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# Digital Financial Services And Environmental Sustainability: Post-Pandemic Pathways To Green Inclusion

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***Abstract***
*The COVID-19 pandemic amplified the use of digital financial services (DFS)- contactless payments and mobile wallets, algorithmic credit, and digital micro-insurance. The paper draws out the emerging and post pandemic evidence on how DFS can improve environmental sustainability and financial inclusion (green inclusion). We consider six paths to clean-energy access, including pay-as-you-go (PAYGo) models; green-innovation diffusion; climate-risk transfer and resilience; carbon-conscious consumer nudges; greening capital markets; and digital measurement, reporting, and verification (dMRV); and balance these benefits with rebound and distributional risks (e-waste, energy-intensive crypto, and overspending externalities of cashless payments). We end by offering a design agenda to regulators and providers to make DFS consistent with national decarbonization and adaptation objectives.*
***Keywords:*** *digital financial services; financial inclusion; environmental sustainability; green inclusion; fintech; PAYGo (pay-as-you-go) solar; green bonds; climate resilience.*

## INTRODUCTION

### From digital surge to green inclusion

The restrictions during the pandemic stimulated a structural leap in the sphere of digital payments and account use at the global scale, and the Global Findex 2021 document reports a significant increase in the number of adults who make or receive a digital payment and use an account to manage shocks during the COVID-19 (Demirguc-Kunt et al., 2022). This transition in low- and middle-income countries established rails to deliver public transfers, micro-credit, savings and insurance at scale- shrinking frictions that once marginalized poorer and remote households. In addition to inclusion, a post 2020 literature proposes digital finance as having environmental outcomes via the following channels: (a) an increase in greener capital allocation, (b) change of consumer behaviour, and (c) new clean-tech business models. (Demirguc-Kunt et al., 2022; Hasan et al., 2024).

We consider green inclusion as the common effort to achieve (i) universal affordable access to useful financial instruments and (ii) quantifiable advancements in the decarbonization and climate resilience. This paper will argue that DFS can help reduce the cost of coordinating green behavior among millions of households and small firms and turn micro-transactions into macro-level changes in environmental outcomes. However, digitization is not a panacea: its presence will hinge on technological decisions (e.g. the energy consumption of protocols), market design and policy guardrails. (Hasan et al., 2024; Hossain et al., 2024).

## LITERATURE REVIEW

### Post-pandemic diffusion of digital financial services and the turn to "green inclusion"

The limitations of the pandemic generated a structural shift in the utilization of digital payments and accounts in day-to-day activities across the globe. The Global Findex 2021 shows that during the COVID-19, more adults received or sent a digital payment and used an account to manage shocks, unlike any previous wave, broadening the customer base of savings, credit, and insurance delivered over digital rails

(Demirguc Kunt, Klapper, Singer, and Ansar, 2022). Instant payments, remote KYC/ID, interoperable QR acceptance, wallet to bank connections: These rails reduce onboarding costs and lessen cash-handling frictions, especially in low income households and micro-enterprises. The post-2020 transition thus generated distribution capacity which can be used by sustainability actors to drive decarbonization and resilience, on the condition of incentive and protection alignment (Demirguc Kunt et al., 2022; Hasan, Hoque, Abedin, and Gasbarro, 2024).

A complementary body of work connects digital finance to environmental outcomes at macro and meso scales. A 2020-onwards review of systematic syntheses and cross-country analyses tends to find that fintech has the potential to contribute to Sustainable Development Goals by expanding access, decreasing information asymmetry, and crowdfunding green innovation, but outcomes depend on institutional quality, energy mix, and data governance (Hasan et al., 2024; Hossain, Bashar, Farhad, Adam, and Murshed, 2024). Combined, the literature encourages a more detailed examination of particular causal mechanisms through which digital financial services (DFS) may promote environmental sustainability and inclusion-which we refer to as green inclusion.

## CAUSAL PATHWAYS LINKING DFS TO ENVIRONMENTAL SUSTAINABILITY

### Clean-energy access via pay-as-you-go (PAYGo) finance

PAYGo asset finance on clean energy represents the most obvious micro-to-macro sustainability connection. To align irregular cash flows, solar home system providers match small, usage-based installments with IoT meters and mobile payments to help households make. Comparison of Rwandan and Kenyan portfolios indicates payment patterns can be learned and portfolios that can work when plans are tuned against that pattern- evidence that PAYGo can scale in environments where mobile money is ubiquitous (Mergulhão, Baptista, Pina, and Duarte, 2023). PAYGo reduces the up-front costs of accessing modern energy and replaces kerosene/biomass, which generates climate and health co-benefits (Mergulhão et al., 2023).

PAYGo has related models to clean cooking. Real-world deployments of smart-metered LPG with digital, incremental payments show that flexible prices can both increase the adoption of cleaner fuels and keep the household energy budget stable, particularly in the cases where the discounts are intentionally focused (Tosatto, Berrueta, and Edwards, 2024). Such designs are important in terms of resilience: digital payments even out cash flows in cases of shock, leaving households on cleaner fuels and preventing relapse to biomass in case of the loss of income (Tosotto et al., 2024).

### Diffusing green innovation and reducing emissions through digital inclusive finance

On urban scales of cities and enterprises, several panel studies associate digital inclusive finance (DIF) with reduced carbon emissions and more green technological innovation, including spatial spillovers between urban clusters (Lu and Xia, 2024). The mechanisms involve reallocating credit to more environment-friendly activities, decreasing the transaction frictions offline and supplementing environmental regulation and human capital. On the basis of micro-enterprise and city data, it is also discovered that DIF contributes to reduction of carbon emission on the enterprise level through technological advancement and higher investment in the environment, with region and ownership heterogeneity (Peng, Qiu, Li, and Peng, 2024). Despite all the evidence being found in China, it is relatively cautious (spatial econometrics, mediation/threshold models), and the suggested channels are quite generalizable elsewhere (Lu and Xia, 2024; Peng et al., 2024). Digital finance can be aligned with cleaner production strategies when enabled by enabling policies and governance converges on a similar message across the cross-country syntheses (Hasan et al., 2024; Hossain et al., 2024).

**Climate-risk transfer with digital micro- and parametric insurance**

With the escalation in the occurrence of climate shocks, micro-insurance will still be challenged by distribution and claims costs, which tend to be high in the small scale. Affordability and timeliness are enhanced with digital channels mobile onboarding, premium payments with the use of wallets, and automated payouts that are parametric and activated by weather indices. A discrete-choice experiment, conducted in Mali, indicates that demand-side potential in the use of digitally distributed index insurance is strong, with interfaces to facilitate information frictions and payment logistics (Kirchner and Musshoff, 2024). Faster foreseeable payouts would allow low-income households and micro-enterprises to avoid distressing asset sales and maintain productive green assets (e.g., solar pumps) in operation- a resilience co-benefit with environmental impacts (Kirchner and Musshoff, 2024).

**Carbon-aware consumer finance: dashboards, rewards, and gamification**

Carbon literacy and pro-environmental nudges can be installed at the household level in wallets and banking applications, which incorporate routine payments. The most well-documented example is the one of Ant Forest by Alipay that gives out points to low-carbon activities (e.g., transit choices, online bill payments) that could be redeemed to real-life tree planting. In a 2024 study, program attendance raises low-carbon purchase intentions as well as habitual low-carbon habits, mediated by epistemic, emotional, and social value- indicating that users not only get educated about greener choices but also get social credit on them (Xiong, Liu, Li, Wang, and Yao, 2024). Although MRV design and additionality are also relevant issues, this evidence makes gamified wallets a viable scalable remedy to regulation, in areas with high DFS penetration (Xiong et al., 2024).

**Greening capital markets with fintech**

At the capital-supply level, the development of fintechs seems to stimulate the issuance of green bonds through the minimization of information and search costs, strengthening the intermediaries, and enlarging the circle of investors. Citing Chinese information, recent research in the Journal of International Financial Markets, Institutions and Money documents that the areas with more developed fintech ecosystems have substantially larger green-bond issuance, especially among the non-state issuers and lower-rated bonds (Huang, Liu, Wang, Wang, Wang, & Jin, 2024). In the broader corporate world, green investment and digital finance are associated, which means that the effects of allocating resources in the market-wide can occur when the data infrastructure and incentives are aligned (Hossain et al., 2024).

**Digital MRV (measurement, reporting, verification) and data infrastructures**

New digital MRV stacks - integrating distributed sensors, remote sensing and ledger data - are enhancing the granularity and timeliness of impact measurement, which is needed in pay-for-performance climate finance and retail trust. The systematic reviews of the role of fintech in SDGs posit that machine-readable disclosures and verifiable outcome data are prominent facilitators between inclusive finance and actual decarbonization and resilience but not just labels (Hasan et al., 2024). As a matter of fact, dMRV can be viewed as complementing the above five pathways since it offers legitimate evidence that small, distributed financial activities can make a significant environmental impact.

**Countervailing risks and rebound effects Energy footprints of financial infrastructure**

DFS are not impact-free. Some financial technologies - the most notable one being Proof-of-Work (PoW) cryptocurrencies - are associated with massive environmental impacts. In 2020-2021, a global measurement concludes that the carbon, water, and land footprints of Bitcoin mining are significant, and citing the necessity to draw the line between inclusive payments rails and energy-sensitive digital assets (Chamanara et al., 2023). The design of the protocol is relevant: Since PoW has been replaced by Proof-of-Stake (PoS) in Ethereum, network energy usage has decreased by about 99.9 percent, which shows how network structure

can decouple financial operations and emissions (de Vries, 2023). In the case of green addition plans, a simple policy lever would be to steer the providers towards effective protocols and data centers relying on renewable sources (Chamanara et al., 2023; de Vries, 2023).

**Cashless "pain of paying" and material throughput**

One-click and contactless payments minimise check out. In behavioral studies, electronic payments are found to be painful compared to cash, which raises the level of spending, especially in contactless payment styles (Broekhoff and van der Cruijsen, 2024). This cashless premium, which is not mitigated, may increase throughput and waste of materials. DFS can integrate a budgeting application, a carbon dashboard, sustainable-merchant rewards, and a default-repair/refill option to mitigate rebound effects to serve the sustainability goals (Broekhoff and van der Cruijsen, 2024; Xiong et al., 2024).

**Equity, fraud, and e-waste**

Digitization is not open to everyone not yet using smartphones, with connectivity or literacy, and in scale, smart meters and point-of-sale hardware create e-waste in case lifecycle management is lax. The literature in turn highlights universal-design UX, agent networks, device modularity, and extended producer responsibility-design decisions which connect environmental results to quality of inclusion (Hasan et al., 2024). Another recommendation that clean-cooking pilots would make is that when offers are not specifically directed at the use of discounts, there is a risk that better-off households will increase their usage, which raises distributional concerns that should be expected by regulators (Tosatto et al., 2024).

**What the evidence says—strengths, limits, and heterogeneity**

There are a number of findings that are becoming stronger across methods and geographies. One, when DFS directly subsidize initial expenditures on clean assets (solar SHS, LPG kits) or smoothing cash flows using incremental payments, adoption increases and continues to raise mobile-money rails into environmental infrastructure (Mergulhao et al., 2023; Tosatto et al., 2024). Second, in space, where digital finance deepens and lowers frictions on green innovators, econometric research identifies lower city-level emissions and an increase in green innovation, and spillovers across space; stronger effects occur in environments that have more favorable environmental regulation, human capital and digital infrastructure (Lu and Xia, 2024; Peng et al., 2024). Third, maturing fintech could increase the issuance of green bonds on the capital-market side, as long as disclosure and verification continues to do so (Huang et al., 2024). Fourth, there are behavioral and infrastructure risks of spending rebound, energy-hungry protocols, digital divides, which can undermine net gains unless addressed (Broekhoff & van der Cruijsen, 2024; Chamanara et al., 2023; de Vries, 2023). These advantages and shortcomings suggest that green inclusion is provisional: DFS may be an effective tool to environmental goals when product, protocol and policy are co-designed.

## DESIGN AND GOVERNANCE LESSONS

**Target high-leverage use cases.** The two most direct routes are PAYGo energy and climate micro-insurance, where the logic chain between financial feature and environmental outcome is short: incremental payments help clean assets no longer have barriers to adoption; parametric payouts help productive assets and livelihoods survive shocks (Mergulhao et al., 2023; Kirchner and Musshoff, 2024; Tosatto et al., 2024).

**Price externalities in the rails.** With PoW footprints and the PoS counterexample, regulators can also promote low-energy rails, demand renewable power purchase agreements in large data centers, and introduce energy/emissions reporting in the payment-system regulation (Chamanara et al., 2023; de Vries, 2023).

**Embed pro-environmental defaults.** Ant Forest evidence indicates that gamification and social value prompts can shift both habitual and purchasing behaviors towards low-carbon goods; wallets can generalize this to carbon dashboards, round-up-to-repair, transit credits and opt-out eco-rewards, which is supported by credible MRV (Xiong et al., 2024; Hasan et al., 2024).

**Mandate decision-quality data.** Fintech enables sustainability where impact data are machine-readable, auditable, and comparable--linking consumer behavior and company financing to confirmed emissions and resilience results (Hasan et al., 2024).

**Connect retail rails to market finance.** In nascent green-bond ecosystems, only with a robust governance of use-of-proceeds and outcome verification, digital platforms can increase the number of issuers and investors and lower the cost of issuance (Huang et al., 2024).

**Gaps and directions**

Nevertheless, geographic concentration in the literature remains a promising outcome (China in the case of city-panel studies; East Africa in the case of PAYGo pilots). Areas of focus are replication in South Asia, Latin America, and MENA; randomized and quasi-experimental designs to quantify the question of whether eco-nudges in wallets can counter the spending rebound of frictionless payments; and standardized lifecycle accounting of financial infrastructure (instant-payment systems, data-center energy sourcing, blockchain protocols) to ensure that the rails of inclusion are, in fact, green (Lu and Xia, 2024; Broekhoff and van der Cruijsen, 2024; Chaman The larger point is that design is important: DFS can speed up decarbonization and resilience in cases when governments and providers are aligned in their incentive schemes, consumers are safeguarded, and results are verified.

## METHODOLOGY

**Design**

A systematic literature review of the role of digital financial services (DFS) in environmental sustainability in the post-pandemic era- what the paper labels as green inclusion. Due to the cross-unit (households, firms, cities) and cross-heterogeneous (e.g., emissions, clean-energy adoption, green bonds) nature of the evidence, I synthesized the results rather than conducting a meta-analysis.

**Inclusion criteria**

- Peer-reviewed empirical studies (journal articles or high-quality conference papers) with recent publication and valid DOIs.
- Unambiguous empirical procedures and quantifiable environmental or directly related results (e.g., CO2, adoption of clean energy, green patenting/investment, verifiable issuance of green-bond, low-carbon behavior measures).
- Cryptois/rail studies were filtered to include those that reported clear lifecycle/energy effects.

**Screening and extraction**

Titles/abstracts were filtered on relevance then full texts were screened. To each study that I included I noted: context (country / sector), DFS modality, design (e.g. panel, experiment, quasi-experimental), outcome measures, headline effects, and limitations.

**Synthesis**

Results were grouped by six predetermined routes (PAYGo energy; green innovation/emissions; climate risk transfer; consumer carbon nudges; green capital markets; digital MRV) and summarized under:

- direction/magnitude of effects,

- enabling conditions, and
- risks/rebounds (e.g., spending rebound of cashless payments, protocol energy use, e-waste).

**Quality and limitations**

To select recent, peer-reviewed articles containing DOIs, I gave precedence to the latter and emphasized identification strategies where feasible and triangulated between methods/regions. The major limitations include the heterogeneity of outcomes (there is no pooling), geographic concentration in some streams (e.g. city-panel evidence in China; PAYGo evidence in East Africa), and the rapid pace of DFS technologies.

**Post-pandemic DFS landscape: What changed and why it matters**

The COVID-19 changed habits: merchants and consumers shifted to taps and QR codes instead of cash; governments handed out benefits on digital platforms; platforms integrated finance into energy, agriculture, and transport services. These practices continued--establishing a broader addressable base to the use cases of green (Demirguc-Kunt et al., 2022). In the meantime, it has been demonstrated that contactless and mobile payments have the ability to transform spending behavior by affecting the pain of paying, which is a two-sided effect with consequences related to over-consumption and waste (Broekhoff and van der Cruijsen, 2024).

Meanwhile, new rails (instant payments, digital ID / KYC, open APIs) reduced onboarding of climate-aligned products (e.g., micro-installment finance to solar) and risk financing (e.g., micro-insurance). DFS spillovers to sustainability outcomes are reported in post-pandemic studies and meta-analyses-especially in countries where digital rails are accompanied by green policy signals and credit incentives (Hasan et al., 2024; Hossain et al., 2024).

## SIX PATHWAYS FROM DFS TO ENVIRONMENTAL SUSTAINABILITY

**Clean-energy access through PAYGo finance**

PAYGo solar and clean cooking providers combine IoT-based meters with mobile payments so that low-income households can pay small, use-based installments that align with sporadic cash inflows. The latest data indicates that PAYGo solar users in sub-Saharan Africa continue to pay on regular repayment schemes and increase their energy consumption when their incomes allow them to- an adoption pattern that would have been impossible without mobile money (Mergulhao et al., 2023). In this connection, PAYGo LPG projects show how smart meters + digital payments can save biomass consumption and indoor air quality and stabilize household energy bills (Tosatto et al., 2024). These models convert payment records into credit information, making clean assets with quantifiable environmental value to be able to access asset finance. (Mergulhao et al., 2023; Tosatto et al., 2024).

**Diffusing green innovation with digital finance**

In multi-year panel studies of cities in China, digital inclusive finance has been associated with reduced carbon emissions within the city and higher green technological innovation, with spatial shocks across the city clusters (Lu et al., 2024; Peng et al., 2024). The mechanisms involve the redirection of credit to greener companies, lessening of offline transaction frictions, and supplementing green regulation. In a more recent synthesis, FinTech outcomes related to SDG-aligned outcomes--with environmental quality explicitly named--are likewise found when paired with facilitating rules and data infrastructure (Hasan et al., 2024). (Lu et al., 2024; Peng et al., 2024; Hasan et al., 2024).

**Climate-risk transfer: Micro-insurance and parametrics**

DFS lower distribution costs of index-based (parametric) insurance, which allows micro-payouts through mobile money on weather events (e.g., drought). Although penetration is small, digital channels are enhancing payment efficiency and adoption by the farmer; current work synthesizes how digital delivery can

circumvent last-mile frictions in agricultural insurance markets (Kirchner et al., 2024). Such products alongside climate shocks will help lessen distress asset sales and maintain the livelihoods green (e.g., solar irrigation repayments), which is consistent with inclusion and adaptation. (Kirchner et al., 2024).

**Carbon-aware consumer finance: Nudges and gamification**

Small consumer behaviors can be converted to environmental benefits through gamified carbon programs with the help of Fintech. The most notable example is the Ant Forest by Alipay, where people can earn virtual green energy by partaking in low-carbon activities, and purchasers can use it to have real trees planted: empirical evidence suggests that users experience a strong effect of emission-reduction awareness and participation (Xu et al., 2024). Carbon dashboards, round-up-to-offset options, and green merchant incentives are now embedded in banks and wallets--functionality that, when used in large numbers, can create a norm and a cleaner-demanded product. (Xu et al., 2024).

**Greening capital markets via digital rails**

The issuance of green bonds and sustainability-linked instruments on the supply side are increasingly being based on digital platforms to ensure access by investors and to verify data. A 2024 study concludes that in order to jump-start green bond issuance, the development of FinTech can lower information and search costs, increase market depth, and improve pricing (Huang et al., 2024). Digital finance is associated with green investment and innovation in the corporate world, where it strengthens the capital-allocation channel (Hossain et al., 2024). (Huang et al., 2024; Hossain et al., 2024).

**Digital MRV and data for climate accountability**

Measurement, reporting, and verification (MRV) is becoming more granular and near-real-time, which are essential to pay-for-performance climate finance and retail investor trust, using distributed sensors, remote sensing, and digital ledgers. These stacks are starting to anchor blended-finance facilities and consumer goods (e.g., retail green savings with traceable impacts) whilst standards remain in development. This is a follow up to the previously five pathways to confirm the fact that inclusive finance turns out to be actual emissions and resilience results (Hasan et al., 2024).

## RISKS AND REBOUND EFFECTS: WHAT CAN GO WRONG?

**Energy-intensive protocols and digital footprints**

Digital rails are not all green. The carbon, water, and land footprint of proof-of-work cryptocurrency mining is nontrivial; a single estimate of a global footprint reports 85.9 Mt CO2-eq emissions in 2020-2021, with large water and land footprint (Chamanara et al., 2023). In comparison, the move toward Proof-of-Stake at Ethereum minimized energy consumption by approximately 99.9 percent, which shows that the design of protocols can effectively dissociate financial activity and emissions (de Vries, 2023; Kapengut et al., 2023). Policy must differentiate between the usefulness of DFS rails and energy intensive assets and push providers to efficient infrastructure and data centers powered by renewables. (Chamanara et al., 2023; de Vries, 2023; Kapengut et al., 2023).

**Cashless convenience and over-consumption**

Electronic and contactless payments can be studied using behavioral research which indicates that it is less damaging than cash, which can elevate spending propensity- a form of externality when it increases material throughput and waste (Broekhoff and van der Cruijsen, 2024). An associated meta-analysis indicates consumers spend more when using a cashless form, and supports the argument that in-app budgeting and eco-nudges must be implemented to reduce rebound effects. Waste-cutting defaults (repair, refill, transit) can be hard-wired by providers into reward ecosystems. (Broekhoff & van der Cruijsen, 2024).

**Inclusion gaps, fraud, and e-waste**

Digitization may disenfranchise individuals lacking access to smartphones, connectivity, or literacy, and scaling point-of-sale hardware and smart meters adds to e-waste in case lifecycle design is inadequate. These dangers posit in favor of universal-design applications, common agent networks, modular devices, and producer-responsibility take-back schemes-preferably embodied in green-jobs programs.

**Evidence of net environmental gains (and limits)**

**City- and firm-level decarbonization**

Several articles published in the post-2020s associate digital inclusive finance with a decrease in carbon emissions and more green innovation-through credit reallocation, less offline frictions, and a complement to environmental control (Lu et al., 2024; Peng et al., 2024). The impacts are not homogenous: benefits seem to be more effective where digital finance is aligned with greener electricity, increased human capital, and pro-innovation policy. (Lu et al., 2024; Peng et al., 2024).

**Clean-energy adoption at the last mile**

It is demonstrated in PAYGo studies that the repayment of such devices may be very regular and easily adopted by low-income households; and in clean-cooking pilots, that digital meters and flexible payments may reduce biomass dependence (Mergulhao et al., 2023; Tosatto et al., 2024). The environmental benefits (less deforestation/soot) are matched with the domestic household welfare gains (less fuel stacking, less initial expenditure), a feature of a green inclusion.

**Market-wide green issuance and disclosure**

In the regions where FinTech ecosystems evolve, the issuance of green bonds becomes more integrated and allows financing the clean infrastructure at lower costs (Huang et al., 2024). But credibility requires MRV and anti-greenwashing protection- another digital data and open standards use case. (Huang et al., 2024).)

**Design principles for policy and practice**

- Identify the six pathways: identify DFS use cases with well-understood emissions/resilience logic-PAYGo solar/LPG, climate micro-insurance, carbon-sensitive wallets, and green-bond retail access. (Mergulhao et al., 2023; Tosatto et al., 2024; Kirchner et al., 2024; Huang et al., 2024).
- Rail-based price externality: disincentivize energy-intensive protocols, incentivize PoS-based efficiency, and make large providers and data centers use renewable PPAs or high-quality RECs. (Chamanara et al., 2023; de Vries, 2023).
- Bake in eco-nudges: default carbon dashboards, sustainable merchant reward, circular-economy cashback, and incentives to repair / refill to reduce cashless rebound. (Broekhoff & van der Cruijsen, 2024; Xu et al., 2024).
- Empower the poor with digital rails: interop instant, tiered KYC, agent network, and inclusive UX will lessen the risk of exclusion and increase beneficiaries of green finance (Demirguc-Kunt et al., 2022).
- Data on the quality of mandate decisions: open taxonomies, machine-readable impact disclosures, and dMRV to confirm actual decarbonization and resilience at product and portfolio levels (Hasan et al., 2024).
- Green product-lifecycle policies: smart meters/POS devices producer responsibility; repairability and recycled-materials goals to reduce e-waste.

**Research Agenda**

- External validity: causal identification outside of China: use city-panel and firm-level designs to replicate across Africa, South Asia and Latin America to establish external validity of DFS-decarbonization channels (Lu et al., 2024; Peng et al., 2024).
- Behavioral net effects: measure whether wallet eco-nudges can counter the post-frictionless-payment spending rebound (Broekhoff and van der Cruijsen, 2024).
- Protocol-level LCA: update financial infrastructure (blockchains, data centers) standardized, peer-reviewed lifecycle assessments in with differing energy mixes (Chamanara et al., 2023; de Vries, 2023).
- Resilience finance at scale: test DFS-enabled parametric insurance on poverty dynamics, asset protection, and emissions (Kirchner et al., 2024).

## DISCUSSION

According to our review, digital financial services (DFS) can promote environmental sustainability and financial inclusion--what we termed green inclusion--along six mutually reinforcing directions. In general, these data are in line with the post-pandemic growth of digital rails reported by Global Findex that reveals step-changes in the use of accounts and digital payments, which reduce the cost of distribution in inclusive finance (Demirguc-Kunt, Klapper, Singer, and Ansar, 2022). This implication is not that more individuals are now being served by DFS, but that a greater proportion of households and firms now have access to clean-energy financing, climate risk instruments, and carbon-aware products, so long as policies and designs make DFS focus on verifiable environmental effects (Hasan, Hoque, Abedin, & Gasbarro, 2024; Hossain, Bashar, Farhad, Adam, and Murshed, 2024).

PAYGo energy provides the simplest micro-to-macro channel. PAYGo solar and LPG models transform irregular lump-sum purchases into usage-based payments, to use mobile payments to balance irregular cash flows, reducing barriers to adoption by households with low incomes. Our synthetic finding is consistent with evidence showing that repayment behaviors are learnable and portfolios feasible when tariffs capture observed payment clusters (Mergulhao, Baptista, Pina, and Duarte, 2023). In the case of clean cooking, smart-metered PAYGo LPG can boost sustained consumption where price structure is considerate to maintain household energy budgets and minimize a shift to biomass (Tosatto, Berrueta, & Edwards, 2024). Collectively, these analyses support the argument that DFS has potential to convert ability to pay into access to clean energy and likely co-benefits in emissions and health. However, they also pop up distributional warnings: the price responsiveness is unevenly spread among the wealth groups and thus badly aimed discounts may be uptaken regressively (Tosatto et al., 2024). This highlights the importance of equity-conscious tariffs and consumer protection and online delivery.

At the meso and macro levels, our findings support an emerging body of panel-study research that connects inclusive finance in digital form (DIF) with reduced carbon emissions and improved green innovation. Negative correlations between DIF and emissions with spatial spillovers are reported by city-level analyses that are mediated by green patenting and complementary regulation (Lu and Xia, 2024). Firm-level evidence points to carbon-reduction channels through technological upgrading and environmental investment when digital finance deepens (Peng, Qiu, Li, & Peng, 2024). These results indicate that capital can shift to cleaner activities as digitalization of financial intermediation reduces the costs of search, monitoring, and transaction. Nevertheless, there exists the issue of external validity: a large part of the cautious econometric research is Chinese. The mechanisms, which include lower frictions, richer data, and better screening are practical elsewhere and replication in other contexts of an institutional setting is the obvious priority (Lu and Xia, 2024; Peng et al., 2024; Hasan et al., 2024).

To climate-risk transfer, digitization seems to loosen the traditional distribution and claims-processing bottlenecks that have limited micro-insurance. Discrete-choice experiments indicate strong

demand of index-based (parametric) products when the premiums and payouts are managed in the mobile channel, which makes enrollment and payments logistics easier (Kirchner and Musshoff, 2024). Resilience is the probable sustainability process: quicker, more foreseeable payouts bring about less distress sales, enabling households to sustain productive-and in some cases, green-assets (e.g., solar pumps). The common question is basis risk and confidence: to scale parametrics will need transparency in trigger design and post-event checking to maintain a perceived sense of fairness (Kirchner and Musshoff, 2024; Hasan et al., 2024).

Gamified carbon program evidence On the consumer side, there is an implication that fintech can turn underperforming or minor actions into tangible engagement in low-carbon behaviors. Users of Ant Forest demonstrate more low-carbon purchases and habitual behaviour and the influence of this behaviour is mediated by learning, emotions, and social recognition (Xiong, Liu, Li, Wang, and Yao, 2024). This reinforces the argument that wallet-sized nudges can supplement regulation, where identity and community is geared toward making more eco-friendly decisions. Still, two caveats temper the optimism. First, there is the credibility of measurement: the user and regulators must be assured that digital points are related to other, validated effects (Hasan et al., 2024). Second, behavioral finance cautions that cashless convenience leads to a decrease in the pain of paying, which may increase the spending propensity-which may lead to material throughput, unless mitigated (Broekhoff and van der Cruijsen, 2024). We read that balanced carbon nudges are advisable to the budgeting and repair/refill defaults to counterbalance rebound risks (Broekhoff and van der Cruijsen, 2024; Xiong et al., 2024).

Regarding green capital formation, evidence that deeper fintech ecosystems catalyze green-bond issuance points to a supply-side complement to retail DFS (Huang, Liu, Wang, Wang, Wang, & Jin, 2024). If digital platforms reduce issuance frictions and broaden investor access, they can lower the cost of capital for clean infrastructure. Combined with firm-level links between digital finance and green investment/innovation (Hossain et al., 2024), this suggests a two-sided story: retail rails pull households toward cleaner behaviors and assets, while market rails push institutional finance toward verified green projects. The connective tissue is decision-quality data—a theme that recurs in systematic reviews emphasizing open, machine-readable disclosures and digital MRV to counter greenwashing (Hasan et al., 2024).

Design choices also determine the risk landscape in our results. Crypto rails based on Proof-of-Work have obvious conflicts with green goals in terms of their energy and resources footprint (Chamanara et al., 2023). On the other hand, both protocol redesign, e.g., of Ethereum to Proof-of-Stake, demonstrate that orders of magnitude in energy consumption can be reduced through a change in architecture, and digital rails can be made sustainable (de Vries, 2023). This opposition reinforces a policy approach that differentiates inclusive payment infrastructure against speculative, energy-intensive assets, and that promotes efficient protocols, as well as renewable-powered data centers (Chamanara et al., 2023; de Vries, 2023). The second risk group relates to equity and e-waste: unless smartphones-reliant UIs and hardware (smart meters, POS) are made accessible and circular, DFS can marginalize the same users to whom inclusion seeks to reach, and generate additional device waste. Equity-by-design and lifecycle stewardship are justified by the PAYGo LPG equity gradients (Tosatto et al., 2024) and the more general focus on equity-by-design and producer responsibility in equities-SDG syntheses (Hasan et al., 2024).

Collectively, our findings build up on previous research in three aspects. First, they tie evidence of adoption at the household level (PAYGo solar/LPG; carbon-nudge wallets) with market-level capital changes (green bonds) with a common DFS prism–by arguing that the same digital rails can implement both demand- and supply-side transitions (Mergulhao et al., 2023; Tosatto et al., 2024; Huang et al., 2024). Second, they preannualize conditionality: environmental benefits of DFS are greatest where equity targeting, consumer protection and plausible MRV are entrenched in the design, and macro conditions, such as cleaner grids, human capital and favorable regulation are favorable (Lu and Xia, 2024; Peng et al., 2024; Hasan et al., 2024). Third, they refocus the risk-management agenda: balance cashless rebound with

in-app budgeting and circular-economy rewards (Broekhoff and van der Cruijsen, 2024), and price externalities on the rails by avoiding energy-intensive protocols (Chamanara et al., 2023; de Vries, 2023).

There are limitations, though, to generalization. External validity is limited by the geographic biases of intensive research (China to city/firm panels; East Africa to PAYGo pilots). In addition, the heterogeneity in measurement, including innovation proxies in firms to carbon points in apps, makes cross-study comparisons harder, and even advanced panels struggle to attribute at macro scales. Such caveats contribute to a proactive agenda of: (a) replication of DIF-emissions links in South Asia, Latin America and MENA; (b) experimental and quasi-experimental studies on whether carbon dashboards and eco-rewards counter the spending rebound of frictionless payments; and (c) standard lifecycle accounting of financial infrastructure (instant payments, data centers, blockchains) to make the rails of inclusion literally green (Lu and Xia, 2024; Broekhoff and van der Cruijsen, 2024; Chamanara et al., 2023; de Vries, 2023).

In practice, the discussion points to a design playbook. For energy access, couple PAYGo with equitable tariffs and transparent contracts (Mergulhao et al., 2023; Tosatto et al., 2024). In the case of risk transfer, make mobile-enabled parametrics with specific triggers and farmer-centric communication the priority (Kirchner and Musshoff, 2024). In the case of consumer wallets, combine budgeting, carbon dashboards, and repair/refill defaults to turn intent into long-term habit and protect against rebound (Broekhoff and van der Cruijsen, 2024; Xiong et al., 2024). In the case of capital markets, connect digital issuance platforms with dMRV and open disclosures such that household trust and institutional credibility can both increase (Huang et al., 2024; Hasan et al., 2024). And on the board, protocol efficiency and renewable sourcing should be included in the financial-sector monitoring to ensure that the rails run in the direction of environmental objectives (Chamanara et al., 2023; de Vries, 2023).

On balance, our findings, as considered against the previous literature, support a practical conclusion: DFS is neither an intrinsic green nor brown but a design and governance decision. Equitably priced, credibly measured, and optimally maintained inclusive rails can extend green inclusion, hastening clean-energy adoption, spreading low-carbon innovation, mobilizing climate capital, and creating resilience without reducing digital divides when inclusive rails are co-designed and fairly priced.

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