# Building a Sustainable Future: A proposed technology solution for demand response management based on blockchain in smart grid

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**ABSTRACT**

Smart grid technology is gathering significant attention, as the world transitions to cleaner and more sustainable energy systems in order to gradually tackle climate change. The critical requirement for rapid decarbonization has led to a reduction in the usage of fossil fuels and the integration of zero-carbon renewable energy sources, electric vehicles and heat pumps. As a result, the complexity of electricity grids has increased, rendering the balance between electricity supply and demand vital. Demand response is an effective solution to this challenge, allowing Electricity Distribution Network Operators (EDNOs) to manage electricity demand during peak hours and incentivizing consumers to reduce electricity demand. This paper proposes a blockchain-enabled demand response technology solution that leverages smart contracts to automate communication between EDNOs and consumers with smart electricity meters. The approach based on Blockchain technology ensures security, reliability and transparency of transactions and the two-way flow of information between stakeholders. The proposed system allows EDNOs to set dynamic pricing signals that motivate consumers to time-shift their energy demand, contributing to the stability of the electricity grid. Furthermore, the solution provides tools to monitor and optimally manage the electricity consumption of Households and SMEs (Small and Medium-sized Enterprises) through a user-friendly and gamified cloud-based platform, utilizing demand response algorithms.

**KEYWORDS**

Blockchain, Demand Response Management, Demand Response, Smart Contract, Smart Grid

## 1. INTRODUCTION

The effects of climate change are increasingly visible. Heatwaves, drought wildfire, flooding and hurricanes have gotten more severe and more frequent (Trenberth, 2018). In addition, the impacts of climate change have now been tracked in every ecosystem on Earth (Scheffers et al., 2016). To tackle climate change, global greenhouse gas (GHG) emissions must be reduced in the coming decades. (Trenberth, 2018). In 2022 it was observed that global CO2 emissions from energy combustion and industrial processes a rose to new all-time high of 36.8 gigatons (Gt), with 40% of emissions coming from electricity and heat generation and 21% from transport (IEA, 2023). Therefore, the global transition to zero-carbon renewable energy sources (RESs) for electricity generation and the increase in the use of heat pumps and electric vehicles (EVs) are essential for the protection of biodiversity over the year. According to Peirelinck (2022), the integration of renewables will lead to volatility in electricity supply and the electrification of heating and transport will dramatically increase electricity demand, both of which can lead to problems of instability in grid operation.

In this context, smart grid technologies offer a way to evolve towards a cleaner electricity grid that is more energy efficient and sustainable, and to meet the challenges of integrating a growing number of RESs and increasing demand. (Kim et al., 2019). Based on Clastres (2011) the Smart Grid (SG) can be defined as "electricity networks that can intelligently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies''. SG provides two-way communication between suppliers and consumers, advanced metering infrastructure, smart meters, load balancing and unauthorize usage detection, as well as detecting and recovering from faults (Saleem et al., 2019). Smart metering and bi-directional communication enable a much more dynamic, reactive pricing mechanism that takes into account the variability of renewables in real time, opening up new opportunities for Demand Response (Saffre and Gedge, 2010).

Demand Response (DR), is an integral part of the SG and encourages consumers to make more efficient choices about electricity demand (Siano, 2014). DR programs aim to balance supply and demand by changing when electricity load is used by giving reward/punishment incentives to consumers (Hao et al., 2016). More specifically, if there is an increase in demand that cannot be supplied, there will be incentives to reduce electricity consumption, and if there is surplus green energy production from RES, there will be incentives to consume at that time. Vardakas et al. (2014) and Vázquez-Canteli and Nagy (2019) suggest the use of intelligent DR algorithms based on reinforcement learning to improve efficiency in DR project. According to Junaidi et al. (2023) a DR program faces a number of challenges, such as transparency of data measurement, reliability of the central database and violation of user privacy. The use of blockchain technology can address these issues by providing a transparent and secure ledger of program data, thereby increasing trust and encouraging consumer acceptance and participation. Blockchain is a distributed ledger that consists of a chain of data packets (blocks), where a block contains multiple transaction information (Nofer et al., 2017). Further, smart contracts, which are self-executing contracts using blockchain technology, can be used to achieve reliable transactions and agreements between different parties in the smart grid (Merrad et. al, 2022). The potential for tokenization is another benefit of using the blockchain. This makes it possible to convert the value of participants' actions in a DR program into marketable units of account, called tokens.

In this paper, the authors propose an integrated technological solution by presenting a DR program that leverages cutting-edge technologies such as smart metering, intelligent DR algorithms, Blockchain and Smart Contract in one cloud-based platform. The main stakeholders of the proposed solution are Electricity Distribution Network Operators (EDNOs), providing them with a valuable tool that will contribute to grid stability and load balancing, and Households and SMEs, enabling them to consume electricity in a more environmentally friendly and at the same time cost effective way. The proposed technology aims to promote the active participation of low-voltage electricity consumers in a smart grid that is resilient, secure, and produces affordable and green electricity. It also serves to highlight the benefits of green energy and the application of demand response management. The massive participation of consumers is crucial for the successful implementation of the proposed solution, therefore the platform will be user-friendly and will use gamification techniques. Gamification, which is "the use of game design elements in non-game contexts to improve user experience and user engagement, loyalty and fun" (Richter et al., 2015), has been shown to contribute to the achievement of the above objective.

For the implementation of the proposed solution to have a significant impact and value, the right conditions are required, i.e. consumers with smart meters and a market with a choice of dynamic pricing. Dynamic pricing is a method by which retail electricity prices change throughout the day by passing at least some of the volatility of wholesale prices to consumers. Its implementation would have high added value in microgrids that are either solely based on renewable energy or are located in isolated areas, such as small islands, where blackouts occur frequently.

## 2. THE PROPOSED SOLUTION

The proposed solution involves the development of an integrated demand response platform that runs on a cloud server and mobile devices, exchanging information between stakeholders and IoT devices. User interface (UI) runs in a mobile application and in a web browser. Citizens and SMEs, hereafter referred to as Users, will be able to efficiently monitor and control their electricity consumption through the platform. Users will need to give permission to use their smart meter data and provide information about their dynamic pricing program, if there is not a universal program for all consumers.

The proposed system will receive real-time data from Users and EDNO on the supply and demand of the grid, the consumption of each User and the price of electricity, in the case of a microgrid the price of electricity is not necessary. This data will be stored in a database where it will be analyzed by an intelligent DR algorithm. The algorithm will also have access to data from specific models that are accurate predictors of supply and demand on a daily basis. Under the analysis of the algorithm, dynamic signals will be sent to consumers to time-shift their electricity consumption. The data from the dynamic signals and the User's response to them will be stored on the blockchain, and smart contracts will be executed based on it. Blockchain and smart contracts will be used to automate the communication between Users and EDNO with absolute transparency and security. In addition, smart contracts will be used to regulate the distribution, transfer and redemption of tokens. The platform will reward Users with tokens based on how much they adjust their consumption and follow the DR concept. In this way, Users will have an additional incentive to participate more actively in the ecosystem. On the other hand, EDNO, local authorities and the government have a strong interest in adding value to the token (by offering discounts on bills, fees and taxes) as it contributes to the stability and sustainability of the grid. In addition, businesses could receive tokens for discounting their products or services. This will allow the contracting businesses to increase their social responsibility and advertise for free on the platform. Furthermore, the use of tokens based on Smart Contact technology provides the EDNO with an additional tool to offer tokens to Users for immediate consumption reduction. This tool can further reduce prices by keeping the marginal cost low and help prevent blackouts.

The user's interaction on the platform will be in a gamified environment. The User will be able to watch short educational videos, on the benefits of renewable energy and demand response, and will be asked to answer comprehension questions in a gamified format. There will also be consumption targets, the achievement of which will be rewarded with additional tokens for the User. In addition, the proposed platform will optionally enable the provision of a Smart Home Hub that will allow consumers to remotely control the use of their electrical appliances and consumption. Moreover, Users can access the platform through the smart home hub to optimally manage a portion of their electricity consumption within the limits they set. For example, the consumers will set the electric vehicle to charge and specify that within the next 12 hours he wants to charge his vehicle for 3 hours, and the platform's algorithm will decide when the consumption occurs. In Figure 1, a schematic of the proposed solution is presented.

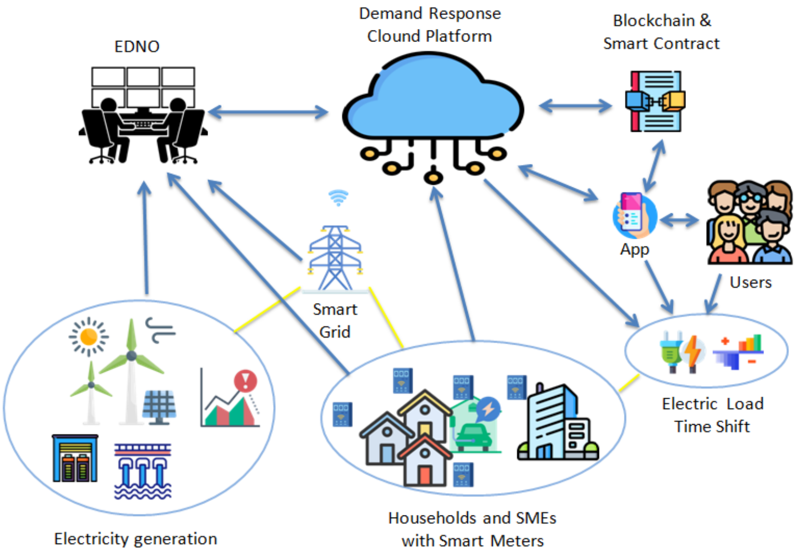


Figure 1. The proposed technology solution

The authors are currently reviewing the system's technological performance and key fundamentals, assessing its technical viability, and looking for potential ideas for upgrades. Their future goal is to create a small, but fully customized and pilot-tested Proof of Concept [POC] of a First of a Kind [FOAK] integrated product service and business model including:

- A cloud-based platform and user-friendly application.
- The intelligent DR algorithm, which analyses the data and sends dynamic signals to Users.
- A suitable mechanism for storing dynamic signals in the blockchain and transmitting them via smart contracts.
- A new calculator of the value of the User's response to dynamic signals, capable of determining, in real time, the impact of the response to grid stability and its environmental footprint.
- An advanced system for securely storing and tokenizing User responses, using blockchain and smart contract.
- An integrated system for remote control and management of electricity consumption.
- A gamified system can increase User participation and promote the environmental benefits of green energy and demand response.

## 3. PURPOSE OF THE PROPOSAL SOLUTION

In this section, a hypothetical and simplified example will be described in order to have a better understanding of how the proposed system will work and its benefits. During a sunny day where it is predicted that there will be an excess of energy produced by the PV systems during the noon hours, that the renewable energy production will not be sufficient to meet the demand during the afternoon hours, while during the other hours of the day there will be a balance between supply and demand, with hydropower acting as a balancer. Depending on whether there is a shortage or surplus of electricity, the price of electricity will fluctuate dynamically. Users will be able to be informed through the application about the price of electricity per hour according to three categories of consumption divided by different colors: green hours (surplus energy), yellow hours (balance) and red hours (shortage energy). The goal of the platform is to influence demand and shift consumption from red hours to green hours as much as possible. Therefore, during red and green hours, the algorithm will send users a dynamic signal through the app to increase or decrease their consumption. Users will have an obvious financial incentive to adjust their consumption, as the price of electricity will be lower during green hours, and they will also be rewarded with tokens. They will therefore have additional environmental, social and indirect economic benefits that are not so obvious. As, during the red hours, when RES production does not cover demand, there are three options: first, a blackout with severe social consequences; second, the use of fossil fuels with environmental consequences; and third, the use of electricity from storage, such as batteries and pumped storage. In a society that does not use fossil fuels, the third option is the only acceptable option because it allows for flexibility in consumption. However, for every additional MWh that must be stored, there is an increase in costs due to losses and depreciation on the huge investments required for these projects, and an environmental footprint due to the construction of the projects.

## 4. CONCLUSION

The proposed solution aims to change the way electricity is consumed by promoting the concept of Demand Response and aims to be an end-to-end solution to address the challenges of volatile renewable energy production and demand growth. This will ensure the resilience, sustainability and efficiency of the Smart Grid and enable faster decarbonization, which will make a significant contribution to the fight against climate change. The proposed solution exploits Blockchain and Smart Contract technology in Demand Response Management to increase the transparency and reliability of transactions and to ensure the security of the data in the bidirectional flow of information between consumers and EDNO. In addition, the gamified environment enhances the user experience and the token-based reward logic increases the level of active participation. The proposed solution accelerates the transition to a sustainable future without the use of fossil fuels for electricity generation, and empowers households and SMEs to advocate for balancing supply and demand, with significant social, environmental and economic impact.

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**REFERENCES**


Clastres, C., 2011. Smart grids: Another step towards competition, energy security and climate change objectives. Energy policy, 39(9), pp.5399-5408.

Hao, H., Corbin, C. D., Kalsi, K., & Pratt, R. G. (2016). Transactive control of commercial buildings for demand response. IEEE Transactions on Power Systems, 32(1), 774-783.

IEA (2023), CO2 Emissions in 2022, IEA, Paris https://www.iea.org/reports/co2-emissions-in-2022, License: CC BY 4.0

Junaidi, N., Abdullah, M. P., Alharbi, B., & Shaaban, M. (2023). Blockchain-based management of demand response in electric energy grids: A systematic review. Energy Reports, 9, 5075-5100.

Kim, S. C., Ray, P., & Reddy, S. S. (2019). Features of smart grid technologies: an overview. ECTI Transactions on Electrical Engineering, Electronics, and Communications, 17(2), 169-180.

Merrad, Y., Habaebi, M. H., Toha, S. F., Islam, M. R., Gunawan, T. S., & Mesri, M. (2022). Fully Decentralized, Cost-Effective Energy Demand Response Management System with a Smart Contracts-Based Optimal Power Flow Solution for Smart Grids. Energies, 15(12), 4461.

Nofer, M., Gomber, P., Hinz, O., &Schiereck, D. (2017). Blockchain. Business & Information Systems Engineering, 59, 183-187.

Peirelinck, T., Kazmi, H., Mbuwir, B. V., Hermans, C., Spiessens, F., Suykens, J., &Deconinck, G. (2022). Transfer learning in demand response: A review of algorithms for data-efficient modelling and control. Energy and AI, 7, 100126.

Richter, G., Raban, D. R., &Rafaeli, S. (2015). Studying gamification: The effect of rewards and incentives on motivation. Gamification in education and business, 21-46.

Saffre, F., &Gedge, R. (2010). Demand-side management for the smart grid. In 2010 IEEE/IFIP Network Operations and Management Symposium Workshops (pp. 300-303). IEEE.

Saleem, Y., Crespi, N., Rehmani, M. H., & Copeland, R. (2019). Internet of things-aided smart grid: technologies, architectures, applications, prototypes, and future research directions. IEEE Access, 7, 62962-63003.

Siano, P. (2014). Demand response and smart grids—A survey. Renewable and sustainable energy reviews, 30, 461-478.

Vardakas, J. S., Zorba, N., &Verikoukis, C. V. (2014). A survey on demand response programs in smart grids: Pricing methods and optimization algorithms. IEEE Communications Surveys & Tutorials, 17(1), 152-178.

Vázquez-Canteli, J. R., & Nagy, Z. (2019). Reinforcement learning for demand response: A review of algorithms and modeling techniques. Applied energy, 235, 1072-1089.