Integrating Ecovisor into Mosaik Co-Simulation

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Abstract—

I. Introduction

THE surge of cloud platforms has had a significant impact on many businesses and individuals, offering access to innovative and valuable applications that frequently require significant computational resources. A notable example for this is represented by OpenAI's chat generative pre-trained transformer (ChatGPT) cloud platform, which is based on the GPT-3 model developed by Brown et al. [1] and achieved more than a million users within the first five days of its launch [2]. The increasing demand for more computational power has lead cloud platforms to become an essential part of the digital landscape [3]. These platforms allow for the storage, processing and management of large amounts of data and computational resources, which can be used to run applications and services that are beyond the capabilities of traditional hardware systems.

However, while the growth of cloud platforms has brought many benefits, it has also raised concerns about their environmental impact. As the demand for computational resources increases, so does the carbon emissions generated by the energy consumption of these platforms [4]. Despite their ecological impact, the growth of cloud platforms shows no signs of slowing down. According to Gartner Inc. worldwide end-user spending on public cloud services is forecasted to grow 20.7% to total $591.8 billion in 2023 [5]. To mitigate their impact on the environment, cloud platforms are now looking for ways to reduce their carbon footprint [6, 7]. It is imperative to adopt cleaner energy sources for powering data centers, both in the cloud and at the edge.

Although clean energy offers numerous advantages, it is perceived as being unreliable due to two key factors. One, the generation of renewable energy sources such as solar and wind is affected by environmental changes, and two, the carbon-intensity of grid power fluctuates as the grid uses different types of generators with varying carbon emissions to meet demand [8]. The field of computing possesses a distinct advantage in terms of reducing its carbon impact through the utilization of cleaner energy sources [9]. However, current cloud applications are unable to apply these benefits to optimize their carbon efficiency. This is because the energy system obscures the instability of clean energy with a reliability abstraction, which gives no control or visibility into the energy supply. As a result, applications cannot adjust their power usage in response to changes in the availability and carbon-intensity of renewable energy [10].

Souza et al. [10] proposed a solution to this issue by creating an "Ecovisor", which virtualises the energy system and provides software-based control over it. This Ecovisor enables each application to manage the instability of clean energy through software, customized to meet its unique requirements. However, even their small-scale prototype is intricately designed and incorporates several expensive components, such as a DC power supply equipped with a solar array simulation capability that costs almost $10,000.

Though the creation of the Ecovisor is a promising solution to the issue of reducing the carbon footprint of cloud platforms, a large scale prototype for research and development purposes would not only be significantly cost intensive, but also time consuming. An alternative approach to consider is to simulate *only* the Ecovisor infrastructure with real applications as a Software-In-The-Loop (SIL) implementation. This would allow for the optimization of energy usage in response to changes in the availability and carbon-intensity of renewable energy, without the need for a physical implementation. By simulating the Ecovisor, applications can still manage the instability of clean energy through software, but at a lower cost and with less time investment.

To this end, we propose the utilization of a co-simulation tool, Mosaik, to integrate this Ecovisor simulation into, and evaluate its impact on the carbon footprint of cloud platforms. Mosaik is a simulation framework for power systems, communication networks, and building automation, which can be used to model and analyze the performance of the Ecovisor in real-world applications [11].

In the following sections of this article, we will commence by presenting the necessary contextual information in Section II to ensure comprehension of our methodology. This includes co-simulation environments with Software- (SIL) and Hardware-In-The-Loop (HIL) methodologies, the Mosaik co-simulation tool and a closer examination of the Ecovisor infrastructure and its interface to applications. We will then review some related literature with similar approaches in Section III. Finally, we present our approach of integrating the Ecovisor into Mosaik in Section IV. The approach is divided into the simulation of the Ecovisor itself and the interface to external applications, beyond the scope of the co-simulation. We evaluate our approach in Section V with exemplary data, representing a realistic scenario that covers all edge cases. After discussing future research directions related to this article in Section VI, we conclude this article in Section VII by summarizing the main points and contributions.

II. Background

A. Co-Simulations and SIL / HIL

Co-simulations are used to model and analyze complex systems with multiple interacting components, each of which
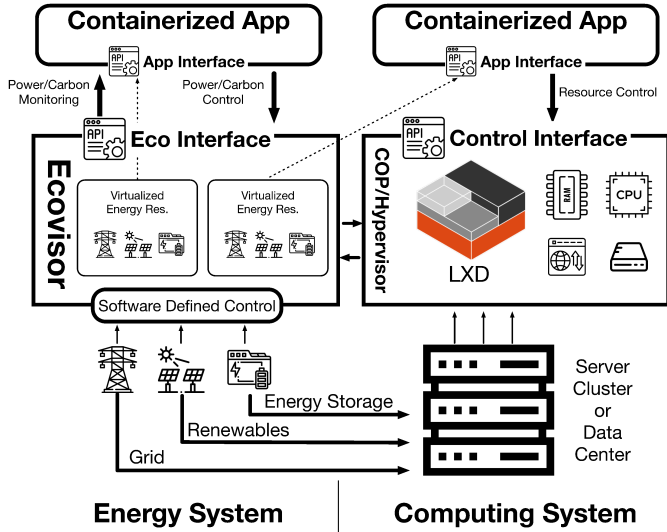
Figure 1. Ecovisor Design (Souza et al.) [10]

Figure 2. System Design

may have different properties and behaviors. They involve combining simulation models from different domains, such as control, power, and thermal management, to create a unified model that accurately represents the behavior of the overall system.

One of the main advantages of co-simulations over regular simulations is their ability to capture the interactions between different components of the system. Regular simulations often make simplifying assumptions that can lead to inaccurate results. Co-simulations, on the other hand, can account for the interactions between components and provide a more accurate representation of the system's behavior. This makes co-simulations particularly useful for designing and optimizing complex systems like datacenters. The virtual environment can save time and resources, reduce the risk of failure, and lead to more efficient and sustainable datacenters. Furthermore, co-simulations can help identify potential problems and bottle-necks in the system, allowing to address them before they become major issues.

B. Mosaik

C. Ecovisor

III. RELATED WORK

In research and development processes, the utilization of physical testbeds is a widespread practice [12, 13]. They serve as a medium for testing and evaluating new technologies, systems, and products prior to their market launch or further development. However, some scenarios and conditions may not be feasible or safe to recreate in a physical testbed. Simu-lations can provide a controlled and cost-effective environment for testing such scenarios and conditions [14]. When specific physical or software components require a certain degree of realism though, simulations or co-simulations with SIL or HIL methodologies can effectively address these limitations.

For instance, Beilharz et al. [15], introduce Marvis, a framework that provides a comprehensive staging environment
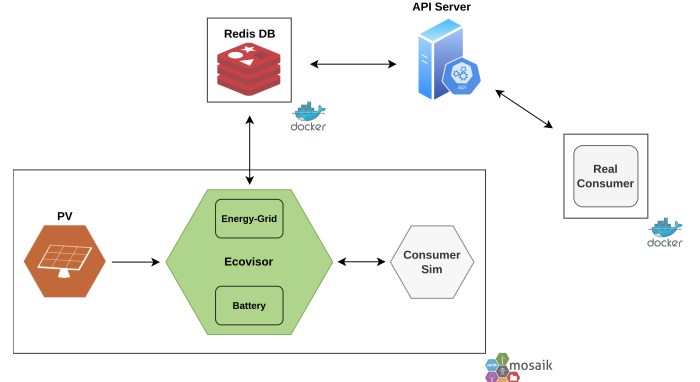
for testing distributed IoT applications. Marvis orchestrates hybrid testbeds, co-simulated domain environments, and a central network simulation to create a representative operating environment for the system. However, Marvis does not provide a virtualized energy system, which is crucial to meet the requirements of our problem statement.

Hagenmeyer et al. [16] investigate the interplay of different forms of energy on various value chains in Energy Lab 2.0. The focus is on finding novel concepts to stabilize the volatile energy supply of renewables through the use of storage systems and the application of information and communication technology tools and algorithms. The smart energy system simulation and control center is a key element of Energy Lab 2.0 and consists of three parts: a power-hardware-in-the-loop experimental field, an energy grid simulation and analysis laboratory, and a control, monitoring, and visualization center. While this smart energy system simulation is similar to the simulated Ecovisor in our approach, the control center is the only entity with software-based control over this energy sys-tem. The Ecovisor infrastructure, however, provides multiple applications with the ability to manage their energy supply themselves which is an essential factor for our approach.

In conclusion, to the best of our knowledge, there is no current approach that can simulate an energy system virtualizer with software-based control, comparable to the Ecovisor, with SIL capabilities.

IV. APPROACH

A. Simulation of the Ecovisor

B. Interface to External Applications

V. EVALUATION

VI. FUTURE WORK

While our approach focused on a single simulation of the Ecovisor, our use of Mosaik demonstrates its effectiveness for large-scale smart grid simulations. In future research, we suggest interconnecting multiple Ecovisor systems to share resources and further reduce carbon emissions. This network could be distributed across different geographic regions, as carbon intensity varies depending on location. By incorpo-rating carbon information services like Electricity Maps [17], this could enable carbon-efficiency optimizations such as Let's

Wait Awhile [18] or Cucumber [19] from Wiesner et al. This would enhance the potential for carbon reduction at a larger scale.

VII. Conclusion

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