Tranched Tokenised Revenue Streams as a Tool for Renewable Energy Financiers and Electrical Offtakers

Almero de Villiers, *Graduate Student Member, IEEE*, Julie Byrne and Paul Cuffe, *Senior Member, IEEE*

***Abstract*—Renewable energy generation is non-dispatchable and notably unpredictable. Furthermore, a volatile electricity spot market means vulnerability to both price and volumetric risk for generation firms. As such, project financiers may be hesitant to invest in renewable energy projects. Electrical offtakers purchase from the same spot market, and thus also suffer its uncertainty. Ideas from the world of blockchain and decentralised finance may present solutions for these cases. This paper proposes tokenised revenue streams *(RevToks)* as a novel mechanism for the electricity industry. A RevTok allows the owning party to directly claim a share of a specific generator's revenue stream. This is combined with tranching, a technique from finance where priority on a revenue flow is divided based on seniority. Project financiers hold this senior RevTok that entitles them to precedence on generator incomes, ensuring loan repayments. A case study using real-world generation, pricing, and consumption data is formulated. A market simulation is performed in the form of optimisation problem to establish an idea market equilibrium. Junior tranch RevToks can be purchased by electrical offtakers to decrease their budget variance by offsetting fluctuations in their monthly energy bill. The tranched revenue profiles of generators are demonstrated visually. For offtakers, monthly variance is universally decreased. The case study market simulations shows evidence that tranched revenue sharing arrangements show benefits for generators, financiers, and offtakers.**

I. Introduction

RENEWABLE Energy Systems (*RES*) offer environmental and sustainability benefits [2]. However, their production is notably volatile and non-dispatchable, owing to dependence on fluctuating weather patterns [2], [3]. This results in high levels of variance and thus risk in generator revenue, that may impede payments to the project financier [4]. As such, banks and other lenders are less willing to provide finance for grid-scale RES projects [5].

In response to these developments, Decentralised Finance (*DeFi*) based solutions have been suggested as a means of incentivising RES investments [6], [7]. DeFi is an emerging blockchain-based technology that has applications in the finance sector, including loans, derivatives, exchanges, insurance, and financial escrow. Constituent monetary operations can be chained together autonomously to enable novel methods of financial distribution. Blockchain and DeFi, however, have seen much debate within the world of power systems research [8]. Proponents suggest these technologies as a potential way of establishing new exotic payment methods and market structures [9]. However, detractors of blockchain often meet these ideas with due scepticism, labelling the technology as unproven and subject to hype [10]. This paper attempts to chart and articulate what a real-world application of the technology may look like.

The present paper investigates DeFi as a tool to facilitate revenue sharing methods. This is inspired by ideas from the blockchain industry, such as *Coinsilium's coded income model* [11], *Smith and Crown's revenue-sharing tokens* [12], and *Malinova et. al's revenue sharing agreement tokens*. The authors develops a novel concept in whicha tradable Non-Fungible Token (NFT) embodies an inalienable claim to a segment of a specific generator's routine electricity market revenue. This is paid out at fixed intervals by a trusted central party. The fundamental nature of electricity market remittances makes them an ideal use case for tokenisable revenue streams, thus serving as a clear topic that can demonstrate the potential value of DeFi for RES. Tokens can be exchanged freely on a dedicated exchange, similar to that currently used in cryptocurrency applications. Once these Revenue-bearing Tokens *(RevToks)* are traded, the token holder is entitled to a pro rata portion of the underlying revenue stream, and can claim the revenues from the pool market operator on a predetermined fixed basis. Having a traditional central authority oversee distribution makes this possible, and the arrangement can be implemented with a smart contract arrangement or on dedicated centralised servers.

Theoretically, a specialised RevTok can be created that represents a priority claim on generator revenues; a potentially attractive idea for financiers and other major project stakeholders worried about risk. *Tranching* presents a finance concept which, when combined with DeFi principals, may present a means of implementing such an arrangement. The term refers to the process whereby a cash flow is subdivided into several classes, divided by predetermined thresholds [13]. These act as financial securities and are labelled by seniority, with more senior tranches having priority over junior tranches for claims on portions of this revenue stream. In other words, as revenue fluctuates over time the most senior tranch will gain all revenues until its upper threshold is reached. Only when this threshold is surpassed does the next most senior tranch receive income. More sophisticated investors will typically acquire more junior tranches [13]. An example of a tranched revenue stream can be seen in figure 3.

In this paper revenue stream tranching is implemented in the form of RevToks as a tool for RES generators. This is inspired by work in [14], where rights to the electrical output of generators is divided by tranch. A unique RevTok is minted that represents the senior tranch of a specific generator's revenues. This token can theoretically be held by the project financier, acting as a lien for loan repayments. The remaining junior tranch of generator revenues thus represents monthly profits, which can in turn be tokenised and sold by generators. These revenues are then distributed pro-rata to junior tranch RevTok holders. This arrangement may increase financier confidence in continued loan repayment, making them more willing to issue funding to RES developers. The proposed arrangement is illustrated in figure 1.

A. de Villiers (amero.devilliers@ucdconnect.ie) and P. Cuffe (paul.cuffe@ucd.ie) are with the School of Electrical and Electronic Engineering, University College Dublin. J. Byrne (julie.byrne@ucd.ie) is with the School of Business, University College Dublin.

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Raw data, figures, and scripts can be viewed at [1].

As a further exploration into the usefulness of a RevTok-based arrangement, the paper examines how the system may benefit electrical offtakers. Large scale industrial electricity users, such as data centres and factories, could participate directly in the electricity spot market. Fluctuations in the spot price thus increase offtaker budget variance [15], even if a predictable load profile is maintained. These erratic monthly costs are viewed as risky in nature, and directly affect the offtaker's commodity price risk [15], [16]. To offset monthly energy bill fluctuations, a offtaker may choose to make revenue-paying investments that mitigate unforeseen electricity costs, decreasing cost variance. However, investments are subject to their own risks and unknowns [17]. Thus, an asset that is correlated to the energy spot price may present a more reliable means of counteracting high electricity prices. In the case study examined here, offtakers act as counter-parties, and can purchase RevToks from electrical generators. By holding these tokens, offtaker receive an income stream that may be beneficial in reducing the variance and thus risk of the monthly electricity cost profile. This novel arrangement is proposed as an alternative means of hedging against price risk for large-scale electrical offtakers that may be cheaper than existing methods.

This paper investigates whether the unique tranched RevToks-based environment presented above is beneficial for grid-scale generators, large offtakers, and RES financiers. This attempts to answer the questions: are tokenised revenue streams a potentially useful tool for grid-scale electrical generators? Could the system incentivise investment in RES? Is an arrangement that makes use of tokenised revenue streams desirable within an energy systems context?

The first part of this paper's case study examines monthly generator revenue profiles for large solar and wind firms. To calculate what portion of each profile becomes the senior tranch (as owned by the project financier) project cost, pay back period, and interest rate are considered. The revenue profile is thus split into the junior and senior tranches. Examining these tranched profiles serves to demonstrate how a RevToks-based system may benefit generators and project financiers. The second part of the case study is focused on offtakers. An optimisation problem is constructed that sees cases study generators most optimally purchase RevToks so as to minimise the variance of their monthly electricity cost profiles. This represents a potential market equilibrium state, serving as a demonstration of tokenised revenue streams' usefulness to electricity offtakers.

II. Assumptions

This section describes the assumptions in the workings of the system described in this paper, concluding with a summarised list.

Thus far there is no form of regulation on DeFi [18]. The present scenario assumes that all necessary legal regulation by official governing bodies is in place to make RevTok transfers and ownership lawful. Similar to existing arrangements, the system presented here sees a regulated energy pool market operator exist that settles electricity market out-turns [19], [20]. Separately to the above exists an autonomous smart contract that receives generator proceeds from the market operator. Generators could transparently opt in to this scheme, receiving cryptocurrency payments directly to their blockchain wallets[1]. Special NFTs called RevToks represent rights to claim a portion of these revenue flows and are recognised by the smart contract. Thus, regular cashflows can automatically be controlled and distributed by the smart contract. The pool market operator publicly commits to participating in this scheme, enforced by the transparent nature of the blockchain ecosystem. This arrangement is inspired by DeFi's *"code as law"* doctrine that foregoes formal regulation for pure transparency with smart contracts and ledgers that can be audited at any time. Similar to existing NFT exchanges, a novel platform exists where RevToks can be bought and sold. Figure 1 summarises the environment described here.

- A central mandatory pool market operator is in place that buys electrical generation from generators and settles revenues based on energy markets outturns [19], [20].
- Absolute, self-enforcing claims on the above-mentioned revenue streams can be partitioned and tokenised into *RevToks*. The tokens can be transferred, stored, and traded in a manner similar to existing NFTs [11], [12], [21].
- The central pool market operator directs funds (in the form of stablecoins) towards a bespoke smart contract that transparently and automatically oversees monetary distribution to financiers and RevTok holders.
- This smart contract divides the generator's revenue profile into *senior* and *junior* tranches. The senior tranch has a higher priority lien on cashflow and will typically go towards monthly project loan repayments. A special RevTok is created that represents the cashflow rights of this senior tranch. The junior tranch is tokenised into RevToks and distributed.
- There exists this platform that allows for the transfer of RevToks, and is integrated with participants' blockchain wallets so as to allow for seamlessly currency exchange.
- While in principle any stakeholder may wish to buy and hold RevToks, in this paper only simple first-party transaction between the case study generators and offtakers are considered.
- Participating generators and offtakers have the necessary hardware and software installed to tokenise, store, and transfer RevToks.
- RevTok transaction costs are negligible. This is a reasonable assumption when considering the magnitudes of electricity and RevTok costs.
- Generators and offtakers have perfect foresight. That is, all generators are aware how much revenue they and all other generators will produce in current and future periods. Similarly, all offtakers know what their energy costs will be during the considered period.
- Offtakers desire to decrease the variance of their electricity consumption profiles. The is analogous to decreasing budget variance and thus risk [15].
- Offtakers are afforded one single opportunity to purchase RevToks from generators at the start of the considered period. An actual marketplace would see continuous RevTok transactions.

III. Methodology

This section develops the methodology used in this paper. It includes the tranching method whereby generator revenues are divided into the distinct tranches, as well as the optimisation-based market simulation that sees offtakers try to minimise the variance of their electricity cost profiles by buying RevToks from generators.

[1]This paper considers a decentralised blockchain-based arrangement as case study. However, a centralised design is also a viable option.

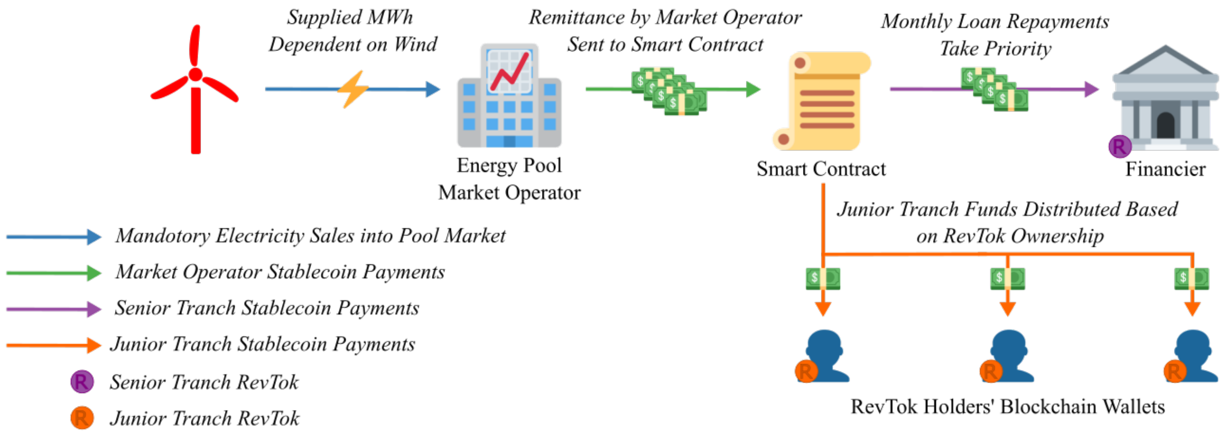

Fig. 1. Regular periodic revenue distribution schemes for electrical generators visual demonstration.

A. Generator revenue tranching

With n generators, a time series of revenues $\boldsymbol{\mathscr{R}_i}$ with τ datapoints is defined for generator i as in (1) and calculated as in (2) [2]. The term r_{it} represents generator i's revenue at time point t. This time series encompasses the entire examined period. The time series vector $\boldsymbol{g_i}$ is the generator i's electrical energy output in MWh. The time series vector $\boldsymbol{c_i}$ is generator i's energy price per MWh in €. $\boldsymbol{\mathscr{R}}$ is the sum of element-wise multiplications of vectors $\boldsymbol{g}$ and $\boldsymbol{c}$[3].

$$\boldsymbol{\mathscr{R}_i} = \left\{\mathscr{R}_{it}\right\}_{t=1}^{\tau} = \left\{r_{i1} \quad r_{i2} \quad \cdots \quad r_{i\tau}\right\} \tag{1}$$

$$\boldsymbol{\mathscr{R}_i} = \mathbf{g_i} \circ \mathbf{c_i} = \left\{g_{i1}c_{i1} \quad g_{i2}c_{i2} \quad \cdots \quad g_{i\tau}c_{i\tau}\right\} \tag{2}$$

Hence forth the term $\mathscr{R}_i$ will refer to the total sum of revenue for generator i, as in equation (3).

$$\mathscr{R}_i = \sum_{t=1}^{\tau} \boldsymbol{\mathscr{R}_{it}} \tag{3}$$

Each generator's revenue stream is now divided in to the senior and junior tranches. This division is based on the magnitude of monthly loan repayments made to the project financier. The symbol $\mathscr{L}_i$ represents generator *i's* monthly loan payment, calculated from the initial cost, interest rate, and payback period. Thus, the senior tranch is set to a baseline monthly value of $\mathscr{L}_i$. However, the case may arise where a generator's monthly generation is below this value. The generator's senior tranch gains a clawback of the outstanding amount, repaid at the soonest opportunity. If the subsequent period also sees insufficient funds for loan repayment, the required clawback value is increased and deferred. This process is illustrated in the flowchart in figure 2, with an example of a tranched revenue time series shown in figure 3. The values $\boldsymbol{\mathscr{S}_i}$ and $\boldsymbol{\mathscr{J}_i}$ will refer to matrices making up the time series of the senior and junior tranches of generator i respectively. Furthermore, $\mathscr{S}_i$ and $\mathscr{J}_i$ will refer to the total sums of the revenues in these tranches for generator i.

[2]The subscript i is the generator index, while the subscript j is the offtaker index.

[3]The symbol $\circ$ represents element-wise multiplication or Hadamard product.

B. Offtaker energy cost variance optimisation

This section describes the optimisation problem that serves as a market simulation to establish how offtakers may purchase RevToks. These offtakers attempt to minimise their electricity costs budget variance.

A time series of offtaker energy costs for m offtakers with τ datapoints is defined as in (4). The terms f_j refers to the energy usage of offtaker j at time t. Multiplying by the spot price c at time t thus results in the energy cost per time period. Hereafter $\boldsymbol{\mathscr{E}_j}$ will refer to the total sum of electricity costs for offtaker j, also shown in equation (6).

$$\boldsymbol{\mathscr{E}_j} = \left\{\mathscr{E}_{jt}\right\}_{t=1}^{\tau} = \left\{e_{j1} \quad e_{j2} \quad \cdots \quad e_{j\tau}\right\} \tag{4}$$

$$\boldsymbol{\mathscr{E}_j} = \mathbf{e_j} \circ \mathbf{c_j} = \left\{f_{j1}c_{j1} \quad f_{j2}c_{j2} \quad \cdots \quad f_{j\tau}c_{j\tau}\right\} \tag{5}$$

$$\mathscr{E}_j = \sum_{t=1}^{\tau} \boldsymbol{\mathscr{E}_{jt}} \tag{6}$$

With the tranches calculated above, generators are now free to tokenise and sell their junior tranch revenues. Offtakers buy RevToks in such a way as to attempt to minimise the variance of their costs. To calculate the optimal way as to accomplish this an optimisation problem is formulated through equations (7) to (10).

The matrix of optimisation variables $\boldsymbol{o}$, as in equation (7) represents the percentage of each generator's revenue owned by each participating offtaker. $\boldsymbol{\mathscr{O}_j}$ represents the ownership row vector for offtaker j. That is, each element of the vector represents what percentage of each generator's available junior tranch revenues is owned by the generator in question. All values in $\boldsymbol{o}$ are defined as non-negative.

$$\mathbf{o} = \begin{bmatrix} o_{11} & o_{12} & \cdots & o_{1n} \\ o_{21} & o_{22} & \cdots & o_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ o_{m1} & o_{m2} & \cdots & o_{mn} \end{bmatrix} = \begin{bmatrix} \boldsymbol{\mathscr{O}_1} \\ \boldsymbol{\mathscr{O}_2} \\ \vdots \\ \boldsymbol{\mathscr{O}_m} \end{bmatrix} \tag{7}$$

1) Optimisation constraints formulation: With the $\boldsymbol{o}$ matrix formulated, the constraints of the optimisation problem can be constructed. The first constraint in (8) assures that the optimisation never allocates more RevToks than those available i.e. those in the junior tranch of all generators. With $\boldsymbol{\mathscr{J}_i}$ as

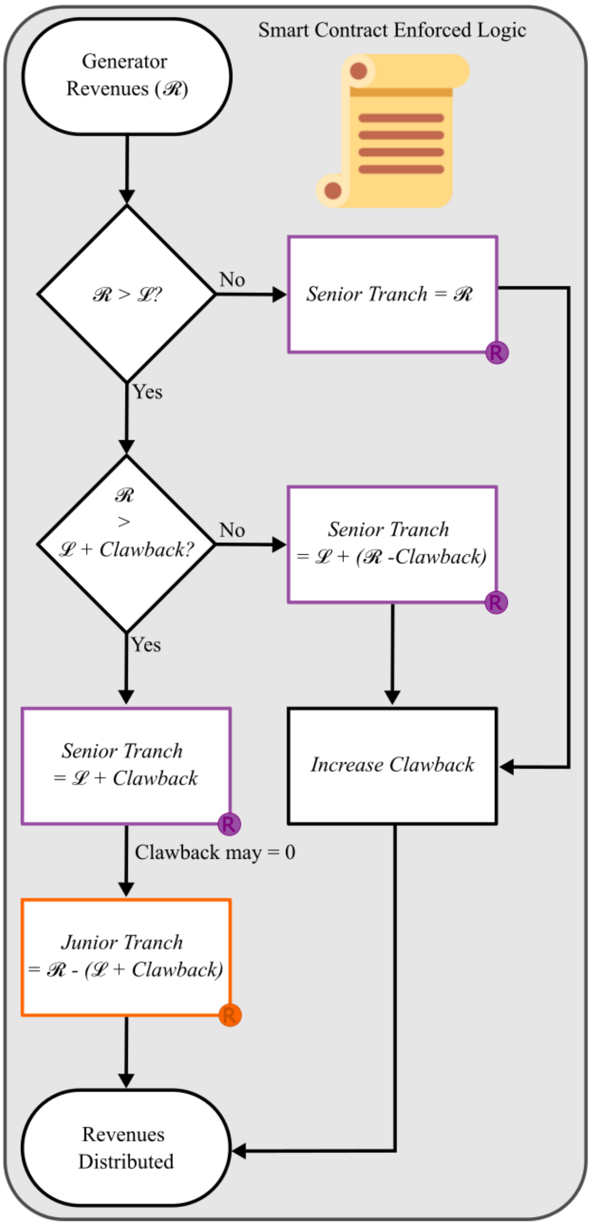

Fig. 2. Flowchart showing tranching mechanism. Tranches correspond to the relevant RevToks as in Fig. 1.

an array representing the junior tranch revenues time series of generator i, the term on the left of (8) represents the total portion if generator i's revenue allocated to all offtakers. The term on the right is simply generator i's available revenue in the junior tranch.

$$\mathcal{O}_i \circ \mathcal{J}_i \leq \mathcal{J}_i \quad \forall i \in 1, 2, \ldots, n \tag{8}$$

The next constraint ensures that no offtaker purchases RevToks worth more than their total costs. Since the price of RevToks are assumed to be equal to the total revenue attached to them in the considered period, no offtaker can gain extra capital from holding a RevTok. This is accomplished in (9). While it is possible that a offtaker would seek to more than offset their entire energy cost with RevTok revenues streams, the assumption in this formulation is that this would not occur. The left hand side of (9) represents the total RevTok revenue for offtaker j in the examined period. The vector $\boldsymbol{o_j}$ is a m-by-1 column of (7) representing what portion of each generator's available junior tranch RevToks is owned by offtaker j. The right hand side of (9) represents offtakers' total electricity cost in the same period.

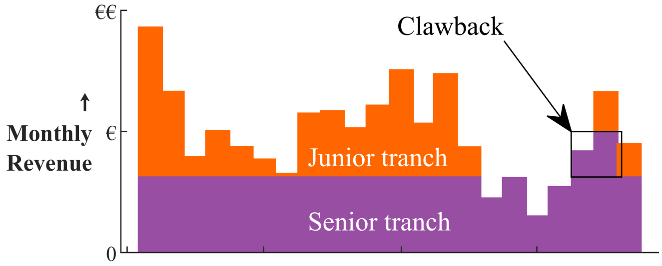

Fig. 3. Tranching example showing senior and junior tranches, as well as clawback incident

$$\boldsymbol{o_j} \circ \mathcal{J}_j \leq \mathcal{E}_j \quad \forall j \in 1, 2, \ldots, m \tag{9}$$

2) Optimisation objective function formulation: With the constraints in place the optimisation's objective function can now be constructed. All offtakers wish to purchase RevToks from generators in such a way as to minimise the budget variance of their monthly electricity costs.

The objective function is defined as in (10), formulated by calculating the variance for every offtaker and taking the sum. This is the *collusive* solution, similar to that in the work of [22]. Each unique offtaker's variance (σ^2) is divided by their maximum demand (MW_{pj}). This term is added so as to prevent the optimisation process from favouring larger offtakers when decreasing the summed magnitudes of total variance, thus ensuring fair conditions in the optimisation.

$$\min \quad \sum_{j=1}^{n} \frac{var(\mathcal{E}_j - (\mathcal{O}_j \circ \mathcal{J}_j))}{MW_{pj}} \tag{10}$$

C. Token Pricing

This methodology does not explicitly calculate the price of RevToks i.e. there is no simulated auction mechanic utilised here. Rather, the value of each RevTok is assumed to be equal to the total revenue it permits in the examined period. Thus, offtakers cannot gain monetary profit by purchasing RevToks as the additional revenue is offset by token costs. This notional simulation instead assumes that offtaker will purchase RevToks to reduce budget variance and its associated risk.

D. Coefficient of Variation

The *Coefficient of Variation (CoV)* is a measure of variability that considers the scale of the dataset, calculated by dividing the standard deviation by the mean as in (11) [23]. This measure is used in section V to quantify and compare offtaker budget variance reduction results.

$$\text{CoV} \quad = \frac{\sigma}{\mu} \tag{11}$$

IV. Test platform

This section describes the test platform and data used in this paper. The case study considers a group of wind and solar PV generators, who are free to tokenise and sell a portion of their revenue.

The generators' test dataset is made up of the time series production for four megawatt-scale wind and four megawatt-scale solar PV generators. This data comes from the Emhires dataset with an hourly resolution from 1 January 2011 to 31 December 2015 [24]. This dataset presents hypothetical generation information generated from meteorological readings measured in the respective regions. For clear comparability, the case study generators are all located in Germany and participate in the electricity spot market, settling every hour. Historical spot price data for Germany in the case study period is taken from *Energi Data Services* [25]. The monthly average spot price is shown in figure 4.

The table I shows the name, Nuts2 code, approximate location, geographical alignment, and generating technology for each generator. The labels *XL*, *L*, *M*, and *S* indicate extra large, large, medium, and small generators capacity sizes. As in table I, these size classes correspond to 10MW, 7MW, 5MW, and 2MW respectively. These maximum megawatt values are applied to the normalised dataset with an hourly data resolution to produced hourly power production values in MWh. This is then summed to monthly values. Generator legend colours are shown in table I, and are kept consistent throughout this paper. Colours are generated from [26].

Aside from the generators, the test dataset also considers 16 large-scale offtakers of varying maximum demand. Data is taken from the *ENTSO-E* data portal [27] on daily resolution. These offtakers are assumed to purchase their energy from the same electricity spot market as mentioned above. Offtaker information is shown in table II.

A simulation is performed with an optimisation problem, acting as an approximation of a potential market equilibrium. This uses the Yalmip optimisation package in the Matlab environment [28]. The objective function in (10) is non-linear, and thus Matlab's FMinCon nonlinear iterative solver is used to find a feasible solution.

V. Results

This section discusses the results of the case study examined in this paper. It shows the tranching mechanism results for generators and market simulation results for offtakers.

A. Tranching Results

This section shows how the senior and junior tranches are formulated for electrical generators. A minimum portion constituting the monthly loan repayments is withheld from each generator's revenue profile. In cases where revenue drops below this threshold, the senior tranch is increased in subsequent months to make up the shortfall This is demonstrated above in Fig. 2 and 3. The novel smart contract automatically performs this action, making for reliable loan payments. Results are shown in Fig. 5.

It can be observed that some generators realise a larger junior tranch, while other less-profitable generators, such as W-S-M, struggle to consistently produce enough revenue to meet loan repayment thresholds. Generator W-S-XL only sees a clawback scenario once in the considered period. In contrast, generator PV-S-XL, a solar generator with an equal megawatt rating, must clawback proceeds after every winter to make loan payments.

B. Market Simulation Results

This section discusses the results of the optimisation problem. These results represent how offtaker purchase RevToks so as to reduce their budget variances i.e. the variances of their monthly energy costs.

Fig. 6 shows a heatmap of the amount of revenue exchanged between offtakers and generators. These represent the purchases of RevToks, as well as the magnitude of revenue generated from these RevToks for each offtaker. Offtaker costs are higher during the initial months when the electricity spot price is higher (as in Fig. 4). As such, the most popular purchase is W-S-XL, which shows sizeable profiles during this period and is thus an ideal tool to offset the high costs. This effect can be seen with other wind generators, as well as PV-S-L and W-S-M. Interestingly, even generator W-S-M, that shows less profits over the examined period, is a common investment amongst offtakers. This is again due to incomes during the initial high-cost period.

The treemap in Fig. 7 show the magnitude of electricity costs covered by generator RevToks for each offtaker. The sizes of each of the greater rectangles represents the total magnitude of each offtaker's electricity costs, while the colour-coded interior portions represent the fragments offset by RevTok revenues from generators. This figure shows that no offtaker chooses to largely offset their bill with RevToks. Rather, they choose to only remove some of the local maximum to achieve a less volatile monthly cost profile. As RevTok trading costs are negligible offtakers aren't penalised for holding a diverse portfolio of revenue sources.

Table III shows offtaker variances before and after RevToks are purchased. That is, the *before* case is simply the monthly variance of offtaker energy costs, while the *after* case is the monthly variance of their new energy cost profile that includes proceeds from generator RevToks. Results are shown as offtaker CoVs for easy comparability between offtakers of different scales. A general improvement can be observed over all offtakers, although less apparent in larger offtakers.

Fig. 10 shows histograms of all 16 offtakers with and without the RevTok revenue contributions, included as a demonstration of how variance is universally improved. All offtakers distributions can be observed to move towards the mean (μ) when RevToks contribute to their electricity costs. For the examined example, offtaker 1's histogram reinforces the information in Fig. 8.

Fig. 8 compares the monthly cost profiles for offtaker 1, examined here as an example. By holding generator RevToks the offtaker offsets some of their electricity costs. Thus, a *With RevToks* and *Without RevToks* plot is show. The prior shows offtaker 1's original energy costs per month. The latter shows their total energy costs but excludes the portion offset by RevTok incomes. The new curve is visibly less volatile, reinforcing results in table III.

Fig. 9 shows offtaker 1's RevTok monthly incomes during the examined period. Colours correspond to the legend in table I, indicating the source of those revenues. During summer periods the red portions from PV generator RevToks are more prevalent, while during winter the blue wind generator RevToks. Furthermore, the total resulting curve is seen to decrease the volatility of the *With RevToks* curve in Fig. 8. For instance, the increase in costs during winter 2012 are *"smoothed out"* by RevTok contributions from wind generators in this time. When compared to 8, the optimisation can be observed to minimise the effect of local maximum peak costs throughout the considered period.

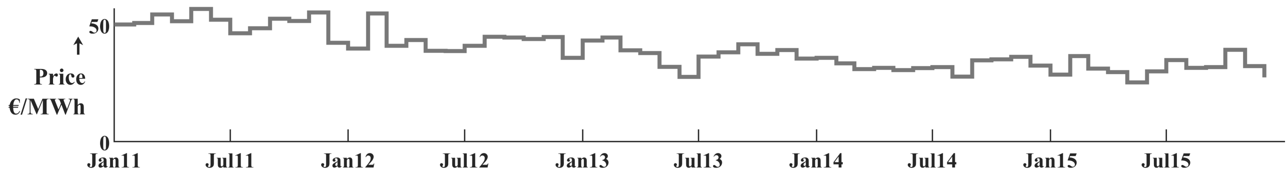

Fig. 4. Monthly average spot price

TABLE I.
Case Study Generators

Name	Legend Colour	Approx. City	Area	Nuts2 Code	Mean Monthly Revenue	Tech.	Size	Capacity	Monthly Loan Payment
W-S-XL		Hamburg	North	DE60	54.6 k€	Wind	XL	10 MW	21.0 k€
W-S-L		Dresden	East	DED2	28.8 k€	Wind	L	7 MW	14.7 k€
W-S-M		Munich	South	DE21	16.6 k€	Wind	M	5 MW	16.8 k€
W-S-S		Bonn	West	DEA2	9 k€	Wind	S	2 MW	4.35 k€
PV-S-XL		Munich	South	DE21	32.6 k€	PV	XL	10 MW	21.8 k€
PV-S-L		Bonn	West	DEA2	24.9 k€	PV	L	7 MW	15.2 k€
PV-S-M		Hamburg	North	DE60	18.9 k€	PV	M	5 MW	10.9 k€
PV-S-S		Dresden	East	DED2	7 k€	PV	S	2 MW	4.35 k€

TABLE II.
Case Study Offtakers

Name	Max Demand	Mean Monthly Cost
Offtaker 1	10 MW_p	€9144
Offtaker 2	10 MW_p	€9101
Offtaker 3	10 MW_p	€8740
Offtaker 4	9 MW_p	€7757
Offtaker 5	9 MW_p	€7096
Offtaker 6	8 MW_p	€6087
Offtaker 7	7 MW_p	€6063
Offtaker 8	6 MW_p	€5158
Offtaker 9	5 MW_p	€3453
Offtaker 10	5 MW_p	€4835
Offtaker 11	4 MW_p	€3221
Offtaker 12	3 MW_p	€3005
Offtaker 13	3 MW_p	€3004
Offtaker 14	2 MW_p	€1975
Offtaker 15	2 MW_p	€1947
Offtaker 16	1 MW_p	€961

TABLE III.
Offtaker CoV Results

Name	Monthly CoV Before	Monthly CoV After
Offtaker 1	0.21	0.19
Offtaker 2	0.23	0.21
Offtaker 3	0.24	0.22
Offtaker 4	0.24	0.23
Offtaker 5	0.27	0.24
Offtaker 6	0.26	0.25
Offtaker 7	0.24	0.23
Offtaker 8	0.24	0.23
Offtaker 9	0.29	0.28
Offtaker 10	0.23	0.19
Offtaker 11	0.28	0.27
Offtaker 12	0.20	0.17
Offtaker 13	0.20	0.17
Offtaker 14	0.20	0.17
Offtaker 15	0.20	0.17
Offtaker 16	0.20	0.17

VI. Conclusions

The unpredictable nature of RES sources results in inconsistent revenue flows for renewable energy firms. This may act as a hindrance in the procurement of project backing, as financiers may be unsure if loan payments could be guaranteed seniority in the application of project proceeds. Blockchain and decentralised finance technologies present a potential means of applying an autonomous lien to revenues so as to guarantee debt is repaid with priority.

Similarly, large-scale electrical offtakers are vulnerable to fluctuations in their monthly energy costs, owing to the sporadic nature of the electricity spot market. As such, they may seek to decrease their cost variance and thus the associated risk. This can be accomplished through external investments, but these are subject to their own risks and fluctuations. A revenue-paying asset that is correlated to the energy spot market price may be a means of offsetting some of the risk associated with monthly spot price-based electricity bills.

Ideas from within the sphere of blockchain and decentralised finance present a novel means of distributing project revenue for energy firms. This paper examines a speculative arrangement whereby generators are able to tokenise a portion of their revenue stream into Revenue Tokens (RevToks). The electricity generated by these firms is sold to the central energy pool market operator, as in traditional arrangements. This entity publicly commits to offering compensation in the form of cryptocurrency stablecoins, a negligible change in their current operating model. These stablecoins are sent to a smart contract that observes RevTok ownership and automatically distributes payments to token owners. This arrangement thus results in recurrent payments to RevTok owners and generators alike. RevToks embody a self-enforcing right to a claim on a portion of the associated cash flow, and can change hands on a dedicated token exchange. This right is guaranteed by the transparent nature of blockchain and smart contracts, and the associated *"code as law"* ecosystem. This paper attempted to show that such

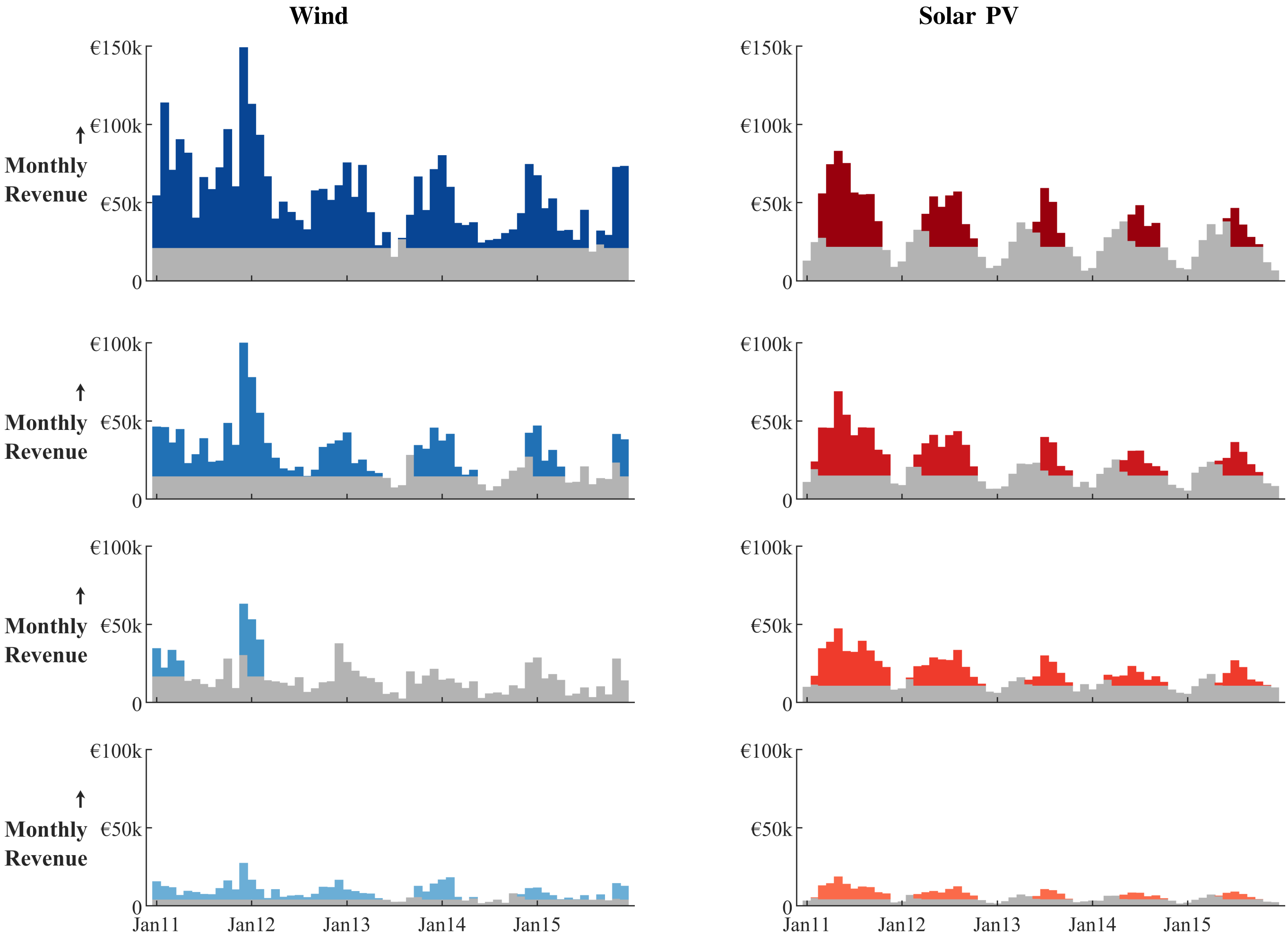

Fig. 5. Tranched generator profiles showing monthly revenues. Blue and red sections represent junior tranches, while grey represents senior tranches. Colours are consistent with the legend in table I.

a smart contract arrangement allows downstream opportunities that improve the business environment for renewable energy firms, accomplished with only minor changes to the existing practice of pool market operators.

Loan payment priority can be guaranteed when tokenised revenue streams are combined with tranching, a concept whereby a cashflow is subdivided by seniority. That is, more senior tranches have priority, and are first in line to benefit from revenues when an income stream is fluctuating. Tranches are divided based on predefined threshold values. Theoretically, a special RevTok can be minted that represents the most senior tranch of a generators revenue stream. This token exists in the blockchain wallet of the relevant generator financier, granting them a claim on revenue that precedes all others. The magnitude of this potential claim is calculated from the required monthly payments the generator is bound to.

This paper examined the use of the tokenised revenue arrangement described above as a potential tool for large-scale electrical generators, energy financiers, and electrical offtakers. It examined if a RevTok arrangement is desirable within an electrical energy markets context. As a worked use case scenario, the present paper attempted to show how novel tokenised revenue streams could allow electrical generators to reduce risk to financiers by allowing them a claim on the senior tranch of tokenised revenue. The system automatically initiates a clawback scenario when the senior tranch upper threshold isn't met, and loan payments are not made in full during a particular month. The senior tranch is increased by the outstanding amount in the subsequent month, rolling over if the scenario repeats. The resulting profiles indicate that some generators are far more profitable than others. Solar PV generators often fail to meet the minimum threshold required for loan repayment during winter months, but the increased profits in summer months allow this to be rectified.

The paper then examined tokenised revenue streams as potentially useful for electrical offtakers. These offtakers partake in the electricity spot market, and are subject to fluctuations in their monthly energy costs. This, in turn, results in a high budget variance (and thus risk) for offtakers. By holding RevToks they can decrease the variance of their monthly bills, effectively lessening the associated risk. The offtakers examined in the case study were found to largely offset months when costs are higher with RevTok revenues, resulting in universal improvements in the variance of their monthly electricity bills. These results thus present evidence of tokenised revenue streams' usefulness as a tool for renewable energy firms, financiers, and electrical offtakers, and builds the case for central pool market operators to facilitate such an arrangement.

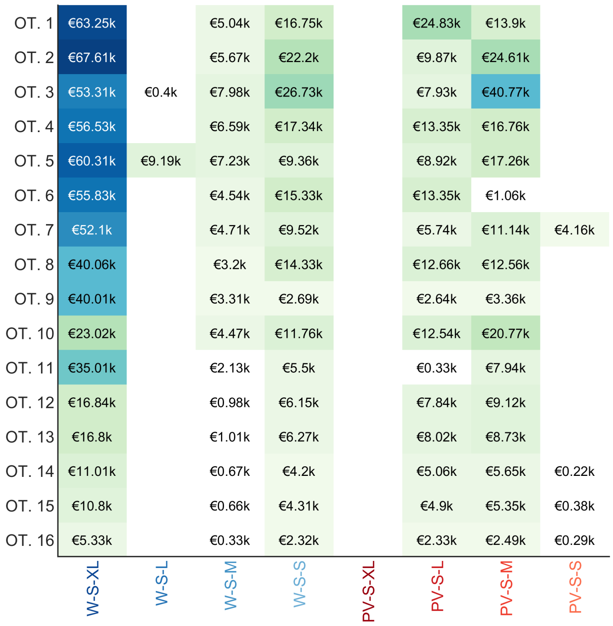

Fig. 6. Exchanges between offtakers (*OT*s) and generators. The magnitude of revenues gained from RevToks is assumed to be equal to the price they are purchased for.

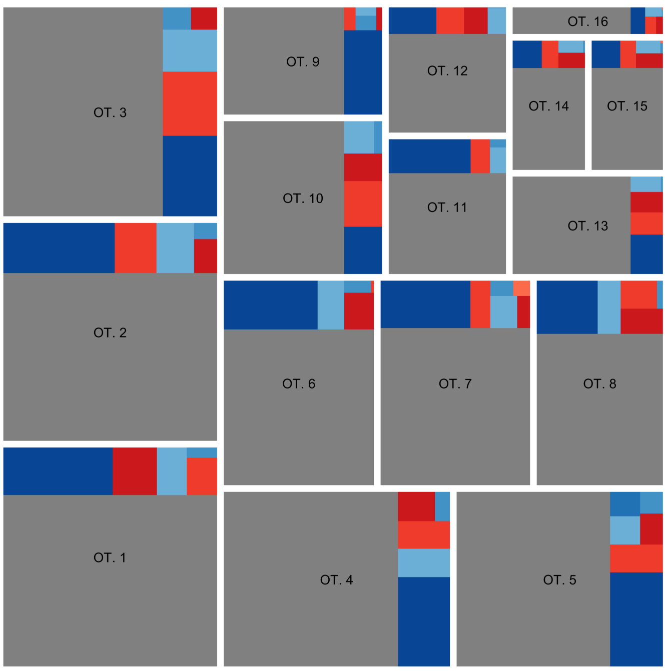

Fig. 7. Treemap of offtaker (*OT*s) costs magnitudes and portions displaced by RevTok revenues

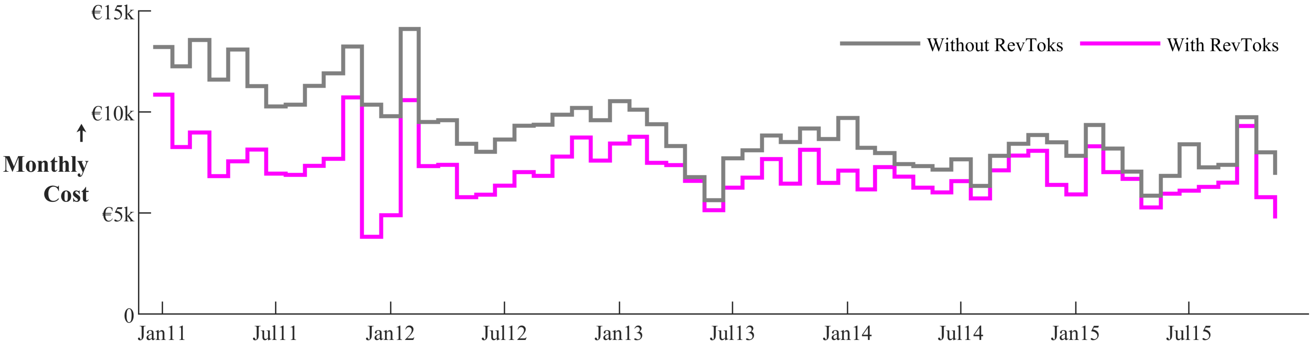

Fig. 8. Offtaker 1 monthly cost profile before and after RevToks revenues are included

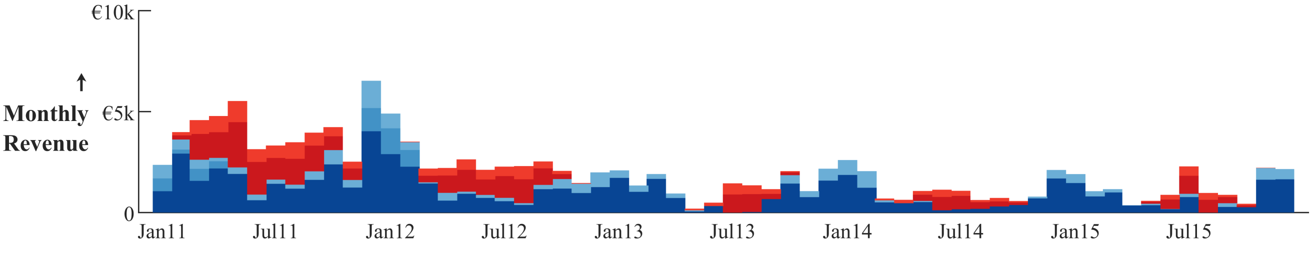

Fig. 9. Offtaker 1 monthly revenues from generator RevToks

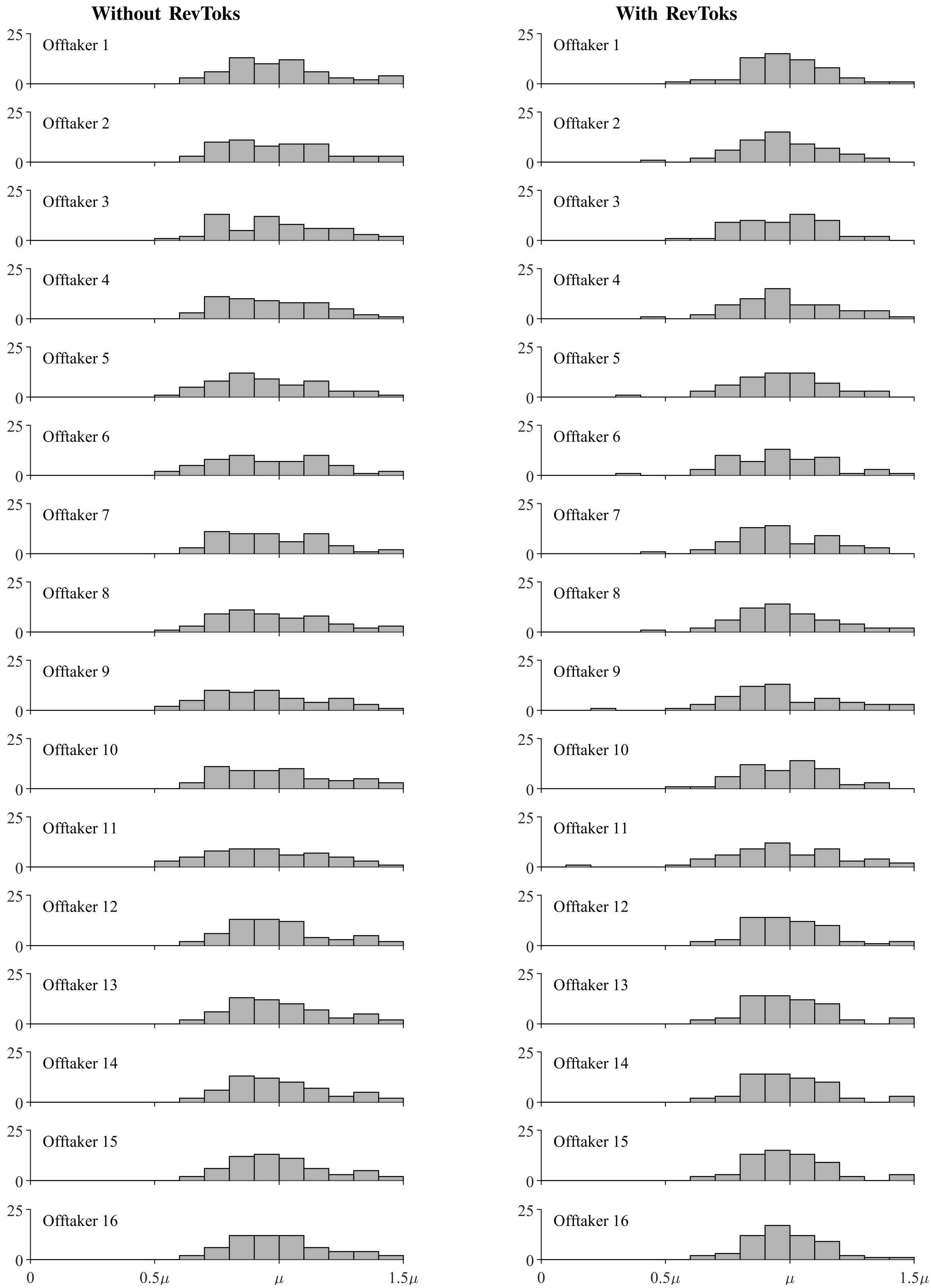

Fig. 10. Histograms of offtaker monthly costs in € normalised by mean

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