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SOCIAL FUNDING OF GREEN FINANCING: AN APPLICATION OF DISTRIBUTED LEDGER TECHNOLOGIES

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Abstract

To achieve the sustainable development goals (SDGs) as well as the Paris Agreement major investments in renewable energy (RE) production are necessary worldwide. In particular, decentralized, small-scale projects offer copious potential to create energy access as well as to contribute to an affordable, reliable and sustainable energy supply system. However, in developing countries such projects often face issues in finding funding. Direct private investment tools like the community-based hometown investment trust (HIT) fund address this issue and offer a way of financing for those projects. Technical developments in the sphere of distributed ledger technologies (DLTs) provide the opportunity to increase the fund's transparency and thus to improve its functioning. On that basis, this paper contributes to the literature in two ways: First, it delineates a concrete application of DLTs in the field of green financing, which offers the potential to increase social welfare. Second, the decision problem of investors is modeled, which illustrates through which channel the use of DLTs impacts the investors' behavior.

Keywords: small-scale, renewable energy, developing countries, crowdfunding, private investment, distributed ledger, IOTA, green financing, social funding

JEL Classification: G11, G23

List of Abbreviations

Directed Acyclic Graph	DAG
Distributed Ledger Technologies	DLTs
Financial Service Agency	FSA
Green Asset Wallet Initiative	GAW
Hometown Investment Trust	HIT
Internal Rates of Return	IRR
Internet of Things	IoT
Net Present Values	NPV
Renewable Energy	RE
Sustainable Development Goals	SDG

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1. INTRODUCTION

To meet obligations under the Paris Agreement as well as to achieve the sustainable development goals (SDGs), major investments in renewable energy (RE) production and infrastructure are necessary. However, as public budgets are tight and because of the Basel capital requirements major public as well as private investments are unlikely to provide sufficient liquidity (Narbel 2013), in particular in developing countries. Since most RE projects are considered to be risky, many financiers are reluctant to lend to them or they lend at high interest rates. However, this lack of financing has to be overcome to make the energy transition a success story (Kaygusuz 2012).

On this score, new innovative forms of raising money are needed. For instance, a Moldavian university uses cryptocurrencies to fund a solar energy project to overcome the lack of financing it is facing (Thomson Reuters 2018). This paper plays through the idea of making use of technological features of distributed ledger technologies (DLTs) to enhance the existing green financing tool of hometown investment trust (HIT) funds. A further trust creation within the funds enables an expansion of the investor pool to private persons in other countries, facilitating investments across borders. As an alternative to classical financial/capital markets, this can serve the purpose of bringing capital to regions that face financial frictions in the classical setting. Based on the idea of a one-world community, the tool aims to bring people together who would not have collaborated before to provide funding for necessary investments in RE projects.

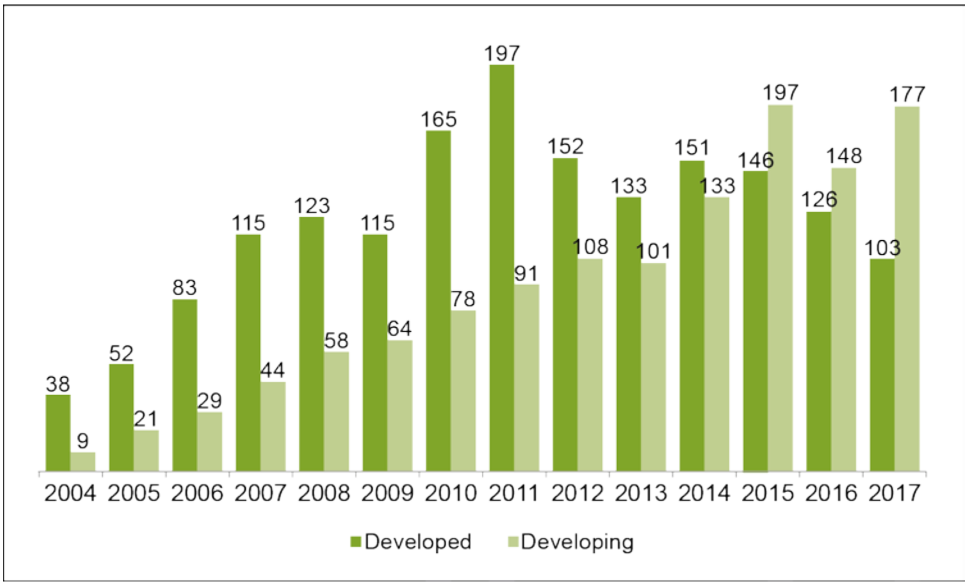
2. LITERATURE REVIEW

2.1 2.1 Background

RE projects in developing countries are mainly financed by loans from banks or equity capital and funded through public sources, international development assistance, private capital and new kinds of finance such as carbon finance (Donastorg et al. 2017). Even though a drop in new RE investments in developing countries was observed in 2016 the general trend of increasing RE investments in developing countries prevails, see Figure 1.

However, achieving the SDGs as well as fulfilling the Paris Agreement requires more intense efforts than are currently undertaken by humankind (McCollum et al. 2018). The authors estimate the yearly investment gap of the global energy system until 2030 for different scenarios and calculate numbers ranging between \$130 billion and \$480 billion. This means that additional investments in renewable energy production, infrastructure and efficiency are absolutely essential. One example is off-grid solar projects, a subset of small-scale solar energy projects, which received in 2017 investments of roughly \$284 million (Gupta and Bhattachary 2018). Small-scale projects are a crucial part of fighting climate change and to achieve the SDGs (International Energy Agency 2018), in particular to “ensure access to affordable, reliable, sustainable and modern energy for all” (United Nations 2015), specifically for rural populations (Terrapon-Pfaff et al. 2014). Global off-grid solar alone has already enabled 73 million households access to energy, while the remaining market potential stretches over 434 million households. However, exploiting this potential would require yearly additional new external funding between 2017 and 2022 of \$485 to \$520 million (Gupta and Bhattachary 2018).

Figure 1: Global New Investment in Renewable Energy: Developed vs Developing Countries, 2004−2017 in billion US$



Note: New investment volume adjusts for reinvested equity. Total values include estimates for undisclosed deals. Developed volumes are based on OECD countries excluding Mexico, Chile, and Turkey.

Source: (McCrone et al. 2018) based on Bloomberg New Energy Finance.

Although those distributed energy systems offer a variety of benefits (Chiradeja and Ramakumar 2004) and are necessary for universal, sustainable energy access and production, scholars point to a lack of financing for small-scale RE projects in developing countries (see e.g. Bhattacharyya (2013) and International Energy Agency (2018)). Indications for the latter statement would be general financial frictions for small-size businesses, limited energy access in rural areas in least-developed countries, where power grids are rare and small-scale projects constitute the primary way to energy access, long time frames looking for financing as well as a higher concentration of past investments in large-size projects in developing than in developed countries. Based on worldwide survey data, Beck et al. (2006) estimate determinants of financing obstacles of firms and provide empirical evidence that size is a robust predictor of financing obstacles in developing countries. This means that small firms face more financial obstacles than large firms, which bolsters the first indication. The second indication is supported by the World Bank (2017), which identifies that “lack of electricity access is predominant in rural areas of Sub-Saharan Africa and South Asia, with 20 countries accounting for 80 percent of the global access deficit in 2014” while data is hard to gather to prove the latter two indications. Furthermore, an additional hint would be projects financed by public entities like multilateral development banks, since those tend to provide selective funding for projects which have issues in terms of being financed by the financial market on their own (see Mazzucato and Semieniuk (2018) or McCrone et al. (2018)). For instance, the Asian Development Bank lent Pakistan $325 million to fund a large-scale installation of small solar as well as micro-hydropower plants (McCrone et al. 2018). The German KfW Development Bank (2018) in cooperation with a local, commercial bank founded a fund equipped with around $100 million to boost investments in small RE projects in South Africa. The World Bank (2018) launched a program funded in total with $60 million to bring small-scale renewable energy to rural communities in Ghana, reaching out to around 100,000 people. Moreover, an additional indication is global investments in small-scale solar energy projects (below one megawatt). In 2017 they amounted to \$49.4 billion, of which \$38.6 billion (McCrone et al. 2018) were made in the People's Republic of China and seven developed countries (see appendix Figure A1). Those investments are skewed and less than \$10.8 billion have been invested in other developing or least-developed countries.

Summing up, at the very least the financial obstacles for small-scale firms, the lack of electricity access in rural areas and the skewness of investments suggest issues in the process of finding funding for small-scale RE projects in developing and least-developed countries. Over the last years a variety of financing opportunities for RE projects have become available (Donastorg, Renukappa and Suresh 2017), which means finance is theoretically accessible. Nelson and Shrimali (2014) compare required returns on equity and debt for financing RE projects in India with them in the US and Europe. For returns on equity the authors find mixed patterns, while the requested interest rates in India for debt financing are roughly double the size of those in the US and Europe. Larger projects offer better opportunities to be financed through equity while smaller projects are inclined to seek funding from debt (Gupta and Bhattachary, 2018). Thus, high interest rates for debt financing is one reason for the issue of finding funding for small-scale projects. In the same vein Gupta and Bhattachary (2018) explain local banks' reluctance to lend with the early-stage nature of off-grid solar projects/companies while the International Energy Agency (2018) constitutes a preference of local banks for larger transactions. Another explanation could simply be that projects are not profitable, thus, they would exhibit low or even negative net present values (NPVs). In their recent Global Energy Insights Report, Mercatus (2018) analyses own data of over 210 gigawatts of managed assets across 100+ countries. Internal rates of return (IRRs) of newly realized RE projects in Africa, Central and South America are higher than those in Europe and North America, while projects in Asia reveal similar levels of IRRs. Aside from the fact that this evidence mirrors high risks associated with RE projects in developing countries, it also reveals the general profitability of those projects, in particular if risks could be reduced. Albeit the considered investor pool is specific, the data suggests that low NPVs of RE projects are not the driving force behind low investment levels in developing countries. However, substantial investments in small-scale projects in developing countries stay out, thus NPVs appear to be too low to overcome associated high risks, particularly since a lack of efficient RE production potential can be excluded (see e.g. da Silva, Cerqueira and Ogbe (2018) and Shahsavari and Akbari (2018)). Moreover, it is well studied that the energy transition and universal energy access require sufficient capital (Best 2017), which is unlikely to be raised within domestic finance markets in developing or least-developed countries alone, so that additional foreign investment is needed. As a matter of course, investors face a variety of risks. For domestic investors, high local financing costs are crucial, just as high country-specific risks (e.g. currency risk) are for international investors. Both investor types' decisions are affected by political instability and uncertainty (see e.g. Feng (2001), Julio and Yook (2016) or Le (2004)), a lack of transparency in banking and governmental structures (Drabek and Payne, 2002) and little knowledge of the respective technology (Donastorg, Renukappa and Suresh 2017). These points should be addressed by governments, but certainly much time is needed so that they reveal substantial positive effects. Concurrently, additional tools can help to access untapped RE investment potential.

2.2 Financing Schemes for Renewable Energy projects

Besides classical financing schemes, green financing (Lindenberg 2014) tools, such as climate funds, green bonds, sustainability bonds or fair world funds, are offered by federal or local governments, green banks and local initiatives.[1] These financing tools reduce the risk for investors by bundling projects. Nonetheless, they are always based on trusting the fund or bond to use the money for the defined purpose. A further issue concerns the validity of the sustainable impact of supported projects. Thus, green banks like the German GLS Bank carry out both roles: the intermediary who channels the investments to projects as well as the validator of the project's impact. Therefore, investors have to put a lot of trust in those omnipresent entities. Another new phenomenon to finance RE projects is crowdfunding platforms. Individuals can invest a chosen amount in a project, mainly small- and medium-scale solar systems or wind turbines, to gain future returns. The robustness and stability of the project's cash flows is crucial since they feed future returns of investors. Therefore, they can be seen as a "proxy for the liquidity, default and credit risk" investors have to bear (De Broeck 2018). Available projects on European platforms vary heavily in their remuneration/support schemes and therefore in the inherent risks for investors. One example is that of projects based on feed-in tariffs or market premiums, which are designed to minimize investors' risks. However, in Europe feed-in tariffs are running out and market premiums are decreasing, so that the risks for RE projects are expected to increase. Even though platform operators appear to be aware of the high credit risk exposure for investors, they are generally not addressing the issue and are likely to overstretch the crowdfunders' capability to deal with the risk they are actually exposed to (De Broeck 2018).

2.3 Hometown Investment Trust Funds

The majority of the aforementioned green financing tools are primarily used in developed countries or designed to bridge the gap between institutional investors in developed and large-scale projects in developing countries. However, there exist successful community-based approaches such as crowdfunding platforms or HIT funds financing small-scale projects, mainly in developed countries. HIT funds are a new source of financing to support solar and wind power projects in Japan. The basic objective of the funds is to connect local investors with projects in their own locality. Individual investors choose their preferred projects and invest small amounts (about $100 to $5,000 per investor) via the Internet (Yoshino and Kaji 2013). Local banks also have started to use the information provided by the HIT funds. If these projects are run properly and received well by individual investors, banks can start to grant loans to them. In this way, renewable projects can be supported by the HIT funds until they are able to borrow from banks. The Hokkaido Green Fund, which was established in 2000 to finance wind-power projects in northern Japan, was mainly generated by donations. As it was difficult to raise money from banks, only 20% of total investments were financed through them while the other 80% were obtained from individual investors and through donations. The community wind-power corporation runs wind power and sells the generated electricity to the local power company that supplies power to the region. In northern Japan more than 19 wind-power projects were realized using a similar method. Moreover, there are examples of solar-power projects in Japan as well where

[1] Climate finance is excluded from our analysis since we explore a market-oriented solution, where private investments are made instead of public investments (Buchner et al. 2011). Nonetheless, climate finance can effectively contribute to boost renewable energy production in developing countries (see e.g. Carfora, Ronghi and Scandurra 2017).

local governments put money (seed money) into the community fund as an incentive for private investors to participate. Another example is the revitalization of an old hydropower plant in Japan's Nara prefecture. It was constructed in 1914, but decades later it was abandoned and abolished. The local community participated and 274 individual investors took part (one unit of investment was $300) and enabled the revitalization via HIT funds through a total investment of $500,000. A total of 184 households received electricity from the revitalized dam and money from the surplus electricity sold to the power supply company in the region.

Asia's finance sectors are still dominated by banks (see Yoshino and Kaji (2013) and Yoshino et al. (2014)), and venture capital markets are generally not well developed. However, Internet sales are gradually expanding and the use of alternative financing vehicles such as HIT funds can help risky sectors in Asia to grow. One example is HIT funds that have assisted the growth of solar and wind projects in Japan (Yoshino and Taghizadeh-Hesary 2017) as illustrated above. HIT funds have since expanded to Cambodia, Viet Nam, and Peru. They are also attracting attention from the government of Thailand as well as Malaysia's and Mongolia's central bank.

Although HIT funds are a form of crowdfunding, there are significant differences to the conventional types of crowdfunds: i) there is a "warm feeling" behind the HIT funds because investors sympathize with the company/project owners and they are not merely seeking to make profit; ii) investors are willing to receive products or services generated by the project (e.g. electricity) instead of solely a share of profits; iii) the intermediator/assessor of a HIT fund frequently monitors the project's functioning and provides advice when the project faces some difficulties. Furthermore, HIT funds distinguish themselves from other tools by creating a trustful, spatially close opportunity to invest small amounts to provide small-scale RE projects with initial liquidity. In this framework, trust is key and any technology that increases the transparency of the fund will improve its functioning. This is where DLTs come into play.

2.4 Distributed Ledger Technologies

These days, a variety of economic sectors explore or have already begun to implement DLTs − mainly blockchain-based − as they offer multifarious potentials (Hanl 2018). Only the future will show whether they revolutionize the shipping (Park 2018), banking (Manson 2017), supply-chain management (Swami 2018) or finance sectors (Tapscott and Tapscott 2017). Nonetheless, with inherent characteristics of all-embracing security, transparency, and auditability, Bitcoin, Ethereum, IOTA and co. offer unique technical features that can be used to shape the energy sector of the future. Distributed ledgers or shared ledgers are able to store data across a distributed network of participants. The correctness of the data is ensured through a consensus process between all interacting parties. To accomplish consensus, different technical approaches can be employed. The most famous one is a blockchain on which the popular cryptocurrencies Bitcoin and Ethereum are based. In this case the distributed ledger is created by combining blocks of valid transactions into a chain of blocks, which is shared by the entire network. Before being attached to the chain, each transaction within each block has to be verified by the majority of the distributed network of participants. This happens through solving cryptographic algorithms, which require proof-of-work of each participant, which means computing power. Participants who provide computing power are commonly referred to as "miners" since they are mining new blocks by verifying bundles of transactions. If they are chosen to mine the next block they gain newly mined coins as well as transaction fees paid by users who want to have their transactions executed. This procedure ensures secure, trusted, auditable, and immutable transactions. If the network is public like Bitcoin or Ethereum, everybody can see each single transaction on the public ledger.[2] Apart from those unique features, classical blockchains face one enormous limitation. “Consensus latencies on the order of an hour and the theoretical peak throughput of only up to 7 transactions per second” became critical since nowadays large amounts of transactions should be carried out on the network (Vukolic 2015). The trend towards the execution of arbitrary distributed applications on blockchains requires a fast throughput of transactions, which cannot be obtained using blockchains. Moreover, the existing financial rewards for miners created networks that became centralized around a few powerful actors, contradicting the initial idea of a decentralized system, as well as the immense amount of energy needed to provide the current computational power (O’Dwyer and Malone 2014) are additional limitations. Against this backdrop, a variety of approaches were initiated to overcome those issues. In particular, the usage of a directed acyclic graph (DAG) instead of a blockchain to sustain consensus appears to be promising. The IOTA protocol is based upon a DAG called the “tangle” and provides a secure, decentralized and permissionless system, which is aimed to be the backbone of the Internet of Things (IoT) (Popov 2016). Each participant in the network who wants to attach his or her transaction to the tangle has to confirm the validity of two other transactions before their transaction can be confirmed by other participants. Confirming a transaction requires only a small proof-of-work since the protocol was designed to enable small devices to participate in the network. This means that users hold up the network and a need for another party like miners does not exist. Consequently, transaction fees become obsolete (Hanl 2018) and less computational power is needed, which reduces energy consumption in comparison to Bitcoin. As a result, it is possible to send non-value transactions, which only consist of information. This means information can be securely stored within tangle transactions. A further feature of the protocol is that the more the system is used the faster transactions will be confirmed. As a whole, the IOTA protocol aims to solve the major technical flaws of blockchains by building on a different consensus mechanism. To further develop the protocol, the non-profit IOTA foundation was founded by the initial developers and early supporters in 2017. The foundation cooperates with the community, academia, and companies to foster its technical enhancement and application in the real world (IOTA Foundation 2017).

Furthermore, some protocols of DLTs support the use of immutable smart contracts. Once started they will carry out their code, which is defined by interacting parties beforehand, whatever happens. Put more simply: if certain criteria are met by all parties, then XY will happen. This concept allows “for proper, distributed, heavily automated workflows” and redefines “how interactions between transacting parties on a network can be set up and automated” (Christidis and Devetsikiotis 2016). Since its development, the Ethereum protocol supports smart contracts, while they were only recently introduced on top of the Bitcoin blockchain (Hertig 2018). Small contracts are not supported by the current IOTA protocol, however, an introduction is announced by the IOTA foundation for the end of 2018 (Rottmann 2018).

[2] However, private blockchains are used as well, which restrict the access of who is able to participate, for instance a company that utilizes a private blockchain to provide a specific service to their customers.

3. BLOCKCHAIN/TANGLE-BASED HOMETOWN INVESTMENT TRUST FUNDS

3.1 Objective

Our goal is to enhance the functioning of HIT funds by utilizing security, transparency, auditability, and smart contract features of DLTs. This may contribute to expand the investor pool to individuals from countries other than the one where the project is realized. Since the spatial closeness feature of HIT funds disperses in such a setting, this world-community-based approach requires another source of risk mitigation. The use of DLTs adds trust in the proper functioning of the funds, which reduces the risk attached to an investment through a HIT fund. Therefore, it enables direct investments between partners who would not have collaborated before, so that individual investors from developed countries can be brought together with projects in developing countries. Optimally, project issuers would be local communities, small companies or individuals who collaborate with private companies, governmental or international organizations to develop a project. Subsequently, those projects are implemented with the help of individual investors via the HIT fund. If projects are conducted properly and received well by individual investors, their credit rating increases and it becomes easier for them to receive further loans from classical financial institutions. In this way, individual investors from abroad help to provide initial funding for local projects to foster the expansion of RE in developing countries. Typically, those projects will be small-scale, which at the moment face issues finding necessary capital, as described in section 2.1. Those projects often appear to be profitable, but not profitable enough to overcome existing high risk levels to enable investments across borders.

3.2 Functioning

Figure 2 illustrates the financial scheme of HIT funds based on blockchain or tangle.

Similar to the classical HIT funds, an intermediating party provides the whole structure to connect investors and projects. Additionally, he or she takes on the role of the assessor, assesses new projects and monitors already running ones.[3] The results are stored in a database, which is grounded on a DLT (blockchain or tangle), so that the stored data cannot be changed once included.[4] Moreover, project issuers provide project details and determine the terms and conditions of future investment contracts they hope to conclude. On the other side, investors are entering a smart contract that regulates the whole business relationship between all three parties. Together with the assessment and hard facts of the project, investors are provided with the necessary information to make their investment decision. If they decide not to invest, nothing happens and they leave the table. However, if investors decide to invest, the contract is automatically set in motion. As soon as enough investors are found to fund the necessary investment sum, the HIT fund is ready to provide funding for the project. The

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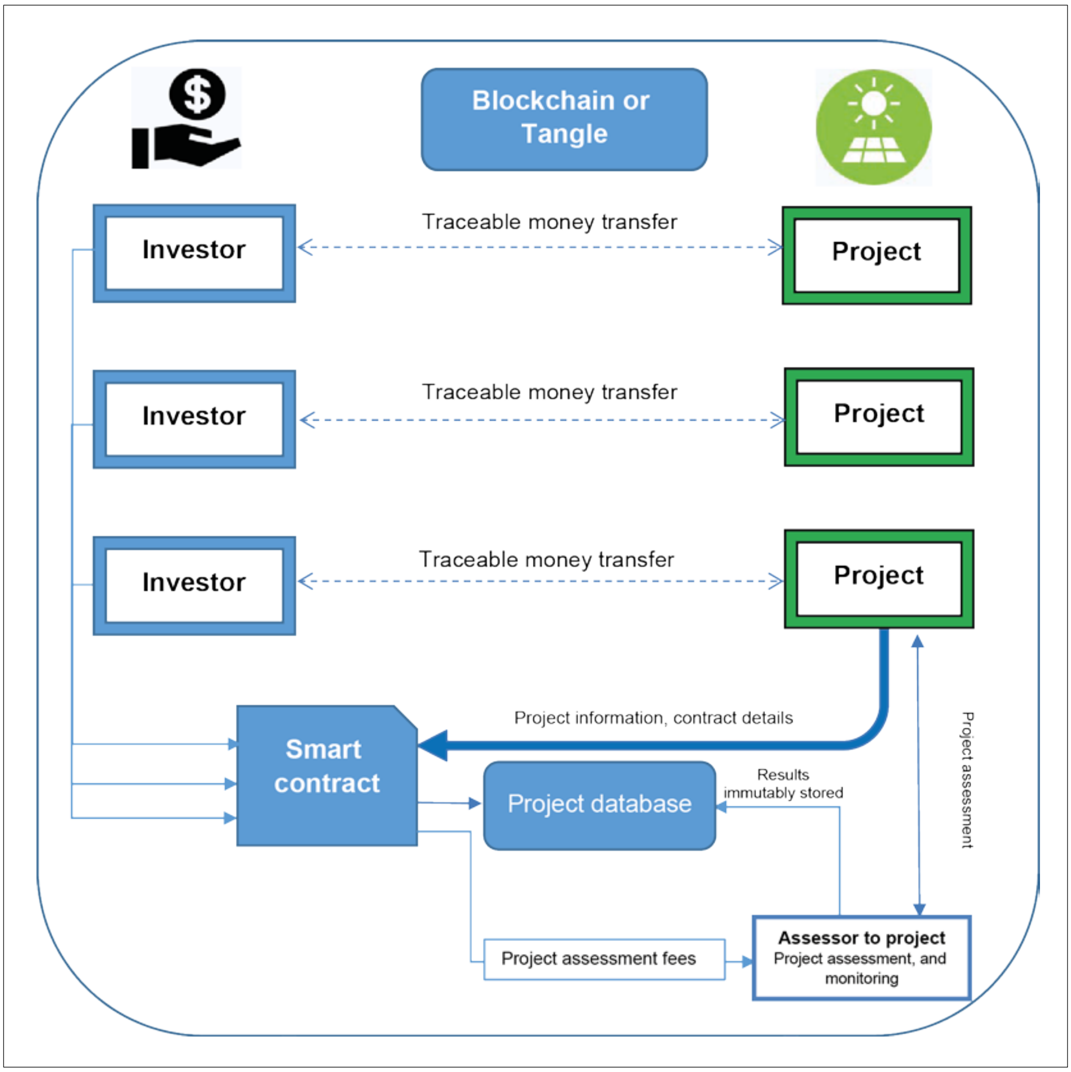
[3] For transparency reasons it is desirable to separate the roles of scheme provider and assessor. However, since this paper is based on HITs we follow their structure, which is already successfully working in the real world.

[4] The incentive for assessors could be a success-based fee in the form of a certain percentage of the investment sum. Therefore, they are additionally incentivized to conduct rigorous risk assessment and to validate only sustainable projects, which are received well by investors.

fee is transferred to the assessor, the investment sum forwarded from investors to the project as well as future revenue shares the opposite way.[5]

Figure 2: Financing Scheme via HIT Funds based on Blockchain or Tangle



Source: Authors compilation.

3.3 Features

The proposed scheme has several benefits. First, it establishes a direct connection between the investor and the project issuer by making use of the auditability characteristic of DLTs. Investors are able to track money streams, thus ensuring that their money reaches the chosen project so that legitimacy of money transfers is continuously secured, which reduces the risk that money is misappropriated on the way between investor and project. This creates transparency and trust. Second, by

5 Investors are free to finance only one project or to bundle investments with different assessment results to diversify their portfolios. Moreover, an investment-matching feature is imaginable where the investor defines his or her requirements for potential investments she would invest in (amount, return, duration, energy sector, country, etc.) and as soon as a project enters the stage that matches those requirements, the smart contract is automatically executed, and the investment made.

reducing the power of the intermediating party, service costs can be reduced, and investments forwarded more efficiently. Third, smart contracts are executed if investors agree with the contract details. This ensures full implementation of the contract details without any possibility to change them in the future. This feature creates trust and security for all parties. Fourth, project issuers determine contract conditions, so that local interests are ensured by design. Fifth, for the functionality of the instrument only the technical features of DLTs are essential and the use of Bitcoin, Ethereum, or IOTA as currency is not a necessary requirement. The money streams could either take on the direct form of cryptocurrencies or the form of an automatic combination with a fiat linkage. The former means that, for example, IOTAs are directly invested in a project. The latter means an investment in, for example, Yen is made and the amount automatically exchanged in the used cryptocurrency to conduct the transfers. Regardless of which of the two designs is used, both ensure traceability, security, and full transparency for all parties. Sixth, an integration of the blockchain-based approach to evaluate and track the green impact of investments of the Green Assets Wallet Initiative (GAW) is desirable and could help investors to gain full transparency about the project’s impact over its lifecycle. Possibilities include power generation data, the fulfilling of milestones, financial statements, and more. The GAW offers a system through which the reporting can take place in a transparent and efficient manner useful for investors as well as issuers.

3.4 Crucial Points

There exist several crucial points for a successful implementation of the proposed scheme that have to be addressed. First, the intermediating party is the key creator of trust, which has to be reliable and trustworthy for investors as well as projects. In existing HIT funds these are Internet companies, which have established a reputation in evaluating RE projects and have a wide reach to potential investors. Moreover, NGOs, green banks, engineering companies or multilateral institutions like the IMF, World Bank or the ADB are also imaginable as intermediating parties. This party only connects investors and projects, assesses the latter and is not involved as a transmitting party of money and information. For existing HIT funds in Japan, the supervision and regulation by the Financial Services Agency (FSA) takes place for intermediating parties and not directly for the HIT funds (Yoshino and Taghizadeh-Hesary 2018). They are not regulated as asset management companies since they are only intermediators and assessors, which means that HIT funds are not guaranteed by the government and the deposit insurance corporation. Second, small-scale projects have to be developed so that investors can help to put them into reality. As outlined in section 2.1, in developing countries small-scale projects are unlikely to be carried out nowadays, particularly in rural areas. The proposed tool makes it possible to provide funding for such projects, which creates an additional incentive for governments to promote the development of small-scale projects as well as for individuals and small companies to develop them. Since decentralized renewable energy production makes power grids partly redundant, which are scarce in developing countries and expensive to expand, the overall necessary expenditures to provide energy supply are reduced. On this score, governments are incentivized to foster the development of small-scale projects. Third, accounts have to be explicitly connected with projects, investors and assessors, which has to be verified by the scheme supplier. This guarantees that every investor and project is existent in reality and nobody is able to pretend to be someone else. Therefore, the legitimacy of interacting parties is ensured. Fourth, the smart contract has to have binding legal status for both parties. If project issuers try to fraud and, for example, try not to pay future revenue shares, the smart contract has to be enforced like a normal contract.[6] Fifth, the design requires an exchange to fiat money, otherwise the investment sum cannot be used in the real world. Their existence in developing countries is scarce, which means that an exchange of cryptocurrency to local currency has to be provided by the tool supplier. However, this exchange can be done automatically and takes place within a short period of time, which means that cryptocurrency price volatility is only faced for a limited period of time. Since the mechanism works in both directions this volatility will only have small financial implications for the exchange provider. On this score, low or no transaction costs at all and fast transaction turnovers are important characteristics the used DLT should inhere to mitigate the described issue. Therefore, we recommend deploying the IOTA protocol. However, as described in Section 2.4, smart contracts are not yet employed and will be available at the earliest at the end of 2018. Sixth, exchange rate fluctuations have to be incorporated since investments are likely to be made in a different currency to the one the project needs (Nelson and Shrimali 2014).

4. MODEL

Investors' (households) utility function depends on the rate of return and risk. Equation (1) shows the utility function of investors, which is a function of rate of return and risk:

$$U = U(r_{t,}\sigma_t) = r_t - \beta\sigma_t^2 \tag{1}$$

where r_t denotes the rate of return, σ_t denotes the risk, and β is the weight for the risk. If an investor gives more weight to the risk, then β will be larger. A smaller β means that the investor is not so concerned about risk.

In blockchain-/tangle-based HIT funds the σ_t (risk factor) is expected to be smaller compared to the conventional HIT funds as the transparency of the investment will be higher as the investors can trace where their money is being invested.

Equation (2) shows the total rate of return of households' investments. We assume that households put their money either in bank deposits or in blockchain-/tangle-based HIT funds that will be invested into green-energy projects.

$$r_t = \alpha_t r_t^D + (1 - \alpha_t) r_t^E \tag{2}$$

In equation (2), we assume that α_t percent of the households' assets is going to bank deposits, and the rate of return on bank deposits or the deposit interest rate is r_t^D. On the other hand $(1 - \alpha_t)$ percent of their assets are invested in blockchain-/tangle-based HIT funds and r_t^E denotes the rate of return on these funds.

$$\sigma_t = \alpha_t \sigma_t^D + (1 - \alpha_t) \sigma_t^E \tag{3}$$

Equation (3) is the aggregated risk. There are two types of risk associated with households' investments. The first risk concerns the deposit (σ_t^D) and the second risk blockchain-/tangle-based HIT funds investment (σ_t^E). If the deposit interest rate is fixed and not fluctuating, then σ_t^D is zero.

[6] However, the possibility of fraud is already mitigated by the use of smart contracts, which automatically execute payments.

Table 1: Return−Risk Trade-Off for Households' Investments

	Return	Risk
Safer Assets	r_t^D	σ_t^D
Green Energy Projects	r_t^E	σ_t^E

Source: Authors.

Table 1 shows the risk−return trade-off for the households' investments. If a household invests in safer assets (here: deposit), the return is r_t^D and the risk is σ_t^D, which we assume to be zero. If the household invests in green-energy projects that have a higher risk (σ_t^E) and expect to make a higher return (r_t^E), there is a trade-off between risk and return.

Next, in equation (4) we are looking at the dynamic welfare function and two constraints that are presented in equations (4.1) and (4.2):

$$W = \int_0^\infty e^{-\theta t} . U(r_t, \sigma_t) \tag{4}$$

$$s.t.\ r_t = \alpha_t r_t^D + (1-\alpha_t) r_t^E \tag{4.1}$$

$$\sigma_t = \alpha_t \sigma_t^D + (1-\alpha_t)\sigma_t^E \tag{4.2}$$

In the next step, we develop the Hamiltonian and present it in equation (5), in which the utility function is shown in parentheses:

$$\begin{aligned} H &= e^{-\theta t}(r_t - \beta\sigma_t^2) \\ &= e^{-\theta t}[\{\alpha_t r_t^D + (1-\alpha_t) r_t^E\} - \beta\{\alpha_t\sigma_t^D + (1-\alpha_t)\sigma_t^E\}^2] \end{aligned} \tag{5}$$

α_t is the ratio of allocation between deposits and blockchain-/tangle-based HIT funds to green-energy projects. If $\alpha_t = 1$, that means households are putting all their money in bank deposits. If α_t becomes smaller, then the ratio of investment in HITs and green energy is increasing. In the next step, we maximize the Hamiltonian with respect to α_t, resulting in equations 6 and 6.1:

$$\frac{\partial H}{\partial \alpha_t} = e^{-\theta t}[(r_t^D - r_t^E) - 2\beta\{\alpha_t\sigma_t^D + (1-\alpha_t)\sigma_t^E\}(\sigma_t^D - \sigma_t^E)] \tag{6}$$

$$(r_t^D - r_t^E) - 2\beta\alpha_t(\sigma_t^D - \sigma_t^E)^2 - 2\beta\sigma_t^E(\sigma_t^D - \sigma_t^E) = 0 \tag{6.1}$$

Equation (7) shows the α_t that is obtained from Hamiltonian maximization:

$$\alpha_t = \frac{(r_t^D - r_t^E) - 2\beta\sigma_t^E(\sigma_t^D - \sigma_t^E)}{2\beta(\sigma_t^D - \sigma_t^E)^2} \tag{7}$$

We can rewrite equation (7) by dividing the numerator and denominator by 2β, and we write equation (8):

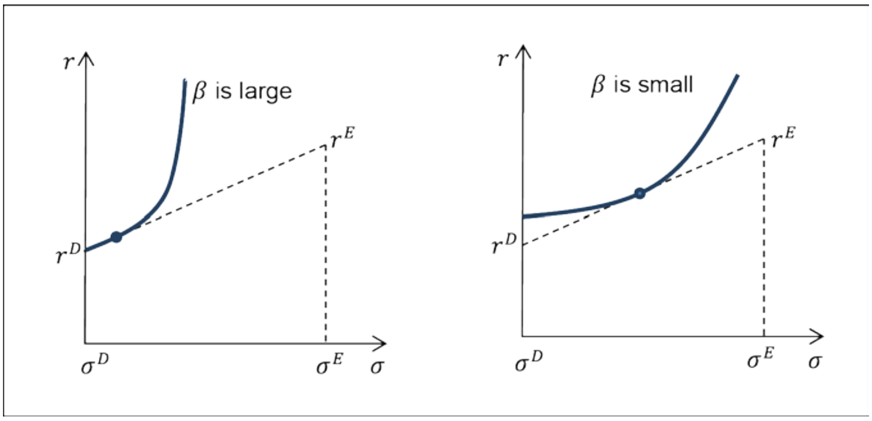
$$\alpha_t = \frac{\frac{1}{2\beta}(r_t^D - r_t^E) - \sigma_t^E(\sigma_t^D - \sigma_t^E)}{(\sigma_t^D - \sigma_t^E)^2} \tag{8}$$

Equation (9) shows changes of α_t with respect to β:

$$\frac{\partial \alpha_t}{\partial \beta} = -\frac{1}{2\beta^2} \cdot \frac{(r_t^D - r_t^E)}{(\sigma_t^D - \sigma_t^E)^2} > 0 \tag{9}$$

Equation (9) shows that if the weight of the risk (β) increases, or if the households become more risk-averse and seek safer types of assets, α_t, which is the share of bank deposits in total assets, will increase, and households will invest less in blockchain-/tangle-based HIT funds for green-energy projects.

Figure 3: Utility Functions with Regard to Different Risk Preferences



Source: Authors' compilation.

Figure 3 shows two cases of utility functions with regard to two different levels of risk preferences. On the left side, β is large, which means households are very concerned about risk and are risk-averse. Therefore, they prefer safer assets and deposit a major part of their assets in banks that have zero risk in this example and a smaller amount in HIT funds that have higher risk and higher return. On the right side, β is small, which means the considered households are risk-taking. Therefore, the utility function becomes flatter compared to the first case. Hence, they are investing a significant portion of their assets in HIT funds that give them r^E return but are associated with σ^E risk.

Equation (10) shows how α_t changes when the deposit interest rate (r_t^D) goes up:

$$\frac{\partial \alpha_t}{\partial r_t^D} = \frac{\frac{1}{2\beta}}{(\sigma_t^D - \sigma_t^E)^2} > 0 \tag{10}$$

Equation (10) shows that if the deposit interest rate goes up $\alpha_{t,}$ the share of savings in bank deposits goes up.

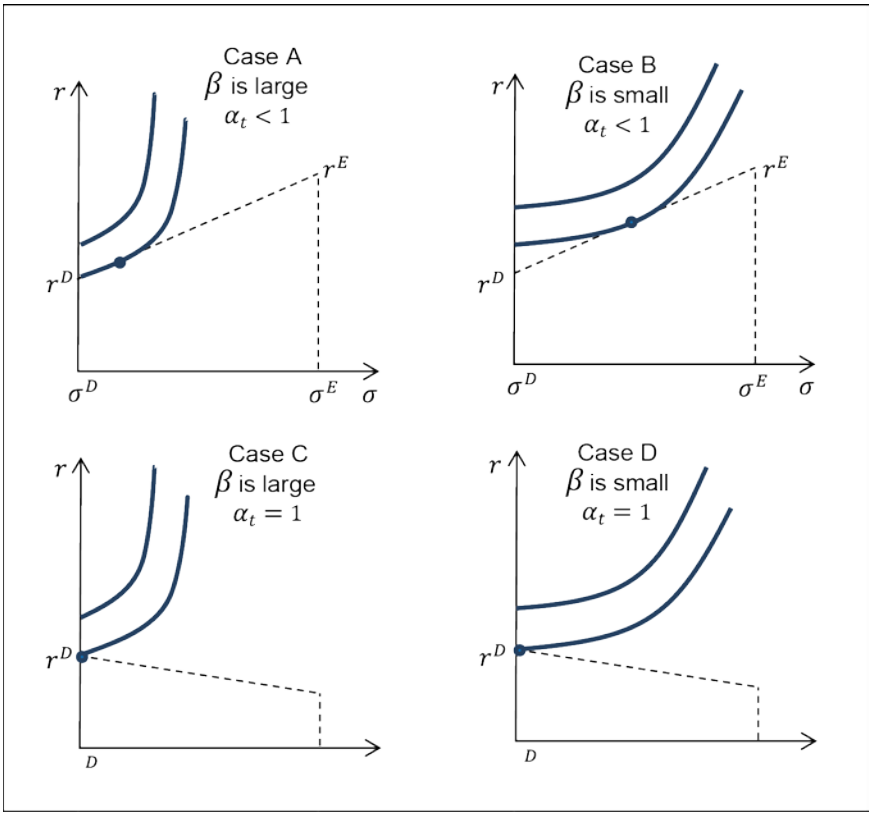
$$\frac{\partial \alpha_t}{\partial r_t^E} = \frac{-\frac{1}{2\beta}}{(\sigma_t^D - \sigma_t^E)^2} < 0 \tag{11}$$

Equation (11) shows that if the rate of return on blockchain-/tangle-based HIT funds for green energy (r_t^E) increases, the share of investments in deposits, or α_t, will be reduced. That means households will be reluctant to put their money in bank deposits and instead will be more interested in investing in blockchain-/tangle-based HIT funds for green-energy projects.

$$\frac{\partial \alpha_t}{\partial \sigma_t^E} = \frac{[-(\sigma_t^D - \sigma_t^E) + \sigma_t^E](\sigma_t^D - \sigma_t^E) - [(r_t^D - r_t^E) - 2\beta\sigma_t^E(\sigma_t^D - \sigma_t^E)](-2\sigma_t^D + 2\sigma_t^E)}{(\sigma_t^D - \sigma_t^E)^2} > 0 \quad (12)$$

Equation (12) shows that if the risk of investment in HIT funds for green energy goes up, the share of investments in deposits or α_t increases. Figure 2 shows that the higher the rate of return on green energy ($r^E > r^D$), the larger the portion of households' investments will be in green-energy projects.

Figure 4: Households' Investment Preferences



Source: Authors' compilation.

Figure 4 graphically summarizes all the mathematical equations presented in this subsection by showing the households' investment preference functions. Households' utility function depends on the rate of return and risk that are shown by r and σ, which is typical in finance theory. Figure 4 displays four different cases. The top two diagrams show cases in which $\alpha_t < 1$, meaning that households are investing their assets in two forms, bank deposits and blockchain-/tangle-based HIT funds for green-energy projects. Case A depicts risk-averse households (β is large) that prefer more risk-free types of assets (deposits) and less high-risk types of assets (green-energy projects). Case B depicts the risk-taker households (β is small) that prefer to take risk and invest more in blockchain-/tangle-based HIT funds for green-energy projects and ultimately gain higher returns compared to Case A households. At the bottom are two cases (Case C and Case D) in which $\alpha_t = 1$, indicating that households keep only deposits without any investment in risky projects (green energy).

$$r = 1. r_D + 0. r_E \tag{13}$$

$$\sigma = 1. \sigma_D + 0. \sigma_E \tag{14}$$

Equations (13) and (14) illustrate Case C and D where households invest their assets only in the form of risk-free assets and not in blockchain-/tangle-based HIT funds for green-energy projects.

5. CONCLUSION

Investments in RE are crucial to achieve the SDGs as well as the Paris Agreements. In particular, small-scale projects face financial frictions that have to be overcome. This paper delineates an integration of DLTs into the current HIT fund framework. The model reveals the investor's decision problem and impacting factors. Through the integration of DLTs, the HIT funds can become more transparent, reducing the associated risk, which would result in a higher share of investments in RE projects, as shown by the model. The integration of DLTs offers the potential to improve HIT funds and raise investments in small-scale RE projects. More transparent HIT funds make them more likely to be adopted in further developing countries since the associated risk for investors is reduced. Therefore, they can serve as fertilizer for future sustainable growth in regions where projects are realized, since energy supply is the backbone for future prosperity. However, for a successful implementation it is essential to create the necessary credibility in all domains. Therefore, a close collaboration with currently intermediating parties, multilateral organizations (e.g. World Bank or ADB) and governments is essential.

This paper has demonstrated a possible application of DLTs to improve a financing scheme that can lead to a wider adoption of REs. This example in the field of green financing is only one example of how DLTs can contribute to solve problems humanity is facing. Often DLTs are reduced to their currency feature, but the underlying technology offers manifold approaches to address real-life issues as well. Future research should explore these potentials, in particular those which promise to have positive impacts on social welfare.

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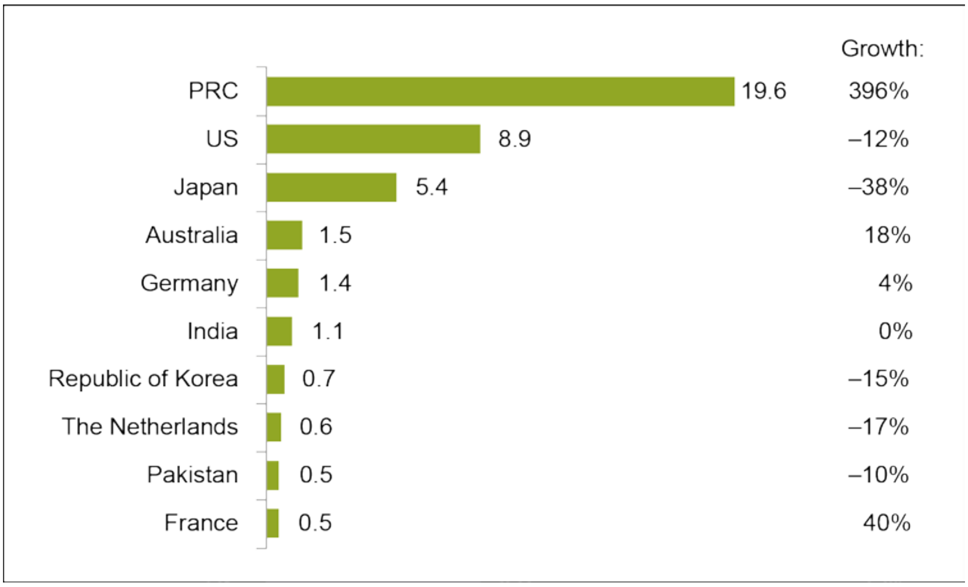
APPENDIX

Figure A1: Small Distributed Capacity Investment by Country, 2017, and Growth on 2016 in billion $



PRC = People's Republic of China, US = United States.

Note: Top 10 countries. Represents investments in solar PV projects with capacities below one megawatt.

Source: (McCrone, Moslener and Gruening et al. 2018) based on Bloomberg New Energy Finance.