IMAGE: A MAP OF THE STARS OF THE ORION CONSTELLATION

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Zoran Marinšek[α], Sašo Brus[σ] & Gerhard Meindl[ρ]

ABSTRACT

A Local energy community (LEC) is a vertically nested system in energy supply and an ecosystem with joint values and objectives. On-site integrated hydrogen-based systems connected to the grid, and consisting of electrolyser, hydrogen storage and fuel cell system - hydrogen prosumers - provide efficient balancing of local energy consumption and local production of renewable energy that can be extended over annual cycles. There is no transport of hydrogen needed. Thus, the H2LEC – Local energy community with integrated hydrogen systems - represents the carrier of dispersed energy and hydrogen production as a complement of concentrated energy and hydrogen production: on average, H2LEC will predictably achieve at least 75% self-supply. Additionally, with Combined Heat-and-Power systems, coupling to the thermal system adds to energy efficiency.

H2LEC represents a virtual socio-economic system based on community values and thus engages initiative, innovation and capital of local actors, new technology start-ups and local industry; and represents opportunities for new disruptive business models. It brings into the energy supply system new players – prosumers who actively trade their flexibilities among themselves and on the external markets, and stimulates new enabling technologies - notably automated close-to-real time trading - thereby boosting end-to-end automated solutions.

The H2LEC create the need and the market for smaller integrated hydrogen-based systems ranging from a few kWe for residential homes to a few MWe units for larger industrial companies or local districts with a complete range of capacities in between, for public or tertiary buildings and smaller enterprises. Thus, they provide an opening for participation of SMEs in local and international value chains and will create a strong complementary energy bottom-up pillar and hydrogen supply system locally and in Europe.

Keywords: local energy community; hydrogen valley; prosumer; hydrogen system; hydrogen storage; harmonization; vertically nested system; sector coupling; ecosystem; flexibility trading; dispersed energy production; distributed generation; renewable energy.

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I. THE DUAL NATURE OF LOCAL ENERGY COMMUNITY

Local energy community (LEC) exhibits a dual nature: it is a subsystem in energy supply, a socio-economic ecosystem.

1.1 LEC as a Subsystem in the Energy Supply

In fully harmonized electricity supply system [1], LEC is a vertically nested subsystem, following the concept of system of systems: each subsystem has similar functions as its parental system and is fully nested in it. As further explained in Section 4, this concept is applied to all the levels of the electricity supply system, including the prosumer level.

Consequently, LEC is defined so that it can optimize its operation: It contains all the processes and roles that participate in a segment of the electricity supply system, and it interacts with other parts of the electricity system:

- It contains electricity production, consumption and stora e
- It exchanges flexible energy products – energy flexibilities internally and externally.

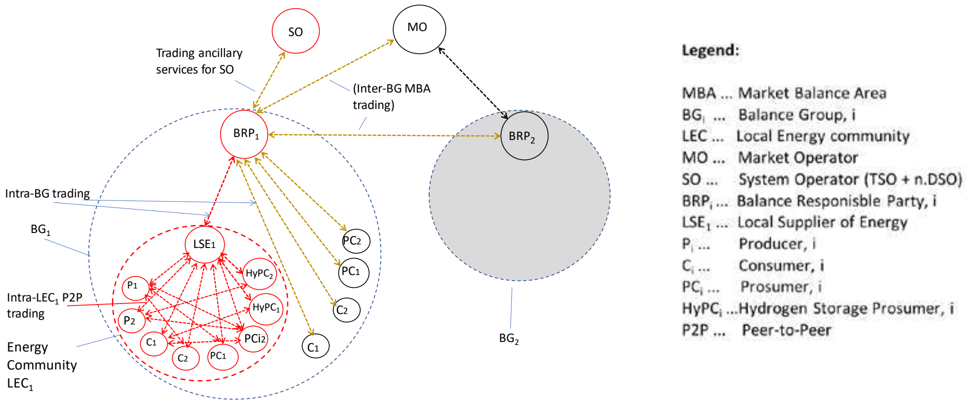

Figure 1: Connected LEC as a subsystem in energy supply

Local energy Community consists of active consumers, producers and prosumers (in this paper all also collectively termed as prosumers) of different size and character: residential homes, tertiary buildings, public buildings, RES producers, industrial companies of various size and technology - they are all connected to the electricity grid.

Prosumers of all categories, members of LEC, become active participants in energy trading: they exchange their energy flexibilities internally in LEC among themselves and trade collectively as a virtual business system on the external markets with traders or system operators. Using their energy reservoirs, virtual or explicit, they can trade in both positive and negative flexibilities, by augmenting or reducing their electricity consumption or production.

In current classification of energy communities, evolved in interaction of H2020 IA projects within Bridge initiative, there are two types of local energy communities – Citizens' energy community (CEC) and Renewable energy community (REC) [2]. CEC is composed of citizens only, while Renewable Energy Community can be composed of prosumers from all categories, including companies. In authors opinion, only this latter type of energy community has adequate characteristics and attributes to act as a subsystem in energy supply. In this paper, we discuss exclusively this type of energy community.

1.2 LEC as a Socio-Economic Ecosystem

The members of the LEC are local inhabitants, institutions and businesses. They share local values and derived joint community objectives. LEC thus represents a socio-economic ecosystem and a virtual business system with joint values and joint objectives: it engages initiative and capital of local actors – inhabitants, new technology start-ups and locally established businesses.

II. LEC AS A SMALL HYDROGEN VALLEY – H2LEC

Hydrogen valleys as defined by Hydrogen Europe [3] represent integrated hydrogen ecosystems. There are two types of valleys – Large and Small. Large Valley combines multiple applications (ports, airports, industrial hubs, cities, energy communities, ...).

Small Valley can focus on sector integration in specific problem domain, for concrete use cases or targeted segments of market and users. It must integrate all the technologies participating in it.

With integrated hydrogen systems as described below, LEC becomes also a Small Hydrogen valley – H2LEC. In it, hydrogen systems play a vital role in green energy storage, balancing electricity consumption and production, whereas smart grid trading system valorises the flexibility from such a system to provide services to the energy sector.

The essential building blocks of H2LEC are:

- HyPro – Integrated hydrogen system
- Local production of renewables
- Cross-sector coupling

2.1 Hypro – Integrated Hydrogen System

A fully integrated hydrogen system in H2LEC is Hydrogen Prosumer – termed HyPro. It consists of the following main building blocks:

- Electrolyser
- Hydrogen storage
- Hydrogen fuel cell (HFC) system with or without CHP
- Energy management system (EMS) with an Intelligent trading interface for purchasing and selling flexible energy on the grid.

Green hydrogen prosumer in the smart grid: i) consumes green electrical energy from the grid for producing hydrogen in electrolyser; ii) provides energy storage in hydrogen until needed; iii) produces green electricity and thermal energy in HFC system; and iv) purchases and sells flexible energy through automated trading platform.

A reduced version of the HyPro system can be either i) Hydrogen Consumer (without HFC system), with produced hydrogen utilized off-community, or ii) Hydrogen Producer (without electrolyser), with hydrogen produced elsewhere, off-community. Either version lacks some of the advantages of the complete HyPro system.

HyPro systems are installed on-site as part of a prosumer energy system or at a community location as part of the H2LEC energy system.

On-site integrated hydrogen systems bring to H2LEC some important advantages: no transport of hydrogen from a central production location is needed; and cross-sector coupling with other energy vectors and sectors is enabled: in particular, thermal energy for heating, but also biomass, and transport. They thus successfully replace conventional non-green power plants in local energy supply.

2.2 Local Production Of RES

Locally produced renewables (RES) are any available sources and installations: PV, windmill, biomass, hydroelectric.

RES systems are installed on-site as part of a prosumer energy system or at a community location, as part of the H2LEC energy system.

2.3 Cross-Sector Coupling

One of the key challenges of the present hydrogen-based solutions is the end-to-end efficiency. Each transformation step introduces certain costs, which are usually expressed as losses in the system. The electrolysis and fuel cell operation typically produce heat, which, if not exploited coherently, represents loss – waste heat.

In the H2LEC, coupling with local subsystems is of crucial importance for sustainable operation on a competitive basis. Sector coupling shall be addressed at the planning phase, when dimensioning the systems – the use of side products has to be implemented techno-economically. Besides the explicit side products from the processes (heat, oxygen), there are also implicit coupling considerations. One such aspect is the compression of hydrogen, particularly related to hydrogen transport at high pressure versus its local use on low pressure. The latter use case has potential for significantly better efficiency and must as such be considered in real-time techno-economic optimization.

In Section 6, we provide some insights into an evolving H2LEC with concrete examples of sector coupling in place. The electrolyser utilized is of PEM type, reaching an efficiency of around 79% (power-to-gas, without heat recuperation).

Typically, PEM electrolysers would reach power-to-gas efficiency between 70% and 80% [4]. In order to exploit the waste heat from the electrolysis process, heat exchanger coupled with heat pump can be integrated with the electrolyser. Heat exchanger efficiency and additional electricity consumption from the heat pump must be considered in the overall efficiency. For a PEM electrolyser such as the one in Section 6, the model [5] yields potential overall efficiency of up to 94.7%, with most of the losses attributed to the heat exchanger. Similar analysis can be made for the fuel cell part of the integrated system. Additionally, oxygen produced as part of the electrolysis process can be exploited if there is a relevant consuming system within the H2LEC. One example of such a system is wastewater treatment, which consumes both heat and oxygen side products. Overall efficiency is further increased while additional income can be secured for locally produced clean oxygen and heat.

Convergence from theoretical cross-sector coupling to practical implementation requires consideration of the dynamics on the consuming side. To exploit the available heat and oxygen potential, a consumption process must be available within the H2LEC, it must not be saturated (able to consume the produced goods), and it must be able to follow the dynamics of production (which is dictated by the volatile RES supply, demand response, explicit and implicit storage). As the multi-dimensional optimum of the complex subsystems, such as H2LEC, is not apparent, automated heuristics and optimization tools - H2LEC Enablers (Section 3), must be employed. This way, the entire local subsystem can cater to fast transients, further increasing the economic benefits.

2.4 How Important is H2LEC

Local energy community is one of the most relevant ecosystems in terms of green transition. With the advent of hydrogen-based systems in the energy supply, H2LEC represents an energy supply subsystem that, additionally to the LEC attributes already identified in Section 1:

- Boosts local production of renewables,
- Supports the inclusion of the cost of degradation of the environment into total CAPEX and OPEX functions
- Links different energy carriers, thus providing cross-sector optimum.

It represents the important building block in the pillar of dispersed energy production (c.f. Discussion in Section 7).

III. H2LEC ENABLERS

3.1 Enabling technologies

To realize H2LEC potential, several technologies are important enablers:

- Integrated hydrogen production, storage and consumption
- Automated trading of energy flexibilities
- Techno-economic symbiosis between integrated hydrogen production, storage and consumption and in-LEC RES production; and
- Coupling of electricity production with the production of thermal energy for heating.

There may be an additional enabler, depending on the character of the resident industry. Such a case represents the case of energy-intensive industries, within their objective of replacing existing energy carriers with hydrogen and enhancing energy efficiency of both energy and production processes.

Integrated hydrogen production, storage and consumption technologies as implemented in HyPro systems (Section 2.1) are tailored to the type and size of the prosumer or the size of the H2LEC. H2LEC can range in size from a small town or industrial zone to a medium-size city; the limiting parameter is the ability to formulate relevant joint values and objectives shared by sufficient number of resident entities - a threshold representative aggregate of prosumers on its territory.

Consequently, typical sizes of HyPro systems for a medium-size community range from a few kWe to a few MWe. In an internal analysis we looked at the sizes and types of the prosumers (asset types) and their distribution, and the indicated Use case. The results are presented in the following Table 1. The important Use case for various asset types is coupling with thermal energy supply system through Combined Heat and Power unit (CHP) as part of the HyPro. The subcase indicates its interaction with the energy system in H2LEC.

Table 1: Typical HyPro sizes for representative Asset types and Use cases in H2LEC

Size HyPro	Asset type	UC description	Subcase
3-5 kW	Domestic individual	HyPro with CHP	individual
		HyPro w/o CHP	individual or link to district heating
30-50 kW	Larger buildings, schools	HyPro with CHP	individual
		HyPro w/o CHP	link to district heating
100-400 kW	Tertiary buildings, smaller companies	HyPro with CHP	will contribute to flex energy trading with environment
		HyPro w/o CHP	link to district heating
1-4 MW	Larger companies	HyPro with CHP	will contribute to flex energy trading with LEC environment
		HyPro Consumer (electrolyser only)	will contribute to flex energy trading with LEC environment
1-4 MW	H2LEC as a system	HyPro Consumer (electrolyser only)	will contribute to flex energy trading with LEC environment
> 4 MW	H2LEC as a system or larger companies	HyPro Consumer (electrolyser only)	production of H2 as energy carrier for external markets

The sizes of HyPro at various prosumers are based on the concept that each prosumer is a subsystem with its own business objectives nested into the community system. The size of its energy systems is designed to service its needs in techno-economic sense optimally; and it exchanges surpluses and deficiencies of energy in flexibility trading. Larger electrolyser units (i.e. large HyPro Consumers), exceeding the techno-economic needs of the community use case, whether installed by a prosumer or by LEC as a system, target competitive production of hydrogen for off-community usage. In this case, hydrogen has to be transported to the place of use and the comparative advantage of on-the -site usage is forsaken.

Automated trading of energy flexibilities.

Prosumers – members of the H2LEC exchange their energy flexibilities. Energy flexibilities are exchanged using automated trading technology. Automated trading is carried out close to real time on automated trading platform, with trading intervals of 15 min or less, depending on the requirements of the Use case (c.f. Section 5).

The platforms for automated trading of energy flexibility beyond state-of-the-art include the possibility for implicit trading of energy transfer capacity between the location of production (generation) and the location of need [6].

Standardized protocol FlexOffer is used, enabling coupling of any EMS or storage management system. The protocol is parametric with provisions for structuring the flexibility offer in time slices with different energies & power and prices; it includes time-ahead and acceptance-before provisions, and others. A complete description of FlexOffer can be found at [7].

In intra-LEC trading, prosumers exchange energy flexibility among themselves, in peer-to-peer trading process.

They can institute a multi-category trading, based on formulated community objectives, in which fiscal currency value is used only as the common value denominator and value reference for trading on external markets ("pseudo-currency") but in intra-LEC trading it can be replaced - structured into several categories, including e.g. joint investments [8].

In communities with sector-coupled energy system, the trading can be formed in parallel in different energy vectors - a multi-dimensional trading, (c.f. Section 2.3). In such systems, the optimization of the complete energy supply system is targeted.

Techno-economic symbiosis between integrated hydrogen production, storage and consumption and in-LEC RES production.

The local production of electricity is predominantly volatile; what is more, the production dynamic is out of phase with consumption dynamics. Integrated hydrogen systems HyPro can provide balance between the two in all time ranges. While in the short-term range they can be successfully complemented by batteries, in the medium term and long term, batteries are no competitor.

The important H2LEC enabler is an integrated energy supply system composed of HyPros and RES production systems including batteries - if installed, and designed, financed and operated in techno-economic symbiosis, i.e. sharing the same business case. Similarly to HyPro systems, these systems are installed both at individual prosumers and at H2LEC as a system, and similar indications apply.

The enabling technology is optimized integration and joint business model; an instantiation of the concept of the H2LEC itself.

Coupling of electricity production with the production of thermal energy for heating.

This cross-sector coupling builds on the concept of total energy efficiency of primary energy and represents the other dominant enabler of H2LEC: it integrates complete energy system of the prosumer and of the community as a system. The design sizes of CHP units are based on requirements for thermal energy; this represents also a parameter in designing the size of the HyPro system: the excessive capacity for energy trading has to be economically justified by the envisaged trading revenues.

3.2 Systemic non-technical enablers

There are several systemic non-technical enablers that go hand in hand with enabling technologies:

Integration of Virtual business system.

LEC and H2LEC are virtual business systems, consisting of hundreds, possibly thousands and tens of thousands of prosumers, linked together by a business operator. The business operator operates the system and has several essential functions, inter alia:

- Manages the entity of the business operator
- Connects, directs and coordinates the H2LEC virtual business system:
  - Current operations
  - Business models
  - Joint activities and investments
- Operates the automated flexibility trading system:

- Supervises internal flexibility trading and represents H2LEC in trading on external markets.

Consequently, the selection of appropriate business operator to fit best the specific social, cultural and industrial specifics of a community can represent an important enabler (c.f. Section 4).

Harmonization of the electricity supply system.

The concept of H2LEc is based on fully harmonized electricity supply system [1]. In actual circumstances, the national systems are only partially harmonized.

The actual structure of the electricity supply system will influence the techno-economic impacts of the H2LEC operation.

The enabling parameters that depend on the scope of harmonization of the system are:

- Energy transfer costs: in a fully harmonized system, the costs of energy transfer along the distribution grid, from the location of production to the location of use of energy are included in the total cost of energy; the indicated method based on inter-MBA transactions is implicit trading of energy transfer capacity. Inclusion of energy transfer costs in the total energy cost equation makes possible objective comparison of cost of flexibility anywhere in the MBA territory and thus enables optimization of complete MBA system. It also activates in economic terms the advantage of H2LEC as a subsystem in energy supply: for all locally produced energy, no transfer costs are incurred. Similar applies to the emerging production of hydrogen.
- Dynamic pricing of both energy and network fee based on actual costs: the typical tariff systems for energy and network fee are based on averages over large geographical territory and over long periods. To enable system-wide optimization of energy production, dynamic pricing of both energy and network fee is necessary. This will provide the condition and criterion needed for properly positioning the concentrated energy production as opposed to the dispersed energy production, and the costs of baseload energy transfer as opposed to the cost of congestions. The enabling parameter is in particular the network fee as it influences the size and the place of investments in the grid.
- The system for partitioning the network fee between TSO and responsible DSO (or sub-DSO): Partitioning the network fee between TSO and DSO to properly reflect the investment and the operation of different segments of the grid according to voltage level enables the scope of dispersed energy production in local energy communities. Growth of this segment of energy supply needs reinforcement in grids up to 20 kV.

IV. H2LEC BUSINESS MODELS AND BUSINESS RELATIONSHIPS AMONG LEC MEMBERS

4.1 Conceptual Background

The optimal form of cooperation between members and the business operator could be a contractual form of collaboration. Ideally, the business operator should operate on a non-profit basis to fulfill this role. It is crucial that resources and profits are equitably distributed among all parties with whom the business operator has a contractual agreement.

If the role of the business operator is assigned to an independent aggregator, it is expected that the aggregator would retain some portion of the profit. However, beyond that, the goal is for the aggregator to cover its costs and any surplus to be transferred back to the H2LEC community for realizing their benefits from participating in the community of joint investment, which will be defined as essential for optimizing the LEC system. This surplus does not represent profit for the aggregator but rather serves as a means of enhancing the community and its systems.

It is vital that the business model also encourages joint investments for further system improvement. Although costs must be covered, surplus capital should not be paid out as profit to members or the aggregator but must be reinvested in system improvement. This is easiest served by the contractual model mentioned.

In such a system, many nested sub-systems are formed: Each member, whether a business entity or residential prosumer, becomes a sub-system with its own goals, business policy, and investments, nested into joint community goals, business policy, and investments. The prosumers will contribute with their investments to optimize their own system in line with the objectives of the overall system.

Derived from emerging cases, there are several business models - attributes for the H2LEC business operator:

- Business operator is a company owned by the local commune (city)
- Business operator is a company in public-private partnership (PPP)
- Business operator is the company responsible for energy supply in the territory of the H2LEC – Local supplier of energy (LSE)
- Business operator is an ESCO company
- Business operator is a BRP or an FSP.

Some of these attributes can be combined. The selection of the type of the business operator will largely influence the business model of a community.

Integrated business model for local supply of energy.

It is stipulated that the H2LEC is a connected – nested subsystem in energy supply (c.f. Section 1 and Section 5). The H2LEC business models must all service this concept. The distinction parameter between them is the level of community self-supply attainable on criteria of techno-economic competitiveness.

The business models that foster high level of self-supply are those in which the systems of all energy supply vectors are treated as subsystems in the complete energy supply system in the community – a sector-coupling case and one with highest social acceptance. This is best attained in a combined business model of Local supplier of energy with business operator as a publicly owned or a PPP company.

Detailed discussion of H2LEC business models is out of scope of this paper.

V. CONNECTED H2LEC USE CASES

As mentioned in the previous sections, the systemic assumption is that H2LEC is a connected vertically nested subsystem in energy supply. The complete portfolio of H2LEC Use cases can include islanded operation, in which H2LEC is self-sufficient and there is no exchange with the external environment. However, this is a borderline – “asymptotic” case that lacks reference to provide economically competitive operation on a sustainable basis.

The range of connected H2LEC Use cases can be classified into several categories:

- Local flexibility markets for DSO (ancillary services for DSO)
- Regional markets for DSOs
- MBA energy exchange markets
- Flexibility market for TSO (ancillary services for TSO)

In the harmonized structure of the electricity supply, the systemic Use cases do not overlap. They represent segments of the market and can be combined. In Figure 1 in Section 1, the presented Connected Local energy community combines 3 systemic Use cases:

- DN congestion avoidance & energy balancing (ancillary services for DSO)
- TN congestion avoidance & energy balancing (Ancillary services for TSO)
- Flexible energy trading on established energy markets in MBA

A complete list of local and regional markets can be inspected in [1].

The trading revenues are associated with the different Use cases and are based on the pricing levels established on the various markets. In principle, the markets with greatest potential for H2LEC trading are the local and regional markets for DSOs as they have the advantage to help solve the local congestion and disbalance problems locally or regionally. This generates additional synergy in objectives and leads to symbiotic relationships between H2LEC and responsible DSO or sub-DSO.

The H2LEC ability and advantage are two-fold: i) the ability to adapt its services to a transient need (congestion management, disbalance between supply and demand on the grid), and ii) the ability to service the transient locally, without transporting the energy from another location along the higher voltage network, be it on distribution or on transmission levels.

The first characteristics enables H2LEC to supply competitive flexibility for tertiary and minutes reserves of system operators, for contractual flexibility market, and for continuous markets for flexibilities; here the dominant price component is the power made available at the needed time interval rather than the energy supplied, or the demand reduced. The conventional approach and competitive solution to servicing these transients are peaker power plants, designed and built to operate only around 200 hours per year.

The second ability lowers the necessary capacity of the grid for transferring the energy at peak loading; consequently, it reduces both the investment and operational costs for the grids at higher voltage levels, typically above 20 kV. This contributes to optimizing the energy supply within MBA (TSO territory). However, it still needs to be adequately implemented in the network fee methodologies, which reside on average and not on actually incurred costs, and in properly partitioning the fee between TSO and involved DSOs, which presently does not reside on avoided costs principle. Proper implementation is a necessary condition for establishing a system-wide optimum.

To participate in established markets (e.g., in day-ahead market in MBA or in the market for ancillary services for TSO), the bidder must fulfill two criteria:

- It has to qualify as a BRP (or in some cases also as a FSP)
- It has to offer the form and the quantity of flexible energy that respects the form traded on the market and the threshold quantity prescribed.

These requirements and constraints necessitate trading through the intermediary of a BRP or FSP. The H2LEC business operator may also become a Balance Responsible Party if it exceeds a certain threshold, as permitted by regulations or as requested by the Market operator or the party issuing the call.

In local DSO flexibility market both the qualification requirements and the threshold bidding quantity is substantially lower due to smaller quantities of energy transferred on the territorial grid; also, there are some emerging systemic use cases which permit direct trading of energy flexibility between H2LEC business operator and the responsible DSO without the intermediary of a BRP. Detailed discussion of these issues is beyond the scope of this paper.

VI. CASE OF H2LEC IN THE MAKING

In the north-eastern corner of Bavaria, the small town of Wunsiedel is located. Starting in the year of 2000, the municipality and SWW Wunsiedel GmbH (SWW) have tested and invested into renewable energy sources to create local business cases to integrate local and regional stakeholders. The instrument of choice for all-over integration of stakeholders on all levels is Public Private Partnership Company (PPP).

6.1 Past

In 2011, the first version of a joint strategy document called "Wunsiedel Way of Energy 1.0" was created and published to combine all existing activities of SWW in grid operations for electricity, natural gas, water, heat and fibre optics as well as energy trading. Over the years, SWW realized the substantial opportunities arising from sector-coupling assets and approaches (e.g. combined heat and power generation CHP) and formed a local RES valley. To date, SWW has issued the version 4.0 of the strategy document and is on the way to becoming a Small hydrogen valley [9].

The focus of the activities had to be shifted from initial renewable energy sources (RES) to storage assets and technologies, to energy efficiency and flexibility considerations and tools, to Internet of

Things (IoT) for monitoring and steering purposes, to modified grid requirements, large-scale assets, market and regulation design considerations and to a very challenging new approach to create an ultimate, "all-in local integration for everybody" setup (termed Zukunftskraftwerk).

Figure 2 sums up the evolution of SWW activities and their present status.

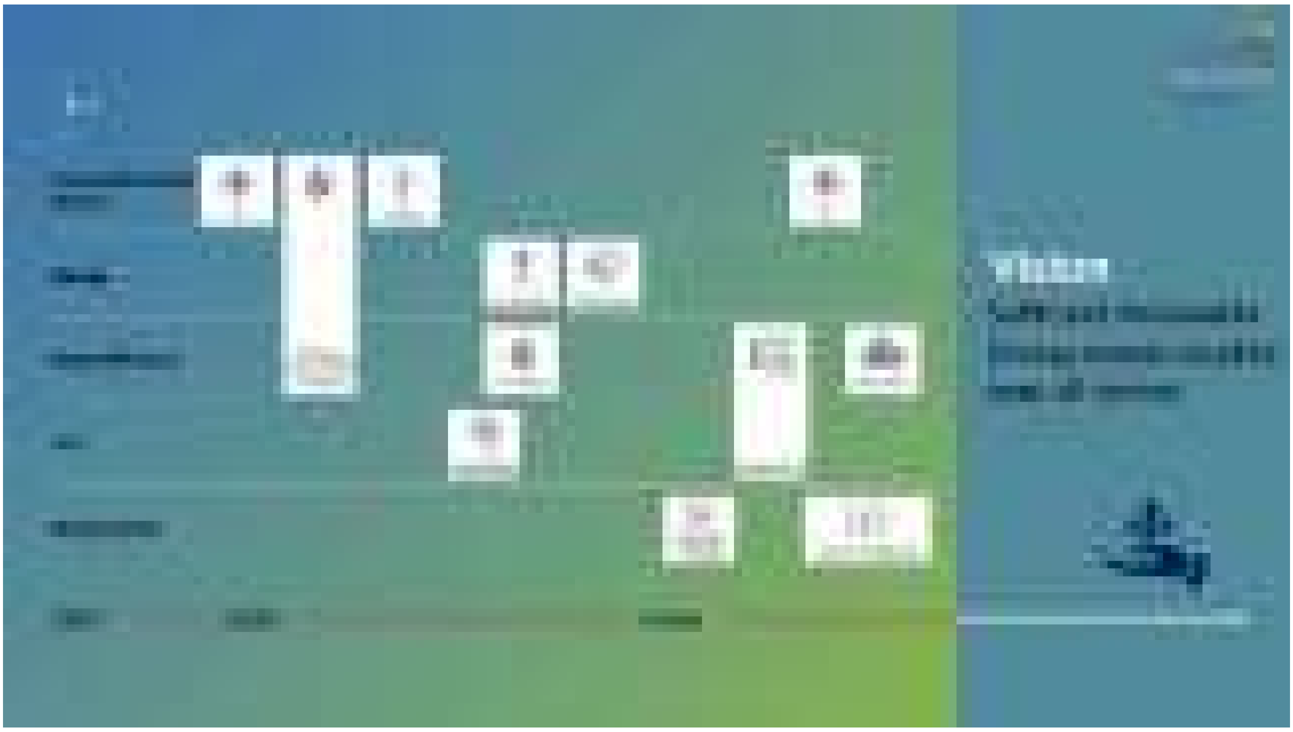

Figure 2: History of activities in SWW [9]

6.2 Present

The core piece of the activities is called "Energy Park Wunsiedel" and is located in the village of Holenbrunn on the eastern outskirts of Wunsiedel. The Energy Park consists of several CHPs of different sizes and with various energy carriers, a large battery energy storage system (BESS), production facilities for wooden pellets and – as the latest asset - a large PEM-electrolyzing unit; some detail of the facility is described in Figure 3. The system for renewable energy generation is completed with a multitude of PV arrays, windmills and CHPs of different sizes feeding district heating systems in three remote villages. The CHP operation is based on automated use of wooden pellets produced in theEnergy park.

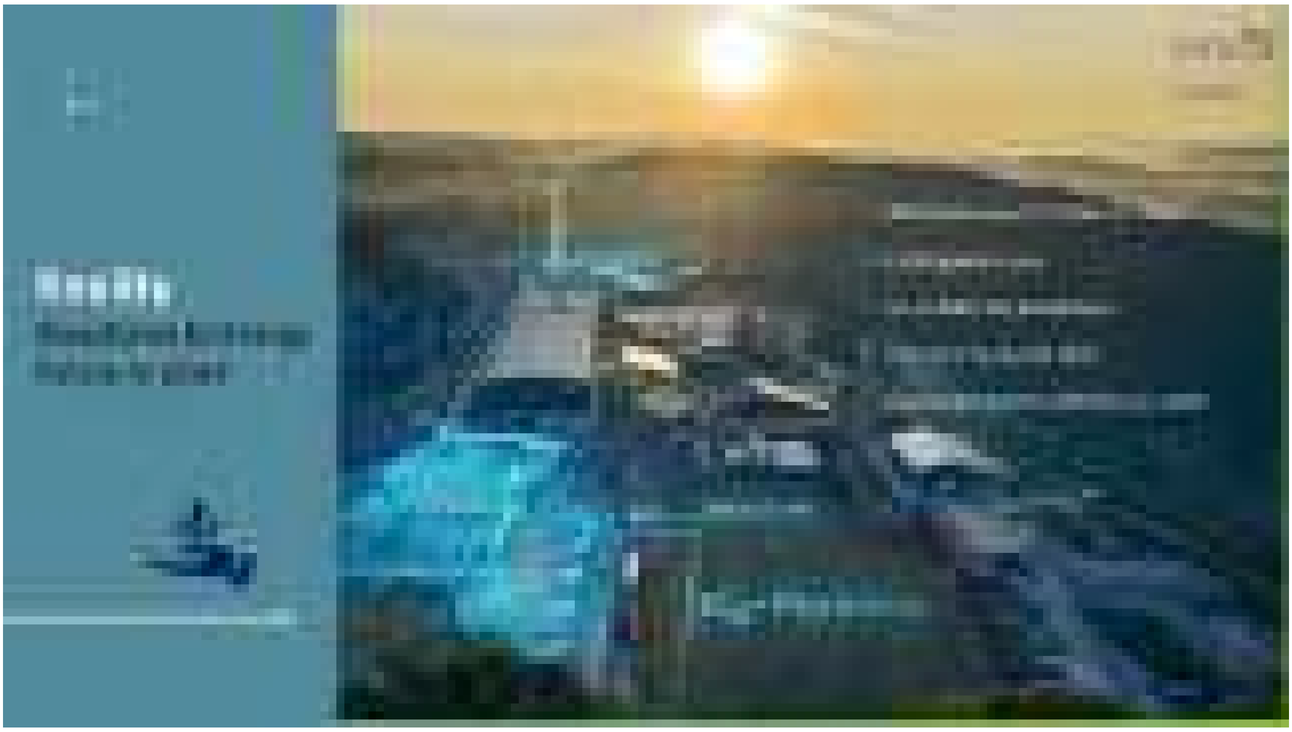

Figure 3: Aerial view of Energy Park Wunsiedel [9]

The electrolyser unit is now up and operating. In combination with sector-coupling activities and a very large-scale generation of green electricity in photovoltaic arrays of all sizes and windmills, a permanent production of green hydrogen is viable, possible and affordable.

For SWW, hydrogen is a gamechanger which takes it to a higher level of business with additional stakeholders and new fields of use, such as industry (energy and process use), storage on local level, mobility use and domestic use in individual households.

6.3 Future

After reaching nearly every goal in the WUNway Energy 4.0 in Wunsiedel and thinking about a multiplication of the local success, the decision was taken to invite all municipalities in the region to join forces and combine efforts to make maximum use of RES in each municipality. The process includes the maximum use of lessons learned in SWW to reduce lead times for the new partners.

SWW is generating a vision of the future energy community (called "Zukunftskraftwerk"): buildings become generation and storage facilities (no matter what size), enabling integration of mobility tools (even bi-directional), distribution grid for natural gas becomes storage and distribution grid for hydrogen giving maximum choice to building owners, electricity grids become balancing grids for residual loads. In addition, a large selection of new hydrogen-based business models for a large selection of stakeholders on all levels will materialize.

In summary, in Wunsiedel an initial RES valley is evolving into a local hydrogen valley with the potential to be developed into a regional hydrogen valley.

VII. DISCUSSION: CONCENTRATED (CENTRALIZED) VS. DISPERSED PRODUCTION OF ELECTRICITY AND HYDROGEN

There are two basic paradigms in the electricity supply system, which can be formulated as:

- Share of concentrated electricity and hydrogen production vs. dispersed electricity and hydrogen production, supported by the following triangulators:

- Concentrated baseload production vs. dispersed flexible production
- Transport of electricity and hydrogen vs. local production of electricity and hydrogen
- Energy production in the "energy sector" vs. energy production in prosumers and energy communities.

Evaluation of both paradigms should include the following elements:

- (Techno-economic optimization of the supply system) The importance of integrated hydrogen systems for the absorption of inflexible renewable energy sources in the electricity grid
- (Techno-economic optimization of the energy supply system) The degree of self-sufficiency and the techno-economic optimum of the system and subsystems
- (Hydrogen strategy) Synergy between local hydrogen production and local renewable energy production
- (Hydrogen strategy) Hydrogen as a market end product vs. hydrogen systems in energy supply ecosystems
- (Objectives of the green transition) Decarbonization of energy production, decarbonization of industry, decarbonization of other areas in society
- Separately by segments or in synergy between segments (indicative example: an energy-intensive company as a member of a Local energy community)
- (Distributed energy production) Prosumers – residential customers, public and tertiary buildings, companies – as producers and co-investors within the Local Energy Community
- (Green transition and industrial strategy) Overseas purchase of RES and hydrogen decarbonisation systems/facilities vs. developing and producing new products, services and systems in the field of renewables and hydrogen technologies and engaging in the construction of domestic infrastructure for the green transition and in international supply chains of value in new technology markets.
- (Security of supply) Transmission of centrally sourced energy vs. a combination of central energy transmission + local energy production.

To properly evaluate and compare the elements of the two paradigms, they have to be put on an equal base, relative to the system at carbon neutrality state. Total cost functions must be defined and applied to all building blocks involved in energy production, transfer and consumption. This is a lengthy process as it includes both technology-based and economic but also political decisions, and it will progress in phases. For electricity and hydrogen, the first step is to include energy transfer costs and calculate energy and network fee prices based on the avoided costs principle, as described in Section 5. For a company in energy intensive sectors, this will involve the costs of replacing the energy carrier with hydrogen or electricity from an external source or the costs of own production of hydrogen generated from own renewables production, coupled with the costs of upgrading energy efficiency of its energy system and of its production processes.

LEC is a facilitator, stimulator and additional enabler of these endeavours. H2LEC - LEC with integrated hydrogen systems HyPro - adds an additional *raison d'etre* to it, by substantially and sustainably increasing the level of self-supply of local energy community as a subsystem in the energy supply.

7.1 LEC Market Size and Benefits (Impact)

The share of the Local energy communities in the energy supply will depend on the region of Europe and the boundary conditions that favour either concentrated or dispersed/distributed production of renewable energy. Territories with big industrial complexes requiring high power and quantities of energy have to be supplied from large power plants using transmission grid; in contrast, regions with small industries and dispersed rural districts are supplied on low voltage distribution grid and a large share of needed energy from small local renewable energy installations. Large power plants are designed to operate continuously, with availability and load factors above 90% and are severely limited in adapting to flexible consumption; the H2LECs can thus competitively supply flexible energy products; taking into account the discussion in Section 5, it can on its territory cover all flexible part above base loading; and in connection with sector coupling also some of its continued energy requirements. The share of baseload supply is country- and region- specific. Figure 4 shows schematically the segmentation of grid loading diagramme; with continued loading/baseload supply around 30% - 40% of peak loading.

The diagramme is indicative of the share that the H2LEC ecosystems can attain in total energy supply due to their characteristics and advantages described in Sections 1, 2 and 3. They enable sustainable multi-dimensional and multi-category integration and optimization in techno-economic terms, a property which cannot be paralleled by concentrated energy production.

To target the goal of techno-economic optimum, H2LEC must be a connected subsystem; autarchy – islanded operation cannot be optimal on a sustained basis and can only be considered as an asymptotic and transient operational state.

The authors estimate that at least 75% of green energy will be produced and used locally. A rough guestimate is that LEC will account for half of the total energy use in the distribution grids below 110 kV.

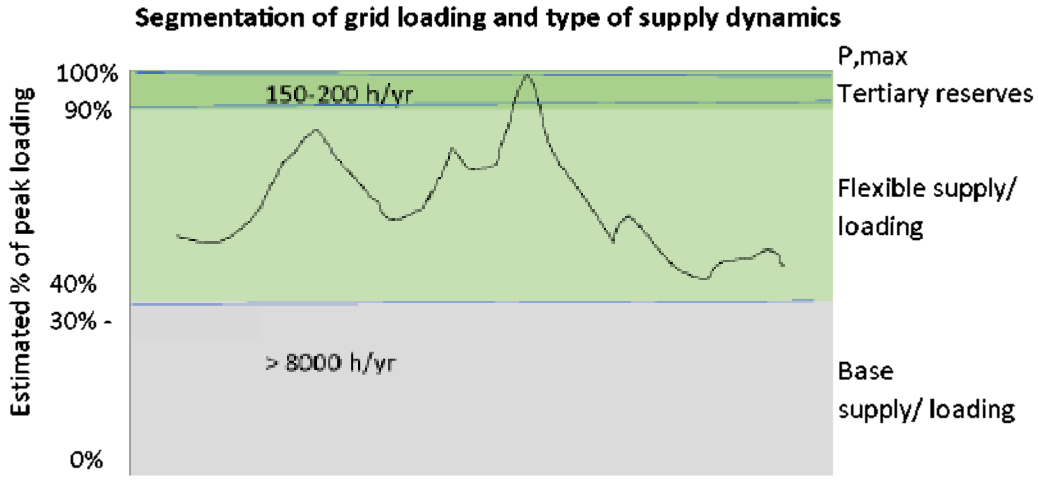

Figure 4: Segmentation of grid loading: base load supply and flexible supply

This will constitute a significant contribution to the dispersed energy supply, but it will also generate a substantial new market, which will foster specific products and services, and new disruptive business models.

H2LEC can be declared as a key enabler of the dispersed electricity and hydrogen production.

In the introduction roadmap of hydrogen in the energy supply system, it is necessary to highlight and compare the two complementary strategies indicated above: hydrogen as energy vector and final product on the market vs. integrated hydrogen systems as building blocks in energy supply ecosystems.

VIII. CONCLUSIONS

The introduction of hydrogen as an energy source is essential for decarbonisation and the internal energy market; the introduction of hydrogen systems as building blocks in electricity supply ecosystems is essential for the creation of a balanced system of electricity production and consumption and for the techno-economic development of the energy sector. This is particularly relevant for and in harmony with small economies. H2LEC ecosystem – Local energy community as a small hydrogen valley represents a facilitator, stimulator and additional enabler of dispersed energy (electricity and hydrogen) production as the pillar complementary to concentrated energy supply.

Any national scenario but also EU-wide concept should include an explicit strategy for the deployment of hydrogen systems in concentrated (central) and in dispersed (distributed) generation.

8.1 Data Availability Statement

All the referenced public documents are available on request from the authors. The data presented in this paper that are not publicly accessible are available on request from the corresponding author.

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Conflicts of Interest: The authors declare no conflicts of interest.

List of Abbreviations and Acronyms Used in the Paper

BG	Balance Group
BRP	Balance Responsible Party
CHP	Combined Heat and Power
DSO	Distribution System Operator
FSP	Flexibility Service Provider
HEMRM	Harmonized Electricity Market Role Model
H2LEC	Local Energy Community as a Small Hydrogen Valley
HyPro	Hydrogen Prosumer (Also: Integrated hydrogen system, or: Hydrogen Storage prosumer)
LEC	Local Energy Community
LSE	Local Supplier of Energy
MBA	Market Balance Area
MO	Market Operator
P2P	Peer-to-peer
RES	Renewable Energy Source
SGB	Sub-Balance Group
Sub-DSO	Sub-Distribution System Operator
TSO	Transmission System Operator
UC	Use Case

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I. INTRODUCTION

Only 2.5% of all water on the planet can be considered good for consumption. However, due to a series of factors, this value becomes even lower. In this sense, environmental contamination has been debated around the world, since the integrity of ecosystems, aquatic life, soil fertility and aquatic resources are being negatively impacted due to the release of wastewater containing different contaminants, mainly synthetic dyes. [1]

Dyes are organic compounds widely used in a wide variety of industries, such as textile, plastic, paper, rubber, wood, medicine, food and cosmetics sectors, with the aim of coloring their products. [2] Its annual global production is estimated at approximately 800,000 tons [3], where between 5-10% of this value is discarded into the environment as colored waste material. [2] The disposal of these materials causes high toxicity, carcinogenic potential, risk of poisoning the ecosystem, drinking water and human health. [3]

Several dyes are characterized by very striking colors, high resilience to deterioration and great resistance to chemical, photochemical and biological processes.

[4] Methylene blue, with molecular formula $C_{16}H_{18}ClN_3S$ and 319.86 g/mol molecular weight [5] is a cationic dye with an organic structure that has great applicability in wool, cotton, silk and acrylic production industries. Disposal of this pollutant in water suitable for consumption generates negative impacts on humans, such as vomiting, increased heart rate, tissue necrosis, among others. [6]

Several methods can remove dyes present in wastewater, such as methylene blue, contributing to improving the drinking water crisis and protecting the environment and ecosystem. [7] In this context, many processes exist and can be divided into physical, physicochemical, chemical and biological methods. [8] Among them, adsorption, a physicochemical process, is considered an efficient method for removing dyes in wastewater due to its characteristics, such as flexibility, easy operation, low cost, high efficiency and selectivity, mechanical stability, and character. non-destructive. [9]

Adsorption consists of a phenomenon in which ions, molecules or atoms, the adsorbate, adhere to the surface of a solid material, known as adsorbent material. This process can occur in a liquid or gaseous medium. [10] The nature of the adsorbent and the adsorbate, the temperature of the medium and the presence of other substances interfere in the interaction between the adsorbent and the adsorbate, affecting the adsorption process. [11] There are several materials used as adsorbents for capturing methylene blue in wastewater. Among them, activated carbon has been the most used adsorbent due to its characteristics such as high efficiency, high surface area and strong surface reactivity, [12] which guarantees high adsorption capacity for organic pollutants, [10] such as methylene blue. However, due to the high costs for its synthesis and regeneration, [10, 11] low-cost adsorbents have been developed to remove methylene blue dye.

Adsorbent materials obtained from biomass can be considered an alternative to conventional adsorbents for capturing methylene blue, since they are widely available, cheap, generally do not require any prior treatment and have high efficiency. [6] Recently, Oladoye et al. [13] published a review work that emphasizes the importance of capturing methylene blue from wastewater due to its high toxicity. In this work, the author presents adsorption technology, among others, highlighting the use of different biomass-based adsorbent materials, due to their high efficiency and low cost, showing what they can or cannot receive treatment before being used as an adsorbent material. However, none of the works presented in the review suggest the use of the mandacaru cactus.

The mandacaru cactus, scientifically named "Cereus jamacaru", is a species whose rigid trunk is approximately 60 cm long and can reach up to 10 meters in height.

[14] It is a typical plant from the Brazilian Caatinga, with a production of 13 tons of dry matter per hectare that is very poorly valued, being mainly used as animal feed, [15] due to its composition. Despite gaining timid attention in the development of artisanal food products, [16] other applicability, such as the adsorption of pollutants, can be studied. In this regard, only one study using this biomass was found for the process of removing the basic fuchsin dye, indicating that much remains to be explored. Therefore, the present work proposes to study the adsorption process of methylene blue dye using the mandacaru cactus as adsorbent material. For this, the parameters initial dye concentration, adsorbent dosage and contact time were evaluated. Furthermore, the adsorption mechanism was studied using pseudo first and pseudo second order models.

II. MATERIAL AND METHODS

2.1 Materials

The adsorbate used in this work was methylene blue (Dinâmica Química Contemporânea LTDA). All solutions used in the experiments were obtained by diluting a previously prepared stock solution with a concentration of 1000 mg/L. The selected adsorbent was the mandacaru cactus (Cereus Jamacaru). This was collected in the interior of the city of Acauã, in the state of Piauí, Brazil, washed, ground in a conventional blender and separated with a paper filter. Then, the filtrate was washed repeatedly with distilled water to remove dirt particles. Subsequently, the sample was kept in contact with a 50% ethanol solution for 3 h, in order to separate extractives present in the sample. [15] Finally, the solid was dried in an oven at 100 °C for 2 hours and stored until further use.

2.2 Methods

2.2.1 Effect of initial concentration

To evaluate the effect of the initial concentration of the adsorbent, a fixed amount of 100 mg of the mandacaru cactus previously treated was placed in 250 mL Erlenmeyer flasks containing 20 mL of a methylene blue solution with varying initial concentrations, at room temperature. After 24 h, to ensure system balance, the solutions were analyzed in a digital spectrophotometer, UV/VIS ESPEC-UV-5100 from Tecnal, at a wavelength of 664 nm. [5, 17] Experiments were performed in triplicate. The amount adsorbed at equilibrium, qe (mg/g), was calculated using equation 1 and the percentage removal of the dye was determined using equation 2:

$$q_e = \frac{(C_o - C_e)V}{m} \quad (1)$$

$$Percentage\ Removal = \frac{(C_o - C_e)}{C_o} x100 \quad (2)$$

Where Co and Ce are the initial and equilibrium concentrations of the methylene blue solution, respectively (mg/L); V is the volume of the solution (L) and m is the mass of the adsorbent (g). [18]

2.2.2 Effect of Adsorbent Dosage

To investigate the influence of the adsorbent dosage, 20 mL of methylene blue solution 5 mg L^{-1} was added to 250 mL Erlenmeyer flasks. Then, 50, 100 or 200 mg of the adsorbent were included in each bottle. The process was carried out in triplicate and at room temperature. After 24 h, the solutions were analyzed in the spectrophotometer, according to the effect of the initial concentration. The amount adsorbed at equilibrium, qe (mg/g), was calculated using equation 1 and the percentage of removal, using equation 2.

2.2.3 Effect of the contact time

To evaluate the contact time, a fixed amount of 100 mg of adsorbent was placed in 250 mL Erlenmeyer flasks containing 20 mL of methylene blue solution of 5 mg/L, at room temperature. After predetermined times, an aliquot of this solution was removed and, according to the effect of initial concentration, it was analyzed. The experiments were carried out in triplicate and the amount adsorbed at time t, qt (mg/g), was calculated using equation 3. [18]

$$q_t = \frac{(C_o - C_t)V}{m} \quad (3)$$

2.2.4 Adsorption kinetics study

Kinetic studies were analyzed based on the results obtained from the studies of the effect of contact time, using the pseudo-first order (equation 4) and pseudo-second order models (equation 5).

$$q_t = q_e(1 - exp^{-k1t}) \quad (4)$$

$$q_t = \frac{q_e^2 k_2 t}{1 + q_e K_2 t} \quad (5)$$

Where k_1 is the pseudo-first order adsorption rate constant (h^{-1}), k_2 is the pseudo-second order adsorption constant ($g.mg^{-1}.h^{-1}$), qe is the amount adsorbed at equilibrium (mg/g) and qt is the amount adsorbed at time t (mg/g). [1]

III. RESULTS AND DISCUSSION

3.1 Effect of Initial Concentration

The effect of the initial concentration for the adsorption process of the methylene blue dye using the mandacaru cactus as an adsorbent material can be seen in Figure 1.

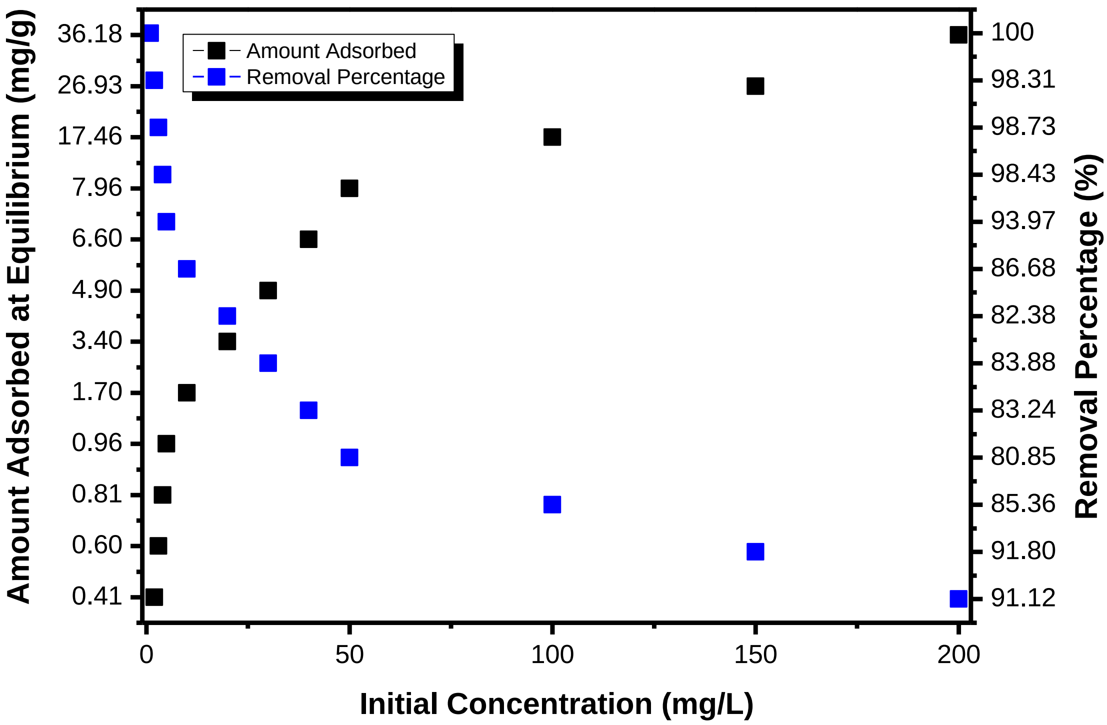

Figure 1: Effect of initial methylene blue concentration using mandacaru cactus as adsorbent (dosage = 100 mg, V = 20 mL, room temperature, t = 24 h)

It can be seen that the adsorbed amount, qe, increases from 0.23 to 36.18 mg/g when the initial dye concentration increases from 1 to 200 mg/L. This occurs due to the mass transfer resistance of the methylene blue molecules to the mandacaru cactus, which is overcome by the driving force with the increase in the initial concentration of the adsorbed, increasing the amount adsorbed. [19] On the other hand, the removal percentage decreased from 100 to 91.12% when the initial adsorbate concentration increased from 1 to 200 mg/L. This happens because the presence of a higher concentration of dye in solution causes less surface availability of the adsorbent, or of active sites present on the adsorbent, available to interact with the dye in question. [20]

3.2 Effect of Adsorbent Dosage

The adsorption process of methylene blue dye using the mandacaru cactus as adsorbent material was also evaluated by the adsorbent dosage parameter. The response to the effect of this parameter can be seen in Figure 2.

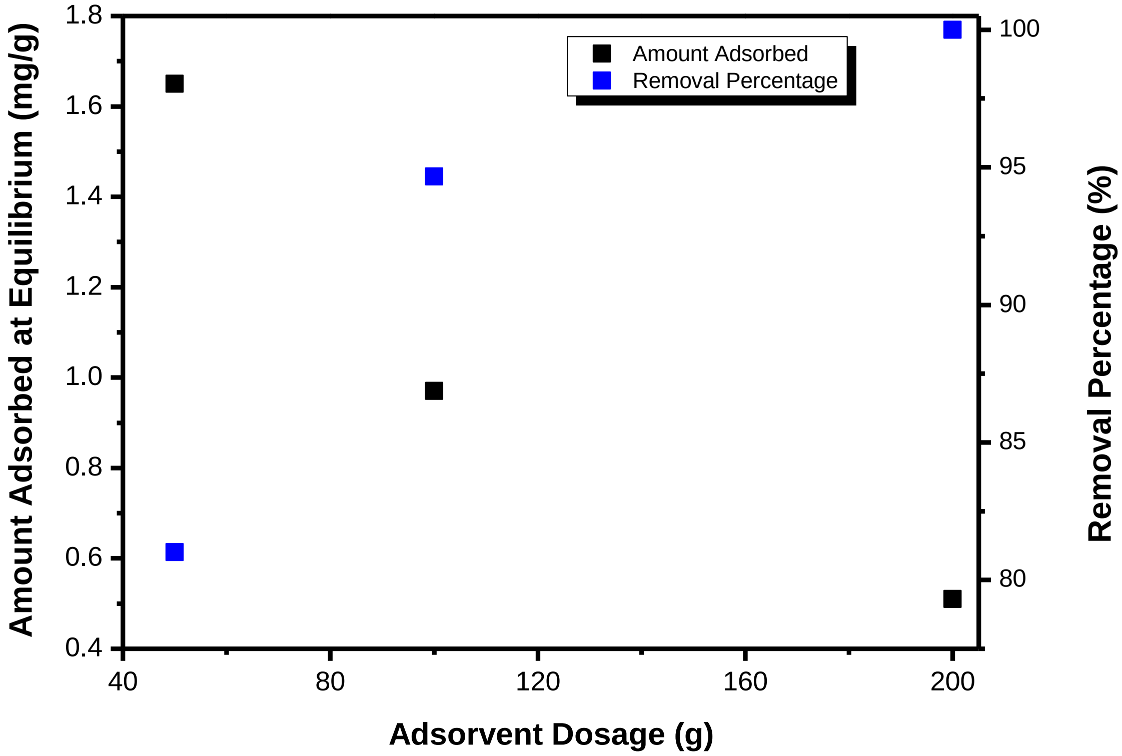

Figure 2: Effect of adsorbent dosage on the adsorption of methylene blue using mandacaru cactus as adsorbent (C_0 = 5 mg/L, V = 20 mL, room temperature, t = 24 h

It is observed that, when the mass of the adsorbent increases from 50 to 200 mg, the amount adsorbed at equilibrium (qe) reduces from 1.65 to 0.51 mg/g while the removal percentage (R%) of the dye at solution increases from 81.01 to 100%. According to the literature, [21] the reduction in qe may be related to the decrease in the amount of adsorbate adsorbed per unit weight of adsorbent, causing a reduction in the active sites used. As for the increase in R%, this is related to the existence of a greater quantity of active sites in the mandacaru cactus to be used in the dye adsorption process in the solution.

3.3 Effect of the Contact Time

The adsorption process of the methylene blue dye using the mandacaru cactus was evaluated over a period of 24 hours, using 100 mg of adsorbent material. The amount adsorbed at time t (qt) calculated by equation 3 and the percentage of removal (equation 4) can be seen in Figure 3.

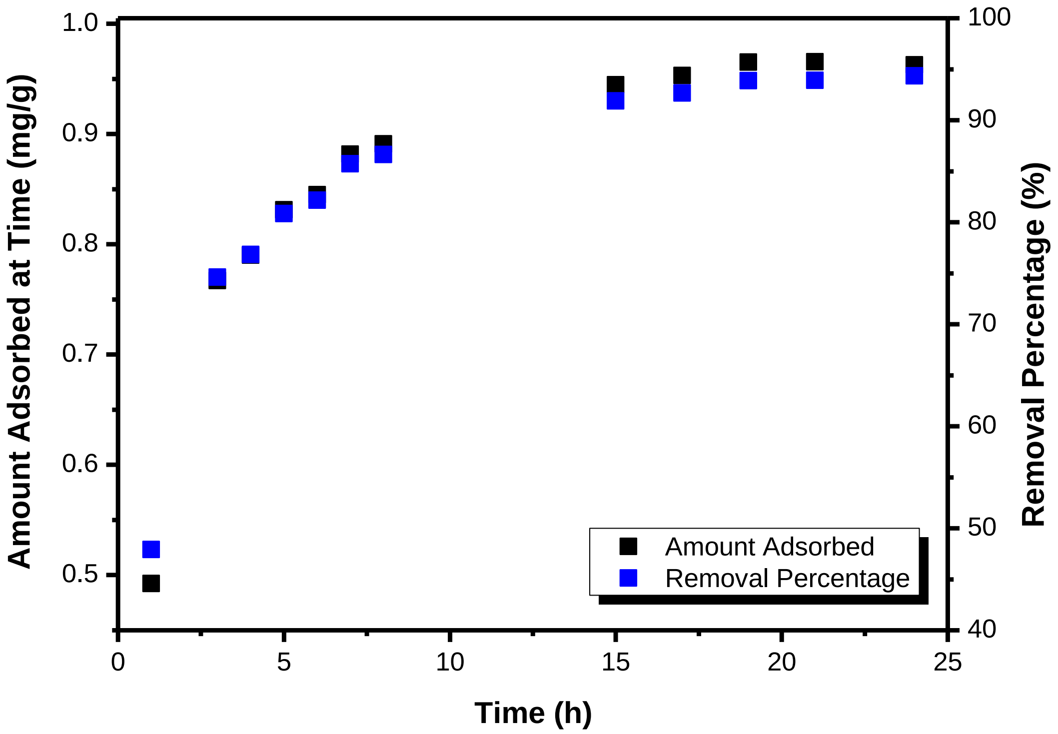

Figure 3: Effect of the contact time on the methylene blue adsorption using mandacaru cactus as adsorbent (C_o = 5 mg/L, V = 20 mL, room temperature, dosage = 100 mg)

It can be observed that, with the increase in contact time, both qt and R% increase, reaching values of 0.96 mg/g and 94.34%, respectively. The adsorption process reached equilibrium around 19 hours. But, it can be seen that in just one hour of contact between the adsorbent and the solution, these values already reach 50% of the final result.

According to literature, [12] the time required to reach equilibrium in an adsorption process depends on the type of adsorbent, as well as the number of active adsorption sites that are available.

3.4 Adsorption Kinetics

The adsorption kinetics data were obtained by applying the Pseudo-First Order (equation 4) and Pseudo-Second Order (equation 5) models to the values observed in Figure 3, with the purpose of investigating the adsorption mechanisms. The results are shown in Figure 4 and Table 1.

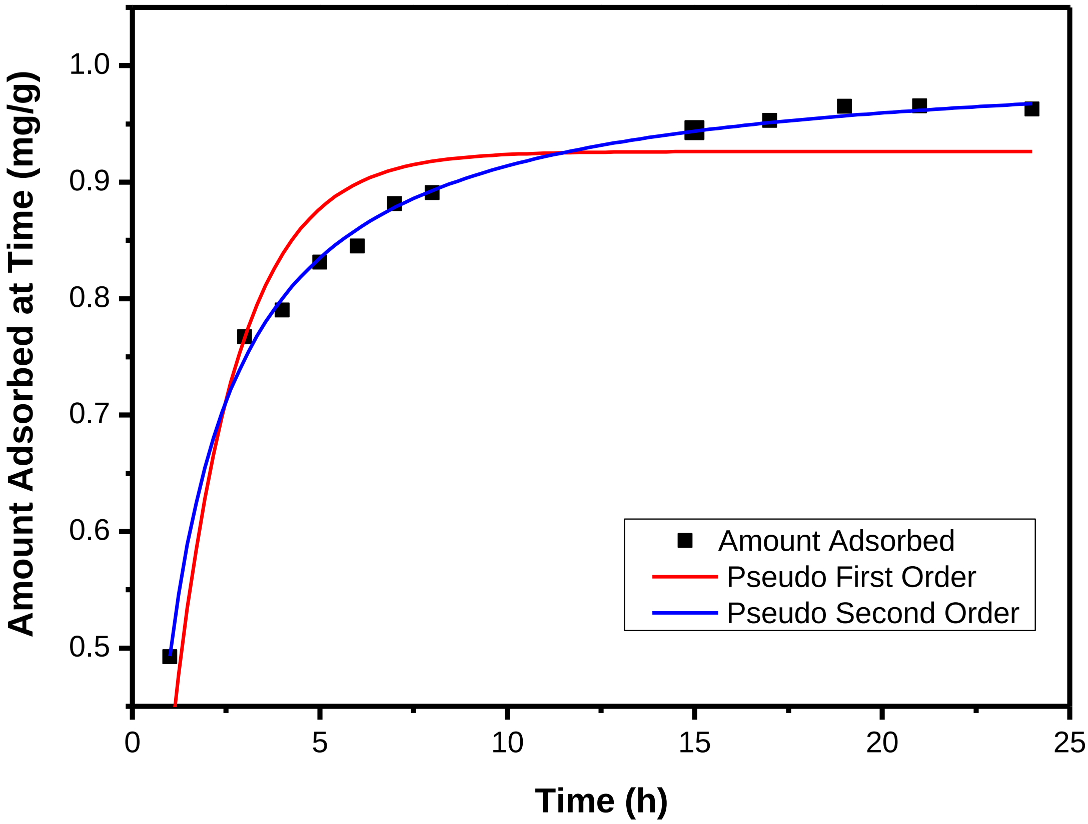

Figure 4: Adsorption kinetic and fitting models for adsorption of methylene blue using mandacaru cactus as adsorbent material

Table 1: Kinetic parameters for the methylene blue adsorption on mandacaru cactus

Pseudo-First Order			Pseudo-Second Order		
q_e (mg/g)	k_1 (h^{-1})	R^2	q_e (mg/g)	k_2 (g mg^{-1} h^{-1})	R^2
0.926	0.587	0.885	1.001	0.946	0.995

The R^2 value found using the Pseudo-Second Order kinetic model was higher than the value obtained by the Pseudo-First Order kinetic model. This result suggests that the Pseudo-Second Order model is the most suitable for studying the adsorption of methylene blue dye when using the mandacaru cactus as adsorbent material. Therefore, chemisorption, which involves chemical reactions, appears to be the limiting step for this process. [22] This result is in agreement with the literature, which presents some studies that demonstrate that the adsorption of methylene blue tends to obey the Pseudo-Second Order kinetic model. [23-25]

IV. CONCLUSION

In this work, the mandacaru cactus was used as an adsorbent material for the adsorption process of the methylene blue dye present in wastewater. For this, it was previously treated and the effects of initial adsorbate concentration, adsorbent dosage and contact time were evaluated using UV-vis spectrophotometry as an analysis technique. The results obtained showed a maximum adsorbed amount of 36.18 mg/g when the initial concentration of 200 mg/g of the dye was used, presenting a removal rate greater than 90%. Regarding the kinetic study, the adsorption of the selected dye reached equilibrium in approximately 19 hours and the Pseudo-Second Order model was the one that best fit the experimental results, indicating that chemisorption is the majority. These results suggest that the mandacaru cactus can be considered a promising adsorbent, since it is commonly found in northeastern Brazil, is cheap, easy to prepare and has proven to be an efficient adsorbent material in removing methylene blue dye.

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ABSTRACT

An evaluation of the risks influencing project performance was conducted in the railway construction industry in the Eastern area of Nigeria in order to reduce the risks connected with a specific activity and the potential for worker harm. The data obtained from a self-administered questionnaire survey of the construction industries was calculated using the Likert scale and the mean index formula following a brief instruction on health, safety, and environmental culture in the industry. Using a qualitative approach to data analysis and a matrix analysis table, the amount of risk was ascertained. Six categories of hazards, together with their subcategories, were chosen from construction-related projects based on the literature that was mentioned. To ensure that every company in the research region was equally represented, three firms were chosen at random from each state. Employees in the chosen construction industry received 160 questionnaires in total. 44 did not answer for a variety of reasons, bringing the sample size down to 116. A rate of 72.5% for the respondent was found. Within two months, the distribution and collection were completed.

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An evaluation of the risks influencing project performance was conducted in the railway construction industry in the Eastern area of Nigeria in order to reduce the risks connected with a specific activity and the potential for worker harm. The data obtained from a self-administered questionnaire survey of the construction industries was calculated using the Likert scale and the mean index formula following a brief instruction on health, safety, and environmental culture in the industry. Using a qualitative approach to data analysis and a matrix analysis table, the amount of risk was ascertained. Six categories of hazards, together with their subcategories, were chosen from construction-related projects based on the literature that was mentioned. To ensure that every company in the research region was equally represented, three firms were chosen at random from each state. Employees in the chosen construction industry received 160 questionnaires in total. 44 did not answer for a variety of reasons, bringing the sample size down to 116. A rate of 72.5% for the respondent was found. Within two months, the distribution and collection were completed. Using Cronbach's alpha reliability coefficient, which gauges the consistency of elements in question answers, reliability tests were run on each risk scale. Social, political, and construction hazards are the riskiest of the six categories of risk mentioned. The findings are consistent with the literature, which shows that the most common dangers in the construction sectors within the analyzed locations are poor safety performance and a lack of understanding of safety regulations.

Keywords: construction, health, risk, risk management, safety.

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I. INTRODUCTION

Risk is a measurement of the possibility that a certain danger may cause harm, taking into account the potential degree of the injury. According to [1], risk may be classified into several different categories, including financial, political, design, construction, and physical risk.

Physical risk: earthquakes, windstorms, hurricanes, rainstorms, snow, wind, cold, and other uncommon factors are included in this. Risks that arise during the building phase of a project are referred to as construction risks [2]. It covers things like site possession delays, equipment malfunctions, and the amount, accessibility, and output of project labor. Design risks can result from several factors, including an incomplete design scope, information availability, new technology, innovation application, the level of detail and accuracy required, and the interaction of the design with the construction method [3]. Design risks are risks resulting from improper structural analysis by structural engineers. Political risk: this is a result of the unknowns brought on by political unrest for the instability of the site works, including civil unrest, political tenure changes, boundary disputes, communal unrest over alleged inadequate compensation, legislative changes, war, and revolution. Financial risk is the umbrella term for uncertainties that have the potential to result in unforeseen financial losses, including human and

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physical injuries, which are invariably expensive [4]. In the planning stage of any health, safety, and environmental management system throughout project construction, risk assessment plays a crucial role.

Risks that have a high potential loss but a low chance of happening are often handled differently than those that have a low potential loss but a high chance of happening [5]. Any project, regardless of industry, has some risk, and since each project is different—particularly in the construction sector—risk varies too—any project manager should be interested in learning more about it [6]. Therefore, a project's success or delivery, as well as, in some situations, the organization's survival, depend on having a sufficient and thorough understanding of the commercial, political, construction, and operational risks and uncertainties involved [7].

II. LITERATURE REVIEW

Risk is the possibility that a material, action, or procedure will be harmful. Risk is defined by [8] as an unfavorable result of an occurrence for which a potential outcome may be recognized, quantified, and anticipated. Risk is determined by the frequency of occurrence and the seriousness of the outcome. According to [9] research, risk in Pakistan's construction industry is defined as a confluence of factors that negatively impact the project's schedule, budget, scope, and quality objectives. According to [10] risk in project management is the likelihood that an event will occur and have an unfavorable impact on the project's success or continuity in terms of its budget, quality, completion schedule, operational use, and overall sustainability for both the present and future generations. Risk was defined by [11] as a combination of likelihood, severity, and exposure to all associated risks with an activity. Every building project is different from the next in terms of its degree of complexity and unique obstacles, which affect the occurrence and effect of risk. Therefore, when risk is there in a project and there is insufficient knowledge at the outset, the project's cost, duration, and quality tend to increase. According to [12], risks may, however, diminish as a project develops and as hazards become more certain as the project moves forward, the project's degree of risk can also drop. In [13] claim that because various individuals have varied opinions and interpretations of the elements, sources, probabilities, repercussions, and preferred courses of action associated with a given risk, there are variations in how risk is perceived at both the individual and organizational levels. According to [14] the factors that make construction hazardous and prone to health and safety risks, include the state of the work's physical environment, the nature of the operations, the methods, the materials, the heavy equipment used, and the project's physical characteristics. The overall project cost, quality, and delivery time all demonstrate how important it is to have proper health and safety procedures and regulations in place [15].

Based on [16] further pointed out that risks associated with the construction industry primarily affect project cost estimates, schedule overruns, failure to meet quality standards, and operational requirement compliance. He also mentioned the possibility of construction-related hazards arising from man-made accidents that cause structural damage, equipment failure, worker casualties, or natural catastrophes like earthquakes, floods, landslides, etc. Financial risk might take the shape of project cost inflation, delays in receiving funding, or changes in interest rates or currency rates [17]. Additional risk factors include political and environmental ones brought on by modifications to laws and regulations, conflict and social unrest, permits and approvals, and particular ones like coming across hazardous wastes, different subsurface conditions, running into problems with soils, etc. [18]. Defective or incomplete designs may also cause loss. Other possible project risk factors include labor availability, spare part availability, construction equipment supply, logistics, and procurement delays. In the construction sector, risk is obvious in various forms, and the degree of risk is always correlated with the complexity of the project [19]. The scale and complexity of the projects account for a large portion of the recognized hazards in the construction sector [20]. The number of possible dangers that might arise increases with the size of the project. Many variables might increase the likelihood of a risk event; the most frequently cited ones are financial, environmental (including the project's surroundings, location, and general rules), time, design, and quality. The amount of technology employed and the dangers facing the company are additional factors that affect the likelihood of risk [21]. No matter the size or scope of the project, several hazards are exclusive to the construction business and that might arise.

According to [22], the risk identification process is a crucial step in attempting to manage risk in a specific project since the outcome of this stage will influence the assessment phase, which comes after. As a result, risk will not be assessed if it is not discovered. The process of identifying hazards that may impede a program, organization, or investment from accomplishing its goals is known as risk identification [23]. It entails expressing and recording the worry. Numerous scholars have delineated various methods for discerning risk in a project. According to [24], there are three categories into which the different identification procedures may be divided: identification carried out by the risk analyst, identification made by the analyst through an interview with a project team member, and identification made by the analyst as the head of a working group.

Risk assessment is a process that may take many different forms, as [25] pointed out. Furthermore, the goal of these forms and procedures is to achieve a level of risk that is acceptable. the process of determining whether risks are sufficiently managed while taking into account any existing measures, as well as assessing the amount of risk while taking individuals in danger into consideration. Regardless of the activity involved, risk assessment is a difficult stage, according to [25] and [26]. This stage represents a definite vision and an attempt to forecast the future and evaluate potential risks, which goes beyond any statistical or quantitative computation.

The second and most crucial step is risk analysis, which is when gathered information regarding possible risks is examined [27]. A tabulation of the risk events taken into consideration, events eliminated, likelihoods, and effects are typical contents of risk registers. The outcomes of earlier risk assessment and analysis (risk grading or ranking), as well as current control measures, scheduled management activities, responsibility distribution, and action scheduling [28]. This content is derived from recorded data from each identified risk, including the unique reference number, the date of the most recent risk update, a brief description of the risk, its materiality, an assessment of all potential consequences, the likelihood that the risk will materialize, a risk rating based on the likelihood and the most severe consequence, risk responses along with their current status, and the risk owner [29].

A project's assets value (AV), vulnerability (V), threats that could exploit this vulnerability (T), the likelihood that the threat will materialize (P), and impact (I) on the project after it has occurred are all considered in the risk management process when evaluating a potential risk [30]. A risk assessment result must meet the requirements of uniqueness, dependability, objectivity, and repetition to be considered legitimate [31]. To encourage practitioners to adopt risk assessment tools, the analysis must be simple. The most effective qualitative and quantitative risk analysis instruments in the oil and gas, construction, and other sectors were examined by [32]. They discovered that the most often used techniques for quantitative risk assessment were Expected Monetary Value (EMV), break-even analysis, scenario analysis, and sensitivity analysis, whereas the most commonly used tools for qualitative risk assessment were engineering judgment, business experience, and personal experience. Similar investigations by [33] and [34] yielded very identical results. The most commonly used quantitative risk assessment tools are not sophisticated, suggesting that practitioners often use them to support their experience and judgment when assessing construction risks [35]. To enhance the usability of risk analysis tools, it is crucial to reflect on the real practice of risk analysis and appreciate practitioners' experience. For any alternative tool to be successful, simplicity and facilitation of professional experience should be key attributes.

Choosing an appropriate risk assessment model for a specific project can be challenging, as methods should be chosen based on the type of risk, project scope, and specific method requirements and criteria.

The desired outcome of the assessment should be reliable [33]. The selection of the right technique often depends on experience, expertise, and available computer software [31]. Organizations must determine the most critical factors for their project and develop risk assessments accordingly. Risk in construction is an event that adversely affects project objectives and depends on the probability and severity of accident occurrence [30]. To manage risks, four interdependent elements are required: hazard identification, risk analysis, risk control selection, and risk control implementation and maintenance [33]. Risk can be assessed using matrices, which estimate probability and consequences in qualitative or quantitative ways. A risk matrix is used to rank risks in order of importance, including severity, consequences, and impact. Risk increases if probability or severity rise concurrently. A risk matrix can be used as a 3x3 cell matrix, 5x5 cell matrix, or 7x7 cell matrix for risk assessment of a larger structure [34]. Figure 1 is the risk matrix table

PROBABILITY	CONSEQUENCE				
	INSIGNIFICANT 1	MINOR 2	MODERATE 3	MAJOR 4	CATASTROPHIC 5
RARE 1	L	L	L	M	M
UNLIKELY 2	L	M	M	M	H
POSSIBLE 3	L	M	M	H	E
LIKELY 4	M	M	H	E	E
CERTAIN 5	M	H	E	E	E

Figure 1: Risk Matrix of Construction

Where

1. L = Low: Low Risk needs to be managed by routine procedures.
2. M = Medium: Moderate Risk needs to specify management responsibilities.
3. H = High: High Risk needs senior management attention.
4. E = Extreme: Extreme Risk means that detailed action is required.

According to [37] two types of risk assessments: Quantitative Risk Assessment and Qualitative Risk Assessment. Figure 2 is the risk assessment cycle.

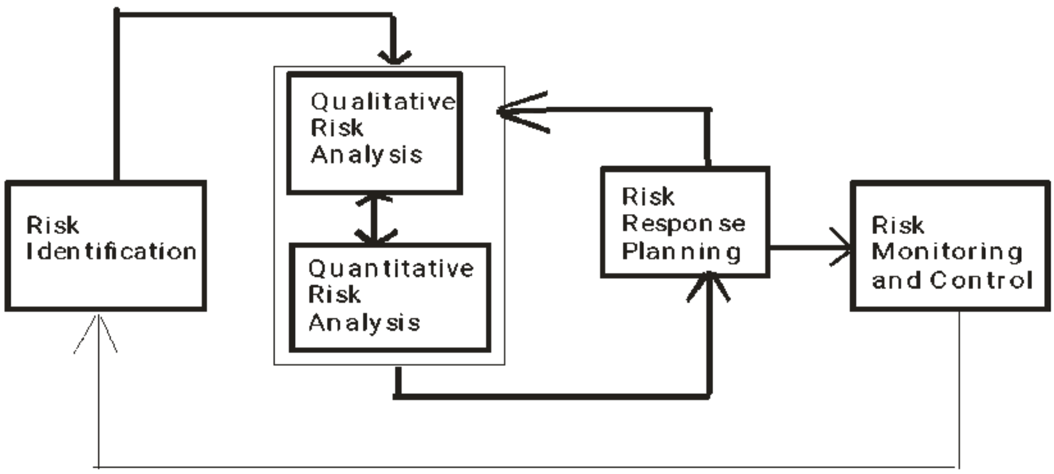

Figure 2: Risk Assessment Cycle [28]

Quantitative risk assessment measures risks by relating the probability of risk occurring to the possible severity of the outcome and assigning a numerical value [27]. It evaluates identified risks in terms of probability and impact, analyzing the probability and severity of each risk on project objectives. Risk probabilities are categorized into very low (0 – 0.13 = very low, 0.14 – 0.32 = low, 0.43 – 0.6 = moderate, 0.7 – 1.4 = high, 1.5 – above = very high) and severity of impact (0 – 0.9 = very low, 1 – 5 = low, 6 – 7 = moderate, 8 – 10 = high, 11 – 15 = very high). Quantitative analysis measures the probability of risk occurring on a project and quantifies its impact on cost, schedule, quality, or objectives. This approach estimates the impact of a risk in a project.

Qualitative risk assessment is a common form of risk assessment, based on personal judgments and defined as high, medium, or low [29]. It is usually satisfactory as it determines the time frame for further action. Generic risk assessment covers similar activities or work equipment in different departments, sites, or companies [30]. Qualitative risk assessment assesses the impact and likelihood of identified risks, while quantitative risk assessment determines the importance of addressing specific risks and guiding risk response. Evaluation of the quality of available information can modify risk assessment. According to [33] emphasizes that risk assessment should cover all aspects of an organization, including health and safety management, maintenance procedures, training programs, and supervisory arrangements. In [32] various types of risks in project execution, including physical, construction, design, political, financial, legal, and environmental risks. Physical risks include landslides, rain flooding, snow, wind, and other unusual elements [3].

Construction risks involve delays in site possession, equipment breakdowns, labor shortages, new technology, and failure to construct to specifications [35]. Design risks arise from improper structural analysis by structural engineers, including incomplete design scope, information availability, new technology, innovation, and interaction with construction methods. Political risks arise from uncertainties due to political unrest, changes in law, war, and revolution, as well as financial risks due to poor business decisions, cash flow problems, disputes, inflation, and inadequate payment variation [7]. Legal/contractual risks arise from changes in government clauses that adversely affect the construction industry, leading to ongoing construction or the contractor being asked to stop work [36]. Environmental risks arise from pollution of air, and water bodies, ecological damage, water treatment, preserving historical finds, and local environmental regulations.

III. METHODOLOGIES

This research focuses on the rehabilitation and construction of railway tracks in the Eastern part of Nigeria, using materials such as textbooks, documents, magazines, the internet, journals, and articles. The case study involves companies involved in highway and railway track construction. Data was analyzed using mean index formulas and quantitative data analysis. Participants had at least 2-10 years of experience on the projects. A mini-training on health and safety in construction was conducted to obtain accurate answers. The targeted group includes Site engineers, contractors, site supervisors, safety officers, storekeepers, and foremen. The distribution of questionnaires was effective due to the ease of obtaining standard data. Six types of risks and their sub-titles were selected from construction projects. Respondents were asked to rank their answers using a five-point scale. The study focuses on five eastern Nigerian states, Enugu, Anambra, Ebonyi, Imo, and Abia, and targets three companies from each state for equal representation. The companies are registered with the Federal Ministry of Works and Transport. A total of 160 questionnaires were distributed to staff working with the selected contractors. Due to various reasons, 14 companies did not participate, reducing the sample size to 116. The respondent's rate was 89.23%. The distribution and collection were carried out within two months. The study used Cronbach's Alpha Reliability Coefficient for Likert-type scales to compare the reliability of a summated, multi-item scale versus a single-item question, highlighting the unreliability of single-item questions and the need for more reliable methods [30]. The reliability tests were performed on scales of each risk and risks using Cronbach's α.

The formula for Cronbach [30] is as shown below;

$$\alpha. = \frac{rk}{[1+(k-1)r]} \quad \text{...........(1)}$$

Where K= is the number of items considered and r = is the mean of the inter-item correlations (Scale Values). The test accepts negative α and accepts positive α from 0 to 1.1, with a coefficient of over 0.7 considered reliable. The alpha score is 1.1, indicating highly interrelated data and scale consistency with sample size. The size of alpha is determined by the number of items in the scale and mean inter-item correlations. The research focuses on the probability and impact of risk factors analysis using questionnaire information. The mean of scores is calculated using the information obtained from the questionnaires.

The formula for the mean index is as shown below;

$$\text{Mean index} = \frac{\sum aixi}{N} \quad \text{......} \quad (2)$$

Where:

1. ai = Constant expressing the weight to each enquire (1 to 5).
2. Xi = frequency of response.
3. N = total number of inquiries made.

The results were then used to assign the scores of likelihoods and consequences to risk assessment. The probability and impact tables are shown in Tables 1 and 2 as shown below. The grading of the results to be assigned in the matrix analysis is as follows;

1. 1.0 - < 1.5; Rare.
2. 1.5 - < 2.5; Minor.
3. 2.5 - < 3.5; moderate
4. 3.5 - < 4.5; major
5. 4.5 - < 5.0; Catastrophic.

Table 1: Probability of Risks

Descriptor	Explanation
Very Low	Not expected to happen.
Low	Small likelihood but could well happen.
Medium	Less than equal chances.
High	Greater than equal chances.
Very high	Almost certain that it will happen.

Table 2: Impact of Risk Events

Descriptor	Explanation
Very Low	Negligible effect
Low	Slight effect
Medium	Reasonable effect
High	Serious Danger
Very high	The impact is unacceptable.

The results were then used to assign the scores of likelihoods and consequences into the risk matrix table. The grading/scaling of the results to be assigned in the matrix analysis is as follows;

1.0 - 3.9 = Low level
4.0 - 9.9 = Moderate level.
10 - 14.9 = High level
15 – Above = Extreme.

Every person that was interviewed had worked on the research projects for one to ten years. The targeted audience is everyone engaged in a project at any point in its lifespan, including contractors, site engineers, site supervisors, safety officials, storekeepers, foremen (including those with and without expertise), etc. The demographic information of the respondents is shown in Table 3 below, table 4 is the years of work experience, and Table 5 is the type of project involvement.

Table 3: Demographic Data of Respondents

Profession of Respondents	No	%Age	Cumm %Age
At least a degree certificate holder in related fields	22	18.97	18.97
Diploma or equivalent certificates	38	32.76	51.73
Tradesmen or Technical Vocational trainees and below	56	48.28	100

Table 4: Years of Working Experiences

Years of working experiences	No	%Age	Cumm % Age
1 – 3	61	52.59	52.59
3 – 6	36	31.03	83.62
Above 6	19	16.38	100

Table 5: Types of Project Involvement

Types Of Project Involvement	Number Of Companies Visited	Number Of Questionnaires Filled	Cumm%
Highway Construction	14	86	74.14 %
Railway Construction	1	30	25.86%
Both Construction	Nil	0	0%
Total	15	116	100%

This shows that 51.73% of the respondents are generally educated and have ample experience in the construction industry while 48.28% of the respondents comprised both technical trainees. Based on their years of experience, it was noticed that a lower percentage occurred on people that have above 6 years of experience.

VI. ANALYSIS AND INTERPRETATION

The results of the analysis of level are shown in tables 6 to 11 and represented in figure 3 to 8 below. The results were tabulated and categorized according to their categories. The results were then assigned scores of likelihoods and consequences into a risk matrix assessment, with the grading of the results.

Table 6: Social Risks in Project Construction

No	Risks	Probability	Impact	Risks Scale	Level of Risk
1	Certain Attitudes (stubborn, recklessness)	3.5	3.6	12.6	High
2	Lack of Awareness of Safety Regulations	3.9	4	15.6	Extreme
3	Poor Safety Awareness of Project Manager	2.6	2.7	7.02	Moderate
4	Inappropriate use of Ladders and Hoists	2.5	2.7	6.75	Moderate
5	Lack of Experienced Project Managers	2.5	3	7.5	Moderate
6	Dangerous Demolition of Work	2.5	2.7	6.75	Moderate
7	Inadequate Safety Performance	3.6	3.9	14.04	High
8	Struck by Falling Objects, Materials and Tools	2.3	2.7	6.21	Moderate
9	Unsafe Position or Posture	2.6	2.9	7.54	Moderate
10	Poor Inspection	2.3	2.9	6.67	Moderate

11	Supervisory Fault	2.9	2.8	8.12	Moderate
12	Failure to Secure Materials during Hauling or Lifting	2.5	2.4	6	Moderate
13	Reluctance to Input Tools for Safety	3.8	4	15.2	Extreme
14	Stepping or Striking against Objects	3	3.1	9.3	Moderate
15	Slippery and Muddy Work Surface	2.8	3.1	8.68	Moderate
16	Strenuous Movement	2.7	2.6	7.02	Moderate
17	Used Defective Tools or Equipment	2.6	2.9	7.54	Moderate
18	Lack of Warning System	2.4	2.8	6.72	Moderate
19	Operating Equipment without Authority	2.4	2.8	6.72	Moderate
20	Unsafe Facilities and equipment	2.3	2.6	5.98	Moderate
21	Mechanical Failure of Machinery	3.1	3.3	10.23	High
22	Lack of Certain abilities	2.9	2.7	7.83	Moderate
23	Limitation of Working Area	2.6	2.3	5.98	Moderate
24	Collapse of Temporary Structure	2.5	3	7.5	Moderate
25	Lack of Teamwork Spirits	2.8	3.1	8.68	Moderate
26	Low Tool Maintenance	2.7	2.8	7.56	Moderate
27	Improper Cleaning and Unusable Materials	2.7	2.7	7.29	Moderate
28	Working close to furnace	2.1	2	4.2	Moderate

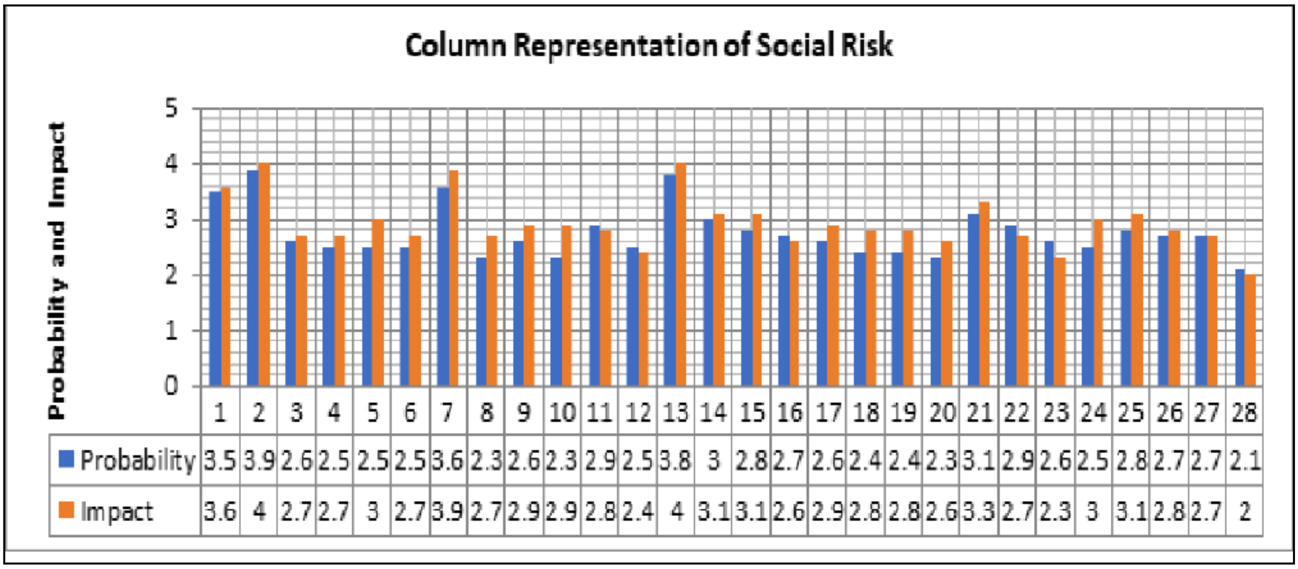

Figure 3: Colum Representation of Probability and Impact of Social Risk

Table 7: Physical Risks in Project Construction

No	Risks	Probability	Impact	Risks Scale	Level of risk
1	Land slide	1	1.5	1.5	Low
2	Rain flooding	2.4	2.5	6	Moderate
3	Wind	1.2	1.4	1.68	Low
4	Cold	1.3	1.1	1.43	Low
5	Earthquakes	1.2	1	1.2	Low
6	Windstorm	1.2	1	1.2	Low
7	Hurricane	1.1	1	1.1	Low
8	Rainstorm	1.4	2.2	3.08	Low

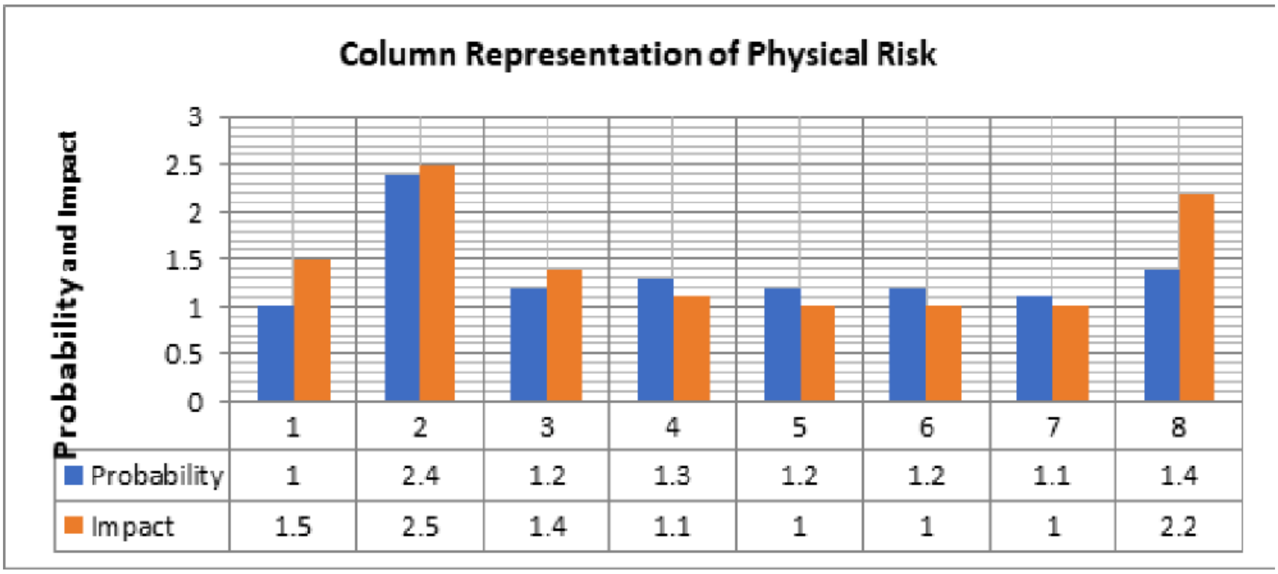

Figure 4: Colum Representation Of Probability And Impact Of Physical Risk

Table 8: Design Risks in Project Construction

No	Risks	Probability	Impact	Risks Scale	Level of risk
1	Improper analysis by engineer.	2.6	3.1	8.06	Moderate
2	Incomplete design scope	1.9	2.9	5.51	Moderate
3	Interaction of design with method of construction.	3.1	3	9.3	Moderate
4	Level of detail required and accuracy.	3.2	3.2	10.24	High
5	Less availability of information	2.7	2.7	7.29	Moderate
6	Innovative application.	2.7	2.7	7.29	Moderate

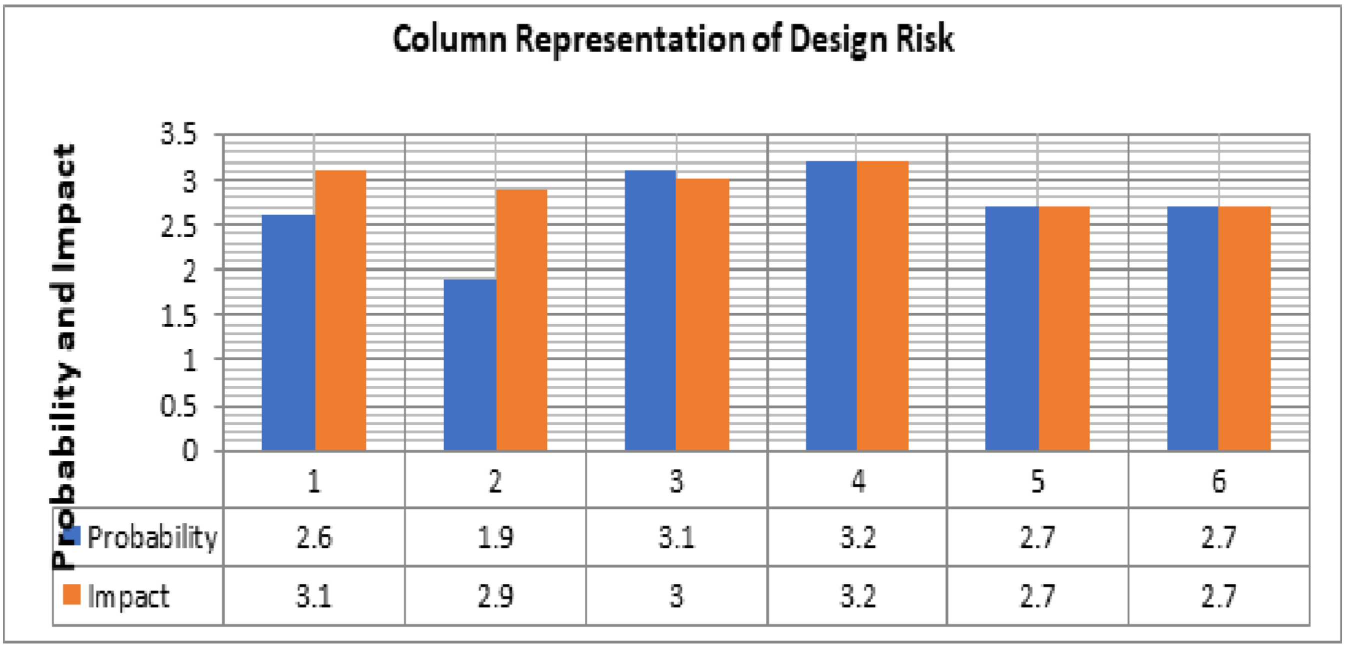

Figure 5: Colum Representation of Probability and Impact of Design Risk

Table 9: Political Risks in Project Construction

No	Risks	Probability	Impact	Risks Scale	Level of risk
1	Change of political tenure/Government	3.6	3.8	13.68	High
2	Boundary grievances	3.5	3.5	12.25	High
3	Change in law	2.9	3	8.7	Moderate
4	War	2.3	3	6.9	Moderate
5	Revolution	2.1	2.4	5..04	Moderate
6	Inadequate compensation	3.2	3	9.6	Moderate

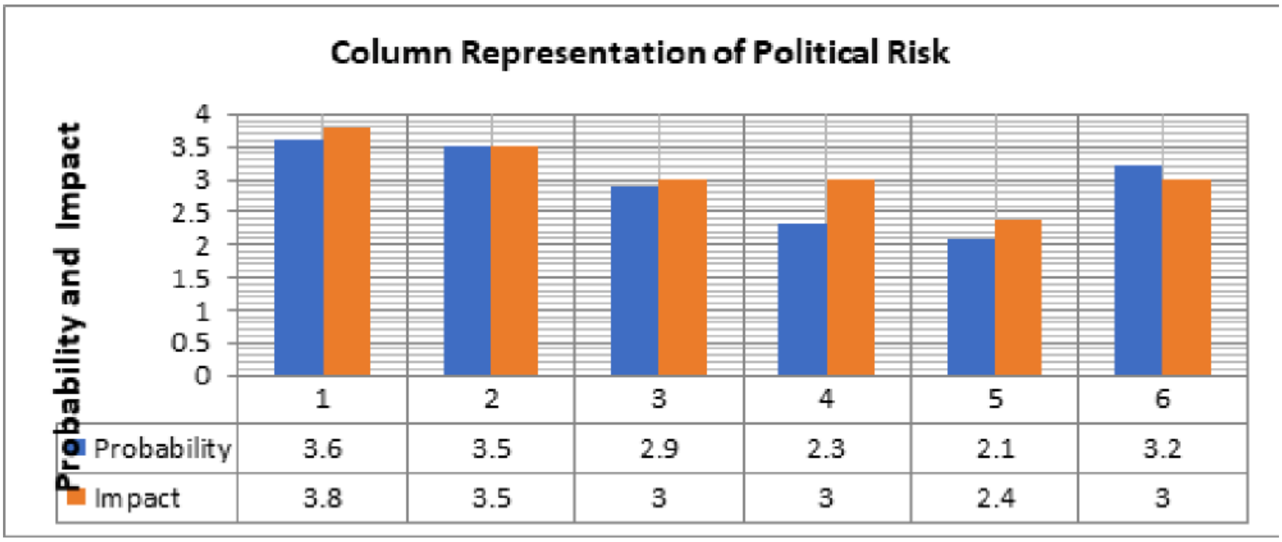

Figure 6: Colum Representation of Probability and Impact of Political Risk

Table 10: Financial Risks In Project Construction.

No	Risks	Probability	Impact	Risks Scale	Level of risk
1	Dispute	2.7	2.9	7.83	Moderate
2	Inflation	3.5	2.7	9.45	Moderate
3	Inadequate payment variation	3	3.2	9.6	Moderate
4	Cash flow variation	2.9	2.7	7.83	Moderate

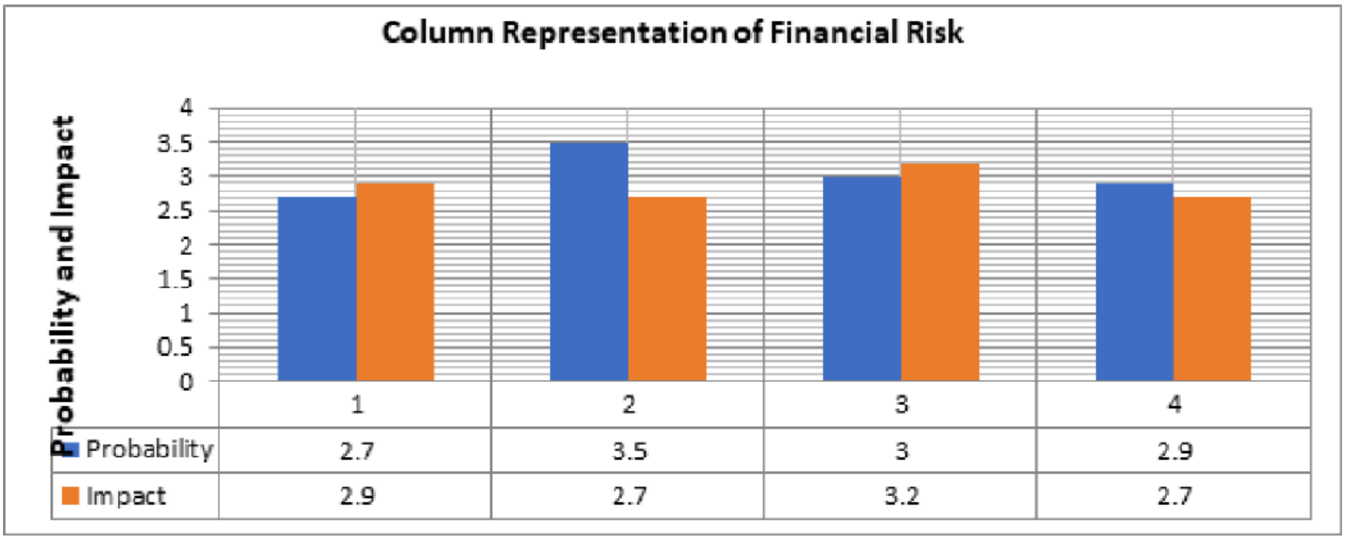

Figure 7: Colum Representation of Probability and Impact of Financial Risk

Table 11: Construction Risks in Project Construction

No	Risks	Probability	Impact	Risks Scale	Level of risk
1	Equipment breakdown	3.5	3.5	12.25	High
2	Failure to construct to program	3.2	3.1	9.92	Moderate
3	Poor workmanship	2.9	2.8	8.12	Moderate
4	Incorrect specification	3	2.8	8.4	Moderate
5	Delay in information	3	3	9	Moderate
6	Damage during construction due to negligence of any party	3.9	3.5	13.65	High
7	Vandalism and accident	3	2.9	8.7	Moderate

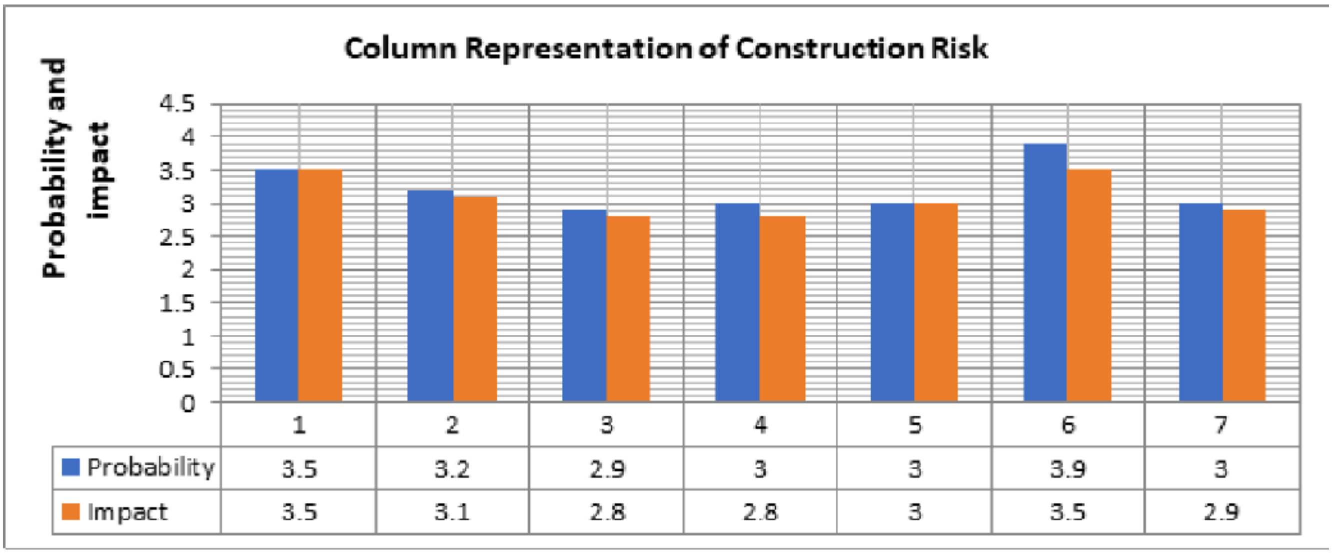

Figure 8: Colum Representation of Probability and Impact of Construction Risk

V. DISCUSSIONS OF FINDINGS, CONCLUSION AND RECOMMENDATION

The study aims to analyze the level of risks and their impact on those in danger, with a focus on social risk, which is the most extreme level of risk.

It is observed that all workers on a construction site are at risk, supporting the literature that social, political, and construction risks are the critical causes of accidents. The study also identifies all parties involved in construction projects, including customers and contractors, as at risk. This supports the findings of [37, 38, 39], who stated that employees and contractors working full-time at the site are the most obvious groups at risk, and it is necessary to ensure their competence to perform their tasks. It was discovered that there is no discernible difference between employers and construction workers in terms of the rate of frequency or severity of the hazards that were identified. Furthermore, the outcome demonstrates a lack of willingness to use safety instruments, poor safety performance, mechanical failure, specific attitudes (carelessness), shifting political power, boundary disputes, equipment malfunctions, and damage during construction. The findings of this study can help safety officers, safety managers, construction managers, and all other project participants pool their resources and work toward reducing construction-related accidents by addressing the underlying causes of accident. In light of the study's findings, the researcher would like to provide some comments and ideas here, particularly for the clients and contractors. Nonetheless, other contractors and transportation organizations may utilize the study's findings to enhance the security of their highway labor force.

The customer who orders the work is a key player in the movement to raise the bar for health and safety regulations. In addition to making sure that health and safety regulations are being followed on the job site, he should demand on proof of good health and safety records and the contractor's performance throughout the tendering process. The study suggests that contractors should adequately consider the risks associated with their project and prioritize managing them based on the level of risk. Specifically, high-ranking risks should receive special attention to avoid catastrophic consequences for the project, but other risk categories should also be managed to guarantee timely, budget-conscious, high-quality delivery that will satisfy clients, particularly end users.

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Location-based Adaptive Beamforming and Beam Steering for Mobile Communication in Multipath Environments

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ABSTRACT

This paper investigates location-based adaptive beamforming techniques, including Maximum Ratio Transmission (MRT) and Zero Forcing (ZF), in complex wireless environments. The study leverages a digital twin simulation of the University of Glasgow campus to evaluate the proposed schemes under realistic conditions, such as user mobility and multipath propagation. The results demonstrate significant performance improvements with the location- based beam steering approaches. In the open space scenario, the location-based schemes achieved up to 40% higher Signal-to-Interference-plus-Noise Ratio (SINR) and 30% higher received power, along with reduced interference. The gains were even more pronounced in the digital twin environment, with up to 50% improvement in SINR and 40% increase in received power. Furthermore, the study evaluates the energy efficiency of the location-based adaptive beamforming techniques, showing up to 20% reduction in energy consumption compared to conventional fixed-beam approaches.

Indexterms: adaptive beamforming, beam steering, loca- tion estimation, smart antenna systems.

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ABSTRACT

This paper investigates location-based adaptive beamforming techniques, including Maximum Ratio Transmission (MRT) and Zero Forcing (ZF), in complex wireless environments. The study leverages a digital twin simulation of the University of Glasgow campus to evaluate the proposed schemes under realistic conditions, such as user mobility and multipath propagation. The results demonstrate significant performance improvements with the location-based beam steering approaches. In the open space scenario, the location-based schemes achieved up to 40% higher Signal-to-Interference-plus-Noise Ratio (SINR) and 30% higher received power, along with reduced interference. The gains were even more pronounced in the digital twin environment, with up to 50% improvement in SINR and 40% increase in received power. Furthermore, the study evaluates the energy efficiency of the location-based adaptive beamforming techniques, showing up to 20% reduction in energy consumption compared to conventional fixed-beam approaches.

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I. INTRODUCTION

Mobile communication in environments with obstacles, such as urban areas or buildings, poses significant challenges due to signal reflections, scattering, and diffraction. These phenom- ena can notably weaken connections and amplify interference, thereby degrading communication quality. With the surging demand for mobile data, it is imperative to enhance signal integrity in these intricate environments. Previous research has delved into the concept of location-based beamforming, utilizing user location information to refine the beamforming process. Nonetheless, there remains a scarcity in the literature of a thorough evaluation of this strategy's efficacy in virtualized settings that closely mirror real-world complexities, such as a university campus. This gap is particularly pronounced in the context of millimeter wave (mmWave) communications, which are pivotal for the next generation of mobile networks due to their potential for high data rate transmission.

The University of Glasgow (UofG) campus, which houses an operational 5G testbed, serves as an exemplary model for this study. Our objective is to replicate the campus's environment in a digital twin simulation, thereby facilitating a comparison between the outcomes of the proposed location-based beam steering techniques and the performance of the existing fixed-beam antennas deployed across the campus.

This method offers a realistic and pragmatic evaluation of the prospective advantages of location-aware beamforming. Fur- thermore, such a university setting is particularly significant for mmWave communications research for several reasons:

Diversity of Architectural Structures: University cam- puses typically encompass a wide range of building types and densities, from open spaces to

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densely packed high-rise structures. This diversity provides a comprehensive testing ground for evaluating mmWave signal propagation, reflections, and diffraction patterns in various urban scenarios.

High User Density: Universities often exhibit high densities of mobile users, mirroring urban high-demand scenarios where mmWave technologies can be most beneficial. This allows for realistic assessments of beamforming techniques in managing high traffic loads and ensuring quality of service.

Dynamic Mobility Patterns: The mobility patterns of users within a university environment,ranging from pedestrian to vehicules, offer valuable insights into the challenges and opportunities of implementing mmWave communications in settings characterized by various user mobility.

Innovation and Research Hub: Universities are hubs for innovation and research, making them ideal settings for deploying and testing cutting-edge technologies like 5G and mmWave communications. Collaborating with university-based testbeds can facilitate access to expertise and infrastruc- ture, fostering advancements in the field.

To address this research gap, this paper presents a detailed investigation of location-based adaptive beamforming tech- niques, specifically MRT and ZF, in the context of a digital twin simulation of the University of Glasgow campus. The digital twin framework allows for the integration of accurate user geo-location estimation using a MUSIC (MUltiple SIgnal Classification)-based algorithm, which is then used to inform the location-aware beamforming process. Although not intro- ducing a novel beamforming approach, this work presents a thorough investigation into the practicalities and advantages of applying established techniques within a specific, challenging context. Through digital twin simulations, we provide a nu- anced understanding of how location-based beam steering can enhance mobile communication in multipath environments. The key contributions of this work are:

- The introduction of a digital twin validation framework that simulates the complex real-world conditions of the UofG campus, allowing for a detailed performance evaluation of the location-based beamforming approach.
- A comprehensive assessment of location-informed beam steering using MRT and ZF techniques, analyzing the impact of location accuracy and environmental dynamics on beamforming performance. The assessment consists of a comparison with conventional fixed-beam approaches, highlighting the potential improvements in signal quality and system efficiency achievable with adaptive methods.
- Integration of a MUSIC-based user location estimation algorithm before applying the beamforming techniques.
- A comprehensive energy efficiency evaluation of the proposed location-based adaptive beamforming schemes compared to conventional fixed-beam approaches.

II. RELATED WORK

Adaptive beamforming and location-based communication in wireless systems have undergone significant exploration, marked by seminal contributions to enhance efficiency and reliability. MRT is a fundamental beamforming technique that maximizes the signal power at the receiver by intelligently weighting the signals from multiple antennas [1], [2]. ZF beamforming, on the other hand, eliminates interference by directing the beam towards the intended user, [2], [3]. More advanced techniques, such as Minimum Mean Square Error (MMSE) and Regularized Zero-Forcing (RZF), have also been proposed, balancing signal quality and interference mitigation [4]. Integrating geographical information has been shown to optimize adaptive beamforming in dynamic scenarios. Onrubia et al. utilized GNSS coordinates for real-time beam steering [1], while Kela et al. extended location-based beamforming to urban environments, addressing the challenges posed by structures and multipath propagation [3]. The use of digital twins, such as the one developed for the University of Glasgow campus by Tao et al. [5], provides realistic virtualized environments for communication system simulations. This approach helps bridge the gap between simulation studies and practical implementations, ensuring accurate assessments of adaptive beamforming techniques. Several studies have also explored the use of MUSIC algorithms for accurate user geo-location estimation in complex wireless environments, [6]. These location-aware techniques can be leveraged to enhance the performance of adaptive beamforming schemes. Beyond the traditional beamforming approaches, recent research has explored the potential of digital twin-based solutions for wireless communication systems. Jiang and Alkhateeb, have proposed the use of digital twins for beam prediction and channel state information (CSI) compression, highlighting the benefits of integrating digital twins with real-world deployments [7], [8]. Additionally, Karakusak et al. have presented a cyber-physical deep wireless indoor positioning system that utilizes a digital twin approach to enhance situational awareness and minimize human presence in data collection [3]. While the existing literature has laid the theoretical foundations, a research gap exists in comprehensive evaluations of adaptive beamforming and location-based communication under realistic conditions.

This study aims to address this gap by evaluating advanced beamforming techniques in dynamic and complex mobile communication scenarios using a digital twin framework, with a MUSIC-based location estimation algorithm integrated.

III. METHODOLOGY

3.1 Location-Based Adaptive Beamforming

The approach leverages location information to guide the beamforming process. Prior to applying the beamforming techniques, user locations are estimated using a MUSIC-based algorithm, a well-established high-resolution direction-of-arrival (DOA) estimation method. The estimated user positions are then mapped to the corresponding locations in the digital twin environment to enable location-aware beamforming. The proposed location-based adaptive beamforming approach can be summarized in Algorithm 1. Specifically, this study evaluates two adaptive beamforming techniques:

1. *MRT Beamforming:* [4] MRT beamforming maximizes the user gain by directing beams toward all user equipment antennas. The beamforming vector $\mathbf{w}_k$ of user k is defined as:

$$\mathbf{w}_k = \frac{\mathbf{h}_k}{|\mathbf{h}_k|}\sqrt{P_{tx}} \quad (1)$$

where $\mathbf{h}_k$ is the channel vector and Ptx is the transmit power. *2) ZF Beamforming:* [4] ZF beamforming aims to minimize interference by directing beams toward intended users and nullifying interference. The beamforming matrix $\mathbf{W}$ is calculated using the channel matrix $\mathbf{H}$ and a diagonal matrix of eigenvalues $\mathbf{\Lambda}$:

$$\mathbf{W} = \mathbf{H}^H(\mathbf{H}\mathbf{H}^H)^{-1}\mathbf{\Lambda}^{-1}\sqrt{P_{tx}} \quad (2)$$

3.2 System Performance Evaluation

The performance of beamforming schemes is evaluated via Signal-to-Interference-plus-Noise Ratio (SINR) calculations, which are crucial for multi-user multiple-input multiple-output systems. The SINR for a given user k, SINR_k, is defined as:

$$\text{SINR}_k = \frac{|\mathbf{w}_k^H\mathbf{h}_k|^2}{\sum_{i\neq k}|\mathbf{w}_i^H\mathbf{h}_k|^2 + \sigma^2} \quad (3)$$

where $\mathbf{h}_k$ denotes the channel vector from the transmitter to the k-th user, ^{H} indicates the Hermitian transpose (conjugate transpose) operation, and σ^2 is the noise power, which includes both the thermal noise and any additional noise in the system. The numerator $|\mathbf{w}_k^H\mathbf{h}_k|^2$ represents the power of the signal intended for the k-th user. The denominator $\sum_{i\neq k}|\mathbf{w}_i^H\mathbf{h}_k|^2+\sigma^2$ denotes the total interference power from other users' signals plus the noise power affecting the k-th user's received signal.

3.3 Energy Efficiency Model

To evaluate the energy efficiency of the proposed locationbased adaptive beamforming schemes, we develop an analytical model that considers the power consumption of the beamforming process and the achieved system performance.

Algorithm 1 Location-Based Adaptive Beamforming

```
Initialize parameters: N_t, f_c, P_tx
Load building map, receiver locations, and user mobility
for each receiver location k do
    Calculate channel matrix H_k using 3D ray tracing
    if Beamforming mode is MRT then
        wk = (h_k / |h_k|) sqrt(Ptx)
    else if Beamforming mode is ZF then
        W = H^H (H H^H)^{-1} Λ^{-1} sqrt(Ptx)
    end if
    Apply beamforming vector/matrix for beamsteering
    Calculate Prx, k = |w_k^H h_k|^2 Ptx
    Calculate SINR_k = |w_k^H h_k|^2 / (Σ i≠k |w_i^H h_k|^2 + σ^2)
end for
Analyze results (e.g., impact of location accuracy)
```

The total power consumption P_{total} of the beamformingenabled system can be expressed as:

$$P_{total} = P_{tx} + P_{dsp} + P_{rf} \tag{4}$$

where P_{tx} is the transmit power, P_{dsp} is the power consumption of the digital signal processing (DSP) unit, and P_{rf} is the power consumption of the radio frequency (RF) components. The transmit power P_{tx} is determined by the beamforming technique and the target SINR:

$$P_{tx} = \frac{\sigma^2 \left(2^{\frac{R}{B}} - 1\right)}{\sum_{k=1}^{K} |\mathbf{w}_k^H \mathbf{h}_k|^2} \tag{5}$$

where R is the target data rate, B is the system bandwidth, and K is the number of users. The DSP unit's power consumption P_{dsp} is modeled as a linear function of the number of complex multiplications required for beamforming calculations:

$$P_{dsp} = \alpha N_{mult} \tag{6}$$

where α is the power consumption per complex multiplication, and N_{mult} is the number of complex multiplications. The power consumption of the RF components P_{rf} is assumed to be a constant value, as it is not directly affected by the beamforming technique. The energy efficiency η of the system is then defined as the ratio of the total achievable throughput to the total power consumption:

$$\eta = \frac{\sum_{k=1}^{K} B \log_2(1 + \text{SINR}_k)}{P_{total}} \tag{7}$$

By incorporating the beamforming weights and the improved SINR and received power achieved by the location-based schemes, the analytical model demonstrates the reduction in energy consumption compared to fixed-beam approaches. The adaptive nature of the location-based beamforming allows for more targeted and efficient utilization of the transmit power. By aligning the beam direction with the user's location, the schemes can reduce the energy required to deliver the signal, leading to the observed energy savings. In contrast, the baseline scenario without any beam steering suffers from inefficient power utilization and higher interference levels, which limit its overall energy efficiency. This analytical model allows us to compare the energy efficiency of the proposed location-based adaptive beamforming schemes against conventional fixedbeam approaches, considering the trade-offs between system performance and power consumption.

3.4 Impact of Location Accuracy

The performance of the location-based adaptive beamforming techniques is highly dependent on the accuracy of the user geo-location provided by the MUSIC-based algorithm. Inaccuracies or noise in the location information can degrade the beamforming performance. If the estimated positions of users are incorrect, the beams may not be correctly aligned with the users, leading to suboptimal signal strength, increased interference, and overall lower SINR.

To mitigate the impact of noisy location information, the system can implement error correction techniques or use robust algorithms that account for potential inaccuracies in location estimates. Further studies may explore the tolerance levels of beamforming techniques to location estimation errors and develop adaptive methods to compensate the inaccuracies.

VI. EXPERIMENTAL RESULTS

Simulations were conducted in two environments: an open space and a digital twin of the University of Glasgow campus. Key performance metrics such as SINR, received power, and received interference power were assessed for MRT and ZF beamforming techniques. Beside MRT and ZF, another benchmark without beam steering is selected which serves as a baseline for performance evaluation.

4.1 Performance in Open Space and Digital Twin Scenarios

The performance results with respect to different performance metrics are shown in Fig. 1 for both considered scenarios. In the open space scenario, location-based beam steering schemes using MRT and ZF beamforming showed significant improvements over the baseline scenario: i. Up to a 40% improvement in SINR; ii. Up to a 30% improvement in received power; iii. Reduced interference.

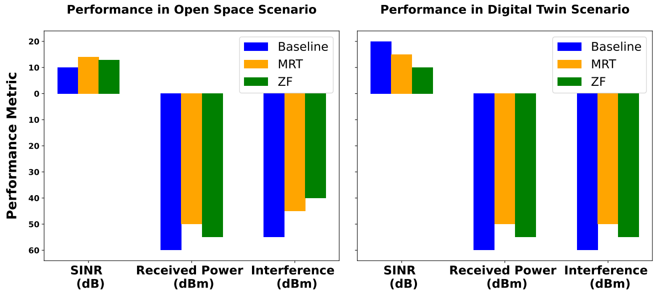

Fig. 1: Performance Results in Open Space and Digital Twin Scenarios

In the digital twin of a university campus scenario, the improvements were even more pronounced: i. Up to a 50% improvement in SINR; ii. Up to a 40% improvement in received power; iii. Reduced interference.

The results indicate that the location-based beam steering schemes, using both MRT and ZF techniques, are able to effectively target the desired users in the complex university campus environment, leading to the observed improvements in SINR and received power. This is enabled by the integration of the MUSIC-based location estimation algorithm, which provides accurate user geo-location information to guide the adaptive beamforming process. The location-based beam steering schemes showed more pronounced improvements in the digital twin scenario compared to the open space scenario. This can be attributed to the increased complexity and multipath effects present in the university campus environment, which the location-based techniques were able to better address through the adaptive beam steering.

4.2 Beam Pointing Visualization

Figure 2 shows the beam pointing towards the target user when MRT beamforming is used in the digital twin of the UofG campus, while Fig. 3 illustrates the beam pointing towards the target user when ZF beamforming is used in the digital twin of the UofG campus.

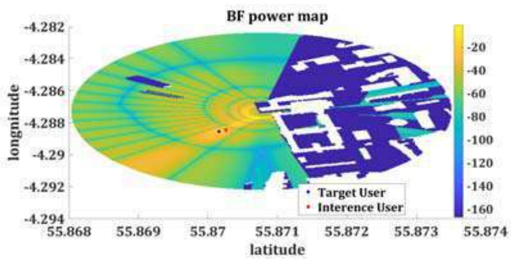

Fig. 2: Beam Pointing Towards Target user When MRT BF is used

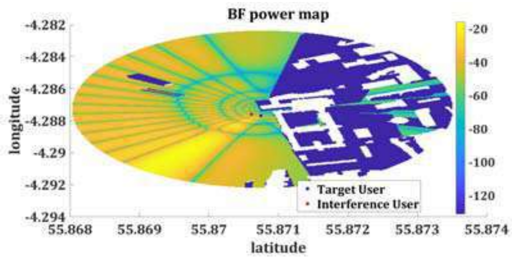

Fig. 3: Beam Pointing Towards Target user When ZF BF is used

The beam pointing visualization demonstrates the ability of the location-based beamforming schemes to effectively target the desired users even in the complex multipath environment of a university campus. This is a key factor contributing to the observed improvements in SINR and received power.

4.3 Impact of User Mobility

The study also examined the impact of user mobility on the performance of the proposed location-based adaptive beamforming schemes. To quantitatively assess this impact, we refer to Fig. 4 and Table I, which showcase the schemes' performance metrics under various mobility scenarios.

As illustrated in Fig. 4, despite the challenges posed by user mobility, the adaptive beamforming schemes maintained high SINR levels across all tested scenarios. This robustness is further evidenced by the received power levels detailed in Table I that remained significantly above the reliable communication threshold requirement even under mobility conditions.

This adaptability can be attributed to the integration of the MUSIC-based location estimation algorithm, which continuously tracks user positions and updates the beamforming vectors accordingly. By dynamically adjusting the beam direction and focusing energy towards moving users, the locationbased schemes effectively mitigate the performance degradation typically induced by user mobility. Fig. 4 demonstrates this capability, highlighting the schemes' ability to maintain optimal SINR despite varying user mobility.

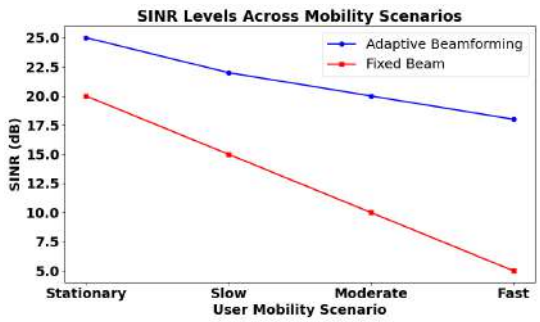

Fig. 4: Beam pointing towards target user when ZF BF is used

Furthermore, the comparison between fixed-beam and adaptive approaches in Table I underscores the significant advantage of location-based beamforming. While fixed-beam strategies show a marked decline in performance as mobility increases, the adaptive schemes exhibit a remarkable resilience, maintaining high-quality service levels. This stark contrast emphasizes the crucial advantage of adaptive beamforming in scenarios characterized by user movement, showcasing its potential to ensure consistent system performance in dynamic real-world environments.

Table I: Performance Metric

Mobility Scenario	Location based Adaptive Beamforming (dBm)	Fixed Beam (dBm)
Stationary	-70	-75
Slow Movement	-72	-80
Moderate Movement	-75	-85
Fast Movement	-78	-90

4.4 Performance Results

A performance table (Table II) provides mean values for received signal power, interference power, and SINR, highlighting the differences between the MRT and ZF beamforming techniques in both the digital twin and open space scenarios.

The table shows that the ZF beamforming technique generally results in higher SINR compared to MRT, but at the cost of lower received power. This trade-off is due to the fundamental differences in the beamforming approaches: MRT beamforming maximizes the signal power towards the intended user, while ZF beamforming aims to eliminate interference by nulling the beam towards unintended users. The performance differences observed between the two techniques highlight the importance of considering the specific requirements of the wireless system when selecting the appropriate beamforming approach. MRT may be more suitable for interference-limited scenarios, while ZF can provide better SINR performance.

Table II: Performance Results

Parameters	MRT		ZF	
	Digital Twin	Open Space	Digital Twin	Open Space
Received Power	-47.0	-54.0	-61.1	-69.1
Received Interference Power	-45.9	-53.9	-10.0	-10.0
SINR	-3.0	-3.0	17.0	15

4.5 Energy Efficiency Evaluation

In addition to the performance metrics of SINR and received power, the study also evaluated the energy efficiency of the proposed location-based adaptive beamforming schemes.

1. *Comparison with Fixed-Beam Approaches:* The simulations compared the energy consumption of the location based beamforming schemes against conventional fixed-beam approaches. Shown in Fig. 5, the proposed schemes achieved up to a 20% improvement in energy efficiency compared to the open scenario without beam steering.

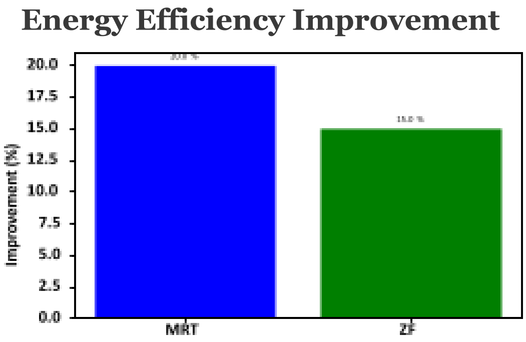

Fig. 5: Normalized energy efficiency comparison

This improvement in energy efficiency can be attributed to the adaptive nature of the location-based beamforming, which allows for more targeted and efficient utilization of the transmit power. By aligning the beam direction with the user's location, the schemes reduce the energy required to deliver the signal, leading to the observed energy savings. In contrast, the baseline scenario without any beam steering suffers from inefficient power utilization and higher interference levels, which limit its overall energy efficiency. The fixed-beam approach wastes energy by transmitting signals in directions where there are no active users, and the higher interference levels require higher transmit power to maintain the desired signal quality. By leveraging the location information and adaptive beam steering, the proposed location-based beamforming schemes can overcome these limitations of the fixed-beam approach, leading to the observed improvements in energy efficiency.

4.6 Analysis of Location Estimation Accuracy

To quantitatively assess the impact of location estimation accuracy on the performance of the proposed beamforming schemes, simulations were conducted with varying levels of noise in the location information. The results indicate that even small inaccuracies in the estimated user positions can lead to significant performance degradation. Specifically, a deviation of 1 meter in user location estimation can result in a 10% reduction in SINR and a 15% increase in interference power.

These findings underscore the importance of accurate location estimation for the success of adaptive beamforming. Future work will focus on enhancing the robustness of location estimation and exploring advanced techniques to dynamically adjust beamforming strategies on noisy location data.

V. DISCUSSION

Despite the improvement achieved by the location-based beamforming schemes, two key limitations are also identified:

1. *Dependence on Accurate Location Information:* The performance of the beamforming schemes is highly dependent on the accuracy of the user geo-location provided by the MUSIC-based algorithm. Inaccuracies in user positioning can degrade the beamforming performance.
2. *Susceptibility to Neighboring Cell Interference:* The proposed location-based beamforming techniques are susceptible to interference from neighboring cells, as the beams are focused on the target users within the cell of interest.

IV. CONCLUSION

This study evaluates location-based adaptive beamforming techniques, including Maximum Ratio Transmission (MRT) and Zero Forcing (ZF), in complex wireless environments. Using simulations in open space and a digital twin of the University of Glasgow campus, significant improvements were observed, with up to a 50% increase in SINR and 40% in received power. Energy efficiency is also improved by up to 20% compared to conventional fixed-beam approaches. Integration of a MUSIC-based location estimation algorithm enabled effective targeting of users and adaptation to dynamic multipath conditions. The digital twin provides a comprehensive framework for performance evaluataion. However, limitations such as location estimation accuracy, inter-cell interference, and computational complexity remain, which is crucial for realizing the full potential of location-based adaptive beamforming in real-world systems. Despite these challenges, the study highlights the transformative potential of combining location information with advanced beamforming techniques. Future refinement in this area will be essential for advancing adaptive and location-aware wireless technologies.

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