Blockchain-Based Smart Contracts for Sustainable Power Investments

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Abstract— Proposed is a communication system, integrating a distributed ledger with ambient intelligence and a data fusion scheme. It introduces a clear distinction between the financial profitability of investment projects and their contribution to environmental sustainability while ensuring performance measurability and flexibility for both aspects of project management as well as the possibility to trade emission certificates. Two key benefits of the system are the possibility to implement a reliable and straightforward methodology for the evaluation of investments, both ongoing and planned, and the potential to connect the emissions trading scheme with pollution control in the real time. Moreover, the system brings about stability where the revisions of governmental subsidy policies tend to move the break-even costs significantly, thus incentivising for innovative or small-scale projects.

Keywords— smart contracts, distributed ledger, power gener-ation, smart grid, infrastructure development

I. Introduction

Cost evaluation represents one of the most controversial aspects of project management in initiatives related to the Flexible Mechanisms and the Clean Development Mech-anism (CDM) in particular [1]. Due to the uncertainties involved in predicting the future and to conflicting objectives between different stakeholders, such as specific governments, NGOs, and various industries, complex power plays tend to influence the values of accepted cost indices as well as applicable accounting methods. Furthermore, the difficulty to ensure a stable relationship between the costs and returns in the long term, related, e.g., to the highly volatile price [2] of Certified Emission Reduction units (CERs), hinders grassroots activities and investments [3]. Nonetheless, money has traditionally represented the sole commonly recognised unit of account.

Distributed ledgers (DLs), a family of ubiquitous computing solutions for peer-to-peer (P2P) transactions, often using technologies based on directed acyclic graphs (DAG) [4], [5], [6], [7] or blockchain [8], [9] for the validation of entries, provide an answer to this issue. DL accounts enable for the presentation of values in physical currencies as well as virtual. A CER is, in the present form, a measurable and mutually exchangeable unit of account; its universal acceptance on behalf of electricity producers meets the last necessary criterion for its use in a DL-based system. It, therefore, qualifies for a unit of account in such a system.

Unlike cryptocurrencies, CERs or CER derivatives are, however, unsuitable for wealth accumulation. Nor do they represent a versatile means of payment. On the contrary, CER-based accounting leads to reversing the financialisation of CDM and facilitates to streamline investment evaluation in the long run.

Separate accounting for financial profitability and sustainability benefits brings advantages for policymakers as well as investors. For the former, it facilitates setting performance-based goals and simplifies the process of drafting regulations. For the latter, on top of simplifying financial models and managerial accounting practice, and consequently bringing more stable business conditions, it detaches the contextual measures from the primary operational goals. Therefore, it puts the entanglement of operational cash flows and subsidies to an end and facilitates the accounting of both. Finally, it fosters innovation and opens up a new area of development by appreciating distributed low-emission power generation by promoting the implementation of more effi-cient technologies rather than prioritising those approved by the government.

II. Smart Contracts

A. Definitions

A smart contract is a communication protocol for the direct and automated verification, negotiation, or performance of transactions. Only recently has the concept gained motion, with the popularisation of the Ethereum blockchain [8]. Smart contracts represent a promising opportunity for 'the creation of a marketplace of services between devices' and for workflow automation [10] as well as automated and semi-automated sourcing of products.

The most significant use of smart contracts is trading cryptocurrencies. Nevertheless, the increasing proliferation of IoT-based supervisory control and data acquisition (SCADA) systems opens up the opportunity to embed the framework for automated transactions in the communication protocol. Moreover, the legal regulation of smart grids provides a sufficient framework for data sourcing to run smart contracts.

In a connected environment, agents interact with one another to mutually supply access to necessary services or re-

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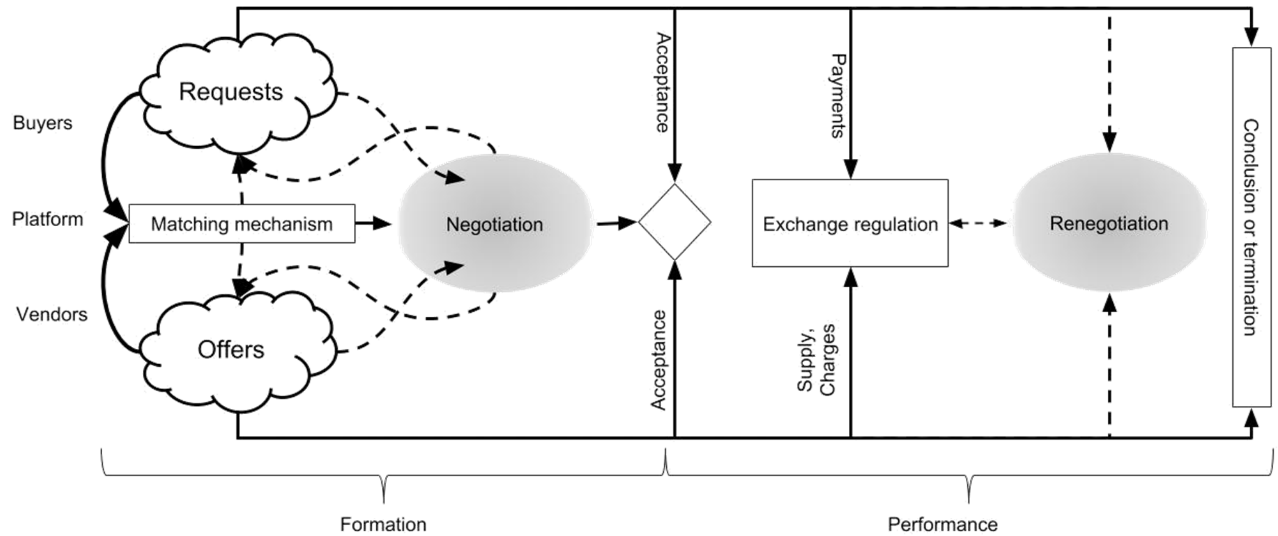

Fig. 1. Data flow in the smart contract

sources thus achieving collaborative synergies. Furthermore, it becomes increasingly easy to acquire high-quality data, to verify it, or to otherwise determine its reliability. Among the key advantages of smart contracts are, e.g.:

- The reduction of general and administrative expense (G&A) including especially legal and marketing costs;
- Fair treatment of all participants of the smart contracts communication platform and increased liquidity [13];
- More efficient market exploration for both the seller and the buyer by easy market discovery [11] and price discovery [12]; and
- The public availability of transparent transaction records, which entails the possibility to monitor the execution of smart contracts.

The architecture of distributed ledgers (DLs) prevents the formation of 'dark pools' [14] except in case of a 'soft fork,' i.e. a temporary split of a ledger. This represents a point of difference between DLs and automated trading systems. Furthermore, it precludes carrying out intra-market arbitrage, thus improving the high quality of the system marketplace [15] and diminishing information asymmetry [16].

The essence of smart contracts is their automation. As such, the formation and performance, as well as possible modifications, can be carried out by one or more computers and without human participation [17], [18]. While a smart contract may or may not be essentially self-executing, its automated performance means that no direct human involve-ment is necessary.

B. Transaction Stages

Just as with traditional contracts, the transaction formally involves the following three stages; however, an efficient mechanism for matching and negotiation reduces the chances of a breach ever to occur (Fig. 1):

1) Formation;
2) Performance or modification; and
3) Breach, enforcement and remedies.

During formation, two or more parties must agree to a set of necessary conditions which initiate the process. By joining a dedicated communication platform, a potential contractual party preliminary approves specific terms. A par-allel algorithm including sufficient preliminary conditions for triggering its implementation is, nonetheless, necessary for the substantiation of a contract. The communication platform may require the additional authorisation of transactions upon the matching of potential buyers and sellers.

In DLs, it is the communication platform that verifies and matches potential contractual partners, as well as streamlines the process of contract formation. As such, not only the speed of transactions increases but also all participants are treated equally provided their characteristics, and the history of transactions leads to their assessment as similarly trustworthy. Furthermore, each network participant has the record consisting of the same verified and immutable [19] ledger entries. Metadata and additional personal transaction data available to specific network participants may somewhat differ, as well as the records of ongoing transactions, the correctness of which has not yet been confirmed by a consensus algorithm; however, their unconfirmed status is clear to any agent.

Additional DL security measures may include granular access control [20], audit [21], and advanced data analytics using data provenance and relevant metadata for the proba-bilistic assessment of entry values correctness. The objectives in designing DLs are:

- Byzantine faults resistance or tolerance;
- Scalability;
- Computational, data storage memory optimisation; and

Robustness, i.e. the integrity of records and
resistance to forking, i.e. the splitting of a database.

IoT efficiency shows when it is possible to contract obligations automatically, without requesting additional activity upon the recognition of an underlying condition satisfying the preliminarily established constraints. In such cases, the identity of the sides of a contract may only become known once it has been accepted. On the other hand, entering into a contractual relationship with an unknown party may jeopardise the security of an agent. Therefore, the need to distinguish trusted parties and to partner exclusively or predominantly with them emerges.

The acceptance of a contract marks the beginning of a relationship characterised by mutual obligations of the parties involved. The conditions regulating the performance of these obligations may be subject to further modifications. One feature of smart contracts is the allowance for the automated modification of contract provisions due to the change of background conditions, as long as such an adjustment should fall within the constraints of all the partners of the initiator.

Even a relatively simple autonomous agent can initiate actions independently, due to the variety of factors conditioning its environment. Direct human involvement, i.e. the programs the agent uses with specific goals, and possible operations are but one of its elements. The performance of an artificial intelligence (AI) unit also depends on endogenous variables, such as the battery level [22], processing capacity or available memory [23], [24]; and external, e.g., the distribution of compatible units in its network [25].

The relative clarity and precision of rules governing smart contracts leave less area for interpretation than in traditional arrangements. It is, however, impossible to rule out the eventuality of non-fulfilment, be it intended, accidental, or due to force majeure. Furthermore, there are few mechanisms to determine whether a case of non-compliance represents 'substantial performance' [26] At present, save for cases regulated by the very contracts or the rules of communication platforms, the enforcement mechanisms and remedies depend on the same legal and institutional framework as for traditional contracts. This raises two significant issues: the lack of preparation of law officers to assess a possible breach, and the substantial costs of a legal process.

III. Emissions Trading

A. Existing Solution

Thus far, trading CERs has consisted in exchanging them for money. While the weaknesses of CDM became evident [27] within a few years since its inception, it was not until the prices of buying CERs persisted at levels much lower than the costs of switching to equivalent low-carbon energy sources that the wide recognition of the low efficiency of CDM ensued [28]. Despite the moral hazard involved in the bureaucratic process of designing carbon reduction projects [29], [30], [31] and the Executive Board registering them, relatively few critics have focused on the very design of the CDM procedures.

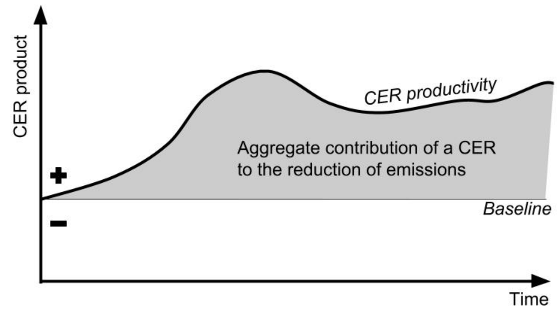

Fig. 2. The impact of a CER in time

Countries listed in Annex I to the Kyoto Protocol are allowed [32] to balance insufficient domestic reduction of carbon emissions by purchasing CERs abroad. An industry-wide consensus leans towards recognising that carrying out initiatives for the reduction of carbon emissions ought to be less costly in developing countries [32]. Such formulation of the problem raises several issues:

Measures taken to reduce the emissions of CO_2 and other greenhouse gases, e.g., NO_2, may not contribute to people's quality of life in any tangible way and, therefore, neither raise social awareness nor address local issues;

Particular governments, while administrating the scheme and assuming the responsibilities involved, tend to have conflicting objectives regarding the methods of reducing emissions and lack effective enforcement measures to control private-sector agents acting globally, especially if they conform with the 'baseline' emission allowances under the jurisdiction of more powerful countries [31];

The reduction of carbon emissions as such is mainly decoupled from business priorities as long as the party concerned can fund its reluctance in reducing emissions; A mechanism to monitor the productivity of CERs assigned to specific registered projects in the real time is inexistant.

B. Ambient Intelligence and CER Pricing

Although the long-term reduction of carbon emissions should influence peoples lives, it does not directly relate to material phenomena, such as the current levels of air pollution. Meanwhile, existing networks of sensors acquire the necessary data for monitoring the deviations between the real-time levels of specific particles in the air. Connected in a smart network, they could become the nucleus of an ambient intelligence system for the determination of emission costs. Three cornerstones of the proposed scheme are:

Pacing emission reductions in time and allocating them to specific regions, countries, or urban areas; as well as the recognition of differences between various types of greenhouse gas emissions;

Establishing an expected productivity function of a CER in a specific location (Fig. 2), the derivative of which

TABLE I

EXAMPLES OF SPECIFIC OBJECTIVES RELATED TO THE REDUCTION OF CARBON EMISSIONS AND POSSIBLE ENFORCEMENT METHODS

Objective	Addressees	Monitored activity	Differentiating factors	Monetisation of CERs
Production of clean energy	Electricity plants	Real-time supply of electricity to the grid	Energy resource used in each station	Local tax (or tax refund) paid by (to) electricity producers
Saving electricity	Businesses, households	Consumption of power from the grid	Time of day and year	Local taxes (tax refunds) paid by (to) businesses, households
Reducing fuel consumption	Drivers	Changes of vehicle location	Used type of fuel, fuel efficiency, time of day and year	A charge similar to a toll

TABLE II

SELECTED *CER PRICE EQUILIBRIUM FORMATION FACTORS

Factor	Impact	Consequences
Baseline emissions reduction	+	General incentive to invest in low-emission technologies
Local emissions penalties	+	Temporary spike in price driven by the government
Common adoption of low-emission technologies	+	The late adopters pay the price for excessive emissions
Current availability of *CERs for buyers	–	Emission producers buy *CERs outside of their location

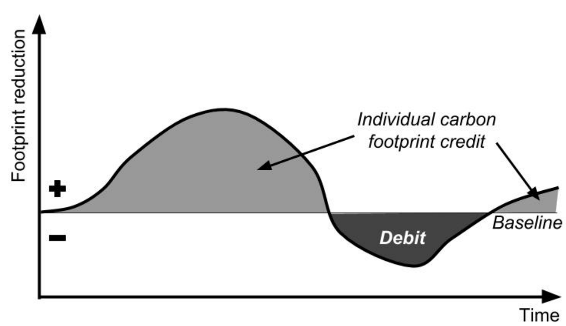

Fig. 3. Accounting for individual carbon footprint

reflects the aggregate contribution of the CER; and
Localisation and demonetisaition of the CER market clearing scheme.

The cost of emissions would, therefore, vary as a function of the type of emissions, time, and place (Tab. II) thus producing an additional incentive to minimise the adverse impact of emissions on the daily life of local dwellers. Cost trendline would still reflect the emission level objectives for the country; therefore CDM assumptions remain valid. Given the location-specific productivity function of a single CER (Fig. 2) it is also possible to convert the actual emissions, as measured, back into reconstructed CER equivalents, i.e. *CERs. Furthermore, modelling the carbon footprints of the activities of people and comparing them with baseline footprints (Fig. 3) would enable them to establish to what extent the behavioural patterns of individuals contribute to emission reductions.

As shown in Table I, specific objectives related to the reduction of carbon emissions concern activities presently monitored for smart grid operations or traffic control, the examples not representing an exhaustive list. The proposed scheme, therefore, relates to data processing rather than the extent of the collected data. Consequently, the proposed scheme requires the fusion of existing data within an integrated communication system rather than the development of new ambient intelligence infrastructure.

C. Transaction Outlines

With a CER productivity function, specific to a place and time, and to the greenhouse gas the emissions of which were intended to be curbed, it is possible to convert the net footprint credit into synthetic units, *CERs. However, es-tablishing a measurable, real-life connection between human activity and CERs is just the first step. The second one is clearing the CER trading system.

While the total quantities of CER and *CER have to be equal at any given moment, their distribution between countries may vary. Therefore, countries or individual legal persons may buy *CERs from the countries owning CERs. Transactions between countries may be carried out on a simi-lar basis as presently, but the extension of potential buyers to people, companies, or other entities changes the market into a potentially highly liquid one. As an alternative to paying for their carbon footprint in taxes or fees, businesses and individual people could buy *CERs and redeem it for CER equivalent according to the productivity function of CERs in the place of their footprint.

The owners of CERs can offer *CERs at any price they find adequate, however, provided that the utility of any *CER is equal, trading them would lead to the convergence of prices worldwide on the market. This does not apply to those who have to pay off their footprint account debits but are absent from the market and therefore have to pay the price dictated by their local authorities. Legal persons who own *CERs at a specific moment can then use them to redeem their footprint accounts or sell to any willing buyer participating in the DL. What the creation of such a market entails is:

Incentives to take actions oriented towards reducing own carbon footprint;
A clear determination of the price of a *CER as an alternative to an organic reform; and
The recognition of the value of investments in green technologies or behaviours.

D. Opening the *CERs Market

Accounting for greenhouse gas emissions in *CERs instead of money implies reversing the financialisation of the present system, as the character of *CERs and that of money are fundamentally different. In the first place, *CERs cannot be used for payments. The only situations allowing for their conversion into cash are the clearing of carbon footprint accounts or speculation; they are not exchangeable for goods or services provided outside of the DL. Therefore, *CERs cannot be used in retail trade transactions.

Secondly, projects for the reduction of greenhouse gas emissions have determined lifespans. This implies the depreciation of the real underlying assets. Regardless of their synthetic character, *CERs are also subject to loss of value, e.g. in the form of transaction fees. Furthermore, organising the DL according to the blockchain data structure, with each *CER representing one 'block', makes it possible to introduce variable amortisation rates for specific *CERs, thus connecting *CERs to real-world projects on a new level.

Neither DAG-based DLs nor money-based accounting permits to automatically readjust the present value of a *CER. This advantage of blockchain has its implications for the type of carbon emission projects that are proposed and registered: the lower the amortisation rate, the higher value the related *CERs maintain. Consequently, the mechanism appreciates long-lasting and high-impact projects regardless of their scale.

Definancialising CERs is also likely to increase the efficiency of servicing clean development. Despite the savings that process automation produces for the energy sector, investment banks and insurance companies might partially offset these changes by entering new markets and increasing activity in existing service areas as well as creating new ones. Although smart contracts involve the automation of support activities in the energy industry and therefore enable for increasing productivity in the legal and administrative areas, they also broaden the CER market by indiscriminately opening it for new entrants.

The technical support required for the programming and ongoing revision of smart contracts under the proposed scheme carries out various functions presently performed by market researchers, contract lawyers, traders, and administrative staff. On the one hand, this reduces the relative disadvantage of smaller companies in doing business; on the other, it smoothens business processes and reduces as well bureaucracy as the unpredictable human factor. A report form 2009 [33] suggest that, on average, less than a third of the money spent on buying CERs contributed directly to project operating and capital expenditure costs and both broker's premium and shareholders' dividend amounted to comparable magnitudes; smart contracts altogether eliminate the need for brokers.

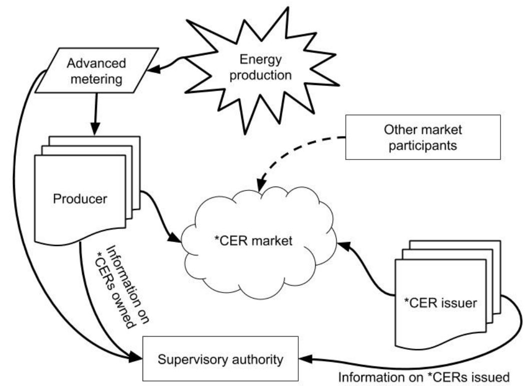

Fig. 4. Proposed *CER trading scheme for power generation

IV. Process Management

A. Systemic Power Generation Issues

The current procedures regulate CER trading as independent of power generation and the third-party verification of the ownership of certificates. This results in a systemic lack of transparency, excessively high transaction costs and a significant risk of errors or fraud, resulting, e.g., from accounting errors or imprecise measurements. Lacking are also mechanisms allowing for quick detection and possible correction of such irregularities.

The mechanism of trading is arbitrary and translates into constraints on the efficiency and scale of investments in alternative energy sources. Automated coordination of resource-specific energy production is thus virtually impos-sible. Coordinating power distribution could not only reduce transmission losses [34] by indicating the best areas for developing distributed generation but also help to enforce the expected energy mix effectively.

Until recently, the understanding of the phenomena involved underplayed the collaborative character and stressed the role of the major electricity suppliers as single actors. Indeed, the widely criticised processes regulating power grid management and the control of power generation predate the emergence of wide-scale DLs. Notwithstanding, the growing importance of distributed power generation in energy mixes tends to withdraw from concentrating merely on the verification and integration of data provided by the major electricity companies but increasingly see power grid management as an independent task.

B. Energy Mix Enforcement

Energy generation in traditional power plants, especially those burning fossil fuels, can be modelled and controlled relatively easily [35]. However, carrying out similar support activities for renewable energy, on the other hand, represents a challenge. Wind and solar power plants are among the most problematic [36].

Consequently, the enforcement of a diverse energy mix involves more than just the control over the grid capacity load in the real time. The necessity to balance the unpre-dictable fluctuations of renewable energy supply, depending on factors such as weather condition, implies that also the exploitation of traditional energy sources needs to adjust.

Since natural gas power plants [37] and pumped-storage hydroelectric plants [38] reach maximum capacity much faster than coal-fueled or atomic plants, their responsiveness is essential for ensuring continuous power supply.

The present energy mix and its fluctuations determine the real carbon footprint. This influences the *CER market in two ways: by shaping the CER productivity curve, and by changing the equilibria between the demand for *CERs and their price. Moreover, the ability to verify the preemptive models of projects oriented towards emission reduction shows to what extent specific investments meet the expectations. Again, blockchain turns out to be an adequate data structure for reflecting in an integrated DL. Fig. 4 outlines the information flow in the proposed energy mix enforcement scheme.

C. Customer Protection

The present CER trading scheme does not reduce ineffi-ciencies of power producers. In view of the concentration of power generation, large electricity producers operate as de-facto monopolists, and they can transfer the cost of purchasing CER to customers. Therefore, the actual business impact of CDM is limited.

Under the proposed mechanism, the usage of electricity and the production of energy from resources with high carbon footprint are accounted for separately. This prevents from the transfer of CER costs due to the inefficiencies of electricity producers onto final customers. Besides, it serves an educational purpose and empowers people to take actions oriented towards a more assertive approach to the govern-ment activity and more conscious electricity consumption.

Moreover, it reduces the impact of discriminatory tar-iffs, which result in charging retail electricity buyers, i.e. households, higher per unit than the customers who buy electricity in large volumes. Other protection mechanisms consist of accurate monitoring of people's behaviour. The proposed scheme brings about two mechanisms for customer protection, presently absent from the electricity market.

The first of those mechanisms is clear accounting for individual carbon footprint. This prevents the electricity companies from concealing their inefficiencies and charging their costs to inadvertent customers. It also establishes a clear connection between human actions and their measurable environmental impact.

Secondly, it gives customers the freedom to purchase *CERs, and consequently not to relate on their local governments in paying for excessive carbon emissions. Although the proposed scheme would radically change the process of CER pricing, it still makes it possible for people to free themselves from certain obligations towards the government, or at least to chose on what terms to fulfil them. Finally, it puts in a perspective on the efficiency of local sustainability projects, thus enabling conscious political choices.

A possible weakness of the idea to popularise trading *CERs consists of the limited computer literacy in the society. Without basic programming skills, an average person may find it impossible to set up their accounts in order for smart contracts meeting their expectations to be executed. However, restricting the modifiable variables to just a few essential ones and providing the end users with a friendly interface, boosts the attractiveness of the communication platform.

V. Investment Evaluation

A. Assumptions

For-profit power generation is an economic enterprise. The large-scale activity of the government, especially in the areas of subsidising the usage of selected energy resources, market regulation, and various type of qualitative control quite effectively prevent the natural formation of supply and demand equilibria at specific price levels. Although the advantages and disadvantages of 'free markets' may be debatable, government activity introduces a factor of instability given possible policy changes.

Liberating the CER–*CER market might represent the first step towards a market-driven system, without producing abrupt changes. Separating the operational cash flow from that produced by government subsidies encourages to evaluate the efficiency of a specific project and their sustainability in the long run. Accordingly, there is a distinction between the 'business' aspect of an investment and the economics of its environmental impact, enabling for a more consistent methodology for the assessment of every investment project.

One of the results of excessive government intervention in power generation is the difficulty in assessing the economic price of such projects accurately. The net present value NPV of a project with an expected rate of return r for a period t of time is the residual value after subtracting the investment expenditures I from cash flows C (1). Subsidies to infrastructure investments improve NPV by reducing I. Consequently, the terms of private-public partnership (PPP)may produce the incentive to allocate own capital in projects with limited economic sense in exchange for merely expanding the asset base of a company.

$$NPV = \sum_{t=1}^{n} \frac{C_t}{(1+r)^t} - I_0 \qquad (1)$$

This is especially pertinent to investments involving real estate in attractive locations or of considerable acreage, the acquiring of which is facilitated by the government. The discounted cash flow method, used for pricing investment real estate determines asset price P as the sum of discounted cash flows and the residual value RV of an asset (2). Consequently, green power producers are in a position to boost the assets of their company even though the rate of return considerably lower than market rates and there could likely be a more economical way to develop the real estate in question.

$$P = \sum_{t=1}^{n} \frac{C_t}{(1+r)^t} + \frac{RV_n}{(1+r)^n} \qquad (2)$$

Furthermore, if subsidies are subject to arbitrary decisions of state officials, any estimation of the weighted average cost of capital W ACC bears a high risk of significant errors. W ACC (3) permits to establish the general cost of financing an investment project with various sources i of funding, based on the source-specific cost of capital k and the proportion w of total project funding involved. Not only does the process of raising funds with the public sector tend to differ from the market standards—thus requiring a different cost-assessment method—but also for ongoing projects, the total amount of the capital originating in the government budget is subject to potential revision due to current policies, with often unpredictable outcomes. As a consequence, the viability of a project may be at stake, should significant amounts be withdrawn.

$$W ACC = \sum_{i=1}^{n} w_i k_i \qquad (3)$$

B. Optimising Asset Allocation

A market-based method of subsidising investment projects could make investors' risk management easier and stimulate them to allocate assets more economically. Furthermore, it reduces the weight of arbitrary decisions taken on behalf of state officials. Organising the system with blockchain would also guarantee full transparency of the process for all stakeholders.

An effective investment project is one in which, in a determined period and provided the expected rate of return and cost of capital, C + RV > I. Complex schemes of subsidies, refunds, and tax exemptions currently implemented by local authorities tend to influence virtually every relevant variable in financial models. The expression of this influence in the same unit of account as market profitability leads to a confusion between the intrinsic economic sustainability of projects and the benefits due to their expected contribution to sustainable economics.

TABLE III

EFFECTS OF THE PROPOSED SOLUTION FOR INVESTMENT PROJECTS

Scenario	Improvement	Consequences
High-emissions solution	Significant	Reduced C
Expensive low-emissions technology	Significant	Increased I and RV
Cheap low-emissions solution	Significant	Increased RV
Access to investment subsidies	Moderate	Reduced k
Private-public partnership	Unclear	Reduced k and I

As a consequence, not only is the present CER price formation mechanism disconnected from environmental management expenditures but also from the costs of preventing the excessive growth of carbon emissions. The establishment of a market-based *CER pricing mechanism permits to calibrate the global CDM goals with location-specific air pollution management costs and those of investing in low-emission technologies. Consequently, the possibility to find out the break-even point between buying *CERs to pay off carbon footprint liability and selecting a specific power generation technology provides a reference for strategising investment decisions (Tab. III).

The proposed scheme does not necessarily abrogate the possibility for the government to stimulate specific types of investments, even within PPP schemes. Public funds could remain available to provide cheap financing of selected projects, just as the eventuality of joint contribution to an investment by public and private-sector agents remains in place. However, the precise definition of the new roles would make a case for streamlining the procedures concerned, and their effectiveness would become easier to assess.

Furthermore, the adoption of a clear framework for PPP investment financing and cash flow modelling brings about the simplification of operational and financial risk manage-ment. The reduction of political impact on the profitability, or even viability, of investments, introduces the element of long-term stability of conditions, indispensable in projects built with a decades-long perspective in mind. Finally, the practice of asset allocation for developing power generation infrastructure would not require the creation of ad-hoc tools but could be managed similarly as other types of investments.

VI. CONCLUSIONS

Power generation is a vital process for contemporary societies, and one characterised by enormous inefficiencies. While radical change needs proper pacing, so as to prevent the destabilisation of local economies and nefarious societal pressures. Blockchain offers an opportunity to both disrupt the PPP mechanisms and reinforce the relationship between humans and nature while contributing to raising the environmental awareness of the general public.

The increasing importance of distributed power generation makes clearly visible the necessity to reform grid management and to reevaluate the terms of cooperation between various stakeholders. Key issues include the increasing complexity of cooperation for a more efficient use of shared infrastructure and the need of better coordination of different electricity producers in order to enforce specific energy mix as well as to guarantee continuous power supply as well as other rudimentary functions of the power grid. Emerging DL technologies provide adequate frameworks for non-discriminatory and automated transactions between different types of market participants; the particular advantage of blockchain consist in the preservation of metadata.

The most notable advantages of DL-based solutions in-clude transparency, consistency, and security. All users of DL have access to identical data verified by a network consensus, although the specifics of consensus algorithms may differ. Data security depends on both cryptography and internal checks of data integrity thus bringing about a more advanced and less error-prone method than those which power com-panies and authorities supervising or regulating the market use at present. Furthermore, the entries are immutable and traceable, which facilitates to identify any irregularities as compared to using traditional tools and methods.

Another relevant benefit is the protection of private people. In the first place, they are able to see for themselves who does what to reduce carbon emissions, and how successfully. The general public also gains important tools to legally avoid funding the inefficiencies of government and large energy companies by participating in CER trade.

The proposed solution makes it possible to connect spe-cific actions with their carbon footprint. On top of educa-tional value, it also forms a more conscious attitude and stimulates to reduce one’s negative impact on the environ-ment where it is the cheapest, easiest, or most effective. The mechanism also provides a reward for those who by their discrete decisions contribute positively to reducing carbon emissions: they may be partially exempt from paying to fund the purchase of CERs by the government or electricity companies.

A final but essential advantage of the blockchain-based solution is the chance to enforce the desired energy mix more effectively by both coordinating the usage of power generation capacity form different sources in the real time, and prospectively planning the development of investments in power infrastructure. Such a disruption would not only help to streamline the transition towards a more environment-friendly energy mix while moderating the social and eco-nomic costs but also represent a milestone regarding the applications of DLs. Never before have metadata from au-tomated processes been used to determine the efficacy of infrastructural projects on a scale comparable to that of an integrated power production and distribution system.

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