

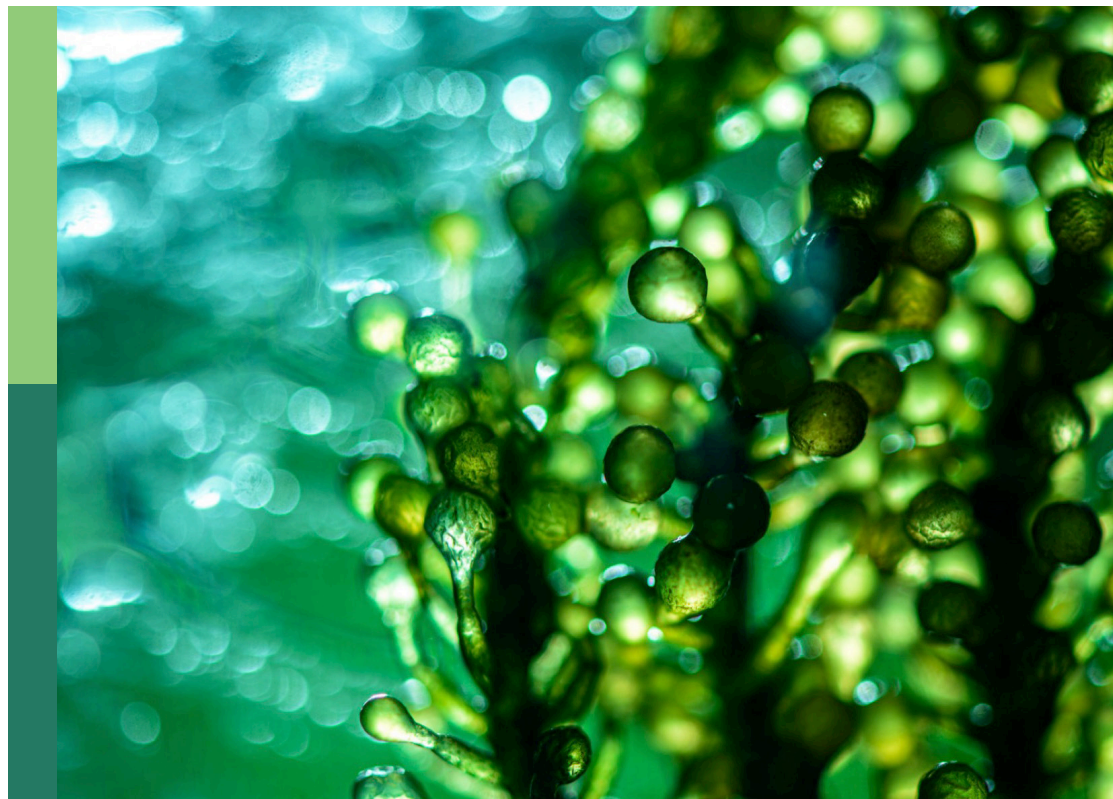
Smart sustainable development: exploring innovative solutions and sustainable practices for a resilient future

Edited by

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Smart sustainable development: exploring innovative solutions and sustainable practices for a resilient future

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Editorial: Smart sustainable development: exploring innovative solutions and sustainable practices for a resilient future

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Editorial on the Research Topic

Smart sustainable development: exploring innovative solutions and sustainable practices for a resilient future

This Research Topic of Frontiers in Sustainability presents a diverse array of articles that collectively contribute to the multifaceted discourse on sustainability. The majority of these articles were presented at an annual international conference and project showcase, Smart Sustainable Development (SSD) 2024, for a community of sustainability practitioners to share research with a focus on innovation.

By grouping the articles produced by subject matter, we can better appreciate how they address common challenges and opportunities from different perspectives. This editorial highlights the commonalities within each group and explores how their findings complement each other in advancing sustainability, all framed within the context of the United Nations' Sustainable Development Goals (SDGs).

Education and inclusivity

Four articles focus on education, emphasising its critical role in fostering sustainable practises and inclusivity:

- AI and student assessment in human centred education (Balducci).
- Quality education for all: a case study of success for a neurodivergent learner (Ker and van Gorp).
- The significance of global nature-based education to ensure a sustainable world: an urgent need for change (Du Plessis and Postlewaigh).
- Embedding Te Whare Ako and Te Hono o Te Kahurangi to achieving SDG-4 in Tertiary Education in Aotearoa New Zealand (Shadbolt et al.).

These articles converge on the theme of enhancing educational frameworks to promote sustainability and inclusivity. They address the need for innovative assessment methods that leverage AI to create equitable learning environments, highlight strategies to support neurodivergent learners, and advocate for the integration of Indigenous knowledge systems into tertiary education. Together, they underscore the importance of accessible and culturally relevant education as a foundation for sustainable development.

When these contributions are framed within **SDG 4: Quality Education**, it becomes evident that achieving inclusive and equitable quality education is essential to fostering sustainable development.

Moreover, these educational initiatives contribute to **SDG 10: Reduced Inequalities** by addressing disparities in educational access and outcomes among diverse populations. These articles advocate for a more equitable approach to education that empowers all individuals by promoting tailored educational strategies that consider different learning needs and cultural backgrounds.

Sustainable practises in agriculture and construction

A second group of articles examines sustainability in specific industries, particularly agriculture and construction:

- Addressing barriers and unveiling opportunities for plastic waste recycling in the New Zealand construction industry (Thomson et al.).
- Tomato disease detection with lightweight recurrent and convolutional deep learning models for sustainable and smart agriculture (Le et al.).

These contributions highlight the significance of adopting sustainable practises in their respective sectors. The construction article identifies barriers to effective recycling of plastic waste and proposes practical solutions to enhance recycling rates and reduce contributions to landfills. In parallel, the agriculture article showcases technological innovations that improve disease detection in crops, thereby increasing efficiency and sustainability. Both articles emphasise the need for industry-specific strategies that not only address waste management but also enhance resource efficiency, ultimately contributing to a circular economy. This aligns with **SDG 12: Responsible Consumption and Production** but the focus on sustainable agriculture practises also links to **SDG 2: Zero Hunger**, as improving agricultural efficiency directly impacts food security.

Motivations and behaviour change

Two articles delve into understanding the motivations that drive sustainable behaviour:

- Exploring the motivation of sustainable commuting: a case study of international students in Otago Polytechnic Auckland International Campus (Petrisia et al.).
- Action learning for change management in digital transformation (Ruhland and Jung).

The commuting article investigates the factors influencing international students' choices regarding sustainable transportation options, providing insights into how personal motivations can lead to broader environmental benefits. The change management article discusses strategies for fostering organisational commitment to sustainability during digital transformations. Together, they illustrate how understanding motivation—whether individual or organisational—can catalyze significant shifts toward more sustainable practises.

This exploration is closely tied to **SDG 11: Sustainable Cities and Communities**, which emphasises the need for inclusive, safe, resilient, and sustainable urbanisation. By understanding what motivates individuals to adopt sustainable commuting habits, cities can develop targeted policies that promote public transport use, cycling, and walking—thereby reducing traffic congestion and lowering greenhouse gas emissions. Additionally, these articles relate to **SDG 13: Climate Action**, as promoting sustainable commuting directly contributes to reducing greenhouse gas emissions associated with transportation, thereby fostering healthier urban environments.

Frameworks for sustainable development

The final group of contributions includes articles that propose transformative frameworks aimed at redefining value dynamics in contemporary contexts:

- Understanding the future of carbon neutrality in the culinary arts through non-representational theory, practise theory, and design (Lynch).
- Sustainable digital rent: a transformative framework for value dynamics in the digital age (Özdilek).

These contributions emphasise the need for innovative frameworks that can guide industries toward sustainability. The culinary arts article explores how carbon neutrality can be achieved through thoughtful design and practise, while the digital rent article introduces a framework for creating sustainable value in digital economies. Both studies advocate for a rethinking of traditional approaches to value creation, suggesting that transformative frameworks are essential to address contemporary sustainability challenges.

These discussions resonate with **SDG 9: Industry, Innovation, and Infrastructure**, which calls for building resilient infrastructure, promoting inclusive and sustainable industrialisation, and fostering innovation.

These frameworks also align with **SDG 8: Decent Work and Economic Growth** by promoting sustainable economic growth through innovative practises. By redefining value creation in

industries such as the culinary arts and the digital economy, these articles illustrate how businesses can thrive while adhering to principles of sustainability.

Conclusion

This Research Topic encapsulates a rich tapestry of international research that collectively advances our understanding of sustainability across multiple domains. By addressing common challenges from multiple angles—education, industry practises, behaviour change, and innovative frameworks—these articles provide valuable insights into how we can collectively navigate the complexities of sustainability.

As we face an increasingly urgent global context marked by environmental degradation and social inequities, these diverse perspectives offer pathways to a more sustainable future grounded in collaboration, innovation, inclusivity, and resilience.

Through continued dialogue between researchers, practitioners, policymakers, and communities worldwide, we can cultivate a resilient society that is equipped to thrive sustainably in the midst of change. This collective effort will be essential as we strive to fulfil our commitments under the SDGs while ensuring a just transition to sustainability for all.

Author contributions

T-AB: Project administration, Writing – review & editing. JB: Writing – original draft. LM-E: Writing – review & editing. FO: Writing – review & editing.

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AI and student assessment in human-centered education

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KEYWORDS

human-centered education, artificial intelligence, assessment, authenticity, collaboration, process

1 Introduction

Sustainable Development Goal #4 is about providing quality education and learning opportunities for all. “Quality” is also indicated in Target 4.3 with reference to technical, vocational and tertiary education, while educational content is described in Target 4.4 as skills development “for employment, decent jobs and entrepreneurship”, and in Indicator 4.7.1 as “global citizenship education” and “education for sustainable development” (UNESCO, 2014). Underlying all these targets is the ability to achieve learning outcomes and measure progress through valid and reliable student assessment.

This ability has now come under threat from the rapid advances made by generative artificial intelligence (AI), i.e., “technology that (i) leverages deep learning models to (ii) generate human-like content (e.g., images, words) in response to (iii) complex and varied prompts” (Lim et al., 2023, p. 2). AI tools such as ChatGPT are seen to “pose a significant threat to the academic integrity of traditional assessments” (Rudolph et al., 2023a, p. 365–366)—especially, but not exclusively, in higher education. There is deep skepticism regarding AI detection tools (Perkins, 2023) and closed-book exams as an alternative assessment strategy (Rudolph et al., 2023b). Overall, as generative AI continues to evolve, the security of many different types of assessments involving text, images, calculations and even computer code will be increasingly at risk, thus undermining the effectiveness of assessment processes, the usefulness of achievement rates (and associated data) and the motivation of students to learn.

The aim of this opinion piece is to propose the application of humanistic principles of task design as a protective measure against the incursion of AI-generated material in the assessment of learning. As noted by Webb et al. (2022, p. 129), the term “human-centered learning” is being used in the literature on AI to denote “pedagogies that are personally relevant to learners and encourage their active learning and engagement”. But although this article addresses the security of assessment tasks, the design of learning tasks should also be considered since “students need the opportunity to practice with the form of assessment before it is used as an assessment” (Gulikens et al., 2004, p. 71). By concentrating on the use of skills and knowledge by real people in realistic situations, as opposed to academic performance in artificial circumstances, student assessment can be safeguarded in the future. But before humanistic strategies are deployed, the principles on which they rest have to be set out and critically examined, an objective this article will seek to fulfill with clarity and concision. A more detailed investigation of how such principles could be implemented in particular disciplines, meanwhile, inevitably remains beyond its scope.

2 Principles of task design

In the face of the new challenges presented by AI, assessments that require creativity or critical thinking are often cited as possible solutions (Ifelebuegu, 2023; Kasneci et al., 2023; Rudolph et al., 2023b). In fact, these capabilities were seen as desirable graduate outcomes long before the arrival of ChatGPT. They were valued on a par with professional,

problem-solving, collaborative and communication skills by Biggs and Tang (2011), who took pains nevertheless to emphasize they should be “embedded” in relevant, discipline-specific contexts. Their advice is now doubly important in that AI, while it lacks conceptual understanding, is capable of generating material that may easily appear creative and innovative, or critical and reflective. In other words, it is contextualization that is needed first and foremost, whereas a focus on creative and critical thinking will not in itself guarantee the safety of assessments.

The question then is: What kind of context is most appropriate for student assessment in the age of AI? And the answer, of course, will depend on the discipline itself. Different subject areas require different methods and approaches. Yet the guiding principle for task designers, regardless of the program involved, must be that it is authentic, thereby avoiding the artificiality of conventional assessments. Ifelebuegu (2023) describes authentic assessment design as “contextual” and “problem-based” (p. 4). Rudolph et al. (2023b) point out that authentic assessment is set “in realistic situations” (p. 355). Gulikers et al. (2004) go further and explain that it “confronts students with activities that are also carried out in professional practice” (p. 71), and should even resemble “social processes that are present in real-life contexts” (p. 74). This will be as much the case for a “theoretical” discipline like mathematics as it is for applied business management. After all, mathematics is used in a wide range of professions and real-world settings which can provide the basis for developing and assessing mathematical ability. Through the careful alignment with learning objectives, a task designer can ensure that assessments are always valid and entirely focused on the relevant discipline.

The social aspect of assessment, as mentioned by Gulikers et al. (2004), brings another key principle to bear, namely collaboration. The ability to work collaboratively with others through teamwork and personal interaction is a skill that transcends knowledge gained from discipline-based education. It is, besides, a type of graduate outcome that education providers have been seeking to address (Biggs and Tang, 2011). Some commentators have identified collaborative assessment as a means of protecting academic integrity from the threat of AI (Ifelebuegu, 2023; Rasul et al., 2023; Rudolph et al., 2023a). Their main justification for adopting collaborative forms of assessment is found in “social constructivist theory’s emphasis on collaboration and social interaction in learning” (Rasul et al., 2023, p. 46). As a point of view, it is certainly consonant with the call for assessments which incorporate social processes. Even so, we may question the authenticity of the constructivist model of learning where, in addition to “social collaboration with others”, knowledge is constructed “through interactions with teachers” (Rasul et al., 2023, p. 47). This can hardly be represented as mirroring the social relationships that students will find outside of education.

The authenticity of the learning process and its repercussions on modes of assessment enables a third principle to come into play, one that relates to the complexity of real-life problems. Although these may at times require solutions that are simple and unique, they are for the most part complicated and “ill-structured”, allowing for a multiplicity of possible solutions (Herrington and Herrington, 1998). Students therefore need to apply higher-order thinking skills to deal with this complexity (Ifelebuegu, 2023), and to have “ownership of the task and the process to develop

a solution” (Gulikers et al., 2004, p. 71). This in turn affects the way that student work is assessed, as well as how the role of AI is perceived. For as Ifelebuegu (2023) remarks, the emphasis now “is on process as much as product” (p. 4), i.e., the work is assessed not only by its product(s), but through the process whereby this outcome is achieved. Although AI might still be involved (as will become increasingly the case in future), the focus remains firmly on the use that is made of it, as opposed to what it generates. The processes that emerge from the complexity of authentic tasks, whether collaborative or not, create opportunities for tracking or overseeing work accomplished by students and preventing the misuse of chatbot technology.

3 Human-centered education in practice

We have, therefore, three principles of task design—authenticity, collaboration, and process—on which the security of assessment is most likely to depend. There may be others that will play a part, and of course the design principles themselves can be formulated or interpreted from different perspectives. The basic strategy, however, remains the same, which is to devise assessable activities around things that humans do and human ways of doing them, instead of merely productive tasks without real world equivalents that may be done just as well by generative AI.

What such assessments mean in practice will vary according to educational aims and contexts, local circumstances and how the factors outlined above are interconnected. As we have seen, an assessment task need not always be collaborative, and what is more, there are diverse forms of cooperation that can be included in its design. Beyond the process/outcome distinction, where the final product is much less significant in the first than in the second, the objective might be to “pinpoint aspects of an individual’s behaviors within a group task” (Child and Shaw, 2016, p. 19). Hence collaborative assessment can provide more than a means of “rewarding students for their collective effort, negotiation skills, and ability to reach consensus” (Ifelebuegu, 2023, p. 4). It is possible, in actual fact, to observe a collaborative process for the purposes of assessing individual performance within a realistic setting.

The shape, content, and scope of innovative, human-centric assessment are all adaptable to multiple kinds of design. Existing student-centered assignments might provide models for new tasks that could be tailored to accommodate the changing reality of AI. It is thought that the practice of project management, for example, will be highly impacted by AI technology. But projects can still be used as a template for assessments that prioritise human skills such as leadership and team management (Fridgeirsson et al., 2021). Similar conclusions can be drawn about data science (Tu et al., 2023).

4 Conclusion

To ensure that quality education is maintained despite the ever-greater challenges that AI will undoubtedly bring about, teachers and educators need (i) authentic, (ii) collaborative, and

(iii) process-driven assessments of student learning where the true capacity of people to apply their skills and knowledge in real-world circumstances may be recognised. This article has outlined key humanistic principles for the future security of student assessment, as well as important factors to bear in mind in the corresponding task designs:

- evidence of creative and critical thinking can be imitated by AI
- students' interaction with their peers takes precedence over interaction with teachers
- individual student performance can be assessed through close monitoring of collaborative processes.

Staying focused on real human interaction must be at the heart of a successful integration of AI in the education of tomorrow. In that brave new world, the ability to separate human from artificial in student assessment will become imperative.

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BB: Conceptualization, Investigation, Methodology, Writing—original draft, Writing—review & editing.

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Embedding Te Whare Ako and Te Hono o Te Kahurangi to achieve SDG-4 in tertiary education in Aotearoa New Zealand

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1 Introduction

Equal and inclusive education is one of the target areas of SDG-4. This intends to eliminate disparities in educational systems by ensuring equal and equitable access to education for all especially for the vulnerable, including indigenous population (SDG Tracker, 2018). Educational aspirations are essentially reflected in SDG-4 which aims to promise inclusive, equal, and equitable quality education and promote opportunities for lifelong learning for everyone by 2030 (Demirbag, 2021). Educational strategies and approaches rely on academic knowledge from many fields such as facilitation, communication, information technology, psychology, sociology, and digital technology in combination with applied teaching and learning practice and successful implementation (An and Oliver, 2021).

Several strategies have been incorporated to achieve SDG-4 in educational policy and framework to engage Māori learners in all levels of education in Aotearoa New Zealand (Ministry of Education, 2022). Indigenous inclusion has been established as a common approach in Aotearoa New Zealand (Hoskins and Jones, 2022). Te Hono o Te Kahurangi framework was established by NZQA for evaluating programmes, courses, and other components, from a Kaupapa Māori perspective. This emanates from the wider framework of Te Whare Ako (study/learning) that addresses teaching and learning practice. As per NZQA's quality assurance guidelines, institutes of tertiary education shall opt for Te Hono o Te Kahurangi framework if the educational organization uses Kaupapa Māori and/or teaches Mātauranga Māori, to engage learners using Māori approaches and values (NZQA, 2017). Te Whare Ako (the house of learning) establishes a framework that underpins concepts of Ako (teaching and learning) and Kaupapa Māori (Māori principles and values) such as rangatiratanga (chieftainship), manaakitanga (respect and care), whānaungatanga (relationships), pūkengatanga (skills and knowledge) intertwined with contemporary inclusive education approaches (Figure 1).

The notion of Ako encompasses a dynamic teaching and learning relationship wherein educators do not only impart knowledge, but also actively engage in learning from their students. This approach emphasizes that educators' methods are informed by current research, characterized by purposeful and introspective actions. Ako is founded on

the principle of reciprocity and acknowledges the inseparable connections between the learner, whānau, and their community (Te Kete Ipurangi, 2009). Te Whare Ako framework provides specific directions to utilize Te Reo Māori (Māori language) and Pāngarau Tirewa Mātāmua (numeracy support resources) from Te Tirewa Marautanga (curriculum resources), which is the updated version of Te Marautanga o Aotearoa. These guidelines will provide applied resources to the educational institutions in New Zealand to utilize from the start of the year 2024 (Ministry of Education, 2023).

This article reviews efforts from non-Māori teaching staff in various postgraduate programmes at EIT – Te-Pūkenga to incorporate Te Whare Ako component of Te Hono o Te Kahurangi framework and kaupapa principles into their teaching practice, including challenges, practical examples, and lessons learned.

Following are some of the examples/reflections from non-Māori teaching staff that they practice in their teaching environment:

2 Rangatiratanga (chieftainship)

As per NZQA (2018), rangatiratanga focuses on autonomy, but other approaches to incorporating rangatiratanga into teaching practice include a range of chiefly characteristics, including leadership, and integrity (Te Momo, 2011; Hawkins, 2017).

One of the ways to integrate mātauranga Māori into the teaching is by incorporating the Rauru Whakarare Evaluation Framework (Feekery and Jeffrey, 2019) into the teaching of information literacy. This creates an opportunity for providing a different perspective on evaluation criteria, allowing students the space to reflect on their own personal and cultural attitudes toward concepts like credibility and authority, and to gain a tangata whenua perspective on what might make information more or less credible and authoritative. This also connects with rangatiratanga through the chiefly attribute of integrity, or pono (truthfulness) and tikanga (correctness).

Reflecting on rangatiratanga defined as “autonomy realized through the enactment of a Māori world-view in response to the aspirations and driving motivators of ākonga, whanau, hapu, and where relevant, the Māori community and sector stakeholders” (NZQA, 2018, p. 6) helped to understand more clearly what staff can do to create opportunities for learners to develop their own autonomy, as academics, professionals, and members of the other communities they belong to.

At EIT, the prevailing approach to teaching, which involves active learning in groups, and often wide latitude in the topics that students work on, provides many opportunities for developing rangatiratanga. This approach implicitly recognizes the rangatiratanga of each student, in the form of their mana, knowledge, and experience, by creating an environment where students learn from each other. In addition, we offer a number of opportunities outside of the classroom for students to develop chiefly characteristics. Two examples of which are a public speaking programme modeled on Toastmasters, and a peer mentoring programme (Lopez, 2020). The public speaking programme is voluntary but popular, and gives students opportunities to exercise autonomy in selecting speaking topics, practice leadership roles in organizing and running meetings, and of course develop their ability to speak in public and influence an audience, which itself is an important chiefly attribute (Te Momo, 2011).

3 Manaakitanga (respect/care) and whānaungatanga (relationships)

The foundations of teaching are manaakitanga and whānaungatanga. Mead (2003, p. 120) sees manaakitanga as “hospitality that extends to all social occasions.” Making sure that students feel welcome and that someone cares about them is manaakitanga that also enhances the wellbeing of students. Since, students are away from their families and friends and in a new country: it is a very human way of treating people and most likely a common practice amongst tertiary staff to offer what they see

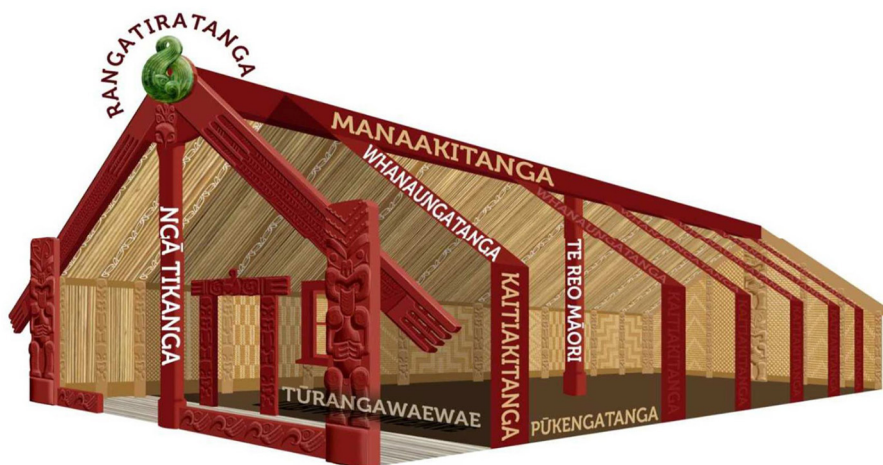


FIGURE 1
Te Whare Ako (Māori house of learning) (NZQA, 2017).

as respectful pastoral care to their students. In this they practice manaakitanga, whether they are conscious of this or not (NZQA, 2017).

Whānaungatanga is another relevant principle for Māori and non-Māori practitioners (NZQA, 2017). A brief interpretation of whānaungatanga is that it “empowers and connects people to each other and the wider community” (Aranga and Ferguson, 2016, p. 4). As a kinship-based society, whānaungatanga is a “fundamental principle” of Māori society and extended “beyond actual whakapapa relationships and included relationships to non-kin persons who became like kin through shared experiences” (Mead, 2003, p. 28). “For example, caring for people means relationships are formed consequently resulting in oneness of spirit, mind and body. In an educational environment, educators/teachers are always connecting with their students and their whānau (family)” (Aranga and Ferguson, 2016, p. 5).

In practice, this includes the use of group work and social activities increase bonds amongst students as well as fostering a feeling of belonging to a group or a class. Beyond group activities designed for learning, teaching and support staff can implement social activities such as holding a shared lunch, having a picnic, practicing waiata (song), or organizing some other fun activities such as sports, art, outings, and coffee and chat sessions. These can be initiated by students too and this also enhances whānaungatanga within the class or across the campus. Where students are on multiple campuses, it is also useful to enhance whānaungatanga through teaching staff to physically visit students at these sites, even though regular teaching for these students may be online.

The following ways were used to model Manaakitanga and Whanaungatanga in classroom:

- Students were asked to present a Pēpeha (self-introduction in Māori) at the beginning of the course and sometimes with a short Whakatauki (proverb or sayings) at the beginning of a workshop. Non-Māori students, respect this as a nice and respectful way to begin the workshop. Māori greetings and even the language of students from other countries is used when taking attendance in order to respect their own cultures too.
- In larger ‘whole class’ settings Manaakitanga and Whanaungatanga are modeled by encouraging respect and inclusiveness for each other. The right of each student to speak in class about the weekly topics were respected and this shows appreciation and value for each participants’ input.

4 Pūkengatanga (skills and knowledge)

Pūkengatanga is the way Māori people learn and transfer skills and Knowledge and “involves the achievement of progressive milestones and skills, enabling individuals to reach their goals and their potential” (Ministry of Health, 2020, p. 27). Pūkengatanga means including explicit learning milestones within the course and learning activities. This supports Māori and other indigenous learners and helps them to keep motivated and see the value and results of what they learn each week. This requires time at the beginning of each topic or unit explaining explicitly why and how

participants are learning each skill or piece of knowledge and how it will be useful and valuable in their lives and careers.

5 Te Reo and Tikanga Māori (Māori language and protocols)

Māori principles such as focus on community and relationships, respect for the environment, and valuing the collective over the individual, are embedded in a postgraduate classroom for non-Māori (international) learners through a variety of strategies. Māori perspectives and ways of knowing are built into the curriculum, building relationships with Māori community members and incorporating their knowledge and perspectives, and creating a classroom environment that is inclusive and respectful of diverse cultures which is a prime target area to achieving SDG-4. Additionally, incorporating Māori language and cultural practices, such as karakia (prayers at the start and end of the session) or waiata (Māori songs), also help to incorporate Te Reo and Tikanga Māori in the classroom teaching and learning environment. It is important to be respectful of the Māori culture, seek guidance from Māori teachers and community members, and be open to learning and adapting to new ways of teaching.

The postgraduate health science course is integrated with Mātauranga Māori in various ways, including Māori pedagogical approaches to learning based on Kaupapa Māori. Mātauranga Māori also incorporates Te Reo Māori and Tikanga Māori (Māori language and protocols) and are connected to Hauora Māori based on New Zealand’s Māori Health Strategy, “He Korowai Oranga sets the overarching framework that guides the Government and the health and disability sector to achieve the best health outcomes for Māori” (Ministry of Health, 2020). Several components and resources are included that have a strong focus on Te Reo Māori or environment and spaces for learning that are conducive to and nurturing of Mātauranga Māori. Māori customs and values are embedded across all the courses of health science programme. Te Reo Māori and Tikanga Māori are used in relation to Hauora Māori and in health and wellbeing context.

In the learning and teaching environment, sustainability in health and wellbeing is a top priority as required by SDG-3 that ensures healthy lives and promotes wellbeing at all ages (United Nations, 2023). Wai ora (healthy environments), Whānau Ora (healthy families), and Mauri Ora (healthy individuals) are the basic principles valued and practiced in the classroom activities and discussions to understand the New Zealand health framework (Ministry of Health, 2020). Learners are always encouraged to lead their courses of study and assessment tasks by providing them freedom to inform the peers and lead the group work by their previous industry and health qualification and experience. This gives learners the best possible knowledge and information to support them to make informed choices, leading the events, negotiating the rules, determining the outcomes.

The majority of classroom activities and learning is based on Te Pae Māori (healthy future for Māori) foundation of New Zealand Health System and Framework. Many specialized terms and products are used throughout the programme from Te Reo Māori. Māori views on health and wellbeing are incorporated in teaching and learning by a holistic approach that encompasses

four key elements - wairua (spiritual), hinengaro (psychological), tinana (physical) and whānau (extended family). Karakia offered at the start and end of the sessions (blessing or prayer) has an essential part in protecting and maintaining these four key elements of health and wellbeing.

Learners get a chance to learn about the Māori health concepts and their importance in overall health and wellbeing, such as Taha Tinana (Physical Health), Taha Wairua (Spiritual Health), Taha Whanau (Family Health) and Taha Hiningaro (Mental Health). The learners also encouraged to participate in an online session to achieve a certificate course on “Foundations in Cultural Competency and Health Literacy” by Mauri Ora Health Education Research (MAURIORA, 2022).

6 Conclusion

Non-Māori teachers’ reflection on best practices of how Te Hono o Te Kahurangi could be implemented in tertiary teaching to help achieving achieve SDG-4 in Aotearoa New Zealand is presented in this article. The specific actions depend on the needs, capacities, and resources of each institution. Incorporating Māori perspectives and knowledge into teaching and learning requires embedding them into course aims, learning outcomes, teaching material as well as assessment tasks. Incorporating Māori language, history, culture, and values into course content is very complex. As well as having guest lectures or workshops led by Māori experts or community members, curriculum design and lessons plans must be supported by relevant experts, which in this case were our Mātauranga Māori Advisers. Cultural competency and safety training, especially for non-Māori faculty and students on how to respectfully engage with the Māori culture and context will help create an inclusive environment for all.

Another way of engaging non-Māori learners could include providing opportunities for them to engage in volunteer work, internships, or other experiences that connect them with Māori communities, such as cultural immersion programs. Embedding the concepts of sustainability and environmental protection in a range of courses and learning activities, with a focus on Māori culture and traditional knowledge will not only help achieving the

integration of Mātauranga Māori in teaching and learning, it will also help toward achieving the sustainable development goals, in general, and SDG-4, in particular.

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Action learning for change management in digital transformation

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action learning, change management, higher education, teaching, digital transformation

1 Introduction and objectives

Digital transformation is not only a technological endeavor but affects the whole organization, such as a company or non-profit organization (Tabrizi et al., 2019). Technologies such as artificial intelligence, data science, and cloud computing are relevant (Sebastian et al., 2017) but rather enable improvements (Vogelsang et al., 2019; Pasqual et al., 2023). Real benefits can only be achieved by new business models or innovative products that will change the way value is created in a company (Matt et al., 2015). As this also implies structural changes, succeeding in such a journey requires skills and competencies in conducting changes in an organization.

Courses on digital transformation at university aim to prepare students to lead organization changes from both technological and management perspectives. However, there are some challenges in teaching change management, as the topic and the consequences of change in a corporate environment are still quite abstract for students. Whilst individual students manage personal changes in their lives, challenges in a large organization are hard to tell by just using words. Change projects, including a digital transformation aimed at revolutionizing a company's business model, alter the organizational structure, impact people and their careers, and may cause uncertainty (Kotter, 2012).

The paper presents a case study on applying action learning (AL) to simulate the situation during a change and how to facilitate a change. The objective, therefore, is to let students experience changes in organizations in order to develop a better understanding of the need for and how to deal with resistance from employees or stakeholders during a digital transformation.

2 Action learning for sustainability in education

AL, an experienced-based learning method, is described as learning by doing, collaborating, sharing ideas, lifelong learning, and reflecting on practice (Zuber-Skerrit, 2002, p. 114). It focusses on taking action on important issues or problems (Hauser et al., 2023, p. 117). In addition, it is “a framework for a group of people to learn and develop through open and trusting interaction” (Pedler et al., 2005 in Hauser et al., 2023, p. 116). The basis of AL is the concept of *question*. By asking questions, AL becomes a social process in which a lot of people start to learn with and from each other, and a learning community comes into being (Revans, 1982, p. 66, 69, 70).

Sustainable education, such as AL, is a cultural shift in how education and learning are understood (Sterling, 2008, p. 65). If the method is applied in higher education, it changes the learning and teaching culture. Whilst the main objective remains knowledge transfer, experience and soft skills become more important, including planning and organizing the learning process. AL can be used as a method to encourage students to be more independent.

An AL project starts with a specific real-world problem for which a simple solution is not readily available, and lecturers provide guidance throughout the learning process. Addressing the problem that confronts participants necessitates a decision-making process within the group. In this project, the primary objective is to make knowledge from the lecture permanently available in the students' minds and also to motivate them to learn more independently, reflect, and think critically. The achievement of the objective is supposed to be determined during oral exams at the end of the semester.

3 Case study

The postgraduate course on business information systems at the Frankfurt University of Applied Sciences (Germany) has a focus on digital transformation. A dedicated module on strategic process management teaches methods and tools for optimizing processes during a transformation, including change management. Whilst teaching, it became clear that most students have never experienced a significant corporate change, making it difficult for them to assess the necessity for facilitating such a change and dealing with resistance from employees or stakeholders. The class was therefore running into the danger of just learning words by heart (written in textbooks on change management) but never understanding what being part of such a change feels like. Hence, the teachers introduced one session using AL to achieve sustainability in learning by experiencing change. The second author, who is the professor in charge, has no active role during the AL training session and is deliberately not in the room since he is examining and grading the students and assumes that it could hinder the training's success. As the examining and grading person, the assumption is that it could hinder the training. The professor is therefore the facilitator of the learning process (Robertson and Heckroodt, 2022, p. 81). The first author accompanies the process as a participant and takes on the role of observer. Two external facilitators guide the students through the training.

This training has integrated work and learning, which is the basis of AL (Maltiba and Marsick, 2008 in Cho and Egan, 2009, p. 441). The learning success was due to the systematic approach of this AL session as well as to the guidance of the trainers. Learning from experience does need structure; otherwise, it can be inefficient (Zuber-Skerrit, 2002, p. 115).

A professional training company with experience in change management and personal development has been hired. Two trainers of this company prepared a curriculum on how to motivate change and also exposed the students to a tough situation. After the training, the students were asked to break a wooden board with their bare hands. Being shocked by this perspective, students listened to the trainers whilst they talked about facilitation as well as motivation and explained everything based on breaking the board.

The whole training took ~5 h, and at the end, each participant broke the board with their bare hands.

4 Findings and conclusion

In the pursuit of insights, data were collected through a combination of student observations, discussions, and reflective exchanges with the students. The master students were hesitant in the beginning as they were expecting a traditional lecture format but were met with quite a different setting: a circle of chairs, a flip chart instead of PowerPoint, and two instructors in the front who did not look familiar. The students were intimidated, unsure, and initially quiet. Over the course of the day, the students relaxed and participated. At first, they could not make the connection to their lecture. The trainers supported the students in building the bridge to change management in the work context. This guidance through the trainers was necessary. Students were encouraged to ask questions and think of examples from their professional contexts; if they did not have them, references to their personal lives or volunteer work should be made. By the end of the day, students were open, asking questions, exchanging knowledge and experience, loosening up, and having fun. As the students were also emotionally involved in the training (because of the challenge), they developed an empathic understanding of how employees feel when being subject to change. This is one of the intended results since AL has a "dual mission": people development and business impact (Cho and Egan, 2009, p. 441). They were able to experience transformation and change.

It was a functional decision not to include the examiner in the training because the observer also noticed that the students were somewhat restrained and sometimes looked at her. The observer was only known to the students from greetings, and she also had the feeling that this made some people feel inhibited. For this reason, the external trainers, who ensure confidentiality, were ideal. The participative observation could have influenced the students' later statements.

This case study is only transferable to a limited extent since it is very specific: it only includes postgraduate student from one-degree programme who mainly have done their undergraduates at the same university. In addition, for German universities, it is a rather smaller study group (10–16 students). Another special feature is the special background of the external trainers: business information specialists and instructors for Jiu-Jitsu both influence the case study/training.

At the end of the semester, the module was concluded with an oral exam. The second author had often encountered students in the past who were able to reproduce knowledge but had limited understanding of its meaning and had difficulty providing examples. This year, things were different: The students were able to give a lively account of change management based on the training and were able to substantiate the contents of the lecture with practical examples. The primary objective, as stated previously, can be seen as achieved, as almost all students were able to reflect on the challenges of the changes. One student struggled to explain reasons for resistance against changes in a company in the oral exam and just repeated words from the lecture slides. In this case, the professor switched back to the role of a learning companion

and encouraged the student to reflect on how they felt whilst being confronted with the wooden board challenge. Now the technical knowledge was connected to the emotional side, and struggles with changes were explained in a livelier way.

AL as an innovative teaching method not only has advantages but also disadvantages in higher education settings. The following disadvantages and how we have tried to mitigate them should be mentioned: Applying for AL is time-consuming, and it has to fit into the university's schedule. We met this challenge through early and transparent (semester) planning. For AL, the sessions were scheduled for a whole day, longer than the usual lecture and exercise slots in the timetable. To signal this change, the lecture room was arranged in a different seating format (seating circle), which suggested a different teaching method. The extended length of the day and the presence of external facilitators made it clear to students that this was not a typical lecture.

The case study makes the authors quite optimistic that AL could be integrated into the curriculum to gain more time for implementation and to enable a sustainable learning effect. Notably, certain factors have emerged as influential in promoting success in our case: the necessity of implementing AL in smaller group settings, the acquisition of external facilitators, the proactive scheduling of additional time slots within the semester plan, and the clear, advanced communication of these schedule adjustments to enable students to align their plans accordingly. Importantly, there was an active expression of interest from some students for more sessions of this nature. In the future, we are also planning to try out shorter formats to test whether AL could also be implemented in a regular course, i.e., 90 min.

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The significance of global nature-based education to ensure a sustainable world: an urgent need for change

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nature curriculum, teacher education and professional learning, holistic learning, wellbeing, sustainability

Introduction and objective

Richardson (2023) reminds us that people are part of the natural world, and that the process of birth is a natural phenomenon. He further discusses that present societal construct slowly erodes that connection through the consumerist lifestyles, and ever-advancing technology that supports this throw-away lifestyle.

Some isolated subjects within current global education curricula, strive to re-connect children with nature but do not go far enough to ensure that future global citizens embrace a different way of thinking about our planet. To some extent this may be attributed to attitudes and motivation of teachers to learning in the outdoors, possibly due to lack of personal involvement or exposure to relevant pedagogies (Ray and Jakubec, 2018; Du Plessis, 2023). A curriculum, embedded in the natural world, has the potential to develop this vital connection to drive a sustainable, ecologically balanced future supporting a more equitable, healthy and balanced lifestyle, enhanced rather than hindered by technological development. An example of such a curriculum framework was developed by Northern Christian School (2015), Australia, and evidences the possibilities discussed in this paper. Furthermore, a curriculum based in local communities, including indigenous people's values and approaches, would support children's learning about sustainability in relation to food production and resources, urban development, and the effects of toxic waste. Understanding and acting on these issues would also lead to a positive impact on health and emotional and physical wellbeing (Penetito, 2009).

Theme 1: present lifestyles and attitudes

Globally, urbanization has seen a decline in the frequency of people's interactions with the natural environment (Richardson, 2023), which is partially due to the lack of natural spaces within built-up work and living areas, and partially the more sedentary and technological pastimes embedded within this style of living (Ritchie, 2013; Postlewaight et al., 2023). Disconnect from nature can result in compromising holistic wellbeing, including the physical, mental and spiritual realms (Du Plessis, 2023; Postlewaight et al., 2023). Enabling opportunities for positive connections in the outdoors will confirm and establish relationships with the natural world and sustainability for future generations, thus creating a healthier balance between the natural and human-made environments.

Previous studies undertaken by Du Plessis (2023) and Postlewaight et al. (2023) focus on early childhood teachers and student teachers experiencing and re-connecting with nature. Learning from these experiences enables recognition of the importance of nature and place-based learning as a catalyst for learning in all domains of the curriculum, alongside relationships and personal identity. The approaches described in these studies are just the beginning of possibilities for long-term change.

Current health studies highlight the negative impact that the reliance on technological devices for learning has on children's social interactions, emotional wellbeing, and physical health (Chung and Seomun, 2021). Conversely, discovery and inquiry-based learning in nature enhance physical development, cognitive development, and risky play, enabling children's agency to drive their own learning (Northern Christian School, 2015). This is equally applicable to adult learners, student teachers and teachers. Inquiry-based learning encourages and supports problem-solving, independent and divergent thinking, and collaborative learning in a holistic way that is not achievable when learning solely with electronic devices or in a classroom. Holistic learning includes devices as a supportive tool, rather than the context for learning (Schilhab et al., 2018). Curricula that are fully immersed in nature-based education, model sustainable ways of being in the world (Louv, 2005). When sustainability is part of your everyday learning, a flow-on effect occurs through children sharing their knowledge and understandings, over time changing societal construct from a disposable consumerist mindset to one that is focused on eco principles and reuse, reduce, repair, recycle resources (Merewether et al., 2023).

Negative dispositions toward engaging with nature may be attributed to personal experience, upbringing, or adverse incidents (Du Plessis, 2023). An individual's beliefs and values of learning in the natural world could furthermore influence their attitude (Postlewaight et al., 2023). For teachers, these attitudes may also be the result of not being exposed to nature-based pedagogical approaches during initial teacher education, or not having access to professional learning and development during years of teaching.

Additionally, one such negative belief pertains to the notion of bureaucracy and regulations, for example, risk management plans, emergency responses, and health and safety protocols, as constricting incentive to change practice (Postlewaight et al., 2023). It is visible in the Northern Christian School (2015) model that these perceived barriers can be overcome. In order to reverse this trend and authenticate personal pedagogies, teacher education and all education curricula need to be aligned to the natural world.

Theme 2: an evolving curriculum

Te Whāriki, the early childhood education curriculum of Aotearoa New Zealand (Ministry of Education, 2017) is a holistic framework that is underpinned by the stance that children's learning is enhanced through connection with the natural world. Within the parameters of the framework, learning goals and outcomes are framed to support children's wellbeing and their understanding that they are part of the wider community. The natural world, place-based learning, and all curricula, including mathematics, science, literacy,

the Arts, history and information technology, are embedded in an integrated way enabling children to discover the connections between them rather than each being taught as separate subjects (Penetito, 2009; Ministry of Education, 2017).

Penetito (2009) asserts that the natural world is the curriculum. Indigenous cultures' stories tell of their spiritual and physical relationship with nature and place (Ministry of Education, 2009), and sustainable practices cannot be separated from this historical knowledge. For example, Durie's (1994) *Te Whare Tapa Whā* health model, based on the beliefs and values of Aotearoa New Zealand's indigenous peoples, emphasizes the connection between *taha tinana* (physical), *taha wairua* (spiritual), *taha whānau* (family and community), and *taha hinengaro* (emotional) wellbeing. These pillars of health are grounded by people's relationship with *whenua* (land). It is imperative that *kaupapa Māori* (Te Ara Encyclopedia of New Zealand, 2007, p. 8), and all such global indigenous cultural sustainable principles, are valued and incorporated in all aspects of nature-based approaches and plans for learning and teaching.

Global curricula currently incorporate sustainability as a stand-alone subject or within science learning, admittedly showing merit as a starting place. However, to fulfill the vision of a natural learning environment, these curricula need to be developed to encompass all subjects, and will ultimately enhance wellbeing and develop a sense of connectedness to and belonging in the space/place (Ministry of Education, 2017; Teton Science Schools, 2023). Forest school movements which evolved in Scandinavia and Germany in the 1950's and 1960's (The Forest School Foundation, 2020) initiated and consistently follow a learning in nature curriculum that has proven to benefit physical, emotional, social and mental development throughout a child's education. Forest schools, or similar, are now recognized globally as a holistic learning approach. The link between children's emotional wellbeing, physical development, relationship-building, and learning in the natural environment is evident in examples such as Toybox early childhood center on Rawhiti (Catto, 2023) where everyone participates in growing, harvesting and preparing food that is chosen each day.

Findings/discussion

A possible education model for curriculum, that is embodied within nature would impact societal constructs of holistic learning, sustainability, health and wellbeing, place-based learning, and community. Children who learn that they are part of, rather than owning or controlling the natural world, will grow up with beliefs and values that will support and protect its resources (Penetito, 2009), as a result of their deepening connectedness with nature and the land. Such an approach needs to be the focus of education going forward.

Rather than the narrow focus of education for sustainability, learning in nature will enable future generations to realize that care of nature is important to human survival. Each of the previously described curriculum foci can be integrated within nature-based learning. For example, a child who has experienced

the bush or the beach environments will learn how plastics are destroying ecosystems and the impact of catastrophic weather events. Mathematics learning could entail collecting rubbish and compiling statistics on how much is present in the area. The child's learning could be documented or presented through the Arts, literacy, or as scientific findings.

Each of the aforementioned changes to curricula development would have a flow on effect on global economy, consumerism, urbanization, food production, toxic waste and a sustainable lifestyle that will ensure a balanced long-term future. However, parallel change needs to occur for initial teacher education alongside the provision of essential professional learning to support teachers' planning and implementation of holistic pedagogies, for example modeling integrated curriculum and opportunities for engaging with experiential learning. Du Plessis (2023) examined and reflected on teacher involvement, values and beliefs, and prior experiences, and how these influenced teacher dispositions toward working with learners in this way. Furthermore, Postlewaight et al. (2023), conducted a pilot study that enabled participants to examine their attitudes, beliefs and experiences. From the initial findings of Postlewaight et al. (2023), Postlewaight has since facilitated professional learning and development to equip the teachers with a range of relevant strategies for working with a holistic curriculum in nature.

The authors' proficiency is in early childhood learning and teaching, and initial teacher education, yet they recognize that it is imperative that a nature-based curriculum underpins learning throughout life. Learning in the natural world needs to assimilate a spiral methodology that keeps progressing through the educational system. A spiral curriculum is not a novel concept since Bruner (1960) advocated for cyclical learning that builds on prior knowledge, adding depth of experience and understanding. He acknowledged how the prior knowledge of learners, and utilizing inquiry-based learning, empowers their agency, deepening their engagement with their learning. For instance, the professional development undertaken by Postlewaight, involved participants contributing to literacy through story-telling in nature, using props from within the environment. Du Plessis (2023), in her autoethnographic narrative, concluded that a combination of spontaneity and planning is the catalyst for problem-solving and agency. Consequently, she intentionally prepared the resources within the natural environment as provocations for engagement by the student teachers.

It is recognized that sustainability encompasses two main concerns, namely sustainable living and protection of the natural world. Present-day consumerism impacts on ecology, partially due to the lack of awareness of the need for consideration, planning, and implementation of sustainable practices in our everyday living. We are informed of the need for greater integration of sustainable energy, transportation, water supply and treatment, building, industrial processes, and the size of our cities (Sodiq et al., 2019). However, the advancement of these is slowly evolving, being ignored, and/or their positive impact is not fully recognized. In order for people to realize the importance of sustainable living, a nature-based curriculum would reveal the effects through learning about the care and protection of nature. For example, one kaupapa

Māori value embraces the concept of kaitiakitanga, that all people are part of, and therefore are guardians of the natural world. Recognition of the importance of community involvement and learning about the place in which we live, is a way of engaging everyone in these undertakings. Initiatives such as (Enviroschools, n.d.) in Aotearoa New Zealand equip learners to become part of the sustainable enterprises within their community. The philosophy of Enviroschools is based on the notion "where young people are empowered to design and lead sustainability projects in their schools, neighborhoods and country" (Enviroschools, n.d., para. 1). Incorporated within working with the community is learning the stories and traditions of place, and historical importance.

Conclusion

While there is urgency in the agreed UNSDG changes, the achievement of longer-term goals requires the assimilation of a societal construct that is based on the balance and relationship between protection of the natural world and technological advancement. This article proposes an alternate way of being in the world through education leading to sustainable awareness, understanding and action, resulting in a balanced lifestyle for people as part of nature.

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Quality education for all: a case study of success for a neurodivergent learner

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Introduction

This article showcases an innovative approach to the acquisition of undergraduate degrees known as the Independent Learning Pathway (ILP) at Capable NZ, a School of the Otago Polytechnic. The ILP offers a unique and learner-centric alternative to traditional degree programs, particularly beneficial for mature learners whose prior learning experiences and diverse skill sets may not be fully recognized by conventional models. Through a personalized learning journey, the ILP empowers participants to demonstrate their competencies and obtain qualifications.

Significance of the study

The ILP is a unique educational approach which aligns with the broader global initiative encapsulated in Sustainable Development Goal (SDG) Goal 4: “Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.” Traditional education models often struggle to cater to the diverse needs and learning styles of adult learners. The ILP addresses this gap by offering a flexible and personalized learning experience, fostering inclusivity, and ensuring that valuable prior knowledge and skills are recognized through a deeply reflective learning process. This, in turn, empowers individuals to pursue further education and contribute more effectively to the workforce and to their communities.

A significant portion of the global population exhibits neurodiverse traits, encompassing conditions like dyslexia, ADHD, and autism. These individuals may face challenges in traditional learning environments due to their unique cognitive strengths and weaknesses. The ILP, with its emphasis on personalized learning strategies and a supportive learning environment, creates a space where neurodiverse learners can thrive.

This article presents a case study exploring the collaborative journey of Rachel, a neurodivergent learner, through the ILP program, alongside her facilitator Glenys, who is a highly experienced facilitator of the ILP approach. By showcasing Rachel’s successful experience, this study aims to demonstrate the effectiveness of both the ILP as an innovative and inclusive approach to degree acquisition, and the nature and scope of effective facilitation of learning, in supporting neurodiverse learners and achieving the goals of inclusive education outlined in SDG 4.

The Sustainable Development Goals

The 17 Sustainable Development Goals, adopted by all United Nations member states in 2015, collectively seek to address pressing social, economic, and environmental challenges to create a more sustainable and equitable world by 2030.

SDG 4, which focuses on Quality Education, includes targets relating to equitable access to vocational and higher education. This goal recognizes the transformative power of education in promoting sustainable development, fostering inclusive and resilient societies, and empowering individuals.

The various targets under SDG 4 include eliminating gender disparities in education and ensuring equal access to all levels of education and vocational training for vulnerable populations. Meeting these targets involves addressing various barriers that hinder individuals from pursuing further education, such as traditional delivery models, time constraints, financial barriers, lack of learner confidence, and the challenges related to recognizing and validating learning from experience.

If the SDG 4 goal and targets are to be met, vocational education delivery will need to adopt innovative and more inclusive approaches, including diversifying learning modalities, greater learner-centricity, redefining qualifications based on outcomes, and recognizing and valuing all forms of valid learning.

The Independent Learning Pathway is one of these innovative and more inclusive approaches.

The Independent Learning Pathway

Definition and background of ILP

In New Zealand, the ILP is a groundbreaking initiative introduced by Capable NZ, a school within Otago Polytechnic. The ILP is an alternative approach to degree acquisition, enabling the highly experienced, mature learner to obtain mainstream qualifications through a unique and highly learner-centric learning journey that affirms and values learning from their diverse experiences, as well as their cultural knowledge.

The ILP is made possible because the NZ Qualifications Authority (NZQA) defines qualifications through graduate profiles, which emphasize graduate outcomes, thereby allowing for a wide range of approaches to the acquisition of the knowledge and skills that enable the graduate outcomes to be met. NZQA also mandates the recognition of relevant prior learning, thereby freeing learners from unnecessary learning activities if graduate outcomes have already been met.

Benefits of ILP for mature learners

The ILP approach is for highly experienced learners, generally in work, who are often poorly served by traditional taught delivery models. These learners already have considerable degree-relevant knowledge and skills, often enriched with cultural knowledge and understanding, which usually does not count as part of a taught degree. These learners typically do not enroll in traditional degree programs because they may not have the time or resources to

study within a typical delivery framework. Also, they have often experienced a lack of success in prior formal education contexts, thereby lacking confidence and being unable to see themselves as legitimate participants in a tertiary credentialled world.

The ILP approach provides equity of access for this group, offering a process that validates work based, cultural and community experiential learning. The approach guides the learner through a range of tasks to make explicit the learning from their experience and to acquire new learning as necessary to enhance it. As they reflect on their experience, learners analyze and articulate their graduate level competencies and are supported to present these by using degree level academic skills.

As a strategy for equitable access, the ILP:

- Is a structured yet personalized learning journey, managed by the learner with facilitator support.
- Recognizes and credits all relevant prior learning.
- Facilitates the acquisition of new skills and knowledge, with the learner at the forefront, determining when and where learning takes place.
- Focuses on workplace-based learning, embracing learning at, through, from, and for work.
- Equips learners for lifelong learning through critical reflection, a powerful tool for continuous education.

Supporting neurodiverse learners—Learnings from practice

In the dynamic landscape of contemporary teaching and learning, facilitators often encounter learners with neurodiverse traits or unidentified learning challenges. Understanding the importance of inclusivity, facilitators must embrace neurodiversity to create supportive learning environments. This article outlines strategies for serving neurodiverse learners to foster their academic and personal growth. Furthermore, the strategies for ensuring the success of neurodiverse learners are also applicable to adult learners at large.

Case study: a neurodiverse learner's journey through the ILP

This case study draws on the joint experiences of the authors and aims to provide guidance for both learners and facilitators on effective facilitation strategies tailored to the success of neurodiverse individuals. Rachel, a neurodivergent learner with ADHD, Irlen Syndrome, and dyslexia, works as a facilitator at Otago Polytechnic's School of Business. Alongside Glenys, a highly experienced facilitator and assessor in Capable NZ, Rachel navigated her transformative learning journey through the Independent Learning Pathway for a management degree, followed by a Master of Professional Practice. Her journey attests to the power of Ako—a teaching and learning relationship that empowers both the learner and the facilitator, exemplifying the potential for neurodiverse individuals to thrive through an innovative educational framework. Rachel, as co-author of this article, has

provided her full approval and consent for the disclosure of her identity and the publication of this case study.

Rachel's transformative journey through the Independent Learning Pathway (ILP) underscores the profound impact of personalized learning and supportive facilitation. Throughout her educational pursuits, Rachel experienced a significant personal and professional progression, centered on the cultivation of her own professional identity. This journey was characterized by the development of a strong sense of self and unwavering self-confidence, facilitated by an environment that celebrated her unique strengths and perspectives, empowering her to embrace her neurodiversity as an asset rather than a limitation.

A pivotal aspect of Rachel's growth was her engagement in rigorous research and continuous learning. This commitment not only enhanced her academic performance but also equipped her with the skills necessary for success in her role as an educator. Rachel's journey also saw her confidently stepping into new roles and opportunities, from organizing symposia to presenting at conferences and writing articles, establishing herself as a respected voice in the field of neurodiversity. Crucial to Rachel's success was the personalized approach provided by the ILP, fostering a strong relationship with Glenys built on trust and open communication. This environment enabled Rachel to comfortably share her thoughts and ideas, supported by Glenys' expertise in identifying and addressing areas of struggle, ultimately demonstrating the potential for neurodiverse individuals to thrive within educational frameworks which prioritize individualized support and empowerment.

By sharing their experiences, Glenys and Rachel hope to inspire other educators and facilitate a collective effort toward creating inclusive and supportive learning environments that enable not just neurodiverse learners, but all learners, to flourish academically and personally.

Neurodiversity encompasses various learning disabilities (e.g., dyspraxia, dyslexia, ADHD, dyscalculia, autism spectrum disorder, Tourette Syndrome) (Clouder et al., 2020; van Gorp, 2022). It asserts that neurological differences are inherent in human diversity, akin to race or gender, emphasizing the unique cognitive strengths of neurodivergent individuals (van Gorp, 2022).

van Gorp (2022) stresses the importance of tailored support in tertiary institutions for neurodiverse learners to succeed, thereby contributing diverse perspectives and strengths to society. Some neurodiverse learners may not disclose their condition(s) for various reasons, such as unawareness, past negative experiences, or discomfort. Scholars argue against pressuring non-voluntary class participation despite potential advantages (Jansen et al., 2017; Hayes, 2021; Kirby, 2021).

Rachel, who successfully completed her studies by way of the ILP program, attests to the tangible growth in her knowledge, skills, and career confidence. Beyond establishing a professional identity, the ILP cultivates essential 21st-century competencies vital for adaptability and lifelong learning. Its transformative impact is particularly significant for neurodiverse learners, often marginalized in traditional educational settings. Unlike conventional methods, the ILP prioritizes a personalized, one-on-one approach, focusing on understanding each learner's individual needs and preferences. The facilitator's expertise is paramount, as they adeptly observe and inquire to tailor the

learning experience accordingly. By enhancing the agency of neurodiverse learners and acknowledging their unique learning styles, the ILP empowers them to excel in their educational journey.

Central to supporting neurodiverse learners is amplifying their voices and experiences, exploring effective workarounds, and breaking negative habits to develop sustainable learning strategies. Effective self-advocacy becomes crucial, and the ILP process equips learners with the tools to assertively communicate their needs. Through seeking support and accessing resources, neurodivergent learners enhance their self-advocacy skills, establishing a supportive network that accommodates their cognitive strengths and challenges effectively.

Discussion: alignment with SDG 4 and sustainable education

In the context of Sustainable Development Goal 4, the ILP journey becomes a catalyst for the development or enhancement of professional identity and 21st-century competencies. These include heightened identity awareness, values exploration, and self-awareness of competencies and transferable skills. These attributes not only fortify a robust sense of self but also instill career confidence and resilience in the face of uncertainty. As learners reflect on their educational journey, it becomes evident that they have honed the ability to adapt to diverse circumstances, recognizing the tangible benefits of conscious adaptability. This holistic approach to education not only fulfills an individual's aspirations but also aligns with the broader objective of fostering inclusivity and sustainable personal and professional development.

Rachel and Glenys discovered valuable strategies for fostering the success of neurodiverse learners. Key approaches include:

Supportive environment - establish inclusivity by setting clear expectations, providing structure, and fostering individualized learning opportunities. Create a safe space for learners to share their thoughts, concerns, and challenges without judgment. Rather than rushing to make a judgment on whether someone is neurodiverse, it is more effective to observe and ask questions with the belief that understanding will lead to determining how best to support the learner. At the appropriate time, the facilitator and learner may engage in a conversation about the potential benefits of obtaining a diagnosis to further support the learner's journey.

Additionally, positive relationships and a sense of relatedness are vital in the learning context. When learners feel connected to facilitators and peers, they experience a sense of belonging, positively impacting motivation, wellbeing, and persistence in academic pursuits. Facilitators must take responsibility for their professional development to effectively support a neurodivergent learner to be successful.

Multi-modal strategies—cater to diverse learning styles with a range of strategies engaging different senses, such as visuals, hands-on activities, and technology tools, promoting effective communication, for example, a facilitator might use videos (visual), experiments (hands-on activities), and interactive apps (technology tools) to explain a concept.

Clear instructions—ensure clarity in instructions by identifying potential challenges in processing complex information. Utilize

clear, concise, and multi-format instructions, incorporating visual aids, written guidelines, and verbal explanations.

Learner agency—empower neurodiverse learners by fostering agency through goal setting, decision-making, and self-assessment. This approach promotes autonomy, resilience, and aligns seamlessly with the ethos of lifelong learning. For instance, a learner with ADHD can be encouraged to set personalized goals for task focus, make decisions regarding break times, and evaluate their own progress. The ILP's flexible online format facilitates this autonomy, allowing learners to take ownership of their learning journey. However, this autonomy is always in collaboration with their facilitator, ensuring that timelines are adhered to for successful completion of learning tasks and assessments. This personalized approach caters to the diverse needs of neurodiverse learners, providing a supportive environment for their academic and personal growth.

Feedback and reinforcement—provide tailored feedback and reinforcement to support learning, ensuring it is specific, constructive, and timely. This approach aids neurodiverse learners in tracking their progress, pinpointing areas for growth, and fostering confidence. While applicable across educational contexts, the importance of tailored feedback and reinforcement is particularly pronounced within the ILP pathway. For example, a facilitator might provide immediate and precise feedback to a learner with autism, ensuring personalized attention that aids in their comprehension and skill development. This individualized support exemplifies the benefits of the ILP for neurodiverse individuals, enhancing their learning experience and facilitating their academic and personal growth.

Flexibility and adaptability—flexibility and adaptability are crucial within the ILP, allowing for the recognition of individual strengths, challenges, and learning paces. Facilitators adeptly modify strategies and offer additional support or accommodations as necessary. For example, in the case of a learner with dyslexia facing difficulties with traditional reading, a facilitator might provide audiobooks, utilize visuals, and extend time, showcasing the ILP's ability to tailor teaching methods to meet unique needs effectively.

Glenys and Rachel discuss the importance of effective facilitation through personalized adaptation of teaching methods within the ILP. For instance, when Rachel encountered difficulties with text-based learning materials, Glenys seamlessly incorporated visual aids alongside text, enhancing comprehension and empowerment. This personalized approach, established in trust and rapport, allowed Rachel to openly address her learning challenges. The transformative impact of tailored learning approaches was evident as Rachel discovered her preferred visual and auditory learning styles, benefiting not only her own journey but also her son's. As an emerging educator, Rachel utilized visual aids to introduce learning styles to her students, promoting self-awareness and autonomy.

In Ker's (2017) Effective Facilitation Model, emphasis is placed on building relationships, fostering trust, and promoting effective communication. Facilitators, equipped with diverse skills in the teaching and learning environment, play a pivotal role in adopting a learner-first approach. This involves empowering learners to take responsibility for their learning and cultivating a sense of agency. Ker stresses intrinsic motivation, emphasizing the importance of

genuine interest in the subject matter for increased engagement, deeper learning, and improved academic outcomes.

However, Ker acknowledges that intrinsic motivation alone is insufficient. Support and encouragement are crucial to sustain learners' efforts. Autonomy-supportive environments, offering choices and self-direction, play a pivotal role in maintaining motivation. Providing feedback that recognizes progress and accomplishments contributes to a sense of competence, encouraging learners to strive for higher performance.

van Gorp (2022) adds valuable insights into the importance of effective facilitation, emphasizing the dynamic nature of learning. Facilitators, according to van Gorp (2022), demonstrate adaptability to evolving learner needs, creating a flexible and responsive environment. This approach involves recognizing and appreciating the diverse backgrounds and experiences learners bring, fostering inclusivity, and promoting a supportive learning community.

Additionally, van Gorp (2022) delves into the long-term benefits of learner success, underscoring the enduring impact of effective facilitation. She believes that sustained facilitator support contributes to ongoing learner achievement and development. This perspective aligns with the overarching goal of facilitating quality education, underscoring the importance of facilitators continuously refining their approaches to meet the diverse needs of learners, including neurodivergent individuals.

Conclusion

This article underscores the importance of addressing the unique needs of neurodiverse learners in higher education, as Ker (2017) and van Gorp (2022) have emphasized. It highlights that facilitators need to possess adept skills in tailoring approaches to the individual's needs, establishing robust relationships, and recognizing the distinctive challenges and strengths of neurodiverse learners. By acknowledging the diverse nature of neurodiversity, facilitators can create an empowering and supportive environment, enabling neurodiverse learners to excel academically. Sustainable education for neurodiverse individuals involves embracing their unique strategies, prioritizing resilience, and promoting self-advocacy.

Overall, this article demonstrates how the ILP aligns with the vision of "inclusive and equitable quality education and lifelong learning opportunities for all" outlined in SDG 4. It discusses how the ILP approach in New Zealand allows experienced mature learners to obtain qualifications through a learner-centric and flexible process, recognizing and valuing all relevant prior learning. The article delves into how the ILP aligns with specific SDG 4 targets, including eliminating gender disparities, ensuring equal access for vulnerable populations, and fostering sustainable development through education. Including a case study featuring a neurodivergent learner and facilitator who successfully completed the ILP journey adds a practical dimension to the discussion.

In essence, this article provides valuable insights for those interested in innovative and inclusive vocational education models,

offering a holistic perspective on supporting neurodiverse learners and contributing to the broader goals of SDG 4.

Author contributions

GK: Writing – original draft, Writing – review & editing. RG: Writing – original draft, Writing – review & editing.

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Tomato disease detection with lightweight recurrent and convolutional deep learning models for sustainable and smart agriculture

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smart agriculture, plant disease detection, deep learning, Convolutional Neural Network, Recurrent Neural Network, Liquid Time-Constant Networks, internet of things, sustainable agriculture

1 Introduction

The detection of plant diseases is a critical concern in agriculture, as it directly impacts crop health, yields, and food security (Fang and Ramasamy, 2015). Traditionally, this task has relied heavily on the observations of farmers and agricultural experts, which is fraught with many shortcomings, including human error and the inability to identify latent or early-stage infections. In response to these limitations, the scientific community has developed multiple innovative solutions. Among these, image classification techniques have gained widespread adoption due to their cost-efficiency (Chhillar et al., 2020) and the ability to enable real-time monitoring, allowing farmers to promptly detect diseases and take timely action (Chen et al., 2020). Additionally, these techniques are highly scalable, adaptable, non-invasive, and non-destructive and can be applied to different crops and disease scenarios (Ramcharan et al., 2017).

However, despite these advantages, image classification methods come with their unique set of challenges. One of the most prominent issues is finding the delicate balance between computational cost and accuracy (Barbedo, 2016). Researchers have delved into various strategies to tackle this challenge, including model pruning (Jiang et al., 2022), transfer learning (Shaha and Pawar, 2018), and hybrid models (Tuncer, 2021). The proposed research seeks to make a valuable contribution to this field by creating a new combination of Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs), known as hybrid CNN-RNN models for detecting tomato plant diseases. This model effectively addresses the computational cost challenge while upholding high accuracy.

The successful implementation of the model marks a significant milestone, paving the way for real-world applications of disease detection in the agriculture industry. The benefits extend beyond reduced crop loss and increased crop quality, leading to higher farmer income and strengthened food security. It also contributes to global economic improvement, reduced pesticide use that positively impacts the environment, and enhanced relationships among farmers, researchers, and corporations.

2 Objectives

The primary goal of this research is to develop and optimize lightweight CNN-RNN models for effectively detecting tomato plant diseases using images. This objective stems from the necessity to create efficient and accessible solutions for disease detection in agricultural settings, particularly where resources are limited. To reach this objective, we will concentrate on several key aspects. Firstly, this research delves into various integrations of CNNs and RNNs to capture both spatial and sequential information within plant images. Additionally, we will evaluate the effectiveness of incorporating Liquid Time-Constant Networks (LTC) (Hasani et al., 2021) alongside CNN models for the image classification task, aiming to understand how LTC enhances our models' ability to capture temporal dependencies within plant images.

Additionally, we will explore the feasibility of deploying our optimized models on Raspberry Pi IoT devices. These devices have become widely used in various image-processing applications worldwide due to their affordability, speed, and efficiency (Kondaveeti et al., 2022). In the agricultural industry, Raspberry Pi devices have found particular prevalence. For example, studies highlighted in Mhaski et al. (2015) and Mustaffa and Khairul (2017) demonstrate the use of Raspberry Pi for real-time image processing to evaluate fruit maturity based on color and size, utilizing CNN models. In another domain, research (Wardana et al., 2021) addresses the challenge of accurate air quality monitoring on resource-constrained edge devices by designing a novel hybrid CNN-RNN deep learning model for hourly PM2.5 pollutant prediction, which is also implemented on Raspberry Pi. Our evaluation of Raspberry Pi will prioritize assessing inference times and energy consumption to ensure that the model remains both functional and efficient within these constraints, facilitating its practical application in real-world scenarios.

By achieving these targets, we aim to make a valuable contribution to the field of plant disease detection, providing accurate and lightweight solutions accessible to a broader agricultural community. Moreover, targeting to solve smart agriculture problems also aligns with and contributes to various Sustainable Development Goals (SDGs).

3 Dataset

The data collection process for this research involves using the Tomato Leaves dataset, which is sourced from Kaggle (Motwani and Khan, 2022). This dataset comprises over 20,000 images categorized into 10 different diseases and a healthy class as shown in Figure 1. The images are collected from two distinct environments: controlled lab settings and real-world, in-the-wild scenes. This diverse dataset provides a comprehensive representation of tomato plant conditions, making it suitable for training and evaluating plant disease detection models.

4 Methodology

The novelty of our approach relies on a combination of transfer learning, and specific neural network components such as CNN,

RNN, and LTC models. Deep Neural Networks are at the core of our research, mimicking the complexity of the human brain to excel in learning intricate patterns from raw data. Particularly suited for image classification tasks like plant disease detection, these networks play a pivotal role in extracting hierarchical features from tomato leaf images.

4.1 Transfer learning

To enhance the efficiency of our disease detection models, we plan to implement a technique known as transfer learning. This method aims to reduce computational costs and training time by leveraging knowledge gained from solving one problem and applying it to a related problem (Torrey and Shavlik, 2010). Unlike traditional machine learning approaches, which train models from scratch on specific datasets, transfer learning reuses pre-trained models and adapts them to new tasks.

Transfer learning involves transferring knowledge from a source domain, where labeled data is abundant, to a target domain, where labeled data may be limited. By doing so, it reduces the need for large amounts of labeled data for training new models, making it more practical and cost-effective in real-world scenarios.

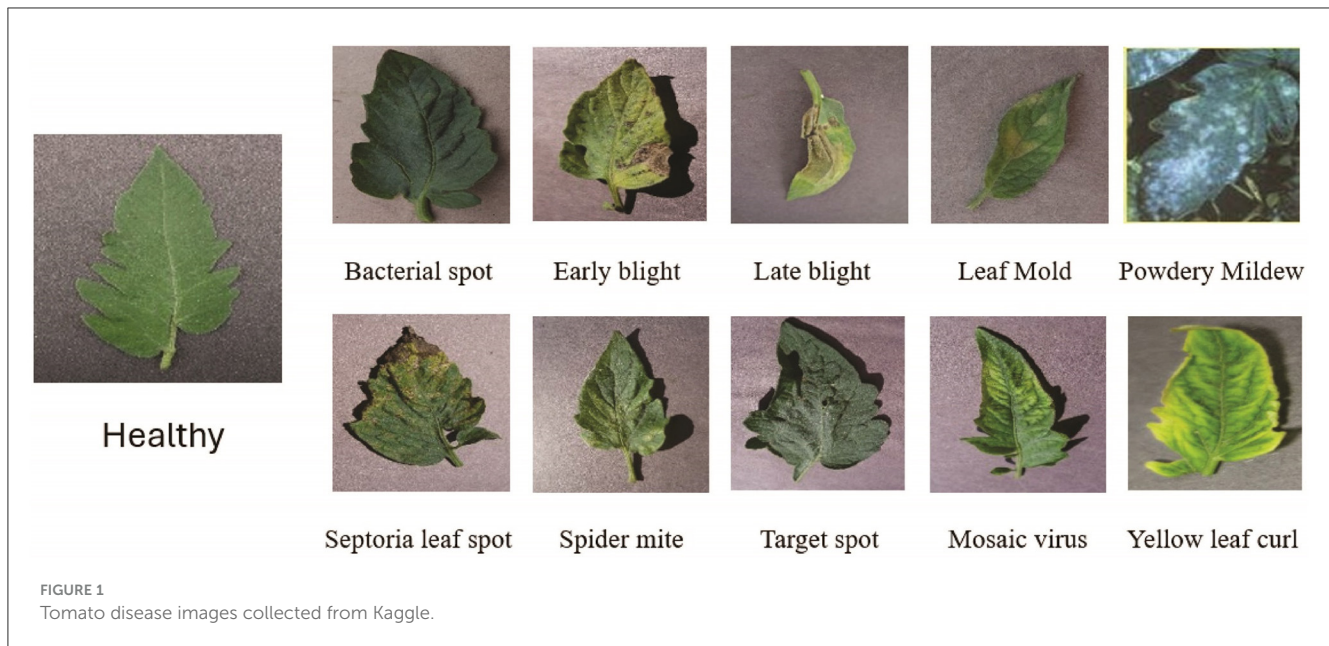
There are two primary types of transfer learning. The first is feature extraction, where the learned representations (features) from a pre-trained model are extracted and used as input to a new model. This involves removing the output layer of the pre-trained model and adding a new output layer tailored to the new task, allowing the model to be fine-tuned on the target dataset.

The second type, which we will apply in this research, is fine-tuning. Instead of freezing the parameters of the pre-trained model, the entire model is further trained on the target dataset with a small learning rate. This enables the model to adapt its learned representations to better suit the different characteristics of the new task while still retaining the knowledge gained from the source domain.

4.2 Convolutional Neural Network

Among neural network types, CNNs are ideal for image tasks that can capture spatial features through convolutional layers (Albawi et al., 2017). CNN is a powerful class of deep learning models inspired by the human visual system. CNNs excel at extracting meaningful features from images, making them highly effective tools in computer vision applications. Therefore in this research, we will use CNNs to analyze tomato leaf images and extract visual cues linked to different diseases.

CNNs typically consist of multiple layers, including convolutional layers, pooling layers, and fully connected layers. Convolutional layers perform the feature extraction process by applying convolution operations. This filter captures local patterns such as edges, textures, and shapes. By repeatedly applying convolutional operations across the entire image, CNNs can learn hierarchical representations of features, starting from simple patterns in the lower layers to more complex ones in the higher layers. Pooling layers reduce the spatial dimensions of the feature



maps, making the network more computationally efficient while preserving important information. Finally, fully connected layers combine the extracted features to make predictions.

One of the key advantages of CNNs is their ability to automatically learn hierarchical representations of features directly from raw pixel data. This end-to-end learning approach eliminates the need for manual feature engineering, allowing CNNs to adapt to a wide range of visual recognition tasks.

However, not all information can be deduced from static spatial features alone, so we will implement RNNs for modeling sequential data and capturing temporal dependencies to further improve the accuracy of the model.

4.3 Recurrent Neural Network

RNN is a class of artificial neural networks specially designed to process sequential data, such as time series, text, and speech (Salehinejad et al., 2017). Unlike traditional feedforward neural networks (like CNNs), RNNs have connections that form directed cycles, allowing them to maintain internal memory and capture temporal dependencies within the input data.

At each time step, an RNN takes an input vector and combines it with the previous hidden state to produce an output and update the hidden state. This process is repeated iteratively for each element in the sequence. The hidden state acts as a memory unit that retains information from previous time steps, allowing the network to incorporate context and make predictions based on the entire sequence.

One of the key advantages of RNNs is their ability to handle input sequences of varying lengths, making them well-suited for tasks such as natural language processing, speech recognition, and time series prediction. Additionally, RNNs can learn long-term dependencies in sequential data, thanks to their recurrent connections and memory cells.

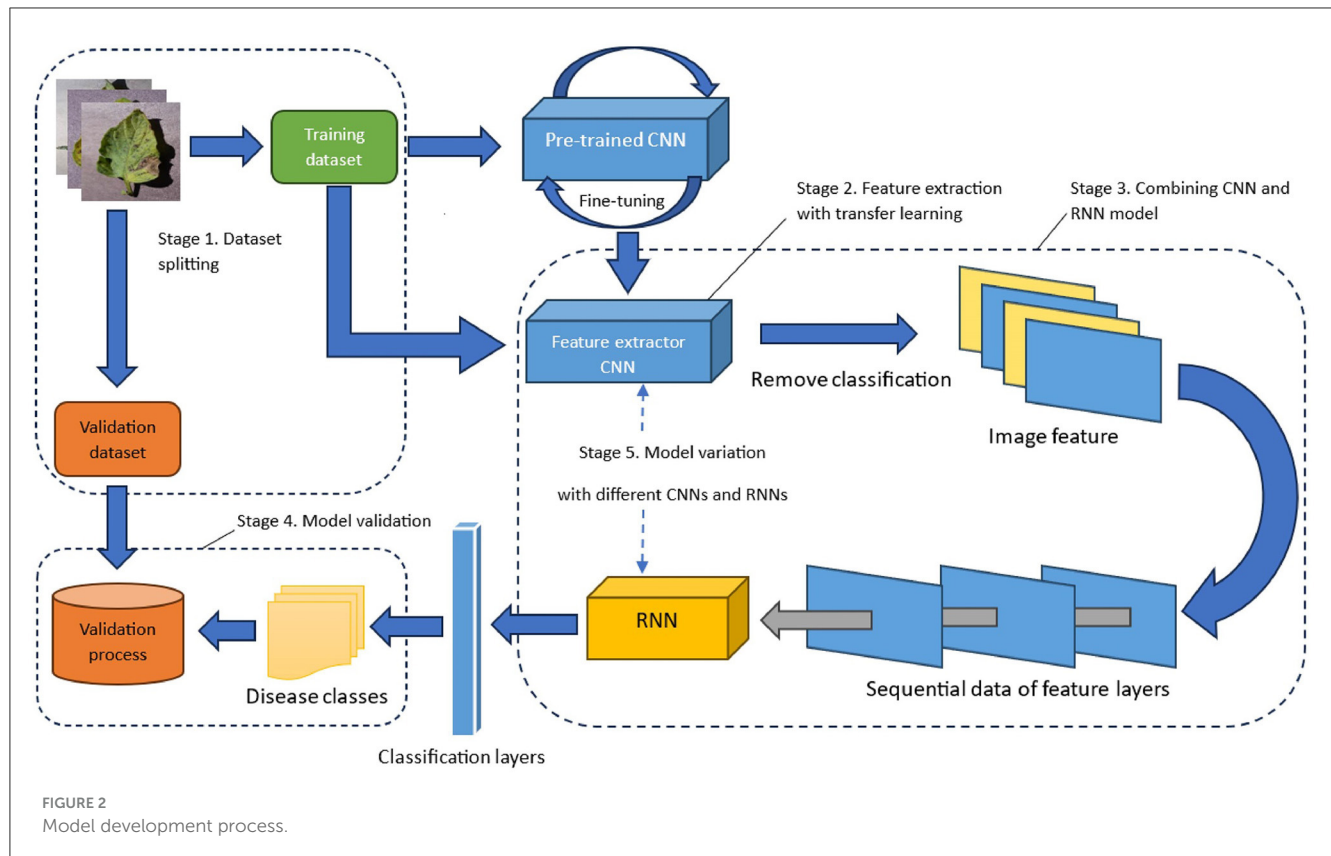
This research has utilized RNNs as we realize that images also contain sequential information. For example, for handwriting recognition tasks (Dutta et al., 2018), after CNNs have extracted the features of the image—each feature stands as a separate character—instead of building another convolutional layer to detect the whole string, we can pass those “character” features as sequential data into RNNs, and it can easily predict the output.

By using similar mechanisms, we can detect special patterns in different disease classes in our tomato leaf images with a lower computational burden on the CNNs structure, resulting in a more efficient model.

It is also worth noting that previous studies on CNN-RNN models have predominantly focused on the combination of CNNs with the Long Short-Term Memory (LSTM) network. However, these researchers commonly face challenges in dealing with image variability and noise in real-world data. The LSTM model struggles to handle these issues effectively, resulting in reduced accuracy in practical scenarios. In response to this challenge, we propose to combine CNNs with the new LTC model, drawing inspiration from liquid-state machines. By dynamically adjusting their hidden state over time in response to input data, LTC models autonomously identify infected regions in plant images. This innovative approach enhances robustness and generalization across various disease symptoms in different real-life scenarios, overcoming the limitations associated with traditional hybrid CNN-RNN approaches.

In this research, a systematic approach in Figure 2 is followed to develop and evaluate models for accurate disease detection while considering computational efficiency. The process involves five key stages, each contributing to the success of the research.

- i. Dataset splitting: after data collection, the dataset is divided into two subsets: training and validation data. This partition, typically with an 80% training and 20% validation ratio, is vital for model evaluation and to prevent overfitting.



- ii. Feature extraction with transfer learning: transfer learning is a fundamental aspect of this project. We will implement multiple pre-trained CNN models as feature extractors and validate their effect on the hybrid model.
- iii. Combining CNN and LTC model: the next phase involves combining the fine-tuned CNN model with the LTC model. Initially, the classification layer of the CNN model is removed, leaving it prepared for feature extraction rather than class prediction. The output features from the CNN model are concatenated into a sequential format before inputting into the LTC model, allowing it to capture sequential relationships between these features.
- iv. Model validation: metrics such as accuracy, precision, recall, F1-score, and confusion matrix are calculated to assess the model's effectiveness in disease detection. Hyperparameter tuning will be conducted to optimize the model's performance, exploring variations in parameters like the number of RNN units, learning rates, and batch sizes.
- v. Model variations: in the project's final phase, various model combinations are explored to assess accuracy, training time, and computational cost. Emphasis is placed on developing lightweight architectures suitable for resource-constrained environments like IoT devices.

At the end of the research, we plan to deploy the model that can achieve the best balance between accuracy and computational cost on an IoT device like Raspberry Pi and validate the accuracy with actual tomato plant images captured from our lab.

5 Discussion

Our research has culminated in the development of an exceptionally efficient hybrid CNN-RNN model. This model significantly reduces training time and computational costs, making it highly suitable for resource-constrained environments, particularly IoT and edge devices. Despite its simplified design, it maintains an impressive level of accuracy in disease detection when compared to more complex models. Furthermore, the innovative implementation of this new LTC model substantially enhances the model's ability to handle noisy and outlier data.

Moreover, this research offers significant potential to contribute to various Sustainable Development Goals (SDGs), addressing challenges not only in New Zealand Aotearoa, where the research is conducted, but also in other regions around the world. By enabling early and precise plant disease detection, this research helps to minimize the damage caused by diseases, and farmers can preserve a larger portion of their harvest, thereby safeguarding their livelihoods. With fewer crop losses, farmers can generate higher yields, leading to increased incomes and economic stability. This reduction in crop losses directly addresses the goal of "No Poverty" by improving the financial wellbeing of farmers and their communities.

Furthermore, by implementing more accurate disease detection models, farmers can maintain a more consistent and reliable food supply. Early intervention helps prevent large-scale crop failures, ensuring that agricultural produce remains available for consumption. This consistency in food availability contributes to

the goal of “Zero Hunger” by ensuring that people have access to an adequate and nutritious diet throughout the year.

Additionally, this model also contributes to the Sustainable Development Goal (SDG) of “Good Health and Wellbeing” by preventing contaminated crops from entering the food supply chain. Detecting diseases early ensures that only safe produce reaches consumers, reducing the risk of foodborne illnesses and related healthcare costs. This model safeguards consumer health, minimizes health risks, and indirectly lowers healthcare expenditures, promoting overall wellbeing and safety.

Economic growth is another area significantly influenced by this research. When crops remain healthy, they yield higher quantities of produce, which farmers can then sell in the market. This increased productivity not only boosts farmers’ incomes but also creates demand for additional labor within the agricultural sector. More workers are needed for various tasks such as planting, harvesting, and maintenance of healthy crops. Additionally, the demand for skilled technicians and researchers may also increase to develop and implement advanced disease prevention measures. As the agricultural sector expands to accommodate these needs, it generates more job opportunities, thereby contributing to the SDG of “Economic Growth.”

In terms of “Industry, Innovation, and Infrastructure,” the development of this model signifies innovation within the agriculture sector. It introduces advanced technology and data-driven solutions that benefit not only farmers but also the broader agricultural industry. Implementing this technology might require the establishment of suitable infrastructure for efficient disease monitoring and control.

By accurately identifying diseases early, farmers can apply treatments only where needed, minimizing pesticide use and promoting environmental sustainability, which promotes “Responsible Consumption.” This also aligns with the SDG of “Climate Action” by reducing the environmental footprint of agriculture and its impact on the environment.

Finally, the successful implementation of this research may necessitate strategic partnerships between researchers, governmental bodies, agricultural organizations, and technology companies. Collaborative efforts are essential to deploy and scale the model effectively, contributing to the SDG of forming “Partnerships” to achieve sustainable goals.

6 Conclusion

Successfully implementing the model in resource-constrained settings is a significant achievement, paving the way for practical disease detection in agriculture. By improving crop health and

reducing costs and energy consumption, this outcome holds the potential to make a substantial impact not only in enhancing food security but also in other sustainable development aspects. However, it’s crucial to acknowledge the limitations and areas for further exploration.

The model may require customization for specific agricultural contexts and broader crop types. Ongoing investigations into its performance under various environmental conditions are warranted. In summary, this research contributes to more efficient disease detection in agriculture, with the need for ongoing refinement and adaptation in diverse settings. It represents a step toward accessible, efficient, and cost-effective disease detection, benefiting the agricultural industry and beyond.

Author contributions

AL: Conceptualization, Formal analysis, Investigation, Methodology, Software, Testing, Validation, Writing—original draft, Writing—review & editing. MS: Conceptualization, Formal analysis, Investigation, Methodology, Software, Validation, Writing—original draft, Supervision, Resources, Writing—review & editing. IA: Conceptualization, Formal analysis, Investigation, Methodology, Validation, Writing—original draft, Supervision, Resources, Writing—review & editing.

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Exploring the motivation of sustainable commuting: a case study of international students in Otago Polytechnic Auckland International Campus

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KEYWORDS

sustainable commuting, international students, commuting pattern, motivational factors, sustainability awareness

1 Introduction and objectives

Sustainability has received increasing attention in many organizations globally, including universities. According to Epstein and Buhovac (2014), sustainability is defined as “a company contributing to the sustainable development of society, which includes economic growth, environmental protection and social progress” (p. 23). As a typical practice for sustainability, an increasing number of universities in various countries have started measuring and analyzing carbon footprints in order to enhance the sustainability of their operations (Ribeiro and Fonseca, 2022). Of this, indirect emissions coming with the commutes of staff members and students have become a concern due to their consequences on the environment (Dreijerink and Paradies, 2020). For example, the use of private vehicles to travel to campus, which is included in the university’s scope three emissions, has a large impact on overall GHG emission (Dreijerink and Paradies, 2020; Hamad et al., 2021; Ribeiro and Fonseca, 2022).

Universities and polytechnics in New Zealand, where a large number of international students pursue their undergraduate and postgraduate studies each year, play an important role in promoting sustainability to support the local government to achieve Net Zero Emissions by 2050 Scenario (Msengi et al., 2019; MBIE New Zealand, 2022). To achieve the objective, ensuring the academic community chooses sustainable commuting options is a key challenge. However, studies on international students’ commuting behaviors are very limited, particularly in the New Zealand context. Therefore, the objectives of this paper are to (a) identify commuting patterns and indirect carbon emissions produced by international students at Otago Polytechnic Auckland International Campus (OPAIC), a tertiary institution in New Zealand, and (b) examine the key motivation factors for sustainable commuting as a way to offset and minimize the impact of international students’ air travel emission through campus engagement.

2 Literature review

2.1 Students commuting behavior

Previous studies revealed that students' commuting behavior had interdependencies on personal characteristics (e.g., car availability and driving license), psychological factors (e.g., habit, attitude, and environmental concern), and was influenced by transportation mode factors (e.g., comfort, cost, and time) (Romanowsk et al., 2019). Additionally, social influence, personal biases, habits, and social comparisons impacted travel behavior (Maggi and Vallino, 2021). Research indicated that university staff in Italy considered cars as their primary mode of transportation (Angelis et al., 2020). Meanwhile, it was found that students were more inclined to use sustainable transportation modes such as public transport or carpooling for short to medium commuting distances (Angelis et al., 2020). In the Auckland context, previous studies identified that most of the students enrolling in the University of Auckland and Auckland University of Technology chose bus as transportation mode (51%–54%) and the rest preferred walking and carpooling (15 and 11%, respectively) (Syam et al., 2012; Mohammadzadeh, 2020). Concerning students' backgrounds and mobility needed in foreign countries, international students tended to travel by provided public transportation or prefer walking or using electric scooters for commuting, especially if they reside nearby (Ribeiro and Fonseca, 2022). Interestingly, students from Asian countries are the majority of public transport users compared to other ethnic backgrounds (Syam et al., 2012).

2.2 Sustainable commuting motivation

Sustainable behaviors, which include responsible waste behavior and sustainable commuting, are related to individual motivation (Molina et al., 2020). Yet, motivations are constructed through the norms in the society which promotes behavioral change and influence motivation (Cogut et al., 2019). Despite policies implemented for sustainable commuting among university students, there was a limited amount of research examining the motivation for sustainable commuting among international students from diverse backgrounds (Molina et al., 2020). Romanowsk et al. (2019) found that the potential to alter transport behavior relied on specific conditions, such as encouragement from universities to provide transport services and the provision of improved cycling infrastructure. Similarly, a study at the University of Western Australia revealed that students' motivation for sustainable commuting relied on the implementation of subsidized public transport passes (Molina et al., 2020). The city's infrastructure, including the implementation of shared spaces for pedestrians and cyclists, has also influenced the motivation of students to rely on bike-sharing and scooter-sharing services (Torrise et al., 2021). These shared mobility options emerged as sustainable solutions, promoting environmental benefits and offering the potential

to reduce car users (Romanowsk et al., 2019; Torrisi et al., 2021).

3 Methodology

This paper employed a mixed-methods research design. It used the quantitative survey and qualitative interview data, which were previously collected by Green Office Toitu at OPAIC. By employing a convenience sampling method (Bell et al., 2022), the survey sample included 278 international students (i.e., around 50% of the total number of students at OPAIC), and 10 students were interviewed. Descriptive analysis was used to describe the characteristics of the population in the survey, which covered country of origin, mode of transportation, and commuting distance. This aimed to identify patterns in data that express meaningful information to interpret the perception of sustainable commuting and the motivation factors behind it, focusing on the geographical origins of students (Loeb et al., 2017; Bell et al., 2022). The result for the commuting distance was calculated using the Carbon Emission Calculator to provide the total emission contributed from each mode of transportation and acknowledge the significantly lower emission compared to individual car usage, as shown in Table 1 (Carbon Footprint, 2023). Meanwhile, the interview covered questions relating to the awareness and motivation of sustainable commuting. In searching for the recurring ideas from the interview, thematic analysis was employed by understanding the interviewees' perspective and providing interpretations (Riger and Sigurvinsdottir, 2016; Bell et al., 2022).

4 Findings and discussion

4.1 Understanding indirect carbon emissions from international students to identify commuting patterns

International students' home-campus commuting behavior was analyzed, focusing on scope three of greenhouse gas (GHG) calculations of OPAIC (see Table 1). Among the 278 surveyed students, 56% used buses for their trips between home and campus, while 29% relied on private vehicles, indicating that the bus is the preferred mode of transportation for more than half of the students. This finding was concerning as a significant portion of students still heavily depended on private vehicles, despite the higher emissions associated with conventional fuel-powered vehicles compared to buses (Logan et al., 2020). Notably, Auckland Transport (2023) had initiated a transition to a fully electric fleet for its latest 24 routes, presenting an opportunity to eliminate 14.5 tons of CO₂-e emissions previously generated by conventional buses, potentially motivating students to opt for public transport over private cars (see Table 1).

It has been previously explained that this commuting pattern is influenced by the distance from the students' accommodations, such as flats or apartments. The fact that the campus is located in the CBD area tends to encourage students to rely on public transport, or to opt for active commuting modes like cycling or

TABLE 1 CO₂ emissions generated by the student cohort by a variety of home-campus commuting options.

	Transport option	kg CO ₂ -e/unit	Total distance (32 weeks)	Total CF calculation (annually)
Land travel*	Bus (average)	0.155	93,840 km	14.5 ton CO ₂ -e
	Train (electric)	0.013	47,642 km	0.62 ton CO ₂ -e
	Ferry	0.0187	1,984 km	0.037 ton CO ₂ -e
	Car (petrol)	0.209	35,094 km	7.34 ton CO ₂ -e
	Walking	–	15,797 km	–
	Scooter	0.051	1,264 km	0.06 ton CO ₂ -e

*Based on average travel of three times per week.

walking (Soltani et al., 2019). This is in line with the finding that the location of the OPAIC campus in the Auckland CBD is a primary reason students use public transport for commuting. However, factors such as comfort, accessibility, and availability also influence the choice of transportation mode (Ayobami et al., 2019).

4.2 Motivational factors influencing students’ choice for sustainable commuting

This paper also investigated students’ motivational factors for choosing sustainable commuting by analyzing the qualitative interview data from 10 international students at OPAIC, who come from diverse backgrounds, with the majority originating from developing countries. A previous study showed that international students’ country of origin can affect the knowledge on sustainable mobility, climate change, and emissions (Ferreira and Liu, 2023). The conducted interview revealed the distinctions between students who were merely aware of sustainable commuting and those students who have previously practiced sustainable behavior in their home countries, persisting in these habits during their studies in New Zealand. Representative quotes are provided below.

“I’m aware of sustainable commuting as we built employee awareness around this in India” (P01, India).

“I’m aware that [sustainable commuting] in my country or actually my capital city Tirana in Albania. In the council, they have regulation between 2–3 years having electric buses that circulate around the city” (P05, Albania).

“I’m aware of sustainable commuting but in Indonesia, we don’t have proper public transportation. So I’m not a regular passenger of bus, even in Auckland I still feel uncomfortable and the bus isn’t reliable” (P06, Indonesia).

These examples demonstrate that while some international students understand the concept of sustainable commuting, they have not utilized public transportation in their home countries due to significant barriers such as limited travel time, indirect routes, and the distance from home to the bus stop (Yumita et al., 2021). This highlights that students possess the knowledge necessary

to grasp the concept of sustainability. Increased awareness can motivate them to implement sustainable practices in their daily lives, especially when supported by ready infrastructure (Garbie, 2015). Therefore, *awareness of sustainability* is a motivator for students in Auckland, reinforced by the availability of public transportation options.

Sustainability awareness has influenced international students’ choices regarding sustainable commuting, aligning with previous studies that link awareness to behavior. Awareness acts as a motivational factor toward sustainable behavior and influences international students to use public transportation. This usage is facilitated by reduced barriers, such as proximity of accommodation to campus and infrastructure readiness, and by social norms within the community (Cogut et al., 2019). Environmentally conscious students are likely to reduce car usage in favor of public transport and active commuting, which also saves costs associated with vehicle maintenance, fuel, and parking fees (Sivasubramaniyam et al., 2019; Torrisi et al., 2021). However, the current study reported that 29% of students still travel by private car due to reasons such as the higher costs of public transport, the need to travel to multiple places, and convenience. This is particularly the case in Auckland, where public transport is perceived as less reliable compared to Wellington and Christchurch (Murray et al., 2010). Therefore, to increase international students’ awareness of sustainable commuting, the role of universities remains crucial in engaging students as a strategy to reduce emissions (Cogut et al., 2019).

Two main recommendations, sustainability literacy programmes and carbon emission tracking, were provided to increase international students’ sustainability awareness, in order to better promote sustainable commuting. First, through online training and assessment tools for sustainability literacy, tertiary institutions can cultivate graduates equipped with sustainability knowledge, fostering a transition toward sustainable behaviors to combat climate change (Décamps et al., 2017). For instance, the carbon literacy program imparts an understanding that every action affects the environment, leading to individual reductions in GHG emissions. However, students participating in the carbon literacy program retain the right to choose whether to adopt green behaviors (Howell, 2018). Hence, it can be inferred that sustainability literacy initiatives may hold the potential to enhance awareness and encourage low-carbon behaviors and lifestyles, thereby offsetting students’ emissions from international mobility.

Second, carbon emission tracking serves as a crucial tool for students, enabling them to comprehend the emissions generated through activities such as air travel, energy consumption, and commuting (Paterson and Strippel, 2010). This tracking approach allows students to compare their emissions against standard benchmarks. Additionally, research suggests that carbon calculators have the potential to instigate behavioral change by stimulating psychological capacities and serving as a motivational tool for making low-carbon decisions (Dreijerink and Paradies, 2020). Similarly, several studies have reported that carbon calculators significantly impact raising awareness and reducing footprints in commuting, consumption, household activities, and waste management (Dreijerink and Paradies, 2020).

5 Conclusion

In achieving a green campus through sustainable commuting, this paper identified the commuting pattern and examined the motivation behind the choice of transportation mode of international students. Through a mix-methods methodology, the finding revealed a significant portion of international students relied on public transportation such as bus (56%), followed by train and ferry. This result is in line with previous research conducted in two universities in Auckland (Syam et al., 2012; Mohammadzadeh, 2020). A small percentage of students chose active commuting, either walking or riding a scooter, to campus, which is influenced by the distance of their accommodation to campus (Soltani et al., 2019). There was still a considerable percentage utilizing private vehicles (29%) despite the environmental concerns associated with such modes of transportation. The motivation for sustainable commuting was found to be influenced by awareness of sustainability practices (Cogut et al., 2019). Thus, the paper highlights the importance of increasing awareness through actively promoting and implementing sustainability initiatives through engagement in the campus' carbon literacy program and individual carbon emission tracking programme, which can stimulate behavioral change as suggested in previous studies (Howell, 2018; Dreijerink and Paradies, 2020).

However, the study acknowledges potential limitations regarding the small size interview respondents, specifically within the context of OPAIC, and the depth of analysis concerning commuting patterns and motivational factors. Additionally, the research findings may be biased by the use of convenience sampling

methods and the measurement of awareness (Bell et al., 2022). Therefore, further research is needed, especially to explore the effectiveness of sustainability initiatives on changing commuting behavior in the context of international students.

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Understanding the future of carbon neutrality in the culinary arts through non-representational theory, practice theory, and design

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KEYWORDS

culinary arts, Bornholm, non-representational theory, design, practice theory, sustainability

Introduction

The hospitality and culinary arts industry stand at a crucial crossroad. With the imperative to reduce carbon emissions in line with 2050 Paris accord ([United Nations, 2024](#)), restaurants and culinary institutions are compelled to rethink their practices; it could also be argued that the rethinking is part of a wider “rebalancing” of the food system ([Public Health Advisory Committee, 2024](#)).

A combination of non-representational theory, practice theory, and design could offer a unique lens to understand and communicate the necessary changes. By integrating these theories, I believe we can pave the way for a more sustainable and resilient culinary sector, as it allows for a greater understanding of sustainability that goes beyond theoretical frameworks and addresses the practical challenges facing the culinary industry. Second, the iterative and user-centric nature of design thinking ensures that the research remains grounded in the realities of culinary professionals, promoting the development of solutions that are both effective and feasible. This is in contrast to the current examples where a combination of siloed information has resulted in a “lack of clear vision” within the hospitality industry ([McMahon, 2024](#)).

Moreover, the combination of design thinking, non-representational and practice theory fosters a transdisciplinary approach, acknowledging the diverse perspectives and expertise needed to tackle complex sustainability issues. It encourages collaboration between culinary arts, design, sociology, and other relevant fields, creating a synergistic environment for innovative problem-solving. This opinion piece explores how these theories can illuminate pathways for the culinary sector to become carbon neutral and considers the transformation experiences of the Danish island of Bornholm into an example of ecological, economic, and social regeneration.

Understanding the challenge

Restaurants are significant contributors to carbon emissions, with the average New Zealand restaurant emitting around 72 tons of CO₂ equivalent annually ([SkootEco, 2024](#)). These emissions stem from various sources, including on-site energy use, electricity, and the broader supply chain and can be assigned under a framework to scope one, two or three for measuring carbon emissions ([Ministry for the Environment, 2020](#)). Addressing this

requires a holistic approach that considers the entire lifecycle of culinary products and services, from sourcing and production to waste management, but also considers the role that people and specifically those who operate in the hospitality sector play in this.

Practice theory and non-representational theory in culinary sustainability

Practice theories, as articulated by scholars such as Elizabeth Shove, delve into the interplay of materials, competencies, and meanings that constitute social practices. Such theories are used to frame problems in such a way as to make specific methodological demands of those who work with them (Shove, 2010). When applied to the culinary arts, practice theory helps us understand how chefs, restaurateurs, and consumers enact sustainability in their daily routines. It reveals the material conditions, skills, and cultural values that shape sustainable culinary practices and explores human behavior against the backdrop of social structures split into three constituent elements: materials, competencies, and meanings (Shove, 2010). Materials, in this context, are not merely physical substances but carriers of cultural, social, and symbolic significance. Practice theory enriches design by highlighting how materials are embedded within social practices, influencing and being influenced by them (Shove, 2017). By acknowledging the interplay between these elements, practice theory enriches our understanding of sustainable culinary practices.

Non-representational theory, developed by Nigel Thrift, complements design thinking by providing a theoretical lens that goes beyond traditional representational approaches (Thrift, 2007). The theory emphasizes the embodied and experiential aspects of social phenomena, recognizing the significance of non-discursive elements in shaping human behavior. By acknowledging the non-discursive aspects, the research gains insights into the tacit knowledge and implicit behaviors that contribute to or hinder sustainable culinary practices. This approach aligns with the holistic nature of sustainability, acknowledging that it extends beyond mere representations and involves lived experiences, emotions, and sensory perceptions.

Design thinking: bridging theory and practice

Design thinking, particularly as outlined by V.J. Kumar in “101 Design Methods,” complements the above theoretical frameworks by providing practical tools for innovation and problem-solving (Kumar, 2012). It emphasizes user-centric and iterative processes, ensuring that sustainability solutions are grounded in the realities of culinary professionals.

While design thinking and non-representational theory provide valuable perspectives, practice theory offers a deeper

understanding of how sustainability practices are enacted and negotiated within culinary settings. Furthermore, these theories can complement each other, in several ways as reflected by Bech-Danielsen (2012) in his paper *The Kitchen: An Architectural Mirror of Everyday Life and Societal Development*, whereby the physical and embodied role of the kitchen is interrogated and reflected upon as it changes over time.

Integrating design thinking with non-representational and practice theory allows for a nuanced approach to sustainability. This synthesis acknowledges the complexity of culinary practices and the diverse factors influencing sustainability outcomes, from material resources to social norms and cultural values. The approach encourages collaboration among culinary arts, design, sociology, and other relevant fields, creating a synergistic environment for innovative problem solving.

Opportunities for sustainable practices on Bornholm

Exploring the sustainable practices on the Danish Island of Bornholm, known as the “Bright Green Island,” provides an opportunity to highlight the adoption of an integrated approach and investigate its merits. Bornholm’s commitment to the United Nations Sustainable Development Goals (SDGs) provides a fertile ground for examining how sustainability can be practically achieved in the culinary sector. The study will investigate how Bornholm’s restaurants and businesses embed SDGs 11 (Sustainable Cities and Communities), 12 (Responsible Consumption and Production), and 13 (Climate Action) into their practices. By observing and analyzing these practices, the aim is to validate a template for change that can be applied to culinary arts education and the wider industry. Dissemination of this information, in the form of podcasts and radio interviews, mediums could be further expanded upon using video or other multimedia platforms (Guo et al., 2014), and is more likely to reach hospitality workers than academic publication.

Conclusion

The combination of non-representational theory, practice theory, and design thinking could provide a powerful framework for understanding and driving sustainable change in the culinary arts. By focusing on the material, embodied, and symbolic dimensions of culinary practices, this integrated approach offers valuable insights and practical solutions for achieving carbon neutrality in the hospitality industry. Such an approach can move beyond theoretical frameworks and address the practical challenges faced by the culinary industry and educators alike. Exploring practices on the Danish Island of Bornholm, could demonstrate how sustainability can be practically achieved in the culinary sector. Educators can draw from the insights gained through the case study on Bornholm to incorporate principles of SDGs into the curriculum. Integrating such practices into culinary arts programs reflects a commitment to shaping future

professionals who are equipped to drive positive change. This approach aligns with targets to achieve carbon neutrality by 2050 as part of global commitments to sustainability, espoused by the United Nations.

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Sustainable digital rent: a transformative framework for value dynamics in the digital age

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Introduction: This paper introduces the concept of Sustainable Digital Rent (SDR), highlighting the shift from traditional economic rent based on tangible assets to rent derived from digital platforms. At the heart of this shift is the “value state,” a dynamic balance between constructive expectations and destructive information. As digital platforms generate increasing amounts of information, expectations are increasingly met and shared more efficiently with all users, leading to a reduction in individual and general motivational, emotional, and cognitive engagement. These platforms, now essential to modern life, facilitate online activities that reduce as well physical engagement and natural interactions, thereby impacting cognitive function and physical health. By extracting rent directly, digital platform operators limit the benefits users could gain to support their mental and physical well-being.

Methods: This paper empirically defines and estimates SDR using the collective estimates of price, cost, and income (PCI) as practiced in North American real estate appraisal, demonstrated through abstract art rent. Our approach provides a new perspective on valuing intangible assets, such as knowledge, by showing the shift from expectation to information, governed by the value state in cognitive evaluations. Emphasizing interdisciplinary relevance, the method underscores the need for an efficient mechanism to redistribute SDR benefits to digital platform users, supporting fair and equitable digital development.

Results and discussion: The results show that digital rent is driven primarily by cognitive and informational content, demonstrating the need for redistribution mechanisms to address the growing inequality on digital platforms. The use of abstract art as a case study provides a convenient and illustrative way to explore how intangible assets, like digital rents, can be evaluated and redistributed. SDR offers insights into how digital rents can be captured and redistributed equitably, ensuring that platform users and creators benefit from the knowledge economy's growth. The findings underscore the relevance of measuring SDR to guide policy recommendations aimed at reducing digital monopolization and promoting sustainable digital development.

KEYWORDS

sustainable digital rent, human expectation, information, value state, evaluation

1 Introduction

The classical concept of economic rent, once firmly rooted in tangible assets like land, has undergone a profound transformation in the digital era. With digital interactions and information emerging as key economic commodities, rent has evolved into what we now identify as “digital rent.” Stemming from this transition, we introduce the concept of

“Sustainable Digital Rent” (SDR), a framework aimed at addressing the sustainability challenges associated with the growing influence of knowledge and cognitive value in the economy. To fully grasp these challenges, it is important to revisit the historical foundations of rent in economic theory.

Examining Ricardo’s (1817) concept of land rent and comparing it to today’s wealth from knowledge reveals a significant transition, showing how this foundational economic matter has “melted” into digital rent. Seminal theories by Marx (1867, 1894) and Mill (1848) lay the groundwork for exploring SDR, linking the production of physical commodities to the dynamics of immaterial knowledge in digital economies. Marx’s insights into monopolization and capital investment remain pertinent as digital platforms transform ‘digital land’ to exploit information, converting human cognitive expectations into non-renewable digital rent (or information). This non-renewable rent, once generated, loses its emotional value (or expectations) and cannot be replenished in the same way within the conditioned cognitive system of value state valuation. Mid–20th-century thinkers like Schumpeter (1942) and Keynes (1936) further refined these ideas. Schumpeter’s theory of creative destruction illustrates how innovation disrupts economic models, paralleling the impact of digital technologies on rent structures. Meanwhile, Keynes’ emphasis on the government’s role in stabilizing economies underscores the need for regulatory frameworks to manage digital platforms and ensure equitable distribution of digital rents.

In the digital economy, user contributions are central to platform value creation (Ahmed et al., 2023). However, digital rent remains a relatively new phenomenon (Fuchs, 2022), with no established methods to understand, evaluate, capture, or fairly attribute it to its originators. At the core of SDR is the concept of the ‘value state,’ shaped by the interplay between human expectations and information. Much like physical land in traditional rent models, cognitive expectations are a non-renewable resource. As users engage with digital platforms—through remote education, virtual work, online banking, telehealth, and digital entertainment (Smith et al., 2018; Mayer-Schönberger and Ramge, 2018)—their expectations transform into information, creating digital rent. This shift from natural cognitive and physical engagements to sedentary digital interactions negatively impacts both biological health and cognitive function (Hu et al., 2017; Shanmugasundaram and Tamilarasu, 2023a). Research indicates that excessive digital engagement can lead to cognitive overload, affecting attention, memory, and decision-making (De-Sola Gutiérrez et al., 2016; Dahmani and Bohbot, 2020; Spitzer, 2022). Unlike natural engagements, which intertwine physical activities with conscious learning, digital activities often lack this depth, resulting in diminished cognitive and physical states.

Expectations transformed into cumulative information generate digital platforms from which digital rent emerges. This rent is captured by platform owners or “Mindowners” without fairly compensating the users who create it (Fuchs, 2014a; Corsani, 2014; Zuboff, 2019). This imbalance mirrors the unsustainable practices of traditional rent models, leading to the depletion of human expectations. Sustainable Digital Rent (SDR) proposes an equitable redistribution of digital rents, thereby preserving human motivation and promoting social equity in the digital economy (Fuchs, 2012; Fisher and Fuchs, 2015; Jin and Feenberg, 2015). While modern sustainability frameworks have largely focused on environmental concerns, there is an increasing recognition of the

need to address the interaction between societies and digital resources (Ghaderi et al., 2023; Benevene and Buonomo, 2023). This shift in focus emphasizes the importance of developing models that capture, manage, and redistribute digital rent, thereby transforming digital platforms into contributors to a more inclusive society.

Institutionalizing digital rent is central to this transformation. Effective regulatory frameworks are necessary to manage and equitably redistribute the benefits of digital assets. Fisher and Fuchs (2015) advocate for mechanisms that align with a human-centric approach, drawing parallels between traditional rent regulations and the protections required in digital markets. They emphasize fair compensation for personal data use through digital dividends, redistributing profits to the users who contribute their data. This approach not only enhances social welfare but also supports policies that prioritize equitable access to digital resources (Fuchs, 2014b). Pasquinelli (2009) and Scholz (2013) further support these concepts, advocating for a commons-focused approach that ensures the well-being of all participants in the digital economy.

However, to truly operationalize SDR and its institutionalization, it is not enough to merely propose theoretical frameworks; an empirical system is necessary to measure and distinguish SDR within real-world contexts. This measurement system must accurately separate SDR from the total value, ensuring its fair attribution to both users and platform owners (Özdilek, 2011a, 2011b). In pursuit of this goal, we applied the economic tripartite method of price, cost, and income (PCI) in the abstract art market, demonstrating that SDR captures the superior value of knowledge over digital infrastructure—much like an artist’s encoded message commands art rent. By establishing a method for empirically measuring SDR, we highlight its potential to prevent monopolization by conglomerates, thereby facilitating a more equitable distribution. This approach aims to realign the digital economy with human priorities, supporting societal welfare, cultural vitality, and cognitive and physical health.

The main contribution of this study is the development and characterization of digital rent as a fundamentally sustainable concept, bridging traditional economic theories with the complexities of the digital economy. We introduce an innovative approach validated through value valuation methodologies using abstract art, offering a novel perspective on assessing intangible assets. By exploring the ‘value state’ with interdisciplinary examples from economics, biology, and physics, we lay the groundwork for comprehending and quantifying SDR. Our historical analysis traces three key transitions: from classical land rent to digital rent, from expectation to information, and from physical production to knowledge production in the digital economy. This context deepens the understanding of SDR and its implications across both tangible and abstract domains. We propose fiscal policies and regulatory frameworks, including institutionalization principles and the empirical measurement of SDR, to promote equitable distribution of digital wealth, thereby enhancing economic stability and social equity. Additionally, we examine the societal and individual effects of digital rent on cognitive and physical well-being, underscoring the importance of managing human expectations sustainably. Ultimately, this multidisciplinary analysis enriches the understanding of digital rent’s transformative potential and outlines strategies for a more sustainable and equitable digital future.

2 Value state definition

In this section, we explore the value state through an interdisciplinary lens, integrating perspectives from economics, cognitive science, biophysics, and real estate appraisal. We begin by tracing the evolution of value from subjective use to measurable exchange, establishing a link between economic theories and contemporary valuation approaches. The discussion then moves into cognitive science, where human expectations and information interact within the value state. Drawing connections between these disciplines, we examine the neurobiological basis of reward systems, particularly how dopamine influences value perception, highlighting its parallels in abstract art and digital platforms. This interdisciplinary approach underscores the shared mechanisms of evaluation across these fields, illustrating how the value state concept bridges tangible markets and intangible digital ecosystems.

The interdisciplinary methodology adopted here integrates economic, cognitive, and real estate appraisal perspectives to provide a comprehensive view of the value state. Economic theories lay the foundation for understanding value, while cognitive science reveals how human expectations interact with information to shape value states. Real estate appraisal methodologies, defined in a later section, offer practical tools for quantifying value in both tangible and intangible markets. This approach is particularly suited for complex systems like digital platforms and abstract art, where traditional models cannot fully capture the dynamic interplay between expectations and information (Van de Cruys and Wagemans, 2011). By merging these fields, we refine value estimation and underscore the evolving nature of value in modern economies.

Over centuries, the concept of value has been a focal debate in economics and other disciplines, with various schools offering differing perspectives and no unified definition (Tripathi et al., 2023; Kaiser, 2024). In the 21st century, mainstream economics shifted towards practical substitutes like prices, costs, and incomes (PCI) for their tangibility. This left the exploration of value to fields such as cognitive science, neuroscience, sociology, and psychology (Friston et al., 2015), where discussions became more diffuse yet gained renewed interest, as explored further in this section. Value is thus a complex interdisciplinary concept debated across economics, sociology, biology, and physics (Robinson, 1962; Heinich, 2020). Often conflated with PCI, it has caused conceptual confusion (Anderson, 1993; Ariely, 2008). Economically, the notion of value evolved from subjective use to measurable exchange value, particularly after the Industrial Revolution, emphasizing PCI observables as practical proxies for subjective value (Jia et al., 2016). Classical economics initially focused on production costs, while neoclassical economics later shifted to utility derived from consumption, influencing price levels (Landreth and Colander, 2002). Marshall's (1920) synthesis of supply-cost and demand-price dynamics into an equilibrium model underscores the complexity of value (Joffily and Coricelli, 2013). Given this extensive background and vast literature on value, our work focuses on key theories relevant to our subject, acknowledging the limitations of a comprehensive review within this paper's scope.

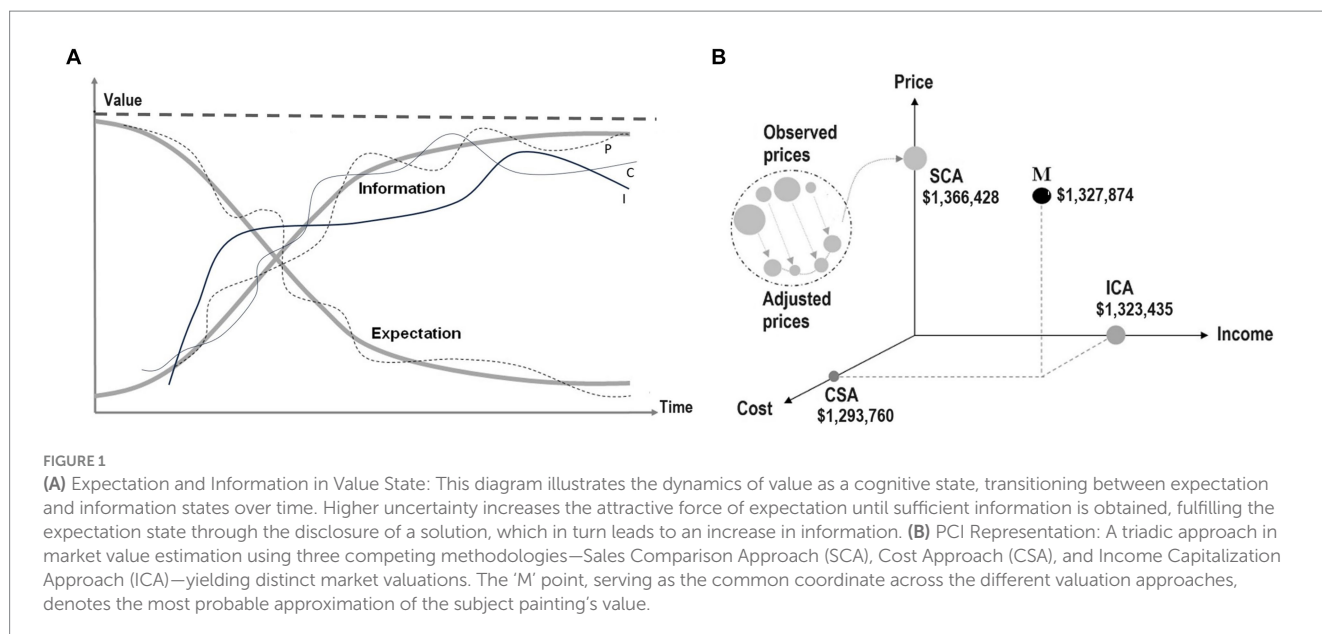
Value, as conceptualized, is a cognitive state probabilistically existing by the combination of its attractive expectation state and its information state. The value of an event attracts us until sufficient information is obtained, at which point the value state collapses into information, fulfilling the expectations. This dynamic holds value in a statewise existence until it becomes a pointwise observable. Higher

uncertainty in value correlates with stronger attractive forces, whereas pointwise estimates provide statistical measures. Expectation persists as long as outcomes remain uncertain (Georgescu-Roegen, 1971) and updates with new information, increasing the probabilities of better prediction of outcomes. For similar events, value tends to remain constant, though its expectation and information states dynamically change as depicted in Figure 1A. In an economic context, PCI represents observed manifestations of value state collapses, processed through complex patterns of seeking, comparing, and evaluating. Individual variations in perception evolve under the value state, following the theoretical logistic behavior of its information component through the consumption of expectation while generating new anticipations in perpetual cycles of assessments. Just as the movement and quantity of matter define an object's total energy, value sets the energetic boundary for a commodity. Potential energy corresponds to unknown information—or expectation—while kinetic energy parallels the observed final decision, or information.

Figure 1B visually demonstrates the application of the triadic approaches and their corresponding PCI estimates as observables through a three-dimensional representation. Detailed computations and adjustments in these methodologies yield three distinct market value estimations for the same subject abstract painting. The SCA estimates a market price of USD \$1,366,428 using data from four comparable paintings, as demonstrated later in the practical example. Adjustments for varied structural, spatial, financial, and temporal attributes align their prices with the subject painting, as highlighted in the boxed region of the illustration. The circles' sizes represent the range of observed prices influencing the SCA's final valuation. The CSA and the ICA, though not depicted for clarity and whose details are provided successively within the empirical demonstration, follow similar processes, resulting in market valuations of USD \$1,293,760 and USD \$1,323,435, respectively. The point 'M' in the figure represents the market value, serving as the most probable approximation of the value state of the subject painting.

Abstract art offers valuable insights into its observer's value creation and destruction mechanisms, serving as a close analogy for user engagements in digital platforms. As a genuine model of intangible value, art exemplifies how intangible value can be far beyond the cost of physical media like canvas and paint. Similar to the value in different media like poetry or music, the high value of abstract art derives from its painted message triggering evaluation, creativity, and intellectual engagement, paralleling the valuation of digital information over physical infrastructures and platforms through which it flows. Fine art articulates complex emotional experiences both in tangible and immaterial media, bringing us closer to the complex dynamic interplay between expectation and experimentation mechanisms in digital environments. Paralleling the cognitive mechanisms in art value and valuation with user engagements and interactions in digital platforms also enhances our understanding of subtle transitions into the digital economy, informing strategies to sustain engagement and enrich societal and cultural connections.

The evaluation of art intertwines with economics and cognitive science, utilizing methods based on value and comparison, with higher valued alternatives favored (Vlaev et al., 2011). Classical economic theories, such as the expected utility theory (EUT), suggest decisions are made to maximize utility or expected utility in probabilistic outcomes (von Neumann and Morgenstern, 1944). The neurological evaluation system is hierarchically organized, with cortical predictive (evaluation) activity flowing top-down to meet bottom-up sensory information



(Manousakis, 2009; Clark, 2013). Neurons communicate and process rates of impulsive signals about expectations and information as the neural currency of value using action potentials (Schultz, 2010; Jia et al., 2016). This neural activity is integrated to form conscious decisions (Ljungberg et al., 1992; Ariano et al., 2005; Bromberg-Martin et al., 2010). Practitioners can use observables such as BOLD imaging (Sabri et al., 2013), fMRI (Silvetti et al., 2013), and EEG (Kawabata and Zeki, 2004) to understand the brain's evaluation system.

Abstract art challenges traditional representation by emphasizing fundamental elements like lines and color patches, thereby inviting unique interpretations and profound cognitive engagement (Aviv, 2014). This interpretative openness enhances the artwork's value through a dynamic interplay between expectation and realization (Vartanian and Goel, 2004), analogous to user interactions on digital platforms. By introducing ambiguity, artists create multiple potential value states and interpretations, which in turn continuously trigger cognitive evaluations (Zolberg, 2007). These interactions align with predictive coding theories, wherein the brain's pleasure centers are activated by the confirmation of expectations and the enhancement of pattern recognition, thereby enriching the aesthetic experience (Dodgson, 2009). This framework elucidates how the brain manages expectations and processes information during art appreciation, enhancing pleasure when prediction errors are resolved (Ogawa and Watanabe, 2011). Navigating these cognitive dynamics heightens aesthetic appreciation and emotional responses, mirroring the satisfaction derived from complex problem-solving in controlled environments that replicate the thrill of discovery without associated risks (Ashenfelter and Graddy, 2003; Van de Cruys, 2017).

The genetic and neurobiological underpinnings of our interaction with art are well illustrated by the roles of the DRD4 gene in novelty-seeking behaviors and how dopamine influences neuronal firing during art engagement (Oak et al., 2000). This system's heightened response to the unpredictability of expected rewards underscores the impact of novel information on reward pathways (Schultz, 2015). Niv and Chan (2011) nuances that the brain's dopaminergic (DA) system does not encode the absolute value of information but responds to changes in expected outcomes, reflecting the dynamic nature of reward perception. The DA system rewards seeking behaviors under

uncertain situations and halts actions once resolution is achieved, explained through anhedonia, incentive salience, and reward prediction error theories (Previc, 1999; Montague et al., 2004; Berridge, 2007; Colombo and Wright, 2017). Theories of liking, learning, and wanting further analyze the DA system's response to the unpredictability of rewards (Wise, 2004; Berridge, 2007; Pecina, 2008). This adaptive evaluation mechanism continually optimizes decision-making by assimilating new information to maximize benefits (or minimize errors) under varying conditions of resource constraints and uncertainty (Glimcher, 2003; Dreher and Tremblay (2016)).

Cognitive science suggests that when expectations align with reality, dopamine release subsides, leading to reduced interest and engagement, a phenomenon known as the hedonic treadmill effect (McSweeney and Murphy, 2009; Friston, 2003; Schultz, 2010). Vygotsky (1971) posits that aesthetic experiences require active engagement to uncover deeper meanings, contrasting with mere information consumption, which 'cools' value states. Art lacking novelty induces boredom and disengagement (Eastwood et al., 2012). This is supported by Hebbian learning experiments, which show that repetitive engagement with art leads to cognitive satiation, diminishing stimulus impact and reducing interest (Citri and Malenka, 2008; Robbins et al., 2007). This reduction in emotional engagement parallels digital interactions where user interest wanes after repeated cycles of expectation fulfillment and information saturation (Watt and Vodanovich, 1999). Preferences for surreal art among those prone to boredom highlight the need for complex artistic expressions to prevent cognitive satiation (Furnham and Avison, 1997). Cognitive satiation, akin to "information overload" (Przybylski et al., 2013; Whelan et al., 2020), undermines cognitive efficiency and emotional well-being, leading to "data smog" and attention deficits (Shenk, 1997; Epstein et al., 2005).

When the outcome of an event becomes entirely predictable, its value state is significantly reduced, thereby eliminating the potential for profit. This is exemplified in stock markets, where the complete disclosure of data, such as PCI, nullifies opportunities for financial gains (Kirkup and Frenkel, 2006). Entities with access to superior information can leverage uncertainties to optimize their returns by accurately forecasting complex value dynamics (Jiang et al., 2021). In a parallel manner, within the art world, the exposure of visual

information diminishes an artwork's intrinsic value, whereas novelty serves to enhance it (Elkins and Fry, 2022). This phenomenon elucidates why personal interest in a piece of art wanes once curiosity has been satisfied, despite the potential for its market PCI to increase due to emerging expectations regarding various facets of the artwork (Kraizberg, 2023). For an informed economic agent, the value state of the event becomes null, providing no scope for emotional engagement (Lazzaro and Coscia, 2022). However, this information continues to hold value for those who have not yet encountered the event, as it can be traded within the market. These individuals navigate through different levels of PCI, thereby engaging with new and uncertain events.

Classical economics traditionally employs algorithmic and statistical models to manage subjectivity in value assessments, acknowledging the probabilistic nature of value within classic decision theory. This theory suggests that rational economic agents optimize for a utility function, typically represented as an optimal selection probability distribution (Khrennikov, 2006; Bruza et al., 2009). These decisions are often modeled using Bayesian probability, indicating that optimal selections are influenced by the accumulation of knowledge (Van den Noort et al., 2016; Bond et al., 2018). Quantum Probability Theory (QPT), however, offers a novel perspective more adept at understanding human information processing and decision-making under uncertainty (Pothos and Busemeyer, 2013; Wang et al., 2013). QPT computes probabilities for different outcomes by incorporating subjective variables such as the observer's measurement process (Busemeyer et al., 2011). It posits that each quantum entity exists in a superposition—a wave-like state of multiple potential outcomes—until observed (Shimony, 1993). The act of measurement forces the quantum state to assume one of these potential states, a process theorized to occur in mental processes, although this remains a contentious issue (Von Neumann, 1932; Wigner, 1967; Jabs, 2016). Wavefunction collapse theory, particularly as interpreted through the Copenhagen or von Neumann–Wigner frameworks, suggests that observation or even consciousness plays a crucial role in this collapse (Faye, 2019), aligning with Penrose's (1996) proposition that observation and wavefunction collapse occur simultaneously.

Measuring the value state is inherently complex due to the variability in concepts, observables, and methods (COMs), compounded by diverse definitions across fields. This necessitates synthesis to avoid terminological proliferation. The evaluation system serves as a common framework across disciplines, rooted in the same cognitive processes for both organic and expert evaluations. Organic evaluations are subjective (Pinker, 1997), reflecting individual use values, while expert evaluations employ observables like exchange values (PCI) to approximate value states economically. These evaluations integrate with the organic system, driven by human expectations, even when conducted by computers programmed by humans. Economic assessment methodologies can adapt to other fields and vice versa, maintaining consistency despite COM diversity. Concurrent use of triadic COMs yields robust results by accommodating various decisional contexts and computational processes (The Appraisal Institute, 2020). This system extends beyond economic parameters, fostering holistic integration and recognizing interconnectivity with other disciplines (Popper, 2001).

The application of the triadic evaluation system to practical cases, such as abstract art, elucidates the evolutionary development of its COMs (Özdilek, 2018). This system evolved to address diverse needs, encompassing survival, optimization, and strategic

planning (Friston, 2005). Initially, humans relied on historical data to meet immediate needs and avoid dangers (Sih et al., 2011), leading to price-based estimates of value states. This approach is mirrored in cost-based evaluations, where unfolding information provides a second type of value state estimate. As cognitive abilities advanced, humans processed past and present information more effectively and explored future simulations, akin to income-based evaluations for the same event (Di Paolo, 2003; Mekel-Bobrov et al., 2005; Clark, 2013). These evolutionary abilities—survival through past data (price), optimization through present data (cost), and planning through future projections (income)—are integrated for comprehensive evaluations, always aiming to minimize errors or maximize information to better approximate value states across various contexts. This evolutionarily conditioned system is universally applicable in every decision-making process, whether evaluating a skyscraper's value, interpreting abstract art, or making everyday choices (choosing between coffee and tea), underscoring its robustness and versatility (Ma et al., 2019; Sterzer et al., 2019).

3 Sustainable digital rent

In this section, we explore the evolution of rent from classical economic models to the contemporary digital economy, culminating in the introduction of Sustainable Digital Rent (SDR). The presentation follows a chronological structure, beginning with tangible assets like land and labor in classical economics, then moving through intermediary stages involving intellectual property and financial derivatives, and finally arriving at the modern era of digital platforms and data-driven assets. An accompanying table visually summarizes this progression, illustrating the transition from physical land rent to digital rent, and serving as a guide for the reader. This step-by-step framework lays the foundation for SDR, which captures the commodification of user data and digital interactions, highlighting the growing importance of human expectations and cognitive contributions in today's knowledge economy. By tracing this transition, we ensure the reader comprehends the layered theoretical foundations of SDR with clarity and coherence. The roadmap further emphasizes the interdisciplinary connections between economics, cognitive science, and digital platforms, showing how these fields intersect to shape modern rent dynamics and their impact on cognitive states and economic structures.

SDR integrates expectational use value into the value state equation, often overshadowed by informational exchange value. Traditional economic models emphasize market exchange value, typically measured through objective metrics like PCI, which often eclipse the intrinsic worth of use value that sustains human expectations. This trend is intensified by digital platforms, where expectations rapidly convert into information, reinforcing the dominance of exchange value. SDR posits that rent, tied to nature's inherent properties, arises from our current inability to fully replicate the fertility of natural resources. Higher rent reflects the challenge of replicating these attributes and is based on physical properties. As technology advances and more information is extracted, rent diminishes, paralleling the conversion of natural resources into usable forms, evolving into information or knowledge and embodying the shift from a physical to a digital basis (Mayer-Schönberger and Cukier, 2013).

Rent serves as an evolving indicator of the shift from classical to digital economics, illustrating how value transitions from use value to exchange value. This transformation redefines our interactions with both physical and digital environments. SDR ensures that technological progress protects and enhances human motivation and engagement by converting non-renewable human expectations into digital information at a naturally regulated rate. Emanating from the consequences of the interplay between cognitive expectation and information across various scientific fields, particularly economics where value states are prevalent, SDR contributes to improving our understanding and practices in digital environments, promoting both economic efficiency and cognitive health. The profound influence of technology on daily life—reshaping how we live, learn, and interact—necessitates a critical reevaluation of digital advancements and their impact on cognitive perceptions and interactions (Zhao and Zhang, 2016). Consequently, rent becomes ‘sustainable,’ representing undisclosed expectations transformed into exchange value through capital (Milne and Chan, 1999; Clark, 2000).

Table 1 illustrates the evolution of economic rent from the Classical to the Contemporary epoch, highlighting the shift from traditional landowners to modern digital platform operators, or “Mindowners,” and detailing the types of rent, their rewards, mobility, and societal impacts across different epochs, supported by key economic theories and authors (Ophir et al., 2009). Historically, rent derived from physical assets like land and labor, as theorized by economists such as Adam Smith (1723–1790) and David Ricardo (1772–1823). In the digital age, the focus has shifted to intangible assets such as information and digital interactions, marking a transition from rent based on our inability to fully understand and exploit the physical properties of commodities to rent derived from abundant information. This shift reflects the move to SDR, generated through the interplay of digital data and user engagement, changing societal structures and economic foundations.

The evolution of rent types shows a progression from location-specific land rent to urbanization, intellectual property, and financial derivatives (Rabianski, 1996). Early debates on organizational creativity expanded the concept of rent to include utility attributes and entrepreneurial knowledge, challenging traditional valuation models (Fisher and Lentz, 1990). Advances in knowledge have progressively neutralized physical constraints, shifting the production basis from physical assets and activities to knowledge, transforming into information (Wheeler, 1989). This shift also signifies a move from location-based rent to the information-centric production of goods and services (Burawoy, 1985; Vandermerwe and Rada, 1988). Technological advancements emphasize platforms anchored in knowledge and creativity, where productivity converges into digital platforms and their rents. SDR examines its sustainability, emphasizing the need to understand and maintain a natural balance in value state mechanisms, where expectation and information drive valuation and decisions. This necessitates a reevaluation of systems across different fields, starting with economics, to reflect the importance of information and cognitive capacity, focusing on knowledge and reduced expectations.

Our analysis reveals a significant transformation in rent distribution, with an increasing focus on sustainability towards the end of the contemporary epoch. This remarkably leads to three pivotal forms of sustainability—cultural, environmental, and human—each reflecting the impact of digital transformation. Cultural sustainability

(Art-Rent) values creativity and intellectual expression, aligning with cultural capital (Özdilek, 2023). Environmental and communal sustainability (Sustainable Land Rent, SLR) conserves resources and promotes ecological balance. Human sustainability (SDR) monetizes personal expectational data and interactions, emphasizing the role of digital platforms in the knowledge economy. These forms of rent adapt traditional concepts within the digital economy, guiding future economic models to prioritize knowledge and information, ensuring digital advancements benefit societal and environmental welfare while considering the human value states.

The shift from a goods-based to a knowledge-based economy necessitates a reevaluation of the value state system’s mechanics (Schumpeter, 1942). Efficiently mining knowledge while protecting use value is crucial for safeguarding human cognitive centers in digital spaces. SDR emphasizes the human factor and cognitive vulnerability in digital economies, addressing environmental and societal challenges. The transition towards digital and intellectual property rents requires sustainable management to ensure equitable profit distribution and prevent monopolistic behaviors, demanding robust governance to enhance transparency in digital rent extraction and protect communal resources (Hardin, 1968; Ostrom, 1990). The modern digital economy prioritizes ‘exchange value,’ commodifying user data at the expense of personal and communal well-being, necessitating a redefinition of rent to capture surplus value from cognitive and social interactions within digital platforms. SDR promotes policies to prevent cognitive overload and create environments nurturing creativity and engagement, safeguarding intrinsic values such as anticipation and motivation.

The content in Table 1 is depicted in the accompanying illustration, which captures the evolution of economic rent from traditional land rent to digital rent across three axes: information (Y-axis), uncertainty (X-axis), and expectation (Z-axis). This illustration maps the extraction of rent from physical assets to cognitive and informational outputs, beginning with land rent (buildings) captured by traditional landowners, progressing through entrepreneurial rent (gears) garnered by business leaders and managers, and art rent (Pollock’s painting) mediated by “Artmasters” (galleries, auctioneers, and intermediaries), culminating in digital rent exploited by “Mindowners” (digital platform operators). Traditional rent from physical land is characterized by high uncertainty, whereas entrepreneurial rent reduces this uncertainty through effective management and decision-making. Art rent, which is closer to the value state, embodies the intangible value of artistic creativity. Digital rent, which is nearest to the value state, exemplifies the efficient transformation of human expectations into commoditized information within digital markets. The Z-coordinate illustrates expectation, which increases with low information or high uncertainty. Any value state in various fields can be represented as a coordinate (an “M” point) on these triadic axes. The larger heads of pumps in the illustration signify higher rates of expectation conversion into digital rent and its extraction from digital spaces. This shift underscores the efficiency of converting cognitive expectations into value, necessitating robust regulatory frameworks to safeguard user rights, ensure equitable access, and prevent monopolistic practices (Figure 2).

This study’s discourse on sustainability anchors in the human condition, recognizing that environmental, communal, and cultural improvements enhance life and cognition. SDR emerges as the central framework integrating all facets of sustainability, placing human

TABLE 1 Land rent transition into digital rent.

Ownership	Agent	Type of rent	Reward	Mobility of agent	Impact on society	Key authors
Classical epoch						
Capitalists	Capital	Capital rent	Interest	Mobile	Affects capital distribution and accumulation	Smith (1776) and Marx (1867)
Landowners	Land	Land rent	Rent from land use	Immobile	Sapes agricultural practices and rural economies	Ricardo (1817), Mill (1848), and George (1879)
Workers	Labor	Labor rent	Wages	Mobile	Impacts labor markets and standards of living (e.g., wages, employment rates)	Marx (1867), Mill (1848), and Keynes (1936)
Economic agents	Space	Location rent	Premium from location advantage	Immobile	Determines population distribution and economic activity (e.g., industrialization, trade)	von Thünen (1826) and Christaller (1933)
Intermediary epoch						
Government	Government bodies	Urbanization rent	Rent from urban development	Immobile	Shapes urban and infrastructure (e.g., transportation and urban planning)	Burgess (1925), Hoyt (1939), and Tiebout (1956)
Real estate developers	Various classes of properties	Real estate rent	Rent from property development	Immobile	Drives real estate markets and housing prices	Moses (1936) and Jacobs (1961)
Creators and patent holders	Intellectual property	Intellectual property rent	Royalties from intellectual property	Mobile	Drives innovational and technological advancements (e.g., Patents and Copyrights)	Machlup (1962) and Arrow (1962)
Financial institutions	Financial derivatives	Derivatives rent	Profits from financial market speculation	Mobile	Influences financial markets and investment strategies	Merton (1973) and Black and Scholes (1973)
Commodity and services	Utility attribute contributions	Utility attribute rent	PCI utility contributions by commodification and servitization	Mobile	Affects consumer choices (e.g., a sweempool contribution to the total PCI of a dwelling)	Lancaster (1966), Burawoy (1985), and Vandermerwe and Rada (1988)
Contemporary epoch						
Organization and corporation	Management	Entrepreneurial rent	Excess profits from better management and innovation	Mobile	Economic growth, labor and innovation cycles	Drucker (1985), Porter (1985), and Fisher and Lentz, 1990
Platform providers	Shared assets	Shared asset rent	Fees from facilitating shared asset usage	Mobile	Changes sharing economy dynamics	Sundararajan (2016), and O'Reilly (2017)
Artists	Art objects	Art-rent	Art-rent rewarding artists for their creativity and imagination	Mobile	Affects cultural development and art markets	Özdilek (2023)
Community and nature	Natural and communal services	Sustainable land rent (SLR)	SLR rewarding community and nature	Mobile	Impacts on environment conservation and sustainability	Özdilek (2024)
Data and digital platform owners	User data (Information)	Sustainable digital rent (SDR)	Monetization of data, E-com analytics, social media	Mobile	Transfromation of digital economy, data monetization practices	

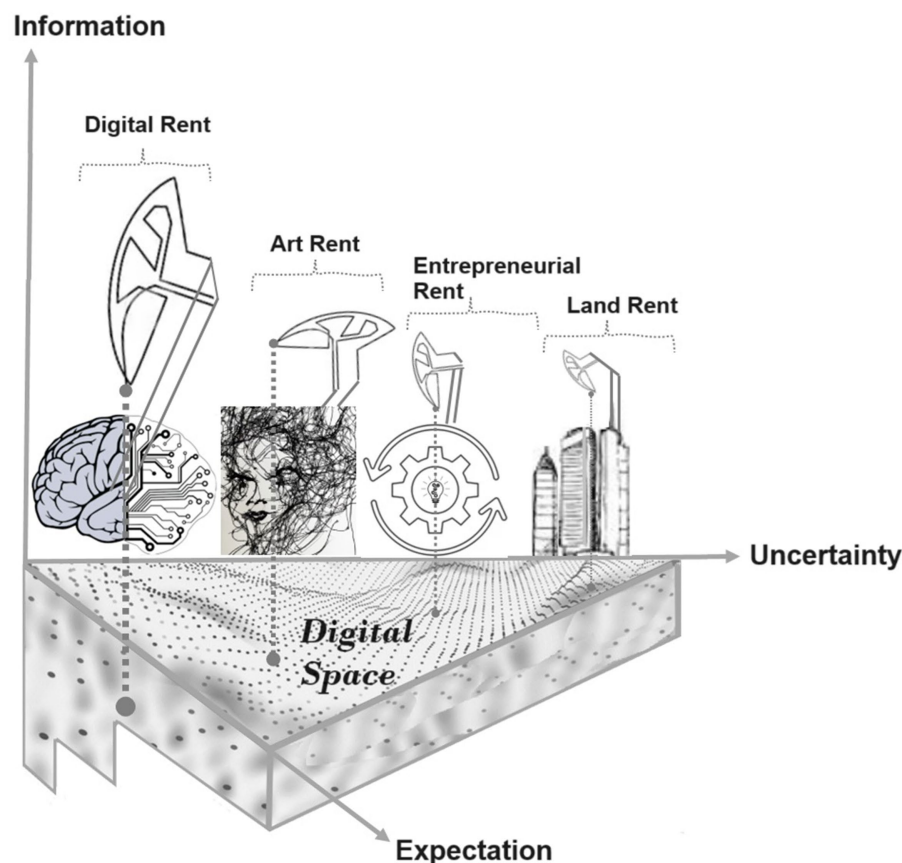


FIGURE 2
Forces determining SDR.

welfare at the forefront. This shift ensures external enhancements enrich human existence, making SDR the foundation of all sustainability strategies. Positioned at the forefront of sustainability discussions, SDR underscores the need to realign efforts to focus on the human cognitive value state, ensuring every aspect of sustainability is connected to this central value state, contributing to a global sustainable human condition. Building SDR as an integrative framework, this study emphasizes the need for a nuanced understanding of value states in the digital context. SDR signifies a shift from tangible to digital assets, redefining rent for today's information-driven realities. Rapid digital evolution profoundly impacts cognitive states, necessitating a reevaluation of economic models and regulatory frameworks to protect human well-being from digital data influx. This reevaluation must balance preserving cognitive expectations and managing information overload. For instance, in digital and abstract art, balancing clarity and ambiguity is essential; too much clarity stifles curiosity, while too much ambiguity risks disengagement (Shanmugasundaram and Tamilarasu, 2023b). Similarly, digital economies must balance preventing cognitive overload and maintaining user engagement (Spitzer, 2012). SDR advocates for an approach where digital advancements enhance societal welfare without compromising intrinsic human values, ensuring equitable digital rent distribution.

Resource management has evolved to emphasize a human-centered approach, focusing on the interaction between human

societies and natural resources. SDR aligns these principles with digital economy challenges, supported by frameworks like the Universal Declaration of Human Rights (1948), the Kyoto Protocol (UNFCCC, 2007), and the World Commission on Environment and Development (1987). These frameworks advocate for sustainable practices to secure future generations' needs. Environmental laws such as the Clean Air Act (EPA, 1970) and the Water Framework Directive (European Commission, 2000), along with sustainable urban development initiatives (Townsend, 2013), emphasize the interdependence of ecological and human health. Policies like the 1992 Rio Declaration and subsequent initiatives (Pearce and Barbier, 2000; Zhang et al., 2021) promote environmentally responsible real estate developments, exemplified by certification systems like BREEAM and LEED (Lazar and Chithra, 2020) and green building initiatives (Kohler, 1999), highlighting the evolution towards smart cities (Doukas et al., 2007; Debastiani et al., 2020). Guided by theories on psychological well-being (Ryff, 1989), these developments ensure that digitization in economic interactions supports cognitive and emotional health. This comprehensive approach addresses the unique challenges of digital economies to human expectations, promoting fair distribution of digital wealth and fostering an equitable digital future.

Digital technologies have transformed the economy from traditional, tangible assets to a knowledge-based framework, altering business models and daily interactions. Enhanced productivity through digital and algorithmic technologies supports activities from

online shopping to virtual consultations, demonstrating the dominance of digital information (Stigler, 1961; OECD, 2017; Peitz and Waldfogel, 2012; Srikanth and Thakur, 2022). This transition redefines economic rent, shifting from agricultural and land-based models to Sustainable Digital Rent (SDR), capturing shifts from physical to informational commodities, impacting environmental sustainability, socio-economic structures, and cognitive states (Ward and Aalbers, 2016; Bliss and Egler, 2020; Pirgmaier, 2021). As digital platforms become primary venues in the economy, exploiting user data and interactions, economic rent digitizes, emphasizing the scarcity of knowledge over physical commodities (Harrison, 2021; Deak, 2022; Qiao and Feng, 2023).

The digital revolution has reshaped societal and economic structures, necessitating a comprehensive overhaul of existing frameworks to address new challenges and opportunities (Iqbal and Horvitz, 2007). Zuboff (2015) and Sadowski (2019) highlight surveillance capitalism's impact on personal data management, advocating for robust regulatory frameworks to ensure fair wealth distribution from digital assets. Karaganis (2007) and Harrison (2021) discuss how digital platforms have transformed creators' and consumers' roles, promoting new economic models like 'digital feudalism' where user data is commodified. This calls for updated regulations to address psychological impacts and ensure fair compensation for creators, as emphasized by Murayama and Jach (2024) and Kozłowski et al. (2014), supporting societal and economic sustainability. Digital technologies also influence non-economic aspects like healthcare, with Chamakiotis et al. (2020) noting significant cognitive and professional advancements. Carayannis et al. (2014) describe this as 'creative destruction', advocating for a balance between innovation and sustainability. Addressing technical challenges, Lanza et al. (2019) highlight the need for effective data sharing and standardization within IoT ecosystems to manage digital rents transparently. Coiera (2000) underscores how digital platforms challenge traditional economic models, highlighting the need for strategies that ensure the utility and sustainability of digital environments.

Theories of predictive coding and the Bayesian brain hypothesis illustrate how excessive information disrupts predictions based on past experiences, leading to cognitive overload. This impairs anticipatory mechanisms, causing decision paralysis (Jacoby, 1977) and reduced productivity due to digital interruptions (Mark et al., 2008). These disruptions also lead to declines in psychological health and life satisfaction (Kross et al., 2013), privacy erosion (Zuboff, 2019), and weakened interpersonal connections (Turkle, 2011), highlighting the need for balanced information management systems. In digital and abstract art, valuation approaches informed by predictive coding integrate expectation with sensory input to minimize prediction errors and maintain balance (Olshausen and Field, 1996; Clark, 2013). The brain's processing, involving top-down predictions and bottom-up feedback (Rao and Ballard, 1999), is regulated by dopamine, adjusting neuronal firing rates to encode reward expectations (Caplin and Dean, 2008; Schultz, 2010). However, habituation to predictable stimuli can reduce cognitive resource allocation, leading to disinterest in triggering evaluation mechanisms (Summerfield et al., 2008; Todorovic and De Lange, 2012). This understanding is crucial for designing digital environments that maintain user engagement and ensure content remains compelling and cognitively stimulating.

Institutionalizing digital rent is essential for equitable digital asset management and fair distribution of digital benefits. Breznitz and Ornston (2018) highlight the effectiveness of such frameworks, while Di Giulio and Vecchi (2023) advocate for dedicated agencies to oversee distributions and integrate digital rent policies with existing economic systems. Creating these agencies can be a potent strategy for implementing technological innovations, ensuring policy sustainability, and addressing trade-offs between long-term effectiveness and the risks of ossification. This integration aims to compensate data and content contributors and prevent monopolistic behaviors, aligning with the SDR concept (Fuchs and Sevignani, 2013). Schwerhoff et al. (2020) and Connellan (2019) argue that digital platforms should be taxed similarly to landowners, harnessing economic value for public benefit. Mansell (2012) and Zuboff (2019) underscore the need for transparency and trust to protect consumer and creator rights and prevent data monopolization. Continuous policy review and adjustment, as noted by Patashnik (2008) and Weiss (2014), are critical for adapting to emerging challenges and promoting societal welfare, supported by revenue-sharing models (Fuchs and Sevignani, 2013; Pohle et al., 2016).

Effectively managing cognitive load is crucial for maintaining user engagement in the digital economy. Sweller (2011) emphasizes optimizing information processing to enhance learning, while Gazzaley and Rosen (2016) focus on designing digital environments aligned with human cognitive capacities. Gamification techniques (Hamari et al., 2014) and engagement strategies (O'Brien and Toms, 2013) are vital for sustaining interest. Educating users about their data rights is essential for informed decision-making (Kang et al., 2013; Acquisti et al., 2015), supported by privacy-enhancing technologies (Balebako and Cranor, 2016) and 'Privacy by Design' principles (Cavoukian, 2012). Open standards for data interoperability (Weber, 2010; Greenstein and Stango, 2007) promote competition and innovation, while partnerships between governments, technology firms, and academic institutions (West, 2015; Ostrom, 1990) address challenges like digital equity and access, ensuring effective integration of technological advancements into societal frameworks.

4 Value state evaluation

Living systems evaluate rewards to satisfy diverse needs, shaping abstract states like happiness and perception. Pinker (1997, p. 21–22) describes the mind as a "system of organs of computation" engineered by natural selection, while Popper (2001) emphasizes that evaluative processes are essential and universal across scientific fields. Determining value is crucial across economic, physical, social, and psychological dimensions, facilitating decision-making. The sustainability of expectations within the value state must reflect human motivations driving the continuous search for information.

In this section, we consider the case of art value valuation as a convenient medium for demonstrating the practicality of SDR. Although the evaluation of art is inherently subjective, unlike real estate valuation in more consolidated markets with richer data (Mooya, 2018), its market has moved towards efficiency with better information, greater liquidity, and increased participation (Louargand and McDaniel, 1991; Agnello, 2002). Despite its economic exceptionalism, art becomes part of the market (Beech, 2015). Modern

techniques like Agent-Based modeling, Deep Learning, and AI add sophistication but still operate within classic PCI frameworks (Özdilek, 2020a, 2020b).

Given the lack of established methods to estimate SDR or the value generated by digital platforms, we developed a novel tripartite PCI evaluation methodology inspired by North American real estate appraisal techniques. The application of these classic approaches in art valuation is adapted to the non-standardized nature of artworks and the dynamics of a knowledge-based economy (USPAP, 2014). By applying this methodology to abstract art, we gain unique insights into valuing intangible assets, such as human expectations and knowledge, which are transformed into information, revealing shifts governed by the value state. To further contextualize this economic approach, we also incorporate interdisciplinary insights from biology and physics, demonstrating how mechanisms of value state creation and destruction operate across various fields.

In the following analysis, we apply three economic evaluation methods—Sales Comparison Approach (SCA), Cost Summation Approach (CSA), and Income Capitalization Approach (ICA)—to estimate the market value of abstract art, specifically a Jackson Pollock painting. Each method offers distinct advantages: the SCA uses comparable market sales to reflect price perceptions in secondary markets, the ICA converts future income streams from art exhibitions or rentals into present value, and the CSA focuses on physical reproduction costs, particularly useful when market data is insufficient. While each method provides a reliable individual value estimate, their simultaneous application enables a more comprehensive assessment, accounting for both tangible and intangible factors. This approach is particularly valuable when considering the Sustainable Artistic Rent (SAR) component, which incorporates the intellectual contributions of the artist. Using all three methods together enhances the accuracy of value estimation in complex, knowledge-driven markets, where converting human expectations into information is essential.

Building on the outlined tripartite PCI evaluation methodology, we now apply this framework to the empirical case of abstract paintings by the American artist Jackson Pollock (1912–1956). Pollock, a pivotal figure in abstract expressionism, revolutionized the art world with his innovative drip painting technique, wherein he poured, dripped, or splattered paint onto a horizontal surface to craft dynamic compositions. Gaining significant fame during the late 1940s and early 1950s, his works are characterized by their chaotic yet harmonious structures, reflecting a deep engagement with spontaneity and subconscious creation. These qualities have secured his paintings a prominent place in the art market, celebrated for their innovation and emotional intensity. For our analysis, we gathered information on a specific Pollock painting and its comparables from publicly accessible databases such as Artnet and Artprice, supplemented by literature and expert opinions from galleries, museums, and auctioneers. This empirical foundation allows us to further explore the nuances of SDR in the context of abstract art.

4.1 SCA opinion

We estimated the market value of a Jackson Pollock painting on December 1st, 2023, through a rigorous analysis of observed prices

and characteristics of similar abstract expressionist paintings sold between 2021 and 2023 in various cities and auction houses. This market segmentation identified closely comparable artworks, facilitating price standardization (Lipscomb and Gray, 1990). Detailed grid-adjustment calculations accounted for the fundamental attributes of the paintings, adjusting their prices to align more precisely with the subject painting. Pairwise comparisons within the Sales Comparison Approach (SCA) allowed for the adjustment of prices of less similar artworks, modifying them based on their relative comparison to the subject painting. This method provided reliable market value references by meticulously accounting for differences in each painting's characteristics.

When estimating the price of an unsold painting using the SCA, we focus on total prices of comparable artworks to derive the SAR component. This component captures the impact of expectations reflected in price variations, particularly related to the artist's renown or the piece's rarity, addressing unique informational demands expressed through price levels. For example, an artwork's distinctiveness and creative elements can justify a higher price, with SAR accounting for these qualitative attributes that contribute to price differences. Increasing the number of comparable artworks in similar physical and financial states enhances the objectivity of SCA estimations, stabilizing the SDR factor as it becomes a more objective price determinant.

Among the attributes considered, the contribution of SAR to the total price was particularly noteworthy, serving as a marginal price factor that rewards the potential impact of the artist's codified message within the painting. Our analysis also revealed other significant findings. Market analysis indicates that art prices experience a positive linear adjustment of 5% annually, and the size of the painting contributes approximately \$130 per square centimeter to the final price. Expert opinions, as reflected in the SCA, suggest that a painting's value appreciates by \$18,000 for each additional year of age highlighting the reputational factors on the market. Furthermore, variations in auctioneer can lead to price adjustments between \$30,000 and \$90,000, depending on geographical locations (Table 2).

The grid-adjustment table's estimates align well with practical considerations. We validated these adjustments using an ordinary least squares (OLS) statistical approach, analyzing data from 197 abstract painting sales during the same period. The model included dummy variables for four artists with similar styles (the same market), yielding comparable results across attributes. The estimated SAR reward for Jackson Pollock is \$1,150,000 when compared to other artists. The SAR estimation represents most of the effects from the popularity of the artist on the market, which also transpires through other adjustment factors such as the increase in paintings' value due to their aging or size. In these attributes, Pollock's popularity effects continue, showing the interaction effects among two or more attributes (the popularity and size effects at the same time). This means the more realistic SDR contribution is higher than the indicated adjustment for artistic rent. While adjusted prices of four comparables are closer, some differences remain. The final market value estimation for the subject painting is \$1,366,428, based on adjustment weights, with less weight given to comparables requiring larger adjustments.

The provided example illustrates the methodology for determining the probable market value of a subject painting by dissecting its individual price components. This approach is akin to how our memory forms connections with similar past experiences. In the art

TABLE 2 SCA estimates.

	Comp. 1	Comp. 2	Comp. 3	Comp. 4	Subject
Artist	Market	Market	J. Pollock	J. Pollock	J. Pollock
Price (Can. \$)	7,56,000	5,06,500	10,08,000	10,85,000	
Year of sell	2023	2023	2022	2022	
Size (sq. cm)	4,980	4,208	1,533	2,299	3,294
Age	80	78	71	75	74
Auctioneer-location	Auct.-Loc. A	Auct.-Loc. A	Auct.-Loc. C	Auct.-Loc. D	
	Adjustments				
Time	0	0	50,400	54,250	
Size	-2,19,267	-1,18,863	2,28,843	1,29,307	
Age	-1,08,000	-72,000	54,000	-18,000	
Auctioner-location			90,000	30,000	
Partial adjustments	-3,27,267	-1,90,863	4,23,243	1,95,557	
Partially adjusted prices	4,28,733	3,15,637	14,31,243	12,80,557	
Sustainable artistic rent (SAR)	11,50,000	11,50,000			
Adjusted prices	15,78,733	14,65,637	14,31,243	12,80,557	
Total - Adjustments	14,77,267	13,40,863	4,23,243	2,31,557	
Weighting	0.08	0.09	0.29	0.53	
SCA market value	13,66,428				

market, the prices of comparable artworks serve as benchmarks, indicating the most likely outcome if the subject piece were listed and negotiated between buyers and sellers. When comparable sales closely match the subject's characteristics, no adjustments are needed. However, if differences are present, appropriate upward or downward adjustments are made. These adjustments help define potential outcomes, reflecting past market behaviors and negotiated prices.

The particularity of this method, in comparison to two others which subsequently follow, rests thus on the observed behavior of buyers and sellers on the market. Their consistent and rational evaluations on each parameter is important as these ones are considered in estimating SAR as well as other parameters affecting prices levels. Assuming these behaviors are sufficiently rational, without forgetting the comparative training effects of observed prices for abstract paintings in the market, the SCA allows to derive quite objectively the artistic rent by comparing different artists of similar style and market, everything else being under control either in that classic grid-adjustment method or OLS regression with high number of sales. Obviously, more sales are included in the model, better are the adjustment estimates for SAR component. The SCA is oriented towards the manifested price levels of abstract painting and these per attribute such as SAR. The estimate on SAR we plugged in the classic grid adjustment method are derived from 197 sales which not only provides a robust estimate, but it also consolidates other parameters taken into account simultaneously.

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4.2 ICA opinion

Compared to traditional assets, paintings can generate stable income streams for artists and investors (Anderson, 1974). Profits primarily derive from sales and periodic rents paid by individuals, museums, and galleries (Zanni, 2020). Dealers play a crucial role in brokering art sales, promoting artwork, attracting buyers, and facilitating transactions. Even in the absence of rent payments from museums and galleries, income is realized through value appreciation driven by the artist's rising popularity and market demand (Caves, 2000).

Evaluating abstract art using the income method involves actualizing net benefits over time, encompassing direct sales, rents, and value appreciation, balanced against expenses such as administration, maintenance, storage, promotion, insurance, security, and logistics (Frey and Pommerehne, 1989). Additionally, sales commissions, typically ranging from 5 to 25% of the artwork's value, must be considered (Kirk, 2019). Stable income from abstract art hinges on effective operational cost management and strategic sales timing to capitalize on market trends (Baumol, 1986). The aesthetic

appeal and reputation of the artist significantly influence the artwork's valuation and investment potential (Throsby, 1994). By understanding these factors and applying rigorous income-based methods, investors can better assess the long-term financial benefits of abstract art (Frey and Eichenberger, 1995).

In considering the income-determining parameters of the same abstract painting, we now apply the Income Capitalization Approach (ICA) to derive an estimate as a second comparable opinion on its market value. The ICA analyzes the expected income generated by this painting, accounting for all relevant expenses, and applies an appropriate capitalization rate. For accuracy, we use parameters consistent with the current market for Pollock's abstract paintings. Accordingly, the estimated yearly effective gross income from exhibition fees is set at \$185,000. Operating expenses, including labor, organization, management, maintenance, and insurance, account for 35% of this income, totaling \$64,750, leaving a net operating income (NOI) of \$120,250. Next, we deduct the return to capital, calculated at 10% (comprising 9% interest and 1% amortization), amounting to \$11,409, which yields an annual surplus or residual of \$108,842. This residual represents the Intellectual or Artistic Rent attributed to Pollock, the creator of the artwork. The sum of the Sustainable Art Rent (SAR) and the Capital Invested indicates \$1,209,350 as the market value of the subject artwork from Pollock according to this ICA (Table 3).

This example demonstrates the utility of the ICA in estimating the market value of artwork and highlights the sustainable allocation of rent to the artist. The residual income, or Artistic Rent, naturally belongs to the artist, ensuring fair compensation for their creative efforts, thus reflecting the sustainable nature of rent allocation. The ICA provides a quantifiable method to assess the value generated by the painting, comprehensively accounting for all relevant income and expenses. This example bridges the understanding of rent from tangible assets like land to intangible assets in the digital economy, illustrating how value transitions from physical to digital platforms. Notably, the canvas serves as an analogy for the digital platform, demonstrating that the true value lies in the content and knowledge created. Using abstract art and estimating its Sustainable Artistic Rent (SAR) portion as a case study helps elucidate the concept of Sustainable Digital Rent (SDR) and offers a comparative measure.

Art and its derived rent play a crucial role in understanding the transition mechanisms from traditional product-based economies to knowledge-based economies. In this context, rent and its bases become ephemeral with the knowledge embedded in these properties. The value of abstract art is derived not from the physical canvas but from the information and knowledge encoded by the artist. Abstract art bridges this transition by demonstrating that its worth lies in creative knowledge and expression rather than material components. Observers often pay exorbitant sums, sometimes tens of millions of dollars, for a piece of art made from simple materials. This analogy extends more receptively to digital platforms, where the ultimate reward is information or knowledge. Abstract art's message, encoded in the canvas (akin to a surface, land, or platform), closely aligns with the digital domain in which rent becomes digital. Similar to a digital platform, observers of art engage in a process of evaluation, striving to unveil new insights and understandings using their cognitive evaluation systems.

As demonstrated in Özdilek (2024), the principle of sustainability in Sustainable Land Rent (SLR) argues that rent, as a surplus of production, naturally benefits its creators—nature and the community. In the realm of art, the creator is clearly the artist. However, “Artmasters” or intermediaries like art galleries frequently appropriate substantial portions of the rent, leaving artists with a fraction of the total value. While these intermediaries are essential for promoting and preserving artwork, they are not the primary source of the intrinsic value. This scenario parallels historical misallocations where landowners capture the rent meant for nature and the community, leading to socio-economic disparities and long-term environmental degradation. The digital realm and knowledge economy transform land rent into digital rent, requiring a revised framework to understand these transitions. The demonstration with ICA showed that abstract art serves as a critical intermediary, helping us grasp the nuanced shifts in the allocation and basis of rent, particularly when the agent or creator is obscured.

4.3 CSA opinion

The Cost Summation Approach (CSA) is frequently used in evaluating unique real estate properties, such as churches or stadiums, where traditional methods like the Sales Comparison Approach (SCA) and the Income Capitalization Approach (ICA) fall short due to insufficient market signals. CSA focuses on the reproduction costs of physical assets, factoring in depreciation over time. When applied to paintings, CSA considers relevant cost factors including the artwork's size, labor, materials (such as canvas, paint, and brushes), and maintenance costs (Beech, 2015). However, CSA often falls short in estimating the total value of renowned, unique paintings from the primary market. To address these limitations, we developed an alternative approach that integrates the Sustainable Artistic Rent (SAR) component, providing a more comprehensive evaluation process that considers both physical and intangible value attributes. This integrated methodology surpasses the conceptual and practical shortcomings of CSA by incorporating broader aspects of value associated with intellectual content. This intellectual content, referred to as “cognitive knowledge capital,” represents the creators' intellectual contributions. In this framework, cognitive knowledge capital becomes predominant, yielding a reward termed “Digital Rent.” The following example demonstrates how our integrated approach provides a more accurate and holistic assessment of value using CSA.

The inclusion of the SAR component in the CSA estimation provides a valuable third perspective, deepening our understanding of the shift from a tangible to an intangible economic basis. As previously discussed, the sustainability of this rent is rooted in the non-renewable nature of human expectation and, most importantly, its capture and exploitation by agents other than those who generated that rent. For example, SAR represents the cognitive satiation or desensitization from exhausted expectation in art, manifesting as disclosed information or acquired knowledge that conditions the cognitive evaluation system. This disclosure is encapsulated within the SAR amount, enabling the owner to sell or rent the painting to others. However, as more market participants engage with a specific painting or similar artworks, cognitive satiation pressure develops, leading to general market obsolescence. This obsolescence can be considered a negative factor, akin to other cost elements within the CSA. In this

TABLE 3 ICA estimates.

Yearly effective gross income	1,85,000
Capital invested	1,14,085
Total income minus	
Operation expenses (35%)	64,750
Net operating income	1,20,250
Minus return to capital	
(9%, plus 1% amortization)	11,409
Annual surplus (residual)	1,08,842
Sustainable artistic rent (SAR)	12,09,350
(9% of return)	
ICA market value	13,23,435

context, the traditional reluctance to incorporate positive value into a cost-based framework is mitigated.

To construct the practical demonstration in Table 4 both direct and indirect cost information for paintings was meticulously gathered from the market in the weeks leading up to the evaluation on December 1st, 2023. This data, supplemented by cost directories and relevant literature, provided average cost estimates, adjustment rates, depreciation figures, and the economic life cycle for comparable artworks. A 10% physical and functional depreciation rate was applied to the indirect costs, revealing a total initial replacement cost of \$125,000. After accounting for \$10,915 in depreciation, the depreciated replacement cost amounted to \$114,085. By incorporating \$1,179,675 of SAR, calculated as an average of the SCA and ICA estimations, we derived the CSA market value of \$1,293,760. SAR represents the exhausted expectation for the comparable paintings in the market, manifested through price and income metrics of previous SCA and ICA evaluations. As previously discussed, PCI content is conceptualized as the dynamic transformation of expectation into information, capturing the impact on the value state and anticipating reduced future appreciation due to market obsolescence or diminished market motivation. This effect, long present in art valuation, becomes more explicit when considering cost depreciation.

The cost method, when comparing painting space to land for real estate, demonstrates that increased knowledge significantly reduces the value basis for the cost dimension, a trend similarly observed in price and income methods. Technological advancements and improved construction design generally lower the value state of materials and labor, to which the cost indicator refers. Consequently, value, or “rent,” increasingly accrues to design and innovation—the unique, non-replicable knowledge (the “blue-print”) that becomes the primary source of value, particularly with advancements in processing and automation. This shift underscores a broader transition from an industrial-based to a knowledge-based economy, where information itself becomes a valuable commodity. Value expectation and realization are progressively linked to intellectual rather than physical capital. As the unknown knowledge within physical mediums decreases, a larger portion of rent shifts to digital rent, transforming its classical concept as a reward in physical objects. The case of abstract painting exemplifies this shift, as evidenced by our calculations. Compared to land rent for physical properties, such as dwellings, it becomes clearer how

this transformation operates concretely in art valuation, making it more tangible rather than purely theoretical. This transition is not about the immaterialization of physical matter but the digitization of its properties and utility basis, enabling the extraction of use value faster and easier. This is especially pertinent as it occurs in a new space—digital platforms—which are themselves digitized. For example, digital activities mapped in computers with digital houses, where telework and other digitized activities will increasingly dominate.

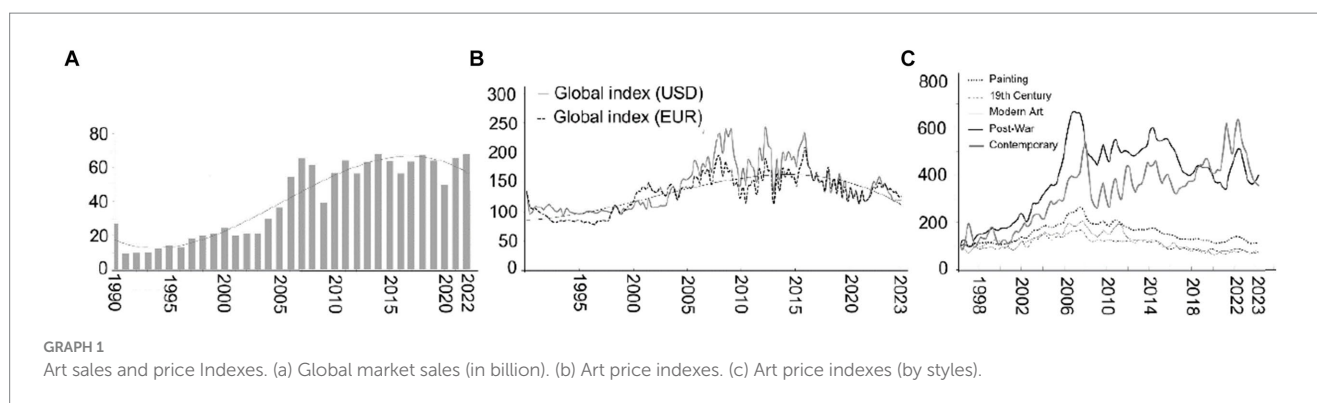
Triadic individual evaluations completed on December 1st, 2023, represented by “M” in Figure 1B, highlight a specific point in time. However, these evaluations lack the comparative dynamics needed to align or diverge from the theoretical evolution of information shown in Figure 1A. They offer a singular snapshot within a broader trend, emphasizing the necessity for multiple evaluations over a long period for more informed decision-making. Ideally, this would include triadic PCI data spanning several years. A recent study on the housing market demonstrated this approach by analyzing triadic evaluations over 148 years (1871–2018) in the USA (Özdilek, 2024). The study revealed that PCI estimates converge and progressively stabilize at a constant value state for the same subject property. In this context, increased PCI observables do not signify a rise in value, which remains constant. Instead, this increase and stabilization indicate reduced expectations, converted into PCI information, particularly in housing. The cooling of PCI towards a constant value state is often accompanied by isolated crises, especially notable in the behaviors of price and income components.

Unlike the real estate market, where long-term trend analysis of PCI observables is feasible, the art market lacks similar extensive data. To demonstrate the utility of integrating a pointwise estimate within broader trends, we present graphics on global market sales, art price indexes, and art price indexes by styles from 1990 to 2023. These aggregates of average observed prices, rather than estimates, underscore the need for comparative cost and income data. Global market sales (Graph 1a) and Art price indexes (Graphs 1b,c) exhibit behaviors akin to a Gaussian cumulative distribution function, where the theoretical decline in expectations slows in rate as PCI growth stabilizes, influenced by intensified competition and diminishing rewards in the value state (see Figure 1A). These graphics generally indicate that price behaviors stabilize over time with market interest shifting towards novel styles of artwork.

The average price estimate of \$1,327,874 for the Pollock abstract art market in 2023, reported over these 33 years of trends in Post-War and Contemporary styles, serves as a benchmark for mitigating risks in transactions, such as offering (or selling for) \$1.5 million for the same piece (based on the average estimate provided here). These studies, which utilize similar data sources, also reflect trends of stabilizing prices, aligning with our observations. Theoretical concepts and these observations can be supported by analyses from literature, such as Baumol (1986) and Filipiak and Filipowska (2016), which indicate rising interest in art as an alternative investment since the 1960s. Artprice.com statistics show that art and antiques sales reached \$67.8 billion in 2022, with significant growth in global Post-War and Contemporary art, accounting for 65% of the market (Artprice, 2023). McAndrew (2023) notes that the market increasingly favors unique pieces, influenced by region, artist, and type, with Contemporary Art driving market growth.

TABLE 4 CSA estimates.

Direct cost	Cost new	Effective age	Economic life	Depreciation (%)	Depreciation (\$)
Canvas, papers, materials	8,000	5	100	0.050	400
Paint, brushes, palette, solvent	6,000	3	200	0.015	90
Other hardware & tools	9,000	5	200	0.025	225
Total:	23,000				715
Indirect cost					
Labor - artist	45,000				
Management	17,000				
Maintenance & reparation	12,000				
Storage & shipping	5,000				
Movement & installation	7,500				
Marketing & insurance	15,500				
Total:	102,000				
Total replacement cost new					125,000
Physical & functional depreciation (10%)					10,915
Total replacement depreciated cost					114,085
SAR (average from SCA & ICA)					1,179,675
CSA market value					1,293,760



5 Discussion

In this discussion, we explore how the evolving dynamics of the rent and the value state, particularly through the lens of abstract art value valuation, reveal the fragile nature of human cognitive expectations. We introduce Sustainable Digital Rent (SDR) and highlight its foundation in classical rent theories, linking it to the modern shift towards a knowledge economy. By examining SDR's implications for digital platforms, we advocate for institutional mechanisms to equitably manage cognitive contributions, focusing on sustainability and human well-being.

The theoretical foundation for SDR stems from classical value, valuation, and rent theories (for further explanation, see Mooya, 2016; Hesselmann and Schendzielorz, 2019; Stratford, 2022), cognitive value processes, and sustainable economics. Classical economists like Ricardo and Marx explored rent as a surplus derived from natural resources. In the digital age, information and knowledge become central to economic activity (Nee et al., 2023). Our study extends these theories by incorporating cognitive evaluation into the value state (Sznycer, 2022), placing human expectations at the center of digital rent creation. This aligns with Fuchs' (2022) work on digital labor and value on platforms. By integrating PCI methods, we demonstrate that digital rent arises not only from production but also from the exchange of cognitive capital, highlighting the need for sustainable digital practices (Stratford, 2022). Evolving discussions around digital rent have

recently focused on user data and cognitive engagement. Zuboff's (2019) 'surveillance capitalism' shows how digital platforms extract value from user data, similar to traditional land rent. Our SDR framework extends this, exploring how cognitive expectations transform into digital rent, affecting user well-being.

In our view, rent fundamentally arises from the exploitation of its origins as the net product of its basis—land—while being constrained by ignorance, which we define as the inability to fully extract or comprehend the full information inherent in exploitable resources. Evolving from this basis of ignorance to one now centered on information, rent has always served as an empirical gauge or measure of economic progress, a role that has become even clearer in today's digital economy. Initially, rent was directly linked to products from natural resources, like corn from land. This evolves into a digital basis where physical land and yield transform into 'digital' versions—knowledge or intelligence embedded in information. For example, chemical treatments to enhance land productivity and machinery for harvesting represent layers of knowledge. If this blueprint of knowledge was available at the start of agricultural development, centuries of learning could have been bypassed. This evolution addresses Marx's concern (Bryan, 1990) of natural rent turning artificial. Today, land, corn, and rent have become digital knowledge, highlighting that rent's original purpose reflected limitations that knowledge has now overcome. In this context, traditional agents of production—labor, capital, and land—and their respective rewards (wages, interest, and rent) merge into knowledge itself.

This transition impacts economic systems as value state becomes information-centric. The traditional economy, once focused on physical goods, now emphasizes knowledge production. This shift fundamentally changes production, interaction, and exchange, moving from physical land to digital platforms. It underscores the increasing importance of knowledge and cognitive contributions in determining value in the digital economy, necessitating a re-evaluation of how production and value are understood and rewarded (Nicolescu and Nicolescu, 2021).

While digital economy is celebrated for its positive impacts on nature and the environment (Yan et al., 2022; Kuang et al., 2024), our work cautions against overlooking the fragility of human cognitive states, emphasizing the need to center human expectations in sustainability. We propose that managing human expectations against the growth of information becomes a new basis for sustainability, as mismanagement can lead to decreased motivation and health. Using abstract art, we demonstrate methods for estimating the balance between digital rent's information and expectations, advocating for policies that ensure an equitable distribution. This approach underscores the importance of cognitive well-being alongside environmental stewardship.

The value state mechanisms reveal that once expectations are fulfilled, they vanish, only to be replaced by new ones. This ongoing cycle shapes human experience but can lead to diminished motivation when predictability sets in. Thus, sustainability becomes crucial as the accumulation of knowledge risks altering cognitive states, necessitating a careful balance between expectations and the digital realm. SDR's implications extend to economic sustainability by recognizing digital platforms as the new 'land,' advocating for an equitable allocation of digital rent to prevent cognitive exploitation. In line with Deak's (2022) discussions on wealth distribution, institutionalizing SDR is key to encourage a balanced knowledge economy. Capturing digital rent should not only compensate cognitive contributions but also alleviate exhaustion and renew expectations. This requires policies for fair digital rent distribution, mirroring the principles of Sustainable Land Rent (SLR), to maintain cognitive health for future societies.

6 Conclusion

The concept of Sustainable Digital Rent (SDR) provides a transformative framework for understanding the dynamics of value state, its extraction, evaluation, and distribution in the digital age. At the core of SDR is the need to balance human expectations with the growing abundance of information, recognizing the interplay of evolutionary and cognitive aspects that drive this equilibrium. This work underscores how cognitive systems rely on non-renewable expectations, which, when disproportionately exploited by powerful digital entities, result in an imbalance between knowledge production and human cognitive resources. Using the case of abstract art, we demonstrated how economic valuation has shifted from land-based models to digital platforms, enabling digital entities to extract rent through the cognitive and emotional engagements of users.

Central to SDR is the 'value state' mechanism, which involves a dynamic equilibrium between cognitive expectations and information. This evolutionarily conditioned balance is crucial for managing digital interactions and sustaining economies in the digital age. Digital platforms have the power to disrupt and influence this cognitive state,

converting large volumes of human expectations into increasing amounts of information. This shift underscores the urgent need for policies that prevent the overexploitation of cognitive resources while fostering creativity and engagement. As cognitive expectations drive knowledge advancement, traditional physical constraints have diminished, resulting in the transformation of classic land rent into digital platform rent.

Our study clarifies the profound meaning of SDR and its economic measurement through the example of Pollock's abstract art, utilizing the triadic Price, Cost, and Income (PCI) methods to illustrate the shift from land rent to digital rent. The price method emphasizes the declining significance of physical attributes in favor of the artist's reputation; the income method demonstrates how higher returns are increasingly driven by the artist's renown; and the cost method shows how the minimal physical cost of the canvas is vastly overshadowed by the value of the encoded information within the art. Together, these valuation methods converge to provide a consistent assessment of both the expectation and information components of SDR, rather than its traditional physical aspects, illustrating the convenience and reliability of Sustainable Artistic Rent (SAR) in understanding rent transition. Technically, these findings suggest also that future valuations will increasingly prioritize the value state of technological attributes (digital rent), further marginalizing traditional structural features of commodities and their associated rent.

As information and knowledge gain more weight in the value state, intricate valuation techniques and their complex processes gradually lose relevance. This is because PCI observables increasingly align with the information component of the value state when expectation is absent. Traditional PCI methodologies have relied on physical determinants, such as location, material costs, and structural features, to explain variations in value. However, in the context of digital rent, information itself becomes the direct measure of the value state, reducing the significance of these traditional determinants, which often involve higher expectations due to greater ignorance. With the advent of intelligent systems, complex valuation techniques may become redundant, as PCI observables now equate to the value state's information when expectation is absent. This paradigm shift indicates that, in the digital economy, knowledge (or information) becomes the ultimate measure and substitute for the value state. Estimating Sustainable Artistic Rent (SAR) not only clarifies this shift through practical parameters but also provides a clear, sustainable, and empirical basis for allocating value to rightful agents. Implementing SDR value-sharing mechanisms can sustainably reward initiatives that enhance both physical and cognitive well-being.

In traditional value state evaluations using CSA, SCA, and ICA, the cost to reproduce a commodity reflects its value state by aggregating the production costs of agents: organizations rewarded by profit, capital by interest, and labor by wages. Any residual value, or surplus, rewards the immobile agent—land—resulting in land rent, which determines the land's value state. However, in the digital realm, physical components are marginalized, and the primary reward shifts to the "digital land" (or platform) as digital rent. This transition simplifies digital rent evaluation and makes traditional methodologies focused on physical parameters less relevant. Digital rent directly rewards digital spaces, now perceived as repositories of knowledge. This transition underscores the need for economic systems to adapt, acknowledging the significance of knowledge and cognitive contributions in the digital age.

To integrate SDR into current economic frameworks, policies must focus on the equitable redistribution of digital rent. Possible mechanisms include compensating individuals for their cognitive inputs, thereby preventing exploitation and creating opportunities for individual creativity. Future research could explore the long-term cognitive impacts of digital rent extraction, refine methodologies for assessing SDR's value, and further investigate the intricate dynamics between digital platforms and human expectations. Addressing these areas will not only deepen our understanding of SDR but also pave the way for a more equitable and sustainable digital economy.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

ÜÖ: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration,

Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Addressing barriers and unveiling opportunities for plastic waste recycling in the New Zealand construction industry

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1 Introduction

Construction and demolition (C&D) waste represents up to 50% of the waste filling New Zealand's (NZ) landfills (Level, 2020), with plastics contributing about 4% (Ministry for the Environment, 2007). This percentage is high compared to the global rate for C&D waste, estimated to represent 36% of waste going to landfills (Alhawamdeh et al., 2024). In Auckland, NZ's most populous city, ~25,000 tons of plastic waste are deposited in landfills annually (Berry et al., 2022). Additionally, NZ's waste management processes lag those in the United Kingdom (UK) and Europe, as most construction waste in NZ is not sorted on-site and instead co-mingled (Low et al., 2020). Berry et al. (2022) ask, "For a single sector that produces such large quantities of waste, including plastics, why is there a lack of any significant focus on waste management?"

The process of extracting fossil fuels and creating plastics emits vast amounts of greenhouse gases, which is a critical driver of climate change. The global call to embrace a circular economy through reuse, renew and reduce practices drives a shift toward earth-based, bio-based and low-carbon materials (Ministry of Business, Innovation and Employment, 2024). To prevent the worst consequences of climate change, humanity needs to limit global temperature increase to 1.5°C. New Zealand has committed to this goal under the Paris Agreement, aiming for net-zero carbon emissions by 2050 [Climate Change Commission NZ (He Pou a Rangi), 2024]. However, the 2022 Global Status Report for Buildings and Construction revealed that the sector has fallen behind its decarbonization target of 2050 (United Nations Environment Programme, 2022). This problem is increasing as the use of plastics in construction has risen in recent years due to the industry's growing reliance on plastic products. This includes new products such as plastic building shrink wrap, and the replacement of traditional materials with plastic alternatives, like plastic pipes (Office of the Prime Minister's Chief Science Advisor, 2023).

The vast array of construction plastics needs to be sorted if they are to be reused or recycled. The most preferred approach is to reduce the amount of plastic used (waste minimization), working through the stages of reuse and recycling before the last resort of landfill disposal (waste management). It is important that there is continued focus on reducing the use of raw virgin materials, which occurs mainly during the design stage of construction and should be supported by a sustainable procurement strategy (Poon et al., 2003; Osmani et al., 2008; Andrews, 2015).

So why is NZ lagging so far behind? This opinion piece consolidates findings from recent research studies to understand the plastic waste problem, and explore both on-site and off-site barriers to reducing, reusing, and recycling plastic waste. Drawing on insights from case studies, we aim to identify solutions to these barriers. First, let us examine the factors in the broader environment that influence plastic waste recycling before construction begins on-site.

2 Discussion

2.1 Off-site factors

To understand specific barriers to waste management, Ferriz-Papi et al. (2024) examined 54 research articles and applied the PESTLE network (Political, Economic, Social, Technological, Legal, and Environmental) to study challenges to C&D waste management. These barriers included high investment requirements, lack of regulations, cultural attitudes, technological limitations, and the need for better data management and innovation in waste segregation. The challenges most discussed in the literature (which could be classified as off-site barriers) were inadequate regulations and additional costs of sustainable waste management. Similarly, Alhawamdeh et al. (2024) undertook a systematic literature review of 55 scientific articles (2020–2023) to determine the drivers that support C&D waste management for a circular economy. The main drivers identified were: a more regulated, digitally connected, collaborative and skilled sector; consideration of the full supply chain in the whole life cycle of a construction project; the waste value chain.

Ferriz-Papi et al. (2024) note the lack of cohesive regulation as a key barrier. In NZ, sending plastic waste to landfills is currently more cost-effective and straightforward than recycling it. Municipal landfill costs in NZ are currently \$60 NZD per ton (Ministry for the Environment, 2022), compared to £103.70 per ton (or \$220 NZD) in the UK (HM Revenue and Customs, 2023). Landfill levies tend to coincide with higher recycling rates; for example, the UK has a recorded recycling rate of 93% (Department for Environment, Food & Rural Affairs, 2024), while NZ has just 28% (Berry et al., 2022). This is especially relevant for plastic due to its low mass and high volume. This regulatory mechanism could easily be changed, but the question remains whether NZ has adequate facilities to meet the resulting recycling demand. Are there cost-effective, low-carbon transport options? What are the recycling options for the regions? How do you identify and sort the plastic? Where can you find resources to train and educate staff? These questions underline a complex and overwhelming issue for an industry already navigating a tough economic environment (Figure 1). Despite these many barriers, there is a growing awareness within the industry and a strong desire to do the right thing for the environment and future generations. Recent on-site trials have shown it is possible to address these questions; the results, in terms of reducing plastic waste, have been extremely promising and achievable (Low et al., 2024).

Additionally, there is growing recognition within the construction industry that building materials are valuable resources. This shift in mindset is fostering a collaborative

effort between government agencies, industry, technology, and communities to drive behavioral change and improve environmental outcomes. One example is a project funded by NZ's Ministry for the Environment, in 2022, through the Plastics Innovation Fund. This \$11.5 million initiative focuses on recycling plastic pipe off-cuts, which have traditionally been sent to landfill due to a lack of recycling facilities for construction waste. This project provides a blueprint of how to establish and fund a successful recycling operation. It includes investments in infrastructure to sort, wash and shred PVC and HDPE plastics, as well as developing a collection network in partnership with a major waste supplier. Additionally, the project conducts research to develop practical on-site solutions for construction sites and raises awareness through a hub of educational resources. The project addresses every step in the process to ensure a seamless circular solution. It underscores the value of collaboration in the NZ construction sector and the potential for the industry to work with global suppliers. This approach supports innovative local waste management initiatives, including supplier stewardship schemes, collaboration with local construction retailers and reverse logistics.

2.2 On-site factors

Over the last 4 years, several studies have sought to improve understanding and awareness of on-site plastic C&D waste in NZ. Hernandez et al. (2023) and Low et al. (2024) conducted plastic waste audits at various construction sites in Auckland to identify and measure the plastic waste stream. Low et al. (2020) identified considerable barriers to reducing, reusing and recycling plastic waste streams, including health and safety considerations, material contamination (such as soil, food, concrete, and non-plastic items) and the need for education and training for on-site waste management. To test these barriers, Berry et al. (2022) conducted a “foundations to completion” plastic waste audit on a new secondary school in Auckland, NZ, to trial separating and sorting waste. Several on-site barriers were identified; in this case, contractors could only recycle 21% by mass of all plastics generated (including all PVC pipework and polystyrene). Berry et al. (2022) concluded that this outcome was partly a reflection of the lack of staff training and site visits (due to COVID-19), the lack of a recycling culture on-site, and the lack of engagement from subcontractors. Berry noted that an essential factor was using dedicated reusable bags for sorting rather than co-mingled skip bins, which encourage poor waste management practices. Another barrier was the lack of clear and appropriate signage on-site (including images of waste types).

Low et al.'s (2024) study found that by implementing on-site plastic waste separation, training and appropriate signage, an Auckland residential construction site was able to divert 66.4% (wt.) of plastic waste from landfill through reuse and recycling. In this case study, the cost of sustainable waste management (separating all waste types) was ~2.3-fold more expensive than “traditional” waste management (using commingled landfill bins). Plastic waste management itself accounted for about 0.11% of the total project costs. However, these costs are specific to this site and will differ based on location, available transportation, recycling operators,

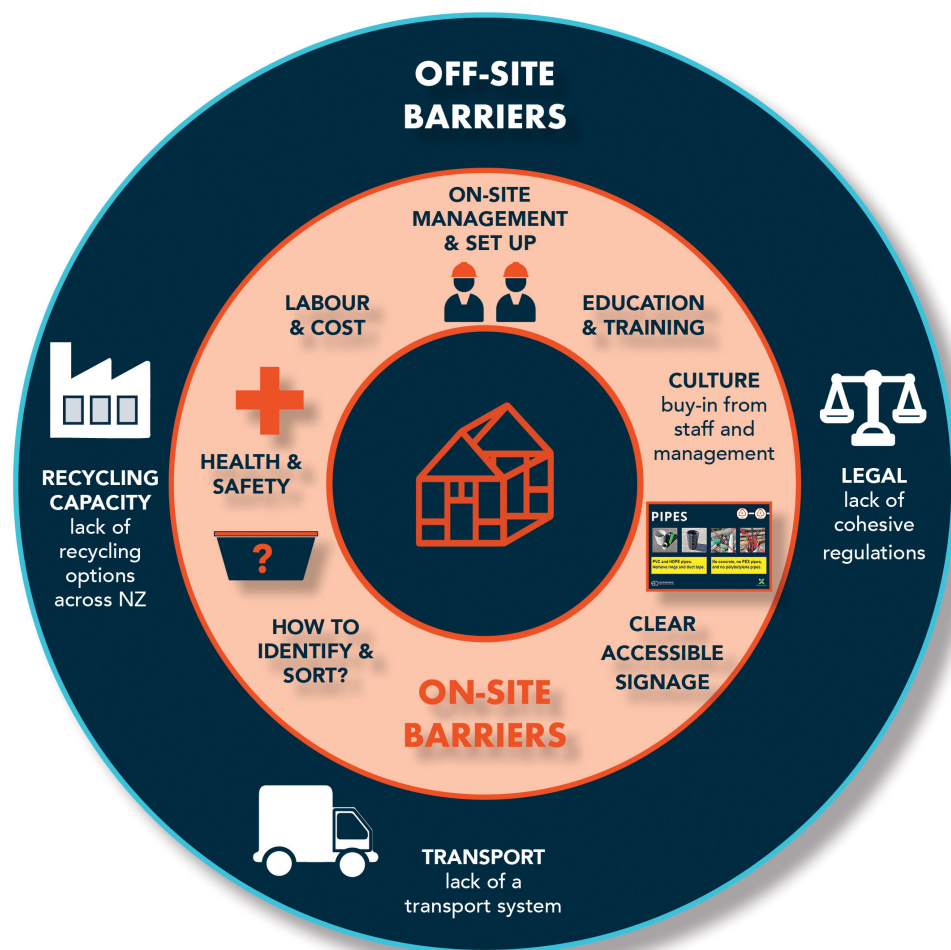


FIGURE 1
Off-site and on-site barriers to construction waste management.

and site size. The site owner did not find the increased cost for sustainable waste management to be unreasonable, and the additional cost passed onto each homebuyer was $\sim 0.16\%$ of the house's selling price.

Insights from informal discussions with on-site managers during case studies (PIF-funded projects) support the research findings (Berry et al., 2022). Signage with imagery is identified as a critical factor in overcoming language barriers for non-English speakers, and for quick identification of waste types. Other printed information such as posters, signage, and images were preferred, as online information is less accessible due to limited internet and phone access on construction sites. Education and training are essential and best kept simple and easy, with roles and responsibilities for waste management being outlined alongside health and safety protocols. While these case studies took place in NZ, many of the findings (factors to drive on-site separation of waste) can be implemented on any site.

Alhawamdeh et al. (2024) investigated why contractors fail to segregate construction waste. They identified key factors such as management effort, site space limitations, labor, cost, and

interference with day-to-day construction activities. Effective waste management requires commitment across all organizational levels, starting with involving the site management early in the project; this ensures they are engaged and will encourage the site team to carry out proper waste segregation. In addition, having a designated person for waste management is another key strategy. This role involves overseeing everyday waste sorting, communicating with both the site team and waste operators and finding solutions for any issues in the process. Successful plastic waste management on any site involves several steps: correctly identifying and sorting plastic waste, ensuring waste is clean, providing staff training, locating recycling operators, arranging waste transport, timely pickups, and maintaining quality control (Figure 1). Simplifying these processes and providing an educational hub of information is vital to support this change. Whilst the current recycling landscape can be overwhelming and confusing, there is a definite shift toward a culture of sustainability in the construction industry. This is often driven by a younger, more environmentally-conscious generation, which creates a valuable opportunity to improve sustainable waste practices in the industry.

3 Conclusion

The path toward effective plastic waste recycling in the New Zealand construction industry has many off-site and on-site challenges. External barriers include regulatory constraints, insufficient funding and infrastructure, entrenched industry norms and culture, and a lack of training and awareness.

However, the tide is turning. Collaborative initiatives, such as the Plastic Innovation Fund project, demonstrate the potential for successful recycling operations through coordinated efforts involving government, industry, and academia. The increasing awareness, urgency, and commitment to sustainable practices in the construction industry, especially among the younger generation, are promising signs for the future.

New Zealand must improve its plastic waste minimization and management to align with global standards and contribute to a more circular economy. Recent plastic waste trials have produced very promising results, but a concerted, ongoing effort from the industry is needed. Site managers need information and tools to set up and consistently use an on-site sorting area. Site workers will require education and training that is accessible and meaningful, with delegated responsibility for someone to ensure waste is properly sorted and clean. Additionally, ongoing feedback mechanisms and encouragement for site staff are crucial. This effort needs to be supported with updated online resources that clearly outline the process, lists of recyclers, and drop-off and transport options.

The construction industry is increasingly recognizing the need for changes in waste management. New Zealand must seize this opportunity to address regulatory gaps, invest in necessary infrastructure, and adopt innovative localized approaches. By fostering a culture of sustainability and collaboration, the

construction industry can lead the way in reducing plastic waste and ensuring long-term environmental sustainability.

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Mapping forestry practices against sustainable development goal targets

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The timber industry, at the crossroads and under severe pressure to achieve the Sustainable Development Goals (SDGs) by 2030, would see forestry practices such as harvesting, processing, trade, and silvicultural management at loggerheads with the SDGs' transformational agenda (Santos et al., 2019). The mismatch originates from the pursuit of short-term monetary benefits over the long-term exigencies of ecosystem health and human wellbeing (Bettles et al., 2021; Galante et al., 2012). Such practices lead to deforestation and loss of biodiversity, soil degradation, and worsened vulnerability to climate change, contrary to SDG6 (clean water), SDG12 (responsible consumption and production), SDG13 (climate action), and SDG15 (life on land) (Mbow et al., 2014; Asamoah et al., 2020).

Despite forestry's role in sustainable development, many forestry policies are reportedly devoid of strong sustainability frameworks (Sayer et al., 2019). Deforestation due to agricultural expansion, infrastructure, and industry creates disruptions for ecosystems and biodiversity. Beyond environmental risks, deforestation has further been assessed by the United Nations Development Programme (UNDP, 1994) in human security terms. Forest loss weakens ecological resilience, heightens economic instability, and threatens food security, especially for communities whose livelihoods are based on forest ecosystems. Research has often focused on carbon sequestration rather than being aligned to SDGs. Among the list of SDGs, SDG15 is vital in addressing biodiversity loss, ecosystem protection, and sustainable land use. Within its goal, SDG15.1 is concerned with conservation, while SDG15.3 strives for land degradation neutrality. However, many forestry policies have failed to incorporate those principles. Economically viable monoculture plantations, such as Radiata Pine in New Zealand, contribute to biodiversity loss, contradicting SDG15.1, which promotes the conservation and sustainable use of terrestrial ecosystems (Ramage et al., 2017; Folke et al., 2019). While monoculture may support restoration on degraded lands, large-scale adoption often prioritizes profit-making over ecological sustainability. Furthermore, SDG6.6 for the protection of water-related ecosystems and their functions suffers from soil degradation as a consequence of deforestation (Amezaga et al., 2019). Although SDG12.2 emphasizes sustainable land use and responsible resource use, forestry policies constantly favor short-term carbon sequestration incentives over long-term ecological resilience (Sayer et al., 2019; Bukoski et al., 2022).

This article is intended to review how forestry practices meet SDGs, outlining gaps in environmental sustainability, governing policies, and economic trade-offs. Using a literature-based analysis, it addresses strategies to balance sustainability with economic livelihoods. However, contemporary forestry governance provides limited information on

broader socioecological concerns to achieving SDGs (Adams and Turner, 2012; Louman et al., 2019; Razafindratsima et al., 2021). As a result, existing research often bypasses forestry's link to public health, poverty, and consumption (Ebi et al., 2020; Harris and Lyon, 2013).

New Zealand's forestry sector exemplifies the causal pathways whereby governance gaps enter into decision-making and create a negative environmental impact. Policy mechanisms like the Emissions Trading Scheme (ETS), actively promote monoculture plantations, often at the loss of biodiversity (MPI, 2022). Through these policies work toward the attainment of SDG8 (economic growth), their social and environmental consequences are yet manifest (Ma et al., 2022). These prioritizing fast-growing exotic over native biodiversity, risk biodiversity loss, contradicting SDG15.1 (Ramage et al., 2017; Bukoski et al., 2022). A more holistic approach is needed to reconcile carbon sequestration with biodiversity conservation (MPI, 2022; Folke et al., 2019). Beyond carbon policies, unsustainable forestry practices, including unregulated chemical use (Coutts and Ulrich, 2020), clear-cutting, and mechanical deforestation (Pizzirani et al., 2019) are some of the major drivers triggering soil degradation, water pollution, and destroy habitats, undermining SDG6 and SDG15 (Louman et al., 2019; Niu et al., 2021). Responsible watershed management, like protecting riparian zones and minimization of soil disturbance support SDG6.6 (Amezaga et al., 2019).

This brings us to the need for a switch toward a more all-inclusive forestry model, given that the gaps in good governance present some trade-offs with respect to the needs of the environment. Sustainable forestry goes beyond timber production to regard forests as essential ecosystems that support the rich biodiversity of various species and offer social and economic benefits to forest-dependent communities (Razafindratsima et al., 2021; Lawlor et al., 2019, p. 1). Sustainability will only be achieved by balancing conservation and economic viability through community participation, equitable benefit-sharing, and ecosystem resilience that aligns SDG1 (poverty alleviation), SDG2 (food security), and SDG10 (reducing inequalities) to advance economic benefit of local communities in conserving forests for future generations (Katila et al., 2020). Finally, the integration of forestry has been moving into the circular economy for the benefit of reinforcing sustainability, waste reduction, and resource use maximization, supporting SDG12.

To reach the targets set by SDGs, forestry should move from short-term models toward timber. For example, monoculture plantations have limped through with issues of immediate economic gain at the cost of ecosystem degradation and diminished ecosystem resilience. By marrying diverse, native tree species in forestry systems, the future-enhanced productivity and biodiversity will mean better soil health and more resilience to pests and climate change stressors beneficial to SDG15. Transitioning initiatives to sustainable models take an economic backsliding. These initiatives may include payments for ecosystem services, tax incentives and biodiversity conservation credits. Therefore, payments are important because they can provide economic incentives for sustainable practices while reducing dependencies

on concentrated logging. Certification schemes such as Forest Stewardship Council (FSC), are promoting responsible forestry by establishing standards for sustainable timber production. However, its action still has limited by the failure to implement and apply them consistently, as a result, not many forests are certificated (Elbakidze et al., 2022). Although certifications can help in the efforts toward sustainability, expanding its adoption and upgrading its standards remain essential for stronger alignment of forestry with SDG goals.

Forest governance is thus relatively simple when seeing the whole forestry sector in the perspective of aligning with SDGs. Governments should develop robust policy frameworks on land conversion, biodiversity, ecosystem, and sustainable practices. Examples include expanding ETS to recognize the ecological value of native forests, not only for potential carbon sequestration, creating a new impetus for sound decisions in the forestry field. Also, such evaluation will enable a wide empirical review of policy and management interventions that will guarantee the economic activities taken do not compromise critical ecosystem functions. To the other end, participation of the community in decisions is critical-to-the-degree that further creates any policy directly reflecting the needs of those people, who stand to be affected by forestry management.

Technology has an indispensable bearing on sustainable forestry. Substantial developments in technology include remote sensing and Geographic Information Systems (GIS), which allow for real-time monitoring of deforestation, carbon storage, and biodiversity health. Data-driven insight allows for more proactive land-use planning and conservation strategies (Negassa et al., 2020). Conversely, climate-smart forestry techniques (including reduced-impact logging, precision silviculture, and biodegradable alternatives to synthetic pesticides) may minimize environmental impact while ensuring economic viability. These innovations reflect the reconciliation between productivity and ecosystem integrity to maintain forest resilience against climate change.

Achieving the SDGs in forestry, finally, will necessitate cooperation at multiple levels in the action of manifold actors. This model needs to be decided through a collaboration between local communities, including Indigenous Forest leaders, and government, corporate players in the forestry business, and researchers. By partnerships, they will share knowledge and pool resources, therefore they can tackle barriers to sustainable development. The strategies to shift forestry away from the extraction mode and toward regenerative ecological management may support biodiversity, livelihoods, and climate resilience.

Author contributions

ARM: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. EKP: Conceptualization, Methodology, Supervision, Writing – review & editing. NP: Conceptualization, Methodology, Supervision, Writing – review & editing.

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