradable alternatives, is gaining momentum propelled by increasing consumer environmental consciousness.

Table 4

Identified Barriers to Sustainability Adoption in the Chinese Wine Industry

Barrier category	Specific barrier	Impact on adoption
Financial	High upfront investment costs	Advanced technologies require large initial investments, often placing a strain on small wineries. Stakeholders expressed concern over the financial risk of abandoning previously accepted practices, as successful returns are not guaranteed.
Knowledge/capacity	Lack of technical know-how	There is insufficient technical knowledge or training opportunities, especially in rural areas, which prevents producers from effectively adopting sustainable practices.
Policy/regulatory	Inconsistent policies and regulatory frameworks	Policies and regulatory frameworks at the regional level have been inconsistent, creating an environment of uncertainty. This discourages wineries from engaging in long-term planning for sustainability.

Table 4 showed that the barriers to the adoption of advanced technologies have always been noted for the large initial investments required, most times placing a strain on small wineries. The stakeholders, in many instances, expressed concern over the financial risk of abandoning previously accepted practices, since any successful returns are not guaranteed. There is no technical know-how or sufficient training opportunities for such purpose especially in rural areas to enable producers to better adopt sustainable practices. Policies and regulatory frameworks at the regional level have been everything but consistent, keeping in place an environment of uncertainty that discourages wineries from long-term planning.

Table 5

Enabling Factors and Opportunities for Sustainability in the Chinese Wine Industry

Category	Specific enabling factor/opportunity	Description/impact
Collaborations	Partnerships with research institutes and agencies	Successful collaborations allow wineries to gain technical know-how, access funding, and innovate.
Consumer demand	Growing interest in sustainable products	Increased sales and brand loyalty due to rising consumer preference for eco-friendly wine and packaging.
Innovations	Experimentation with alternative grape varieties	Unique climatic conditions in Ningxia offer opportunities to develop drought-resistant grape varieties.
Market incentives	Competitive advantage of sustainability	Eco-conscious practices provide wineries with a marketing edge and meet global sustainability trends.
Government support	Potential for policy and financial incentives	Support through grants, subsidies, and low-interest loans reduces the financial burden of sustainability.
Technological advancements	Use of precision agriculture and renewable energy	Adoption of advanced tools and renewable energy helps reduce costs and improve resource efficiency.

Table 5 summarizes the enabling factors and opportunities that create a pathway for Chinese wineries to implement sustainable practices effectively. It is usually believed that realizing sustainability programs contingent upon partnership must be formed among wineries, research institutes, and government agencies. Stakeholders have mentioned successful collaborations that involved the sharing of technical know-how and worthy competition for grants. The eco-conscious consumer waits patiently for the sustainable option, which is the incentive for wineries to explore sustainability. Hence, many stakeholders have felt the increase in sales along with brand loyalty due to their green initiatives. Ningxia's specific climatic situation may serve as a favourable ground for testing alternative grape varieties or irrigation practices, inducing innovation.

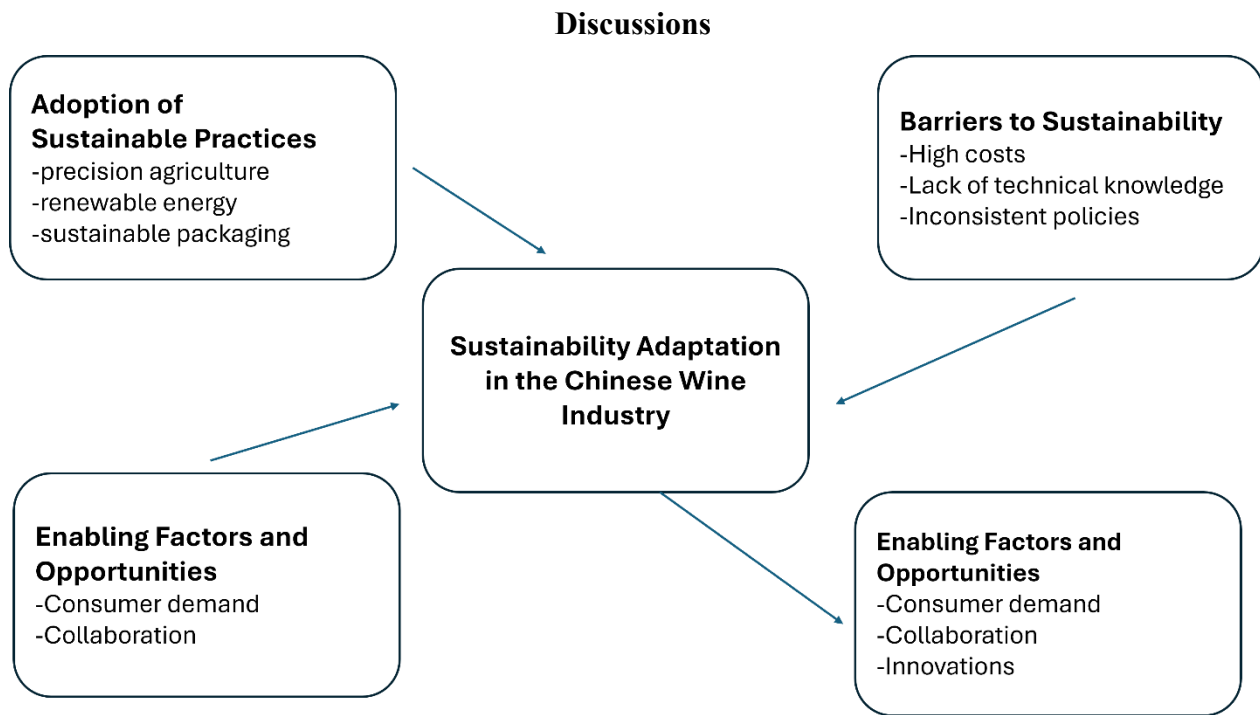


Figure 1. Relationships between the challenges and opportunities.

Figure 1 would illustrate the complex web of obstacles and favourable conditions influencing the Chinese wine industry's sustainability adaptation. This would show how structural constraints such as capital constraints, lack of technical know-how, and fragmented regulatory frameworks present serious impediments. At the same time, it brings to light opportunities such as the rising consumer demand for sustainable products, potential collaborative partnerships among industry players, research institutions, and government bodies, and the distinct climate of regions such as Ningxia that engenders innovation for grape varieties and irrigation methods. Essentially, this chart shows through addressing these barriers how they can explore and take advantage of these opportunities to achieve sustainable development of the sector. The discussion focuses on four major aspects.

Adaptation Strategies and Their Effectiveness

Precision agriculture, renewable energy technologies, and organic methods are adopted on a proactive basis to offset climate risks; yet their use and efficiency may vary within the sector. Better-capitalized large wineries are at the forefront of adaptation, with small producers unable to keep up. This situation highlights that targeted assistance is needed to ensure that sustainable practices are within reach of all.

Structural Constraints to Sustainability

The barriers identified by this study—financial constraints, technical knowledge gaps, and regulatory inconsistencies—highlight the structure that impedes the large-scale implementation of sustainable work. To overcome these barriers, policy interventions must be undertaken at all levels and by various bodies ranging from the government to industry associations and educational institutes. For instance, grants for sustainable technologies, capacity-building programs, and creation of a harmonized policy environment will go a long way in enhancing the industry's robustness.

How Consumer Demand Affects Change

Increased demand for sustainability is becoming a major force of change in the wine industry. The rising acceptance of environmentally based packaging and organic wines corroborates this trend. Certainly, this trend stands to benefit the wineries that have made the conscious decision to associate their brand with sustainability while simultaneously encouraging others to walk the same path. On the other hand, the greatest challenge to attaining consumer trust and keeping it will continue to be maintaining an image of sustainability without sacrificing profuse application.

Global Implications

From Ningxia's perspective, various lessons learned carry greater weight for other wine regions that might qualify under this type of climate to produce wine. The adaptation of technology, renewable energy, and farming techniques are adaptable models. Conversely, looking at systemic barriers and consumer demand exemplifies that practice cannot sustain itself.

Sustainability practices have certainly witnessed giant strides in adoption. The industry will now have to tackle residual issues to become resilient over the long run. Stakeholders attempting to cooperate, with more outcome-focused policy interventions and market incentives, would strongly buttress sustainability in the way of tackling climate change.

Recommendations

Table 6

Consolidated Recommendations for Sustainability Adaptation

Category	Recommendations	Description/impact
Industry actors	Prioritize investment in adaptive technologies	Invest in precision agriculture tools, such as crop diagnostics and weather forecasting, and adopt renewable energy solutions like solar and wind power to improve efficiency and reduce carbon footprints.
	Embrace organic and sustainable agronomic practices	Implement organic farming practices to enhance soil health, promote biodiversity, minimize chemical use, and explore drought-resistant grape varieties and efficient irrigation methods.
	Actively seek partnerships and knowledge sharing	Collaborate with research institutes and other wineries to exchange technical knowledge, gain access to grants, and address common sustainability challenges.
Policymakers	Develop consistent and supportive policy frameworks	Establish unified policies and provide financial incentives (grants, subsidies, low-interest loans) to reduce financial barriers for small- and medium-sized wineries adopting sustainable practices.
	Invest in capacity building and technical training	Organize workshops and training programs for rural producers to improve technical knowledge and support the adoption of sustainable viticulture practices.
	Promote and support research and development	Fund research on climate-resilient grape varieties, water-saving irrigation technologies, and other innovative solutions tailored to diverse wine-producing regions.
	Leverage consumer demand for sustainability	Develop certification and labeling programs for sustainable wine production and conduct public awareness campaigns to educate consumers on the benefits of eco-friendly wines.

Table 6 consolidates the key recommendations for both industry actors and policymakers to enhance the resilience of the Chinese wine sector and promote sustainability amid climate change challenges. According to the comments from six vineyard managers, some suggestions could be imparted to the industry and policymakers that would lead the Chinese wine industry to face climate change in a stronger and more sustainable manner.

For Industry Actors (Wineries and Vineyard Managers)

Prioritize investment in adaptive technologies. Adoption of precision agriculture tools to include crop diagnostics and weather-dependent forecasting systems must be continued to ensure optimum use of resources and buffer through climate variabilities. Those solar panels or wind turbines are integrated to reduce carbon footprints and rather to set operational costs in the long term. Consumer awareness being ever so predominant, eco-friendly packaging solutions such as light glass bottles or biodegradable options should be invested in and adopted, which also hold their own competitive advantage.

Embrace organic and sustainable agronomic practices. The Chinese wineries now should pursue development, research, and execution of further organic agricultural management systems with the aim of improving soil health, biodiversity, and ecosystem services, using the least amount of chemicals. Set up trials for some alternative grape varieties and efficient irrigation techniques and technologies that could be more drought-hardy and suitable to changing climates, using the uniqueness of the climate of Ningxia for such innovations.

Actively seek partnerships and knowledge sharing. To gain technical know-how, knowledge of the most recent climate adaptation methods, and to be included in grant applications for sustainable projects, partner with research institutes. Another platform for the exchange of know-how should be created between wineries so that larger, well-capitalized wineries can learn from the small wineries in terms of best practices and common technical problems.

For Policymakers and Government Agencies

Develop consistent and supportive policy frameworks. Working towards more unified and harmonized frameworks for policy and regulation at regional and national levels is bound to minimize uncertainties, thus helping in long-term planning for the sustainability of the industry with growing poses. Targeted financial incentives in the form of grants, subsidies, and low-interest loans should be furnished with the objective of aiding wineries, primarily small- and medium-sized enterprises, in overcoming the huge upfront costs associated with the implementation of advanced sustainable technologies and practices.

Invest in capacity building and technical training. Develop and fund workshops and comprehensive training programs for rural producers to address the lack of technical know-how and improve access to information relevant to sustainable viticulture and climate adaptation. Another way of implementing this action is strengthening agricultural extension services specifically for the wine industry to provide on-the-ground technical support and technical advice to wineries in the implementation of sustainable practices.

Promote and support research and development. Funding should be provided for research on climate-resilient grape varieties, for water-saving irrigation systems, and for other novel solutions fit for the different wine-producing regions in China. Likewise, the collection and sharing of climate data and forecasting services should be supported to enable wineries to better identify crop management and risk mitigation queries.

Leverage consumer demand for sustainability. Initiate clear and credible certification and labelling schemes for the sustainable manufacture of wines so that consumers may identify and pick eco-friendly products, increasing demand for sustainable practices in the market at least as strong. Carry out public awareness programs to educate consumers on the importance of sustainable wine production and on the benefits of choosing environmentally responsible products.

By following these suggestions, the wine industry of China can become more resistant to climate change while also transforming itself into a leader for sustainable viticulture globally, thereby offering some valuable lessons for other wine-growing regions hit by similar climate stressors.

Conclusions

Dedicated to this study was the investigation of the sustainability adaptation strategies within the changing wine sector of China, specifically Ningxia, given the ever-growing threats of climate change. Using a qualitative interpretative approach with semi-structured interviews, key stakeholders contributed to describing the current sustainable practices, revealing the obstructions to a wider use, and identifying key enabling factors and opportunities for further implementation.

The results reference Chinese wineries that are adopting proactive sustainable behaviours, namely precision agriculture investment, the use of various sources of renewable energy, and organic management. On the other side, the growing need for awareness regarding sustainable packaging is influencing the industries. A handful of challenges stand in the way of full sustainability, such as heavy upfront capital investment, an obvious gap in technical know-how and trained technical service, and sometimes counterproductive policy and regulatory frameworks. Notwithstanding challenges, the study pointed out that cross-sector partnerships, the increasing demand from green consumers, and the potential of Ningxia's unique climatic conditions present powerful drivers for a sustainable change.

In essence, although there is a marked trend of the Chinese wine industry towards sustainable growth, its long-term resilience is hostage to the structural constraints that characterize the situation. The recommendations forwarded are for industry actors as well as policymakers—from financial incentives to capacity-building programs, a concrete and consistent policy framework, and the use of consumer demand—as measures to create a more resilient and flexible sector. Ultimately, the findings from Ningxia highlight specially tailored lessons to look at and follow by other wine-producing regions around the world that find themselves facing similar climate-based challenges, pointing to a universal call for cooperative efforts, strategic interventions, and market incentives towards securing a sustainable future for viticulture.

References

- Aijaz, N., Lan, H., Raza, T., Yaqub, M., Iqbal, R., & Pathan, M. S. (2025). Artificial intelligence in agriculture: Advancing crop productivity and sustainability. *Journal of Agriculture and Food Research*, 20(6), 101762. Retrieved from <https://doi.org/10.1016/j.jafr.2025.101762>
- Baran, R. (2024). *NASA analysis confirms 2023 as warmest year on record*. NASA. Retrieved from <https://www.nasa.gov/news-release/nasa-analysis-confirms-2023-as-warmest-year-on-record>
- Latessa, S. H., Hanley, L., & Tao, W. (2023). Characteristics and practical treatment technologies of winery wastewater: A review for wastewater management at small wineries. *Journal of Environmental Management*, 342, 118343. Retrieved from <https://doi.org/10.1016/j.jenvman.2023.118343>
- Mura, R., Vicentini, F., Botti, L. M., & Chiriaco, M. V. (2022). Economic and environmental outcomes of a sustainable and circular approach: Case study of an Italian wine-producing firm. *Journal of Business Research*, 154, 113300. Retrieved from <https://doi.org/10.1016/j.jbusres.2022.113300>
- Mutascu, M., Lessoua, A., & Murgea, A. (2024). Tropospheric ozone—Hidden cost for the financial performance of French wineries. *Journal of Environmental Management*, 368, 122112. Retrieved from <https://doi.org/10.1016/j.jenvman.2024.122112>
- Orlowski, M., Lefebvre, S., & Back, R. M. (2022). Thinking outside the bottle: Effects of alternative wine packaging. *Journal of Retailing and Consumer Services*, 69, 103117. Retrieved from <https://doi.org/10.1016/j.jretconser.2022.103117>
- Pahr, A., Grunow, M., & Amorim, P. (2024). Learning from the aggregated optimum: Managing port wine inventory in the face of climate risks. *European Journal of Operational Research*, 323(2), 671-685. Retrieved from <https://doi.org/10.1016/j.ejor.2024.11.046>
- Volanti, M., Martínez, C. C., Cespi, D., Lopez-Baeza, E., Vassura, I., & Passarini, F. (2021). Environmental sustainability assessment of organic vineyard practices from a life cycle perspective. *International Journal of Environmental Science and Technology*, 19(6), 4645-4658. Retrieved from <https://doi.org/10.1007/s13762-021-03688-2>

- Wang, L., He, X. H., Yu, H., & Li, Y. (2024). What influences the development of wine-producing regions? New economic opportunities in the eastern foothills of the Helan Mountains in China. *Journal of Rural Studies*, 112, 103453. Retrieved from <https://doi.org/10.1016/j.jrurstud.2024.103453>
- Wheeler, S. A., & Marning, A. (2019). Turning water into wine: Exploring water security perceptions and adaptation behaviour amongst conventional, organic and biodynamic grape growers. *Land Use Policy*, 82, 528-537. Retrieved from <https://doi.org/10.1016/j.landusepol.2018.12.034>