Green Intelligent Content Rendering Paradigm

A.A. Periola
Department of Electrical, Electronic and Computer Engineering
Cape Peninsula University of Technology
periolaa@cput.ac.za

A.A Alonge
Department of Electrical, and Electronics Engineering Technology
University of Johannesburg
aalonge@uj.ac.za

K.A Ogudo
Department of Electrical and Electronics Engineering Technology
University of Johannesburg
kingsleyo@uj.ac.za

***Abstract*— Multi-media content rendering is an important computing intensive task required for multi-media content generation. The content rendering is executed aboard ground based data centres. The operation of terrestrial data centres is inefficient when a significant amount of power is expended on cooling alongside a high-water footprint (WF). This results in a high-power usage effectiveness (PUE). The high PUE, and WF can be reduced via the use of alternative freely cooled data centre such as the underwater data centre. The research proposes render workload migration strategy enabling an underwater data centre to execute the render workload. Furthermore, the underwater data centre hosts mini - nuclear reactors that enhance its power accessibility instead of only relying on highly variable renewable energy resources in the underwater environment. Performance evaluation shows that the use of the PUE, and accessible power is improved by proposed approach by an average of 26.5%, and 63.8%, respectively.**

Keywords – Non – terrestrial platforms ; multimedia content ; rendering ; energy access.

I. INTRODUCTION

Data centres play an important role in next–generation cloud integrated radio access networks. This is because it hosts content that subscribers seek to access via mobile and wireless communication networks. The quest to minimize the operational costs (cooling costs) has led to the consideration of hosting future data centres in non–terrestrial locations. In this regard, the locations that have been identified are the stratosphere [1–2], underwater [3–4], and space [5–6]. The citing of the future data centre in non – terrestrial locations has also received attention in initiatives such as EU ASCEND [7 – 8], Project Natick [9], Subsea Cloud [10], and Highlander [11].

The provisioning of power to enable non–terrestrial data centre functioning is of important concern. The data centre in the terrestrial environment have been recognized to have a significant power consumption and pose a load to the conventional terrestrial grid. The use of non–terrestrial data centres shouldn't lead to increased load on the power grid. The use of underwater based non–terrestrial data centres is recognized to benefit from underwater renewable energy [12–13]. Therefore, there is significant consideration as regards reducing the reliance of underwater data centres on the grid.

Alternatively, data centres in the underwater data centres can also be powered via interactions with mini–grids that are powered by renewable energy farms. In this regard, the use of offshore based wind power farms, onshore based wind power farms, and terrestrial based solar power farms are most suitable. However, the use of energy from these renewable power farms has challenges related to energy access.

The access challenge arises due to the need to connect significant cable length from the central entity of the renewable energy power farm to the sub–ocean-based data centre. The requirement of significant cable length causes the use of underwater data centre to become cost prohibitive. Nevertheless, the use of an alternative energy source to variable underwater renewable energy is required.

The choice of the alternative energy source should consider the incorporation of mobility in underwater data centres. The research in [14] recognizes the need to incorporate mobility features in underwater data centres. The rationale for this feature inclusion is the need to make underwater data centres performance robust to underwater seismic events.

A suitable energy source that is suitable in this regard is one that enables the underwater data centre to meet the challenges of overcoming the variability of the underwater renewable energy sources while recognizing the need to host mobility is required. An energy source that is recognized to meet this requirement is nuclear. Nuclear energy has been recognized to be suitable for future data centres. The study in [15–19] proposes that future data centres should host nuclear reactors. In this case, the use of mini–nuclear reactor arrays to provide an alternative power source. The alternative source is intended to be beneficial for the submarine data centre.

Furthermore, the deployment and use of underwater data centres is intended to deliver value across multiple applications. The specification of the applications that benefit from the high compute capacity of the underwater data centre is of importance. This is because operators need to deploy the underwater data centre to provide value to realize revenue generation. An important application area that should be considered is multi–media content rendering. Multi–media content rendering is recognized to be computing intensive [20–21]. The deployment of underwater data centres with environment friendly operation and their use in rendering enabling the realization of green underwater rendering.

Computing platforms play an important role in the generation of multimedia content. This is because they provide computing resources to enable the rendering of frames that have been aggregated as scenes in multimedia content production, and editing. The process of content rendering is computing intensive given that a multimedia content comprises millions of frames.in a case where the frame length is in the order of tens of milliseconds, and the multimedia file is more than 1 hour long. The increased amount of multimedia content has enabled the increasing adoption of online content download, and streaming. Therefore, the execution of content rendering is computationally intensive and requires access to computing platforms. Given the high-water footprint (due to the necessity of using water for data centre cooling) associated with computing platform usage it is important that content rendering is environmentally friendly.

The problem being addressed in the paper is the design of a rendering framework that is environment friendly i.e., reducing the water footprint associated with terrestrial render farm cooling ; and also enhancing the power efficiency by improving the power usage effectiveness (PUE). In the existing use of terrestrial data centres i.e., terrestrial render farms, the power being provided for operation also meets the cooling requirement and is not totally available to the server payload for rendering. This reduces the power efficiency. An approach that reduces the amount of power expended on cooling and increases the power available to the server for workload rendering is beneficial. The research proposes using underwater computing platforms as a content renderer alongside an oversubscribed terrestrial render farm. The

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terrestrial render farm is a cluster of servers aboard a terrestrial data centre facility. The research contributions are:

1) First, the research proposes the green multi– media content rendering. Green multi–media content rendering is the development of animated content in a manner that considers the realization of environment friendly content rendering i.e., green rendering. In the green rendering paradigm, it is important to design an architecture (and supporting mechanisms). The concerned architecture enables performance data exchange and interaction between the terrestrial data centre (with terrestrial render farm), and the underwater data centre (with underwater render farm). The interaction enables the use of the underwater render farm when the terrestrial data centre is observed to have an increasing power usage effectiveness profile i.e., high operational overhead.
2) Second, the research proposes an intelligent switching solution for the power subsystem of the underwater data centre. The intelligent switching solution determines the power source used in enabling function execution in the underwater data centre. The proposed intelligent solution considers the profile of the underwater renewable energy source i.e., output of the onboard underwater wave generator. It classifies the profile as increasing, stable, and decreasing. The profile classification results enable the activation of nuclear reactors hosted in the underwater render farm.
3) Third, the research formulates the power usage effectiveness with and without the incorporation of the proposed green multi–media content rendering. In addition, the presented research formulates the operational power accessible to the underwater data centre (underwater render platform) with and without the incorporation of the proposed mini – nuclear reactors. The concerned formulation is presented in a mobile underwater data centre. In addition, the presented presents the performance evaluation results concerning the power usage effectiveness (PUE), and the accessed power.

The rest of the presented research is structured as follows. Section II presents the proposed green multi–media content rendering paradigm. Section III focuses on the intelligent solution incorporated into the power subsystem of the underwater data centre (underwater render farm). Section IV formulates the performance metrics of the power usage effectiveness (PUE), and the accessible power. Section V describes the results of performance evaluation as obtained via MATLAB simulation. Section VII is the conclusion.

II. GREEN RENDERING PARADIGM

The green rendering is deemed necessary due to the significant increase in the number of animated multimedia content on the internet [22–23]. Each animated multimedia content on the internet is realized via the execution of content rendering. Content rendering is crucial for the realization of animated content regardless of the length (short, medium, or long). Currently, animation content rendering is executed aboard terrestrial render farms i.e., cluster of servers located aboard terrestrial data centres.

The use of terrestrial render farms for the computing intensive task of rendering as expected utilizes power and computing resources. This leads to non–optimal power usage effectiveness in terrestrial data centres. The use of terrestrial render farms is initialized by the submission of a render workload and accompanying instructions. The submission is done by multimedia content producer (MCP). The submission of the render workload, alongside instructions can be done by multiple MCPs. Each MCP has access to the terrestrial render farm via a high-speed internet gateway. The content to be rendered has varying lengths i.e., duration. The rationale for this consideration is the need to accommodate heterogenous render workload in the proposed scenario. However, all render workloads are accepted by the computing platform service provider. Render workload execution is done in a first in first out manner. The computing platform also has resources capable of enabling concurrent render workload execution.

The realization of green rendering requires the monitoring of the environmentally friendly status of the terrestrial render farms hosting a significant number of servers. In this case, the parameters of interest are the PUE and the water footprint (WF). The consideration of the WF arises as the terrestrial render farm uses water for cooling its server payload. An increasing PUE, and WF presents a profile which implies that the terrestrial render farm has a high-water consumption (for cooling purposes), and that a significant proportion of the supplied power is expended on operational tasks that are not related to server operation. A profile described by a low PUE and high WF also signifies that a high volume of water is used for the cooling of the terrestrial render farm focused servers within the terrestrial data centre. The use of the terrestrial data centre for content rendering becomes challenging when the profile indicates a high PUE and WF across different server clusters (clusters form the terrestrial render farm) for a long duration. A long duration high PUE, and WF across multiple server clusters for multiple MCPs signifies long duration high water consumption and inefficient power usage.

In the case where the long duration operational profile for a high demand render farm, the solution of workload migration becomes necessary. The necessity of the workload migration is to ensure power efficient, and environment friendly operation. A plausible solution is to execute workload migration to another terrestrial data centre (with a hosted render farm). However, the discussion has not considered such an approach. The non–consideration is because of the relatively high use and demand for terrestrial data centre services.

In green multi–media content rendering paradigm, the terrestrial data centre hosts an entity which checks the validity of the operational status when there is high PUE and WF in the terrestrial data centre (and terrestrial render farm). The concerned entity is called the operational profile monitoring entity (OPME). The OPME acquires data on the power expended by the servers and the components of other data centre subsystems. In addition, the OPME receives data on the volume of water used in the course of the operation of the terrestrial data centre in a given duration. The concerned duration is the same as that used in the computation of the PUE.

The OPME is linked to the workload migration signaling entity (WMSE). In its function, the WMSE determines which ongoing rendering workloads are transmitted to the underwater data centre (underwater render farm). The workloads to be migrated are described by their contextual information. The concerned contextual information is the: (1) proportion of completed rendering, and (2) required computational resources. In its function, the WMSE considers that workloads with a low proportion of completion should be migrated alongside their contextual information.

The workloads with a high proportion of completion are not migrated as they are scheduled to be completed. A completion threshold enables the differentiation of rendering workloads as having low or completion proportion given a non – computing resource constrained context. In the case of the terrestrial render farm, and the underwater render farm, rendering workloads are kept in a buffer till there is availability of computing resources. The introduction of the role of buffer is deemed appropriate as content rendering is delay insensitive considering the duration between MCP initialization and the desired time of content viewing by subscribers. The terrestrial render farm communicates with the underwater render farm via the internet gateways. Access to the underwater render farm is via an offshore station accessible via the internet. The station is connected to the underwater render farm via optic fibre cable (high speed).

The network and associated architecture are presented in Figure 1. In Figure 1, the terrestrial data centre comprises several clusters of servers, each having own OPME. Each of the OPME is connected to the WMSE. The WMSE is linked to the internet gateway enabling communication with the shore-based station. The shore-based station is linked to the underwater data centre via a high–speed enabling fibre optic link. It is connected to underwater data centres. Each underwater data centre has an identifier that is known to the WMSE. In executing its functionality, the WMSE selects the underwater data centre (described by its identifier) that has the highest proportion of workloads with the lowest proportion of completed rendering workloads.

The relations influencing render workload migration are presented in Figure 1. The OPME is a data specific entity that monitors the WF and PUE of the concerned data center. The detection of a high PUE and WF by the OPME indicates non-environment friendly operation of the concerned terrestrial data centre. The OPME communicates with the WMSE to indicate the initialization of render workload initially being executed aboard the terrestrial data centre. The WMSE signals the external gateway which is linked to the shore-based station. The shore-based station provides the WMSE with the identifier of the suitable underwater data centre. The suitable underwater data centre is one having the highest amount of idle computational resources.

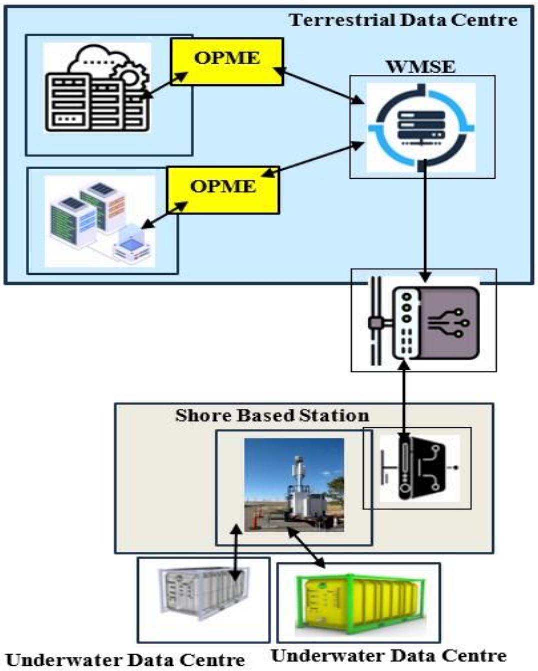

Figure 1: Interacting entities in the green multi–media content rendering paradigm.

The flowchart showing the execution of tasks by the OPME and WMSE is presented in Figure 2.

III. INTELLIGENT POWER SOLUTION

The underwater data centre accesses two power sources i.e., the underwater renewable energy source (accessible via wave generators), and mini nuclear reactors. The use of the conventional grid is not used because of the need to reduce its load and energy insecurity. The use of renewable energy sources in the underwater environment is subject to high variability from the dynamics of the marine environment. This implies that the ability of underwater renewable energy to yield a significantly high-power output is limited. Therefore, an alternative energy source that is able to yield a consistent high-power output is required. In the presented research, the alternative energy source is realized from a mini–nuclear reactor.

In the event that the onboard battery is nearly depleted, the use of an alternative power source is required. In the proposed underwater data centre (render farm), the underwater renewable energy system operates in two modes. These modes are the active, and dormant modes. The underwater renewable energy system is charging the onboard battery and accesses the underwater currents in the dormant mode. Active mode operation of the underwater renewable energy system is one in which there are significant accessible underwater renewable energy sources.

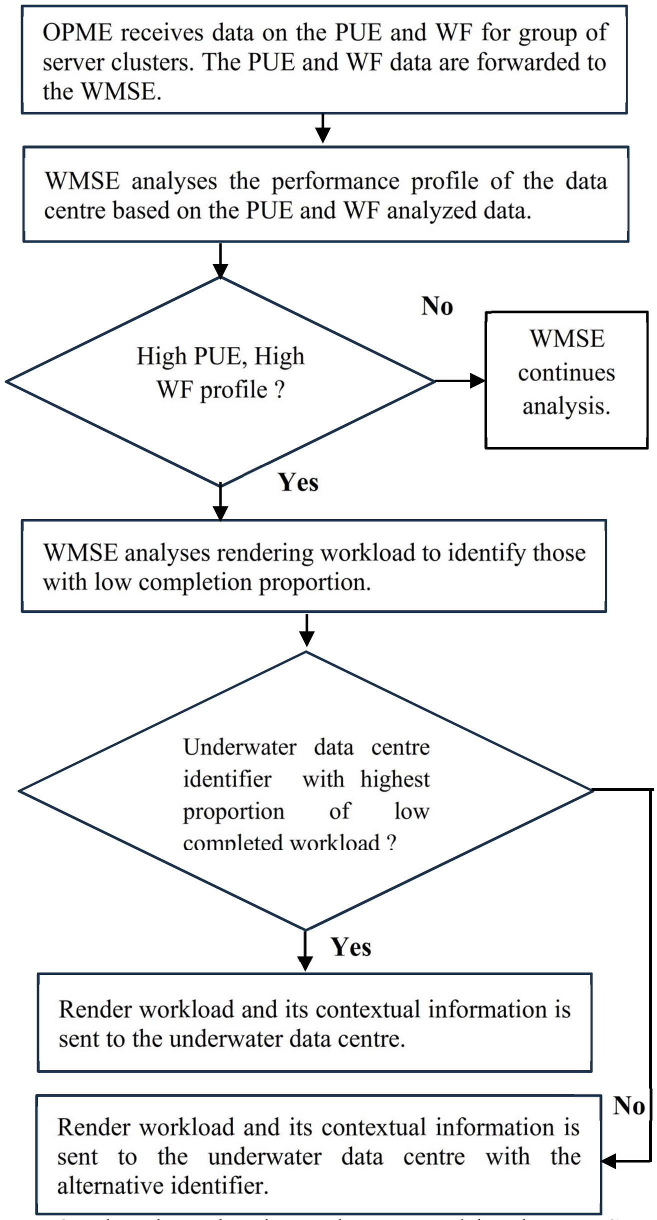

Figure 2: Flowchart showing tasks executed by the WMSE during multi–media content rendering workload migration.

In the active mode, there is appreciable underwater current, and the battery is being charged at a higher rate than in the dormant mode. In the underwater renewable energy system active mode, the mini– nuclear reactor is in dormant mode and does not actively provide power to enable underwater render farm operation. In the case where the underwater renewable energy source is in the dormant mode, the mini–nuclear reactor is in the active mode. Therefore, the mini–nuclear reactor provides power to enable the operation of the underwater render farm when the underwater energy source is in dormant mode. The use of the underwater renewable energy system is accompanied by the execution of a transition from its dormant mode to the active mode. Another important transition that occurs is that which involves moving from the active mode to the dormant mode. Both transitions are associated with the underwater renewable energy system being in the near active mode. The role of the near active mode is crucial during the transition from active mode to the dormant mode.

A long duration near active mode is one in which the underwater renewable energy system has access to appreciable energy (though not its maximum). In this state, the occurrence of a long duration implies a slower depletion of the onboard battery's power resources. In the alternative i.e., dormant mode to active mode transition, the occurrence of the near active mode implies a gradual realization of the maximum power output from the underwater renewable energy system.

In the proposed system, only the long duration near active mode is important. The occurrence of the short duration and medium duration near active mode are less important. This is because of the implied low amount of energy accessible when the transition period is fast as implied. The relations showing the dormant mode, active mode and near active mode are presented in Figure 3. In addition, the power subsystem of the underwater data centre (render farm) is presented in Figure 4.

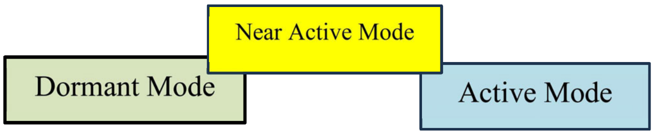

Figure 3: Relations between the concerned modes in the underwater computing platform's renewable energy system.

The power subsystem being proposed in the presented research is shown in Figure 4. In the proposed underwater data centre i.e., underwater render farm, provides power to the computing system (which completes the rendering job), cooling system, and the communication system (which executes information exchange with the shore-based station).

The power subsystem comprises two power sources i.e., the mini–nuclear reactors where the power output of each mini–nuclear reactor is fed into the nuclear system entity (NSE). The total power in the NSE is fed into the power supply selection entity. In addition, the power subsystem hosts underwater turbines generating energy from wave generators. In this case, the output of the wave turbine generators is used to charge batteries in an array i.e., pool configuration. The output of the array pool is fed into the power supply selection entity.

In the system model and architecture shown in Figure 4, the power supply selection entity analyses the power output from the battery pool. The power analytic entity (PAE) is associated with the renewable power source. The PAE conducts the analysis of the output of the renewable power source. The considered analysis is intended to classify the renewable power source as being in the dormant mode, active mode or near active mode. It also conducts analysis of the output related data aiming to determine the validity of the long duration in the near active mode. The renewable power source is selected by the power supply selection entity when the PAE's classification output implies an active mode or long duration near active mode. In the case where the PAE indicates that the output renewable power source is classified as dormant mode, or short duration near active mode, the power supply selection entity utilizes power derived from the nuclear power source i.e., onboard mini nuclear reactors.

IV. PERFORMANCE FORMULATION

The performance model associated with the use of the proposed solution is formulated and presented in this section. The formulated performance metrics are the: (1) PUE, (2) Accessible Power, and (3) Functioning Duration.

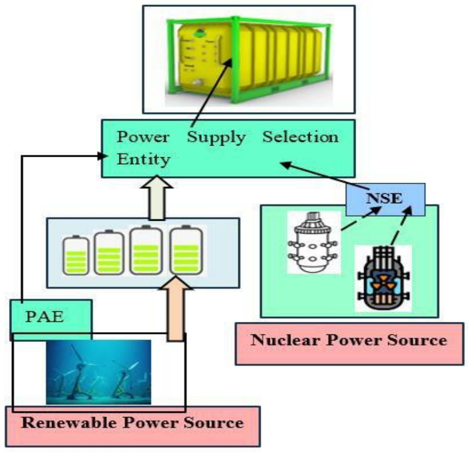

Figure 4: Power subsystem in the proposed underwater data centre (render farm).

The PUE for the terrestrial render farm and the underwater render farm at the epoch $t_y, t_y \epsilon\, t, t = \{t_1, t_2, \ldots, t_Y\}$ are denoted $\gamma_{ter}(t_y)$, and $\gamma_{und}(t_y)$, respectively. In the formulation, the underwater data centre (render farm) benefits from the free cooling environment of the marine environment. In the terrestrial render farm, and the underwater render farm, the increase in the PUE is at the epoch t_y are denoted $\theta_{ter}(t_y)$, and $\theta_{und}(t_y)$, respectively. In the existing case, the mean PUE of the data centre (render farm) realized via the terrestrial data centre is denoted ϑ_1 and given as:

$$\vartheta_1 = \frac{1}{(Y-1)} \sum_{y=1}^{Y} \gamma_{ter}(t_y)\left(1 + \theta_{ter}(t_y)\right) \quad (1)$$

Furthermore, the PUE is also formulated. In the proposed case, the render farm is realized using data centres (with server clusters) in the terrestrial and underwater environment. In this case, the PUE ϑ_2 and given as:

$$\vartheta_2 = \frac{1}{(Y-1)} \sum_{j=1}^{2} C_j \quad (2)$$

$$C_1 = \sum_{y=1}^{Y-P} \gamma_{ter}(t_y)\left(1 + \theta_{ter}(t_y)\right) \quad (3)$$

$$C_2 = \sum_{y=1}^{P} \gamma_{und}(t_y)\left(1 + \theta_{und}(t_y)\right) \quad (4)$$

In formulating the accessible power, let α_1 and α_2 denote the set of underwater renewable power source elements (underwater turbines), and nuclear power source elements (mini – nuclear power reactors) such that:

$$\alpha_1 = \{\alpha_1^1, \alpha_1^2, \ldots, \alpha_1^M\} \quad (5)$$

$$\alpha_2 = \{\alpha_2^1, \alpha_2^2, \ldots, \alpha_2^N\} \quad (6)$$

The power output of the m^{th} underwater turbine $\alpha_1^m, \alpha_1^m \epsilon\, \alpha_1$ and the n^{th} nuclear power source $\alpha_2^n, \alpha_2^n \epsilon\, \alpha_2$ at the epoch $t_y, t_y \epsilon\, t, t = \{t_1, t_2, \ldots, t_Y\}$ are denoted $P(\alpha_1^m, t_y)$, and $P(\alpha_2^n, t_y)$, respectively. The power output from the power sources α_1^m, and α_2^n at the epoch t_y have constancy factor that is denoted as $\beta(\alpha_1^m, t_y)$, and $\beta(\alpha_2^n, t_y)$, respectively. A high constancy factor is considered beneficial. It signifies that the output of the concerned power source is fairly high and also constant i.e., non–rapidly varying. A low constancy factor is not beneficial. It signifies that the output of the concerned power source is highly variable. In the performance formulation, the relations between the parameters $\beta(\alpha_1^m, t_y)$, and $\beta(\alpha_2^n, t_y)$ is descried as $\beta(\alpha_2^n, t_y) > \beta(\alpha_1^m, t_y)$. In the case of the existing case where the underwater data centre (render farm) utilizes only marine sub–surface renewable energy farm, the power accessible to the underwater data centre (render farm), P_1 is:

$$P_1 = \sum_{y=1}^{Y} \sum_{m=1}^{M} P(\alpha_1^m, t_y)\beta(\alpha_1^m, t_y) \quad (7)$$

The discussion also considers the proposed case. In the proposed case, the underwater data centre (render farm) uses the marine sub–surface renewable energy farm power source alongside the onboard mini–nuclear reactor power source. The power accessible to the underwater render farm, P_2 is:

$$P_2 = \sum_{i=1}^{2} A_i \quad (8)$$

$$A_1 = \sum_{y=1}^{Y} \sum_{m=1}^{M} P(\alpha_1^m, t_y)\beta(\alpha_1^m, t_y) \quad (9)$$

$$A_2 = \sum_{y=1}^{Y} \sum_{n=1}^{N} P(\alpha_2^n, t_y)\beta(\alpha_2^n, t_y) \quad (10)$$

The functional duration is formulated considering that the concerned data centre (render farm) utilizes multiple servers. Let the set of servers be given as ς such that:

$$\varsigma = \{\varsigma_1, \varsigma_2, \dots, \varsigma_Q\} \quad (11)$$

For the purposes of the performance modelling, the power consumed per second by the server aboard the terrestrial and underwater render farm is assumed known and utilized. The power consumed per second by the q^{th} server $\varsigma_q, \varsigma_q \epsilon \varsigma$ at the epoch t_y is denoted $P(\varsigma_q, t_y)$. The functional duration in the existing and proposed case are denoted Γ_1, and Γ_2, respectively.

$$\Gamma_n = P_n \left(\sum_{y=1}^{Y} \sum_{q=1}^{Q} P(\varsigma_q, t_y) \right)^{-1} \quad , n \epsilon \{1,2\} \quad (12)$$

V. PERFORMANCE EVALUATION

This section presents the performance evaluation results for the proposed mechanism. The performance evaluation is done via MATLAB simulations. The simulation parameters are presented in Table 1. The performance evaluation has utilized the methodology of quantitative analysis via simulation. The simulation parameters have been considered in a manner that ensures a conservative determination of the performance benefits. For example, the power output value is in the order of tens of kW. In addition, the PUE evaluation considers different cooling system performance and power usage in the concerned computing clusters. Hence, there is a wide range in the PUE values used in the simulation.

In the simulation parameters presented in Table 1, the underwater render farm (data centre) has a better PUE performance than the terrestrial render farm (data centre). This is because of the reduction in power spent in cooling underwater render farm due to the free cooling environment of the ocean. In addition, there is a significant increase in the terrestrial environment in comparison to the underwater data centre. This approach has been considered to make a case for the initiation of the workload migration.

Furthermore, the discussion has not examined the functional duration. This is because it can be inferred that the functional duration in (12) in the existing case and proposed case has the common factor of the power consumed per second by the server. Hence, the improvement in the accessible power directly gives a measure of the improvement in the functional duration.

In addition, a conservative approach has been adopted in evaluating the accessible power by the underwater data centre. The power derived from the renewable energy source exceeds that of the nuclear power source in the simulation. However, the renewable energy source has a lower constancy factor due to its higher variability in comparison to the nuclear power source (a higher constancy factor). The results on the PUE and the accessible power are in Figures 5, and 6, respectively.

The result In Figure 5 focuses on the PUE performance associated with the use of the proposed approach. In this case, a low PUE indicates enhanced power efficiency in comparison to a high PUE. It can be seen that the proposed approach has a lower PUE figure than the case associated with the existing approach. Therefore, the use of the proposed approach improves power efficiency. Analysis of the presented results shows that the PUE is enhanced by 26.5% on average.

In addition, the results on the power accessible is presented in Figure 6. It can also be seen that the use of the proposed approach (incorporating nuclear power) is beneficial. The benefit arises because of the inclusion of multiple power sources. In this case, analysis shows that the use of the proposed mechanism enhances the accessible power by 63.8% on average.

Table 1: Performance Evaluation Parameters.

S/N	Parameter	Value
	PUE Related Performance Evaluation	
1	Number of Analytic Epochs	25
2	Maximum PUE Terrestrial Data Centre	0.1914
3	Minimum PUE Terrestrial Data Centre	8.3526
4	Mean PUE Terrestrial Data Centre	4.0255
5	Maximum PUE Underwater Data Centre	0.0504
6	Minimum PUE Underwater Data Centre	1.4530
7	Mean PUE Underwater Data Centre	0.7037
8	Minimum Increase in Terrestrial Data Centre PUE	0.12 %
9	Maximum Increase in Terrestrial Data Centre PUE	95.77 %
10	Mean Increase in Terrestrial Data Centre PUE	51.00 %
11	Minimum Increase in Underwater Data Centre PUE	2.32 %
12	Maximum Increase in Underwater Data Centre PUE	59.63 %
13	Mean Increase in Underwater Data Centre PUE	29.71 %
	Accessible Power Related Performance Evaluation	
14	Minimum Nuclear Power Output (kW)	1.267
15	Maximum Nuclear Power Output(kW)	13.13
16	Mean Nuclear Power Output(kW)	7.67
17	Minimum Renewable Power Output (kW)	0.954
18	Mean Renewable Power Output(kW)	7.08
19	Maximum Renewable Power Output(kW)	14.91
20	Minimum Constancy Factor - Nuclear	0.119
21	Maximum Constancy Factor – Nuclear	0.940
22	Mean Constancy Factor - Nuclear	0.557
23	Minimum Constancy Factor – Renewable	0.066
24	Maximum Constancy Factor – Renewable	0.299
25	Mean Constancy Factor – Renewable	0.5200

The performance results show that the use of the proposed approach enhances the PUE. This is beneficial as the use of underwater render farms limits the WF and the associated harmful effects on habitat preservation. In addition, the enhancement of the PUE also enhances data centre power efficiency. Furthermore, an increase in the accessible power increases the uptime of the proposed approach. This increases the amount of workload rendering that can be executed.

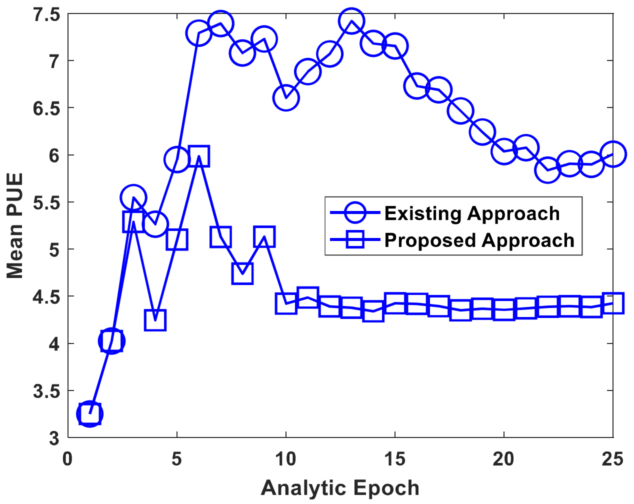

Figure 5 : Results of PUE metric performance evaluation.

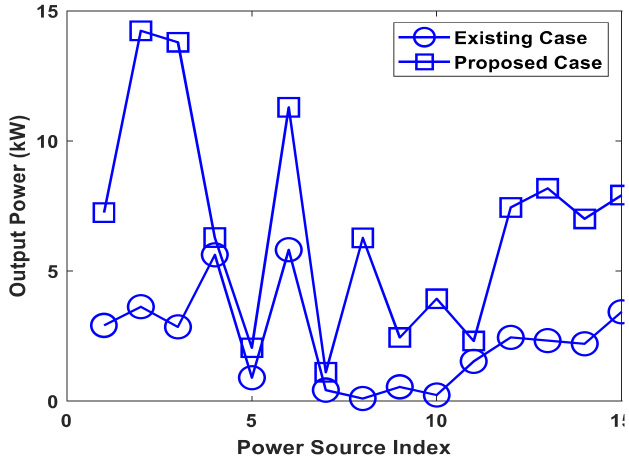

Figure 6 : Results of Output Power (kW) metric.

VI. CONCLUSION

Green rendering paradigm is proposed in the presented research as an approach to render multimedia content in an environment friendly manner. The environmentally friendly rendering is realized by using low emission underwater render farm alongside the conventional terrestrial render farm (data centre). Both data centres host render farms i.e., a cluster of servers. The proposed approach utilizes render workload transfer from the terrestrial render farm to the underwater render farm (when terrestrial data centres have a high-power usage effectiveness, and water footprint. The execution of the render workload transfer due to the proposed approach enhances the power usage effectiveness and reduces the water footprint by 26.5%, and 63.8% on average, respectively. In addition, future work will focus on integration of mini-nuclear reactors and incorporating scalability while ensuring sustainability as regards water usage in the proposed underwater render farm.

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