Sustainability: Science, Practice and Policy

ISSN: 1548-7733 (Online) Journal homepage: www.tandfonline.com/journals/tsus20

How to reconcile technology and justice in the circular economy: the innovation of open-source mid-tech solutions

Vasilis Kostakis & Dimitris Dalakoglou

To cite this article: Vasilis Kostakis & Dimitris Dalakoglou (2025) How to reconcile technology and justice in the circular economy: the innovation of open-source mid-tech solutions, Sustainability: Science, Practice and Policy, 21:1, 2546166, DOI: 10.1080/15487733.2025.2546166

To link to this article: https://doi.org/10.1080/15487733.2025.2546166

Published online: 13 Aug 2025.

SUSTAINABILITY: SCIENCE, PRACTICE AND POLICY
2025, VOL. 21, NO. 1, 2546166
https://doi.org/10.1080/15487733.2025.2546166

Taylor & Francis
Taylor & Francis Group

ARTICLE COMMENTARY

OPEN ACCESS Check for updates

How to reconcile technology and justice in the circular economy: the innovation of open-source mid-tech solutions

Vasilis Kostakis[a,b] and Dimitris Dalakoglou[c]

[a]Ragnar Nurkse Department of Innovation and Governance, Tallinn University of Technology, Tallinn, Estonia; [b]Berkman Klein Center for Internet and Society, Harvard University, Cambridge, MA, USA; [c]Faculty of Social Sciences and Humanities, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands

ABSTRACT
This article explores how open-source practices can reconcile the often-competing demands of technological advancement and social justice in the circular economy (CE). While conventional CE frameworks prioritize technical sophistication over social equity, and low-tech solutions sometimes lack scalability and effectiveness, we propose that open-source mid-tech solutions offer a promising synthesis. Through two illustrative examples, we demonstrate how this approach embeds both social justice and technical effectiveness from the outset through community ownership, local technical sovereignty, and inclusive participation. This article thus examines how open-source practices may address environmental, labor, and gender justice while maintaining technical rigor. Though implementation challenges remain, particularly around sustainable funding and quality assurance, emerging examples suggest promising pathways for creating truly transformative CE initiatives that serve both technical and social goals.

ARTICLE HISTORY
Received 9 February 2025
Accepted 6 August 2025

KEYWORDS
Circular economy; just transition; commons; open-source; environmental justice

Introduction

The circular economy (CE) has emerged as a promising framework for achieving sustainability, yet current CE approaches often preserve problematic patterns of the linear economy they aim to replace. Recent research by Pansera et al. (2024) argues that circularity alone does not guarantee sustainability: CE activities must be evaluated through comprehensive economic, environmental, and social sustainability lenses. Their analysis reveals that conventional CE frameworks tend to stress technical and business aspects while neglecting critical issues of social justice, including the uneven distribution of environmental burdens between the Global North and South, workers' rights, and the systematic devaluation of care work, which is predominantly carried out by women.

The dominant CE approach has primarily prioritized engineering and economics-oriented solutions, emphasizing material flows and high-tech solutions for recycling and reuse (Blum, Haupt, and Bening 2020). However, this technocratic emphasis faces several challenges. The most significant is that the circular solutions presented as a panacea for planetary problems often replicate the same problematic blueprints that caused issues in linear economy models. For instance, most CE technologies are patented, restricted by proprietary legal frameworks, and treated as trade secrets. This phenomenon not only slows down innovation but also increases adoption costs, making local implementation difficult, especially in low-income contexts (Benkler 2017; Boldrin and Levine 2013). Moreover, these high-tech CE solutions often overlook fundamental issues related to resource extraction, labor exploitation, energy use, and material flows (Lange, Pohl, and Santarius 2020; Sovacool, Del Rio, and Griffiths 2020). How can we talk about a CE as a socially inclusive solution when laborers in one part of the circle have fewer rights than those in another, due to geographic or social class inequalities?

In response to these limitations, researchers have begun exploring alternative approaches. Tanguy, Carrière, and Laforest (2023) demonstrate that low-tech solutions provide more than simplified

CONTACT Vasilis Kostakis vasileios.kostakis@taltech.ee Ragnar Nurkse Department of Innovation and Governance, Tallinn University of Technology, Akadeemia tee 3, 12618 Tallinn, Estonia
This article has been corrected with minor changes. These changes do not impact the academic content of the article.

technologies; they represent a holistic vision for sustainability that integrates technical, social, and organizational dimensions. Their analysis shows that while resource efficiency and material reuse remain important, small-scale, localized technical appropriation – rendering technology understandable and usable by individuals and communities – emerges as the most frequently cited principle in both literature and practice. This focus on social accessibility and socio-cultural embeddedness fundamentally distinguishes low-tech solutions from mainstream CE approaches. Low-tech principles such as "context-dependency" and "collective networks" emphasize tailoring solutions to local environmental, cultural, and social conditions, rather than adopting a one-size-fits-all approach (Tanguy, Carrière, and Laforest 2023). By reconnecting human activities with their direct natural and socio-cultural environments, low-tech approaches may reduce resource consumption while considering local ecosystem capacities, promoting technical sovereignty, and organizing solutions through decentralized, community-driven networks (Tanguy, Carrière, and Laforest 2023).

We thus understand "low-tech approaches" not merely as simplified technologies but as holistic socio-technical arrangements that integrate technical, social, and organizational dimensions (Alexander and Yacoumis 2018). These approaches emphasize three core "low-tech principles": technical appropriation that makes technology understandable and modifiable by users; context-dependency that adapts solutions to local environmental and cultural conditions; and reduced external dependency that promotes local technical sovereignty and resilience (Alexander and Yacoumis 2018; Tanguy, Carrière, and Laforest 2023).

As De Decker (2018) argues, CE concepts often focus narrowly on waste management while ignoring thermodynamic constraints, revealing fundamental limitations of circularity in industrial contexts. This critique further highlights the need for alternative approaches that acknowledge both physical and social dimensions of sustainability. Throughout this article, we understand "CE approaches" as methodologies aimed at minimizing waste and maximizing resource reuse; "CE goals" as the specific outcomes these approaches target; "CE ecosystems" as networks of actors enabling circular material flows; and "open-source CE" as the application of transparent design, collaborative development, and distributed manufacturing principles to circular initiatives. This conceptual framework allows us to evaluate how different technological paradigms might contribute to a more socially just and environmentally sustainable circular economy.

We thus attempt to further the debate about how to create a more just CE, building on research by Pansera et al. (2024) and Tanguy, Carrière, and Laforest (2023) published in this journal. We demonstrate how an inclusive CE may be achieved through socially transformative processes similar to those in low-tech approaches. In the second section, we introduce a "mid-tech" approach and explore its synthesis of high-tech and low-tech strengths, illustrated through cases of open-source prosthetics and agricultural machinery. The third and final section discusses future directions and challenges, emphasizing the importance of openness and accessibility in design and production infrastructure.

Theorizing mid-tech: a framework for a just circular economy

The pursuit of sustainability has often been polarized between high-tech and low-tech approaches, each with significant limitations (Kerschner and Ehlers 2016; Scoones, Leach, and Newell 2015). High-tech solutions, while powerful, frequently prioritize technical sophistication and efficiency over social equity and accessibility, often reinforcing existing power asymmetries and resource-distribution patterns (Hickel and Kallis 2020; Sovacool, Del Rio, and Griffiths 2020). Low-tech approaches, though more inclusive and locally adaptable as demonstrated by Tanguy, Carrière, and Laforest (2023), may lack the capacity to address sustainability challenges at the necessary scale and speed required by urgent transgressions of planetary boundaries (Hornborg 2014; Steffen et al. 2015).

From this tension emerges the concept of "mid-tech" synthesis (see also Kostakis, Pazaitis, and Liarokapis 2023), which is a framework that combines high-tech capabilities with low-tech principles to create solutions that are both technically effective and socially just. This balanced approach offers a promising path toward addressing complex sustainability challenges while ensuring equitable access and control of technology. Before presenting a conceptual framework to visualize these different approaches, we first explore two examples that demonstrate mid-tech synthesis in practice, showing how these initiatives navigate the tensions between technological sophistication and social justice concerns in real-world contexts.

Two illustrative examples

To ground our framework, we draw on two initiatives that exemplify mid-tech synthesis in practice. Rather than presenting new empirical case studies with formal methodological design, we synthesize insights from existing research (including our previous work on OpenBionics and Giotitsas's (2019) analysis of open-source agricultural initiatives). These conceptual illustrations demonstrate how mid-tech approaches can bridge technological sophistication with social justice concerns in real-world contexts.

OpenBionics, currently part of the New Dexterity Lab at the University of Auckland, demonstrates how integrating advanced technology with local control can make medical devices more accessible. The OpenBionics initiative produces anthropomorphic, modular prosthetic hands that cost only US$200–300 (marginal cost) compared to US$20,000–100,000 for conventional prosthetics, while achieving similar functional capabilities through clever mechanical design (Kostakis et al. 2018, Kostakis, Pazaitis, and Liarokapis 2023). This dramatic cost reduction is achieved not by compromising on capability, but through deliberate design choices that balance sophistication with simplicity. For example, the prosthetics use a selectively lockable differential mechanism that allows a single actuator to produce 144 different grasping postures – achieving versatility through mechanical design rather than complex electronics (Kostakis et al. 2018, Kostakis, Pazaitis, and Liarokapis 2023).

The initiative takes a mid-tech approach that goes beyond just the technical design. While the OpenBionics projects incorporate high-tech tools like 3D printing and digital design, they also embrace low-tech principles. As Tanguy, Carrière, and Laforest (2023) emphasize, low-tech solutions represent more than just low-energy technical objects, as they embody a design philosophy that is not centered on technology itself. This is evident in OpenBionics' emphasis on repairability, localized manufacturing, and user modification. Indeed, their focus on maintenance and repair aligns with what Tanguy, Carrière, and Laforest (2023) identify as the ultimate expression of low-tech approaches. The designs are specifically engineered to be produced using off-the-shelf, low-cost, and lightweight materials that can easily be found in typical hardware stores (Kostakis et al. 2018). Some versions of OpenBionics prosthetics do not include electronics, which reduces the need for certain minerals and may even utilize the kinetic energy generated by the movement of the elbow (Kostakis, Pazaitis, and Liarokapis 2023).

Moreover, through digital fabrication labs and online knowledge-sharing platforms, communities can produce customized prosthetics at significantly lower costs than traditional medical devices, exemplifying what Tanguy, Carrière, and Laforest (2023) refer to as "collective networks" (i.e., decentralized communities of practice sharing knowledge and capabilities). The modular design allows users to replace individual fingers for around US$10–$20 each, rather than requiring specialized expertise or complete device replacement. The initiative's success – with designs downloaded thousands of times across more than 150 countries – demonstrates how mid-tech solutions can achieve scale while remaining grounded in local communities and user needs (Kostakis, Pazaitis, and Liarokapis 2023).

Similarly, open-source agricultural initiatives such as L'Atelier Paysan (a French cooperative) and Farm Hack (a United States-based network) demonstrate how a mid-tech approach can democratize technology while effectively addressing real-life problems (Giotitsas 2019; Kostakis, Niaros, and Giotitsas 2023). L'Atelier Paysan and Farm Hack enable farmers to collectively design and share agricultural tools by creating spaces where traditional farming knowledge converges with modern technological capabilities (Giotitsas 2019). The communities develop governance models that maintain local control while facilitating global knowledge-sharing through online platforms and documentation practices that preserve crucial tacit knowledge. Both initiatives are interconnected through their shared use of digital commons (i.e., designs, software, and knowledge related to agricultural machinery for small-scale farming). This decentralized, collaborative approach creates "technological sovereignty", whereby farmers maintain control over their tools while participating in broader networks of innovation and mutual support (Giotitsas 2019).

The social movement aspects of these initiatives are particularly significant. Giotitsas (2019) and Kostakis, Niaros, and Giotitsas (2023) have documented how open-source agricultural communities build collective identity through shared technological practices, creating alternative economic models that prioritize community needs over market imperatives. These networks of farmer-innovators share designs, improvements, and expertise in ways that align with Pansera et al.'s (2024) vision of worker-led technological development, and Tanguy, Carrière, and Laforest's (2023) emphasis on "back to basics" (i.e., focusing on essential needs and practical solutions rather than technological complexity for its own sake).

Synthesizing insights

Drawing from these illustrative examples and the broader literature, we can identify patterns in how different technological approaches address key dimensions of sustainability and justice in CE contexts. Table 1 presents a conceptual comparison of how different technological approaches tend to address key dimensions of sustainability and justice in CE contexts, serving as a heuristic tool that synthesizes patterns observed across cases and literature. This comparative framework highlights characteristic tendencies rather than absolute properties, acknowledging that actual implementations vary significantly based on context, implementation, and governance. Rather than suggesting the superiority of any single approach, this heuristic mapping identifies complementary elements that can inform context-specific CE solutions. The dimensions and characterizations presented are not meant to be exhaustive or rigid categories, but rather to provide conceptual guidance for analyzing technological choices in CE initiatives through a justice-oriented lens. Each approach offers distinct advantages and limitations that may be suitable for different circumstances and needs.

It is important to note that these categorizations represent tendencies rather than absolute characteristics. For instance, low-tech approaches may sometimes require highly specialized traditional knowledge and craftsmanship, as seen in traditional cooperage (barrel-making) or cartwrighting (wagon-making), which contradicts the simplified notion of universal do-it-yourself (DIY) repairability. Similarly, high-tech solutions occasionally enable democratic participation, while some low-tech implementations may reinforce existing social hierarchies. This tension reflects a broader evolution from the more individualistic DIY approach toward collaborative do-it-together (DIT) approaches that emphasize collective knowledge-sharing, decentralized problem-solving, and community ownership

Table 1. Mid-tech approach as synthesis of high-tech and low-tech approaches.

Dimension	High-tech	Mid-tech	Low-tech
Technical approach	Centralized, complex solutions requiring specialized knowledge	Balanced sophistication with accessibility, modular designs, and open-source	Simple, locally-appropriate solutions
Knowledge distribution	Proprietary, patented	Open-source, shared through digital platforms while maintaining local control	Local, traditional knowledge
Resource requirements	High capital, specialized materials	Moderate cost, commonly available materials	Low-cost, locally sourced materials
Social integration	Limited community involvement	Strong community ownership with global connections	Strong local embedding
Maintenance and repair	Dependent on specialists	User-maintainable, supported by global and local community networks	DIY, local community-based
Scale of impact	Global but exclusionary	Global-local synthesis ("cosmolocal")	Local but limited reach
Power relations	Centralized control	Distributed authority with coordination	Local autonomy
Sustainability model	Technology-driven efficiency	Balanced technical and social sustainability	Resource minimization
Key limitations	High barriers to entry, dependency on global supply chains, and potential technological lock-in	Requires digital infrastructure access, complex governance needs, and quality-assurance challenges	Scalability constraints, limited standardization, may preserve traditional power imbalances, difficulty addressing complex problems

of technological development. Mid-tech approaches attempt to address these complexities by combining elements strategically, but also face unique challenges in balancing standardization with adaptability and in developing governance models that truly enable broad participation.

Toward a just and open-source circular economy?

These practical examples of OpenBionics and open-source agricultural initiatives reveal how a mid-tech synthesis offers more than just a technological compromise; it presents a framework for addressing social justice within CE goals. As outlined in Table 1, this mid-tech synthesis combines elements from both high-tech and low-tech approaches to create solutions that are both technically effective and socially just. Building on these cases, we now examine how this approach tackles three critical dimensions of justice that Pansera et al. (2024) identify as frequently neglected in mainstream CE approaches: environmental justice, labor justice, and gender justice. Each of these dimensions requires careful consideration to ensure that CE transitions do not merely replicate existing inequalities in new forms.

The environmental justice dimension recognizes that technological transitions often perpetuate North-South inequalities through the uneven distribution of environmental costs and benefits. Mid-tech approaches explicitly aim to repair these ecological and climate debts by enabling Global South communities to develop and control their technological solutions, rather than depending on imported high-tech systems. This aligns with what Tanguy, Carrière, and Laforest (2023, 9) identify as the principle of "limited external dependency" (i.e., reducing reliance on complex global supply chains in favor of local technological sovereignty).

From a labor-justice perspective, mid-tech approaches empower workers as active agents of technological change rather than passive recipients. This is particularly important given that, as Pansera et al. (2024, 11) note, CE models "tend to be top-down and to take a global rather than a local approach, which prevents us from considering the situated viewpoints of workers in different contexts." Giotitsas (2019) demonstrates how open-source agricultural initiatives challenge conventional agricultural technology development by democratizing design and manufacturing processes. This activity goes beyond simply creating "green jobs" to enable workers' leadership in designing and implementing new technologies, connecting to the principle of "appropriation" (Tanguy, Carrière, and Laforest 2023, 13).

The principle of appropriation – rendering technology understandable and modifiable by users – is fundamental to mid-tech approaches. Unlike black-boxed high-tech interventions, appropriation in OpenBionics manifests through accessible materials and documentation, enabling users to repair devices independently. Similarly, L'Atelier Paysan and Farm Hack demonstrate appropriation by translating complex engineering into farmer-comprehensible designs, creating "technological sovereignty" (i.e., control over tools while participating in innovation networks). This directly supports environmental justice through reduced dependency, labor justice by validating workers' knowledge, and making technical spaces more accessible. The implementation of this appropriation depends on standardization efforts. As Behnert and Arlinghaus (2023) emphasize, standardization is an essential prerequisite for enabling circularity, particularly when it comes to repairing complex products. This objective aligns with open-source principles of modular design and accessibility, enabling workers to maintain and repair technologies themselves (Behnert and Arlinghaus 2023), further advancing labor justice through technical sovereignty.

Regarding gender justice, mid-tech synthesis explicitly values and incorporates traditionally feminized forms of labor like repair, maintenance, and care work. This addresses what Pansera et al. (2024) identify as a key blind spot in mainstream CE approaches, namely the devaluation of reproductive and care work that is essential for genuine sustainability. Giotitsas (2019) reveals how open-source agricultural communities often challenge traditional gender roles through collective learning practices that value diverse forms of knowledge and expertise. However, it remains unclear whether simply recognizing and incorporating traditionally feminized labor is sufficient to transform deeper structural inequalities, as these communities may still reproduce gendered divisions of labor even while claiming to value all forms of work equally.

The promise of open-source CE faces several practical challenges in implementation. Regarding environmental justice, Global South communities often encounter limited access to basic infrastructure, which prevents meaningful participation in digital knowledge-sharing platforms. As Giotitsas (2019) documents in his study of Farm Hack and L'Atelier Paysan, language barriers in predominantly English-language open-source communities create exclusion. More fundamentally, power imbalances persist in terms of who shapes the open-source agenda, with Northern institutions and actors often dominating despite intentions of democratic participation. In response, some communities are developing local manufacturing hubs equipped with both digital and traditional tools, enabling them to produce and maintain equipment according to their needs while building technical sovereignty.

Labor-justice implementation encounters tensions between quality-assurance requirements and local adaptation needs. Giotitsas (2019) and Kostakis, Niaros, and Giotitsas (2023) show how agricultural communities navigate these challenges through peer-learning networks that preserve and enhance traditional farming knowledge while incorporating new technical capabilities. Technical expertise prerequisites can create new hierarchies despite the aims of accessibility, while many worker-led initiatives struggle to achieve economic viability while maintaining their principles. Yet, emerging models show promise, with some cooperatives, like L'Atelier Paysan, balancing worker control with technical rigor through peer-review systems. Others have developed hybrid approaches combining open and proprietary elements to achieve financial sustainability, while preserving worker agency.

Making technical spaces truly inclusive for gender justice requires addressing deeply embedded cultural and structural barriers. Current CE initiatives often reproduce gender segregation, with women concentrated in traditionally feminized roles around repair and maintenance rather than technical innovation. In response, some communities have developed women-led makerspaces that combine technical training with conscious efforts to validate diverse forms of knowledge (Capel et al. 2021; Cohen 2016). Mentorship networks specifically supporting women from marginalized backgrounds in developing technical leadership have emerged, while programs recognizing informal expertise alongside formal qualifications help bridge traditional gender divides.

The successful implementation of these approaches requires novel governance models that help manage tensions between standardization and local adaptation. Various open-source initiatives have developed governance structures that maintain community control while enabling global collaboration (Benkler 2006; Giotitsas 2019; Kostakis, Lemos, and Kouvara 2024). Alternative funding mechanisms, like solidarity funds and community-ownership models, support social goals alongside economic viability (see, in particular, chapter 6 in Cohen 2016). Networks connecting practitioners across regions enable knowledge sharing while respecting local autonomy.

Digital platforms play a crucial but complex role in enabling global collaboration, though care must be taken to prevent reproducing existing inequalities. Giotitsas (2019) demonstrates how Farm Hack's and L'Atelier Paysan's online platforms facilitate knowledge-sharing while maintaining community control through careful documentation practices and participatory governance. Some open-source communities are developing hybrid online-offline models that combine digital tools with face-to-face interaction to ensure inclusive participation (O'Neil, Pentzold, and Toupin 2021).

Analysis of successful implementations reveals several interconnected success factors. Strong community ownership and governance structures work alongside hybrid-funding models that combine market and non-market resources (O'Neil, Pentzold, and Toupin 2021). Careful attention to power dynamics in knowledge-sharing proves essential, as does investment in building local technical capabilities and recognition of diverse forms of expertise (O'Neil, Pentzold, and Toupin 2021). Successful projects take patient approaches that prioritize genuine participation over quick scaling (Kostakis, Lemos, and Kouvara 2024; O'Neil, Pentzold, and Toupin 2021).

The mid-tech synthesis creates new opportunities for sustainable business models based on implementation services, customization, training, and maintenance rather than traditional intellectual property (IP) rights. While open-source practices limit traditional IP-based revenue, they enable new business models focused on local manufacturing and support services (Benkler 2006; Kostakis, Niaros, and Giotitsas 2023; O'Neil, Pentzold, and Toupin 2021). These models particularly emphasize what Pansera et al. (2024) identify as the need to properly value the reproductive and maintenance work essential for genuine circularity.

The experience of implementing open-source CE suggests several key priorities moving forward. Policy frameworks need to actively support open-source legal frameworks, while funding mechanisms must value social outcomes alongside technical innovation (Kallis et al. 2018; O'Neil et al. 2024). Capacity building should focus on developing local technical sovereignty through inclusive digital infrastructure (O'Neil et al. 2024). O'Neil et al. (2024) emphasize that government-procurement mechanisms should include training programs to help public sector staff understand digital commons principles and support productive communities effectively. O'Neil et al. (2024) also recommends quality-assurance labels based on indicators such as contribution, shared resources, open governance, and eco-design to build trust with public sector partners, while balancing standardization with local adaptation needs (Kostakis, Niaros, and Giotitsas 2023; O'Neil et al. 2024).

While the gap between theoretical possibility and practical reality in achieving social justice through open-source CE remains significant, emerging examples demonstrate promising paths forward when careful attention is paid to power dynamics, local ownership, and inclusive participation. The integration of social justice into CE frameworks requires a fundamental shift from purely technical or economic considerations to a holistic approach that addresses systemic inequalities. As both Pansera et al. (2024) and Tanguy, Carrière, and Laforest (2023) emphasize, this requires balancing technical sophistication with social accessibility and local adaptability. The success of such initiatives depends on ongoing collaboration between workers, communities, researchers, policymakers, and civil society organizations in creating truly transformative CE solutions.

Future directions: embedding justice in circular economy design

The examples and theoretical framework presented in this article demonstrate that achieving a just CE requires more than simply finding a middle ground between high-tech and low-tech approaches. Rather, it demands a fundamental reimagining of how we develop and implement circular solutions. Mid-tech synthesis offers this path forward not by compromising between extremes, but by consciously combining the most valuable elements of both approaches: the sophisticated knowledge-sharing and technical capabilities of high-tech solutions with the autonomy, adaptability, and social-embedding characteristic of low-tech approaches.

The mid-tech synthesis we propose is not an arbitrary compromise or "anything goes" approach. Rather, it adheres to specific guiding principles, for example: open-source licensing enhances knowledge accessibility; modularity enables local adaptation while maintaining compatibility; design for repairability promotes product longevity; using locally available materials reduces dependency; and democratic governance preserves community control while facilitating global collaboration. These principles create certain outcomes in accessibility, environmental impact, and social justice as illustrated by our examples. Mid-tech's success could be measured through specific indicators: user modification capabilities, repair rates, knowledge-sharing, and community ownership, providing criteria that help prevent the dilution seen in other sustainability frameworks.

Critical to this synthesis is the recognition that social justice and sustainability principles must be embedded from the very beginning in any CE initiative. Our examples demonstrate the advantages of this approach: when OpenBionics designed its prosthetics with dual imperatives of technical functionality and social accessibility from the outset, they made fundamental design choices that would have been difficult to implement retroactively. Similarly, L'Atelier Paysan's and Farm Hack's impact stems from their initial commitment to farmer control and knowledge sovereignty, which shaped their entire technical development process in ways that conventional agricultural technology providers struggle to retrofit.

The potential of mid-tech CE to reduce environmental impacts operates through multiple channels: decreasing transportation needs via localized manufacturing, extending product lifespans through enhanced repairability, improving resource efficiency through knowledge-sharing, lowering barriers to adoption, and enabling context-specific adaptation. This open-source approach fosters cooperation rather than competition between market participants by removing monopolistic barriers while maintaining innovation incentives.

However, realizing this potential requires addressing several critical challenges: developing sustainable funding models that support open-source development while maintaining community control; upholding quality and safety standards without compromising openness; supporting local communities in building technical capabilities; establishing appropriate regulatory frameworks; and managing intellectual property transitions to promote sharing.

Another critical challenge for mid-tech approaches is the increasingly private ownership of enabling infrastructures – from digital platforms to manufacturing facilities. Without reconfiguring these ownership models through commons-based alternatives or public ownership options, the democratic ideals of mid-tech solutions may remain constrained. Future research should examine how community ownership of both physical and digital infrastructure can be advanced to realize the full potential of just CE practices. Building on this infrastructure challenge, policy frameworks and institutional arrangements should actively support community ownership of circular technologies while promoting inclusive participation and local technical sovereignty. This includes developing hybrid-funding mechanisms that value social outcomes alongside technical innovation, creating quality-assurance systems that balance standardization with local adaptation, and designing digital infrastructure for inclusive participation.

While significant challenges remain in achieving social justice through open-source CE, viable pathways exist when careful attention is paid to power dynamics, local ownership, and inclusive participation. Ongoing collaboration among workers, communities, researchers, policymakers, and civil society organizations is required to create truly transformative CE eco-systems that address environmental, social, and technical dimensions of sustainability.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

Vasilis Kostakis acknowledges support from the Estonian Center of Excellence in Energy Efficiency, ENER [grant TK230], funded by the Estonian Ministry of Education and Research. Dimitris Dalakoglou was funded from a Stimulation grant of the Dutch Ministry of Education, Culture and Science awarded to him as the PI for the project 'Infrastructures, Sustainability and Commons'.

ORCID

Vasilis Kostakis http://orcid.org/0000-0002-3276-9282
Dimitris Dalakoglou http://orcid.org/0000-0002-8505-1776

References

Alexander, S., and P. Yacoumis. 2018. "Degrowth, Energy Descent, and 'Low-Tech' Living: Potential Pathways for Increased Resilience in Times of Crisis." *Journal of Cleaner Production* 197: 1840–1848. doi:10.1016/j.jclepro.2016.09.100.

Behnert, A., and J. Arlinghaus. 2023. "Open Source as an Enabler for Circularity: A Systematic Literature Review." *Procedia CIRP* 120: 75–80. doi:10.1016/j.procir.2023.08.014.

Benkler, Y. 2006. *The Wealth of Networks: How Social Production Transforms Markets and Freedom*. New Haven, CT: Yale University Press.

Benkler, Y. 2017. "Law, Innovation, and Collaboration in Networked Economy and Society." *Annual Review of Law and Social Science* 13 (1): 231–250. doi:10.1146/annurev-lawsocsci-110316-113340.

Blum, N., M. Haupt, and C. Bening. 2020. "Why 'Circular' Doesn't Always Mean 'Sustainable'." *Resources, Conservation and Recycling* 162: 105042. doi:10.1016/j.resconrec.2020.105042.

Boldrin, M., and D. Levine. 2013. "The Case Against Patents." *Journal of Economic Perspectives* 27 (1): 3–22. doi:10.1257/jep.27.1.3.

Capel, T., B. Ploderer, M. Brereton, and M. O'Connor Solly. 2021. "The Making of Women: Creating Trajectories for Women's Participation in Makerspaces." *Proceedings of the ACM on Human-Computer Interaction* 5: 1–38. https://dl.acm.org/doi/10.1145/3449109.

Cohen, M. 2016. *The Future of Consumer Society: Prospects for Sustainability in the New Economy*. Oxford: Oxford University Press.

De Decker, K. 2018. "How Circular Is the Circular Economy?" *LOW←TECH MAGAZINE*, November 3. https://solar.lowtechmagazine.com/2018/11/how-circular-is-the-circular-economy

Giotitsas, C. 2019. *Open Source Agriculture: Grassroots Technology in the Digital Era*. London: Palgrave Macmillan.

Hickel, J., and G. Kallis. 2020. "Is Green Growth Possible?" *New Political Economy* 25 (4): 469–486. doi:10.1080/13563467.2019.1598964.

Hornborg, A. 2014. "Technology as Fetish: Marx, Latour, and the Cultural Foundations of Capitalism." *Theory, Culture and Society* 31 (4): 119–140. doi:10.1177/0263276413488960.

Kallis, G., V. Kostakis, S. Lange, B. Muraca, S. Paulson, and M. Schmelzer. 2018. "Research on Degrowth." *Annual Review of Environment and Resources* 43 (1): 291–316. doi:10.1146/annurev-environ-102017-025941.

Kerschner, C., and M. Ehlers. 2016. "A Framework of Attitudes Towards Technology in Theory and Practice." *Ecological Economics* 126: 139–151. doi:10.1016/j.ecolecon.2016.02.010.

Kostakis, V., K. Latoufis, M. Liarokapis, and M. Bauwens. 2018. "The Convergence of Digital Commons with Local Manufacturing from a Degrowth Perspective: Two Illustrative Cases." *Journal of Cleaner Production* 197: 1684–1693. doi:10.1016/j.jclepro.2016.09.077.

Kostakis, V., A. Pazaitis, and M. Liarokapis. 2023. "Beyond High-Tech Versus Low-Tech: A Tentative Framework for Sustainable Urban Data Governance." *Big Data & Society* 10 (1): 15. doi:10.1177/20539517231180583.

Kostakis, V., V. Niaros, and C. Giotitsas. 2023. "Beyond Global Versus Local: Illuminating a Cosmolocal Framework for Convivial Technology Development." *Sustainability Science* 18 (5): 2309–2322. doi:10.1007/s11625-023-01378-1.

Kostakis, V., L. Lemos, and A. Kouvara. 2024. "Another Scalability Is Possible! From Non-Scalability to Cosmolocal Scalability." *tripleC: Communication, Capitalism & Critique* 22 (2): 620–629. doi:10.31269/triplec.v22i2.1535.

Lange, S., J. Pohl, and T. Santarius. 2020. "Digitalization and Energy Consumption: Does ICT Reduce Energy Demand?" *Ecological Economics* 176: 106760. doi:10.1016/j.ecolecon.2020.106760.

O'Neil, M., C. Pentzold, and S. Toupin, eds. 2021. *The Handbook of Peer Production*. Hoboken, NJ: Wiley-Blackwell.

O'Neil, M., A. Daly, M. Corneille, G. Leeming, and R. Nanni. 2024. "Best Practices Guide for Digital Commons: Government Relations." Digital Commons Policy Council. 10.60836/tsx6-wc02.

Pansera, M., S. Barca, B. Alvarez, E. Leonardi, G. D'Alisa, T. Meira, and P. Guillibert. 2024. "Toward a Just Circular Economy: Conceptualizing Environmental Labor and Gender Justice in Circularity Studies." *Sustainability: Science, Practice, and Policy* 20 (1): 2338592. doi:10.1080/15487733.2024.2338592.

Scoones, I., M. Leach, and P. Newell, eds. 2015. *The Politics of Green Transformations*. London: Routledge.

Sovacool, B., D. Del Rio, and S. Griffiths. 2020. "Contextualizing the Covid-19 Pandemic for a Carbon-Constrained World: Insights for Sustainability Transitions, Energy Justice, and Research Methodology." *Energy Research & Social Science* 68: 101701. doi:10.1016/j.erss.2020.101701.

Steffen, W., K. Richardson, J. Rockström, S. Cornell, I. Fetzer, E. Bennett, R. Biggs, et al. 2015. "Planetary Boundaries: Guiding Human Development on a Changing Planet." *Science* 347 (6223): 1259855. doi:10.1126/science.1259855.

Tanguy, A., L. Carrière, and V. Laforest. 2023. "Low-Tech Approaches for Sustainability: Key Principles from the Literature and Practice." *Sustainability: Science, Practice and Policy* 19 (1): 2170143. doi:10.1080/15487733.2023.2170143.