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"SUSTAINABLE SYNTHETIC ROUTES IN CHEMISTRY: A REVIEW ON THE GREEN SYNTHESIS OF COUMARIN DERIVATIVES"

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Abstract: As key components of vitamins, hormones, and proteins necessary for human growth and biological activity, heterocyclic compounds are crucial to the biochemical processes of both plants and animals. The 1,2-benzopyrone ring system contains coumarins, which have a variety of pharmacological characteristics, including anti-inflammatory, anticoagulant, anticancer, and neuroprotective actions. The development of synthetic techniques is necessary since coumarin extraction, which is traditionally taken from natural sources, is labor-intensive, time-consuming, and ecologically demanding. The synthesis of coumarin derivatives has been carried out by several researchers due to its biological activity and possible uses. High synthesis needs can lead to a rise in the production of certain waste compounds. Green synthetic techniques are used to reduce the use and production of hazardous organic materials. Green chemistry, which is based on the 12 principles, seeks to reduce environmental impact through sustainable processes. Energy consumption and hazardous waste in coumarin synthesis are decreased by using green techniques such solvent-free processes, microwave or ultrasonic synthesis, and designer solvents. The goal of contemporary coumarin derivative synthesis techniques is to increase yields and product purity while reducing energy, chemicals, and processes. These derivatives, which are made by processes like Knoevenagel condensation and Claisen rearrangement, exhibit improved biological activity and characteristics. Problems like contamination from conventional synthesis processes are addressed by the move to eco-friendly methods. Green synthetic methods lessen environmental damage and support sustainable pharmaceutical practices. This review provides an overview of the literature which highlights the application of green synthetic methods in the coumarin synthesis.

Keywords: Coumarin derivatives, Green chemistry, Sustainable processes, Solvent-free processes, Microwave synthesis

Introduction:

In the Biochemical process of plants and animals many heterocyclic compounds play a very important role [1]. Vitamins, Hormones and proteins which are essential for human's growth and their biological activity contain aromatic heterocyclic compounds [2] [3]. In the synthesis of new biologically active scaffolds, such as antimicrobial, anthelmintic, analgesic, anti-inflammatory, antiepileptic, antihypertensive, antineoplastic, antimalarial, antidepressant, antianxiety, antihistaminic, antioxidant, antidiabetic, antiviral, antitubercular, and antiparkinson's agents, compounds containing heterocyclic atoms are very important [4]. In medicinal chemistry, a variety of physiologically active compounds with oxygen, nitrogen, and sulfur are utilized as medications. These medications including oxygen have a significant function in medicinal chemistry [5]. Due to the existence of oxygen as a heteroatom, many compounds in synthetic organic chemistry exhibit potent medicinal properties.

Coumarins are a type of organic compound that belongs to the 1, 2-benzopyrone ring system group. Natural coumarins have various pharmacological effects, such as anti-inflammatory, anticoagulant, anticancer, antibacterial, antimalarial, antifungal, antiviral, Alzheimer's disease inhibition, neuroprotective, anti-HIV, antidiabetic, anticonvulsant, and antihypertensive effects [6]. Coumarins are used as industrial additives, cosmetics, and scents. Additionally, they are used to enhance the aroma of tobacco goods and some alcoholic beverages [7]. Their main areas of responsibility include pharmaceutical chemistry, natural products chemistry, and organic chemistry. Originally, herbs were utilized to cure a wide range of illnesses. After a few years, chemists developed pure forms of medications that were derived from plants using various chemical purification techniques. However, more chemicals and solvents were used in the extraction and purification processes of natural pharmaceuticals, and waste products were also created. More medications are needed as the population grows and more ailments arise. More extraction from nature is needed to meet population demand. It has an indirect negative impact on the environment and ecology. The method of extracting natural coumarin is laborious and time-consuming, and turning it into its derivatives takes a long time. Therefore, it becomes essential for the future to synthesize coumarin and its various derivatives without affecting the environment.

Green chemistry:

The goal of green chemistry is to create chemical products and procedures that minimize pollution and environmental harm. Twelve green chemistry principles were proposed by Anastas and Warner in the 1990s to direct sustainable activities. [8] The production of hazardous waste from procedures like phloroglucinol synthesis is one of the major environmental issues that the chemical and pharmaceutical sectors have had to deal with. Initiatives like the creation of the Environmental Protection Agency (EPA) in the 1970s were prompted by the book Silent Spring, which increased public awareness of the harm that chemicals inflict to the environment. Green chemistry principles were formalized as a result of international initiatives to encourage sustainable chemical practices, including the Stockholm Conference and OECD meetings [9] [10]. Paul Anastas and John Warner give 12th principle of green chemistry, Green chemistry draw chemical which are not harm to the environment and reduce hazardous substance from environment [11]. Figure 1

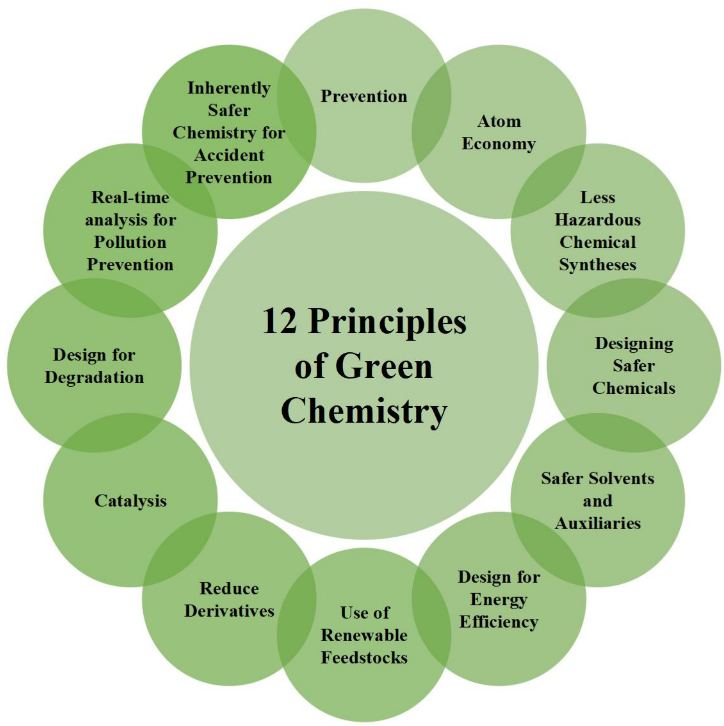


Figure 1

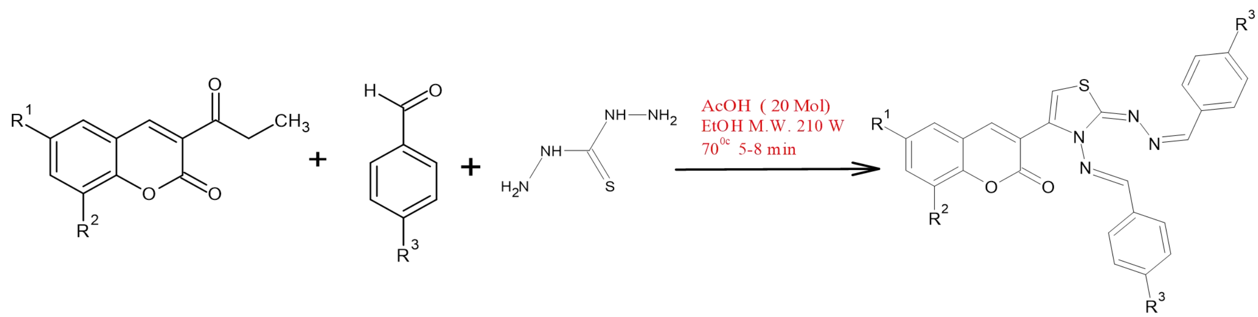
Discussion

Coumarins are important in the biological activity of many diseases due to their unique and versatile structure. Bioactive compounds, both synthetic and natural, need molecules having two or more heterocyclic rings. Adding another heterocyclic ring or group to coumarin, either as a fused component or as a substituent, improves the properties of the parent material as well as its biological activity and reactive capacity. Many organic chemists have been drawn to highly active coumarin heterocyclic derivatives as a result. Such coumarin heterocyclic compounds can be prepared using a variety of starting materials and techniques. The synthesis of coumarin derivatives from various starting materials, such as aldehydes, ketones, acids, etc., by using different reactions like the Claisen rearrangement, Perkin reaction, Pechmann reaction, Witting reaction, and Knoevenagel condensation reaction. [12] Large, complex, bulky heterocyclic coumarin molecules are created in a multistep process. However, as the number of stages grows, so does the amount of energy and chemicals used, and derivatization likewise increases. These days, scientists are working on creating intricate structures using environmentally friendly processes that need fewer stages, less chemicals, and less energy [13]

Conventional synthetic methods for coumarin synthesis have been modified or even replaced in recent decades by greener alternatives like solvent-free, mechanosynthesis, microwave, or ultrasound synthesis, and synthesis using so-called designer solvents like deep eutectic solvents or ionic liquids. All of these green techniques are being created and used to complete reactions in softer environments with greater yields and purity of the end products, hence reducing or eliminating the production or usage of hazardous volatile organic solvents, catalysts, or other hazardous compounds [14]. In addition to providing a literature survey that includes the data, this review paper provides an overview of the use of green synthetic techniques in the synthesis of coumarin derivatives.

Microwave - Assisted Synthesis Of Coumarins:

New coumarin-based thiazoles were synthesized by Srikanth M et al using microwave irradiation of thiocarbohydrazide, aldehydes, and 3-(2-bromoacetyl) coumarins, with structures confirmed by 1H & 13C NMR, FTIR, Mass, and analytical data. These compounds were evaluated for in vitro cytotoxic activity against a Gram-positive spheroid firmicute. This coumarin-based thiazoles were prepared by reacting thiocarbohydrazide, aldehydes and substituted 3-(2-bromoacetyl) coumarins in a 1:2:1 molar ratio in ethanol, using a catalytic amount of acetic acid under microwave irradiation, yielding the products in good yields [15] Scheme 1.

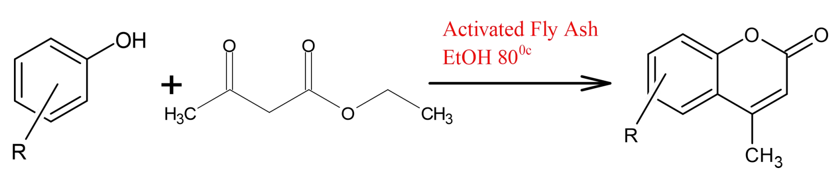


Scheme 1: Three components of microwave-irradiated synthesis of coumarin–thiazole derivatives

Coumarin synthesis using catalyst:

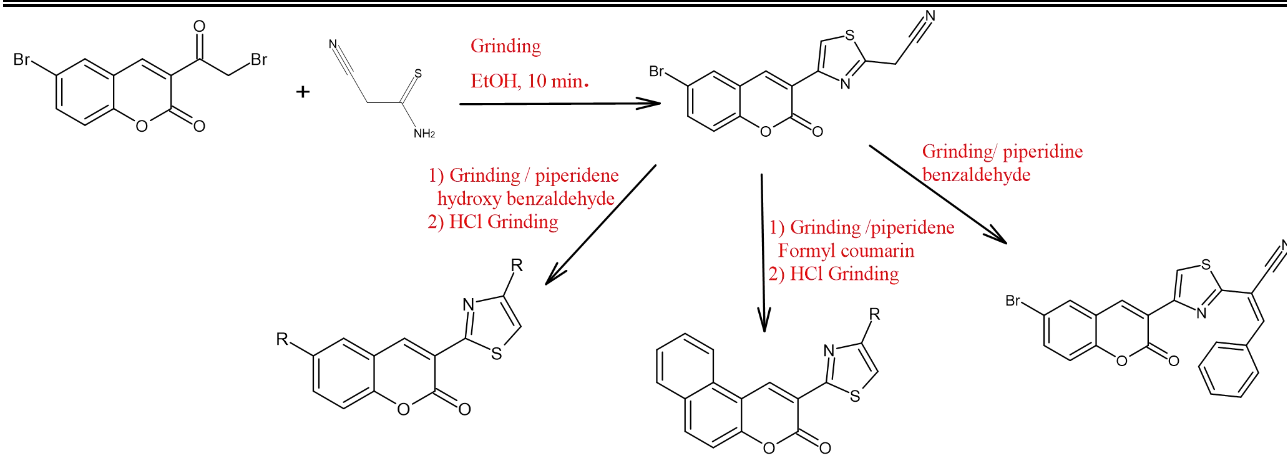
Khonsole S and colleague did Green Synthesis of Coumarin Derivatives Using Activated Fly Ash as Catalyst, A general procedure for synthesizing coumarin derivatives involved dissolving 2 mmol of phenol in 2 mL of ethanol, adding 2 mmol (0.3 mL) of ethyl acetoacetate with stirring and warming, followed by incremental addition of Activated Fly Ash. The reaction mixtures were refluxed at 80 °C with stirring, and the progress was monitored using thin-layer chromatography (TLC). Upon completion, solvents were evaporated, and solid residues were extracted with hot water [16].

Scheme 2

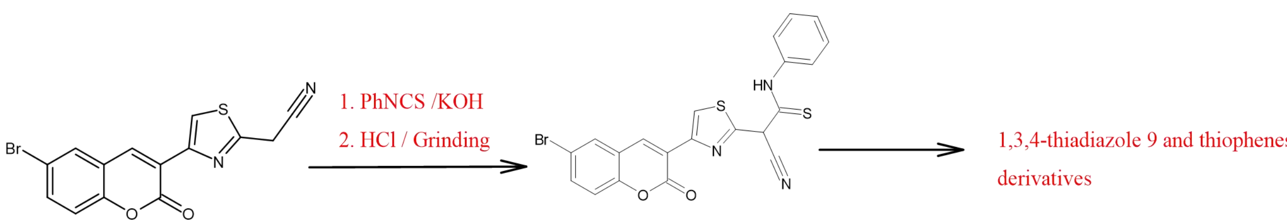


Scheme 2: Coumarin Derivatives Using Activated Fly Ash as Catalyst

A new family of coumarins comprising thiazoles or 1,3,4-thiadiazoles was synthesized by Abdel-Aziem, A. employing a solvent-free grinding technique in a quick, economical, and environmentally friendly manner. 6-bromo-3-(2-bromoacetyl)-2-chromen-2-one first formed a thiazole-2-acetonitrile derivative by reacting with cyanothioacetamide. Through reactions with hydroxyaldehydes, this derivative was further transformed into iminocoumarins. It was then hydrolyzed with concentrated HCl to produce coumarins scheme 3. Furthermore, 1,3,4-thiadiazole and thiophene derivatives were produced by the thiazole-2-acetonitrile derivative reacting with phenylisothiocyanate, hydrazonoyl chloride, or α-halocarbonyl compounds scheme 4. The antibacterial activity of each synthesized coumarin was assessed against six harmful pathogens [17].

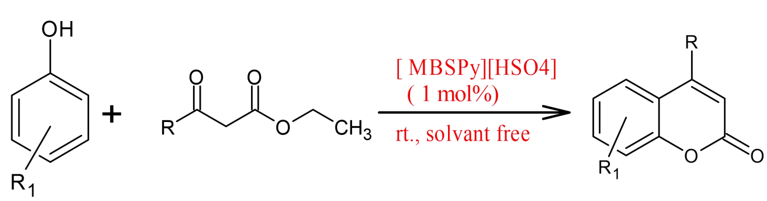


Scheme 3: Synthesis of thiazole derivatives



Scheme 4: Synthesis 1,3,4-thiadiazole and thiophenes derivatives.

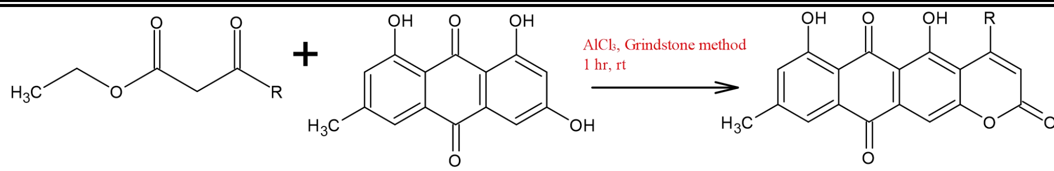
Using a doubly Brønsted acidic task-specific ionic liquid (TSIL) as a catalyst under ambient settings without the use of solvents is an environmentally friendly method for creating coumarin derivatives. High yields and shorter reaction times are provided by the technique, which also permits up to five reuses of the reusable TSIL catalyst. 3-methylpyridine (10 mmol) and 1,4-butanesultone (10 mmol) were added to a round-bottom flask, which was then refluxed at 80 °C while being constantly stirred until a white solid formed. After adding 10 mmol of sulfuric acid to the white solid, the mixture was refluxed at 80 °C. Sulfuric acid and the white solid combined to produce a pale yellowish viscous liquid, and the reaction was allowed to continue until it was finished. At room temperature, phenol (1 mmol), β-ketoester (1.2 mmol), and [MBSPy][HSO4] (0.01 mmol) were mixed, and thin layer chromatography was used to track the reaction's development. The mixture was cooled, worked up with distilled water, and the crystalline result was filtered and recrystallized using ethanol once the product formation was confirmed scheme 5. [18]



Scheme 5: Synthesis of coumarin derivatives from different substituted phenols using [MBSPy][HSO_4] as a catalyst.

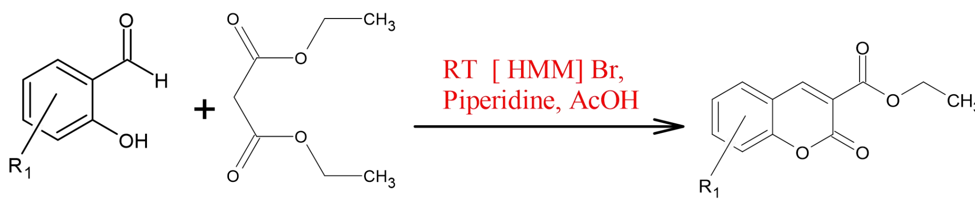
One-pot multicomponent coumarin synthesis:

Velmurugan Loganathan et al. synthesized anthraquinone-connected coumarin derivatives via the grindstone method. The grindstone technique (one-pot multicomponent synthesis) was used to create anthraquinone-connected coumarin (1a-t) derivatives. AlCl3 was mixed with anthracene-9,10-dione and ethyl 3-oxobutanoate using the grindstone technique for one hour at room temperature. Scheme 6. The product was separated using a column and identified and verified using thin-layer chromatography (TLC). The product yield ranged from 89% to 65% [19].

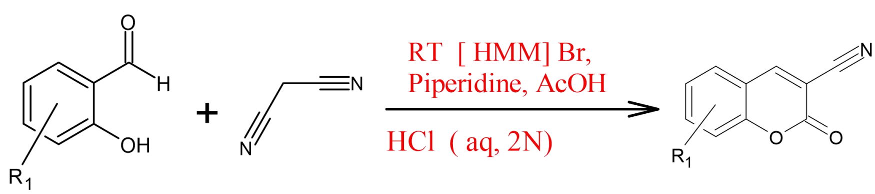


Scheme 6: synthesis anthraquinone-connected coumarin derivatives

Leila Dinparast and his colleague developed an environmentally friendly process for synthesizing coumarin derivatives and then conducting biological analyses of them. To do this, coumarins were produced with relatively quick reaction durations in a one-pot process at room temperature without the use of solvents, yielding excellent results. 1-hexyl-3-methylimidazolium bromide was employed as a substitute for typical hazardous solvents and as a reaction medium. When the aforementioned ionic liquid was present, the reactions happened extremely quickly at room temperature, and as soon as salicylaldehyde was added, good yields (>90%) of the compounds were generated. It should be mentioned that diethyl malonate (Scheme 7) or malononitrile (Scheme 8) to salicylaldehyde derivatives at 1.2/1 molar ratios produced the highest product yield [20].



Scheme 7: coumarin derivatives in the presence of ionic liquid at room temperature with diethyl malonate via Knoevenagel condensation.



Scheme 8: coumarin derivatives in the presence of ionic liquid at room temperature with malononitrile via Knoevenagel condensation.

Conclusion:

This study emphasizes the importance of coumarins, a broad family of heterocyclic compounds with a variety of pharmacological characteristics, in medicinal chemistry. Greener synthetic methodologies are needed since traditional extraction processes are bad for the environment. To effectively synthesis coumarin derivatives while lowering waste and energy consumption, green chemistry concepts such solvent-free methods, microwave irradiation, and ionic liquids have been used. Numerous cutting-edge techniques, such as catalyst reuse and mechanosynthesis, have produced high-purity coumarin-based molecules with improved biological activity. In addition to addressing environmental issues, these environmentally friendly tactics satisfy the rising need for bioactive substances in medicinal applications.

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A REVIEW: NANOCATALYST FOR BIODIESEL SYNTHESIS

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Abstract

Due to its attractive properties, nanotechnology and nanomaterial applications are currently garnering attention across a broad range of research fields. Research worldwide is concentrated on the application of nanotechnology and nanomaterials in the production and processing of biodiesel. More attention is being paid to the use of cutting-edge nanotechnology for maximum yield at low cost in order to speed up the development and advancement of biodiesel manufacturing. Therefore, the use of various nanomaterials and Nanocatalyst for the synthesis of biodiesel from various feedstocks will be covered in this study. Applications of nanomaterials in lipid extraction and algae cultivation will also be the main focus of this investigation. Additionally, the current study will provide a thorough assessment of the major obstacles and potential future developments around biodiesel combined with nano additives in diesel engines.

Keyword: Nanocatalyst, Transesterification, Environmental Sustainability, Catalyst Recovery, Eco-Friendly Nanocatalysts

Introduction:

The increasing energy demand and environmental concern over fossil fuel use have driven interest in alternative fuels like biodiesel. The application of nanotechnology and nanomaterials in biodiesel research has become a practical tool for providing effective ways to improve production quality at a fair price. Nanoparticles (NPs) offer a number of advantages over biodiesel synthesis because of their small size, unique properties, and attributes, such as a high surface area to volume ratio, notable crystallinity, catalytic activity, adsorption capacity, and stability[1]. Metal oxide nanoparticles and carbon nanotubes are frequently used as nanocatalysts to produce biofuel and biodiesel because of their extra characteristics that support high potential recovery[1]. This research critically examines the use of nanotechnology in the production and enhancement of biodiesel, highlighting the primary challenges and encouraging prospects for the future.

In the presence of a catalyst, such as homogeneous and heterogenous, oils or fats are transesterified with a methanol or ethanol to production of biodiesel.[2] The feedstock first pre treated to prevent the impurities and water from interfering with the reaction. After that, a catalyst and alcohol solution are added to oil for transesterification at 50-60^{0}C stirring for one to two hours. Transesterification, a chemical reaction between triglycerides and an alcohol in the presence of a catalyst, is the most widely used method for biodiesel production. Catalysts are essential in accelerating this reaction, reducing the production time, and improving the yield. Glycerol is a byproduct of the reaction, which is transform to biodiesel layers to separate out. After separated the biodiesel is washed with warm water for removing impurities then it is dried to remove remaining water content.[3]

Overview of nanoparticle:

Usually ranging in size from 1 to 100 nanometres, nanoparticles are extremely small materials having special qualities derived from their high surface area-to-volume ratio and quantum effects. These qualities enable applications in a variety of industries by making them extremely versatile and flexible.[4] The optical, electrical, magnetic, and biological properties of nanoparticles vary according to their composition, which includes metals, oxides, polymers, carbon, and lipids. Their behaviour is further influenced by their structures and forms, which makes them appropriate for specific uses in electronics, energy, medicine, and other fields.

Nanoparticles have a wide range of significant applications. They are employed in electronics to create flexible circuits and cutting-edge displays, and in medicine for targeted medication delivery, diagnostics, and cancer treatments. They are also essential to consumer goods like sunscreens and food additives, solar and energy storage technology, and environmental cleanup. To ensure its safe and sustainable usage, however, issues like toxicity, environmental concerns, regulatory barriers, and production scaling must be resolved. Nanoparticles have enormous potential to change industries and enhance daily living in spite of these reservations.[5]

Nanocatalyst:

Nanocatalyst are catalysts at the nanoscale that demonstrate improved catalytic activity, selectivity, and stability owing to their elevated surface area-to-volume ratio and distinctive surface characteristics. These nanoparticles, typically composed of metals such as platinum, palladium, or gold, or oxides like titanium dioxide, enhance chemical reactions more effectively than their bulk equivalents. Their flexible size, shape, and composition provide precise control over reaction pathways, rendering them essential in applications like as energy conversion (e.g., fuel cells and hydrogen production), environmental remediation (e.g., pollutant degradation), and industrial chemical synthesis. For broad use, issues including aggregation, stability under reaction conditions, and possible environmental impact must be resolved despite their benefits.[5]

Block Diagram of Biodiesel production:

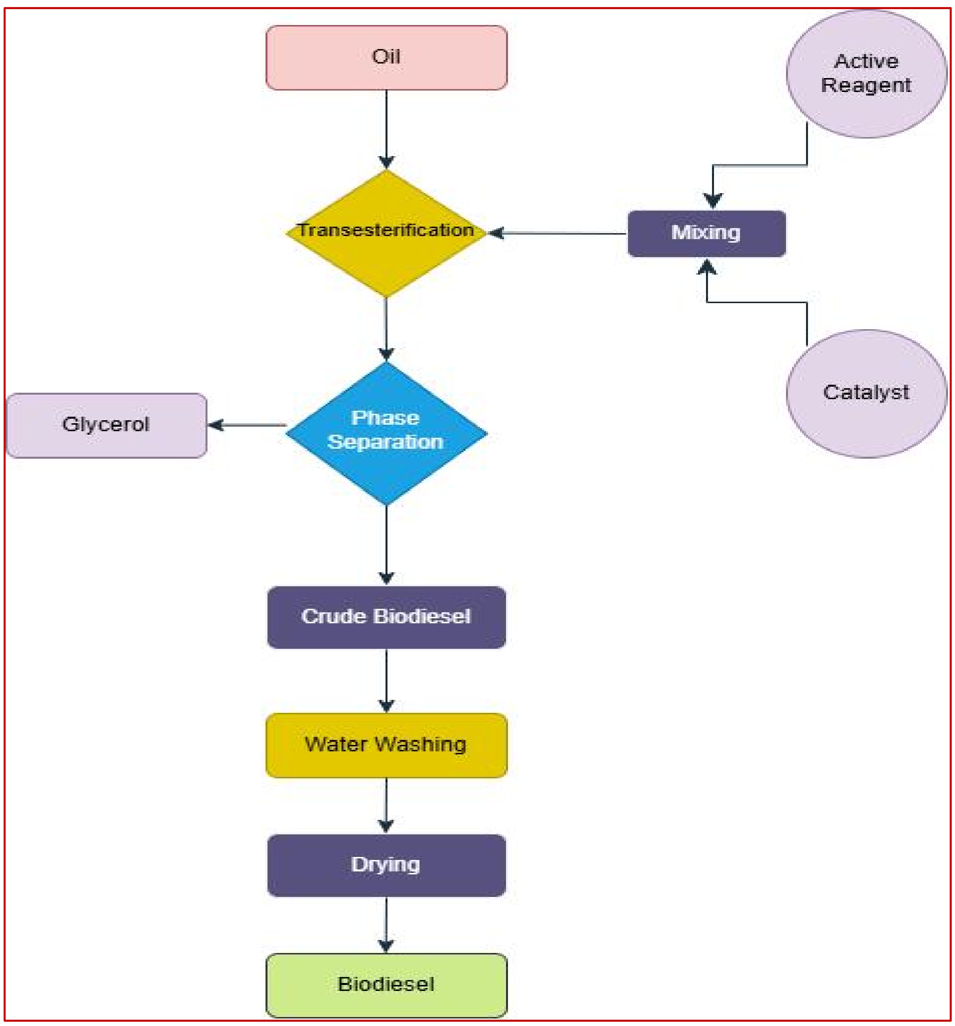

Figure No. 1 flow chart for production of Bio desal

Transesterification:

The general term for chemical reactions in which an ester is changed into another by the exchange of the alkoxy group is transesterification. Alcoholysis is the term for the transesterification process that occurs when an alcohol reacts with the initial ester. In accordance with the majority of papers in this topic, the term "transesterification" will be used interchangeably with "alcoholysis of carboxylic esters" in this study. Transesterification is an equilibrium reaction in which the reactants are mixed to achieve the transformation. However, the equilibrium adjustment is significantly accelerated when a catalyst is present, usually a strong acid or basic. The alcohol must be utilised excessively to provide a high ester yield. [3]

General Reaction: -

$$RCOOR' + ROH \rightleftharpoons \mathrm{RCOOR} + R'OH \ [3]$$

Comparative study of catalyst in biodiesel production:

Using Homogenous catalyst for Transesterification in Biodiesel Production

Type of Catalyst	Examples	Advantages	Disadvantages	Applications
Base Catalysts	Sodium Hydroxide (NaOH), Potassium Hydroxide (KOH)	- High catalytic activity - Fast reaction rates - Suitable for oils with low free fatty acid (FFA) content	- Requires anhydrous alcohol and moisture-free oils - Soap formation may occur with high FFA content - Difficult catalyst recovery	Most commonly used for transesterification of vegetable oils with low FFA content
Acid Catalysts	Sulfuric Acid (H_2SO_4), Hydrochloric Acid (HCl)	- Effective for feedstocks with high FFA content - Less sensitive to moisture and impurities - Suitable for low-quality feedstocks	- Slower reaction rates - Higher temperatures and longer reaction times required - More challenging catalyst separation	Used for biodiesel production from feedstocks with high FFA content (e.g., used cooking oils)

Table No. 1 catalyst use in synthesis of biodiesel its advantage and application

They do have some serious drawbacks, though. The challenge of removing the catalyst from the finished product is a significant disadvantage that frequently leads to increased purification expenses and a decline in product quality.[6] Furthermore, homogeneous catalysts are frequently employed in liquid-phase processes, necessitating cautious reaction environment management to prevent contamination and adverse reactions. Reduced stability and shorter catalyst lifespans may result from their susceptibility to reaction parameters like pH and temperature. Additionally, homogeneous catalysts are more difficult to recycle or dispose of, which raises environmental issues. Notwithstanding these drawbacks, they are nevertheless used in particular applications where great selectivity.[7]

Using Heterogenous catalyst for Transesterification in Biodiesel production:

Type of Catalyst	Examples	Advantages	Disadvantages	Applications
Metal Oxide Catalysts	Calcium Oxide (CaO), Magnesium Oxide (MgO), Zinc Oxide (ZnO)	- High activity and selectivity - Can be reused multiple times - Suitable for feedstocks with low to medium FFA content - Less soap formation compared to homogeneous catalysts	- Requires high temperatures - Can lose activity after multiple uses - Sensitivity to moisture	Commonly used for biodiesel production from vegetable oils and animal fats with low FFA content
Solid Acid	Sulfonated	- Effective for	- Slower reaction	Used for biodiesel

Catalysts	Zirconia, Tungstated Zirconia, Amberlyst	feedstocks with high FFA content - No soap formation - Can operate under milder conditions compared to acid homogeneous catalysts	rates compared to base catalysts - Catalyst deactivation over time	production from waste oils and fats with high FFA content
Enzyme Catalysts	Lipase (from *Candida antarctica* or *Pseudomonas* spp.)	- Biodegradable and environmentally friendly - Operates under mild conditions (low temperature, ambient pressure) - High selectivity	- High cost of enzymes - Slower reaction rates - Reusability issues	Suitable for biodiesel production from high-FFA oils, particularly for small-scale production
Supported Metal Catalysts	Nickel (Ni), Sodium (Na), Potassium (K) supported on silica (SiO_2) or alumina (Al_2O_3)	- High catalytic efficiency - Can be reused - Suitable for large-scale production	- High cost of metals - Sensitive to impurities and FFA content	Used for large-scale biodiesel production from vegetable oils and animal fats
Magnetic Nanocatalysts	Iron Oxide (Fe_3O_4), Magnetite (Fe_3O_4)	- Easy catalyst recovery using magnetic separation - Can be reused multiple times - High catalytic performance	- May lose activity with repeated use - High synthesis cost	Used in transesterification for easier catalyst recovery and reuse
Biomass-Derived Catalysts	Biochar, Biomass Ash	- Renewable and low-cost - Environmentally friendly - Can be made from waste materials	- Lower catalytic activity compared to other catalysts - Potential issues with stability	Used for small-scale biodiesel production, particularly in rural or low-resource areas

Table No. 2 catalyst use in synthesis of biodiesel its advantage and application

Surbhi Semwal, Ajay K. Arora, Rajendra P. Badoni, Deepak K. Tuli this researcher conclude that various solid acidic and basic heterogeneous catalysts have been explored for biodiesel synthesis, but their use is limited due to lower reaction rates and side reactions. Acid-base catalysts are potential due to their simultaneous esterification and transesterification. Enzymatic catalysts are promising but slow. Successful commercial catalysts must have long life, recyclability, and lower cost, as these directly impact the process's cost.[8]

Because of their ease of separation and reusability, heterogeneous catalysts are frequently utilised in the synthesis of biodiesel. They do, however, have a number of drawbacks. Their reduced catalytic activity in comparison to Nanocatalyst, which necessitates higher temperatures and longer reaction times to provide comparable results, is one of their main disadvantages. Furthermore, contaminants such as water and free fatty acids can cause soap formation and catalyst deactivation, which lowers efficiency and raises the requirement for meticulous feedstock preparation.[9] Additionally, over time, heterogeneous catalysts may perform worse due to their poor stability and reusability over several cycles. Despite these difficulties, they are nevertheless often employed in large-scale biodiesel production due to their affordability and ease of usage.

Nanocatalyst using for Transesterification in Biodiesel Production

Nanocatalysts represent a cutting-edge approach in biodiesel production. These catalysts, typically metal or metal oxide nanoparticles, offer high surface area, improved reactivity, and enhanced selectivity for transesterification reactions. They operate efficiently under mild reaction conditions, tolerate impurities like water and free fatty acids, and exhibit superior stability. Magnetic nanocatalysts provide an additional advantage in easy separation from the product using external magnetic fields, reducing processing costs.[1]

Nanomaterials can be produced through two primary methodologies: top-down and bottom-up approaches. The top-down method, which is frequently useful for producing patterns but has little control over uniformity, entails reducing bulk materials into nanoscale structures using processes like mechanical milling, lithography, or etching. Using techniques including chemical vapour deposition (CVD), sol-gel synthesis, hydrothermal processes, and biological (green) synthesis, the bottom-up approach creates nanomaterials atom by atom or molecule by molecule. Although they may call for exact circumstances, bottom-up approaches provide you more control over size, shape, and composition. The advantages of both methods are combined in hybrid processes such as spray pyrolysis and laser ablation. From electronics to medicine and environmental cleanup, each technique is selected according to the intended material qualities, scalability, and applications.[1]

Type of Nanocatalyst	Example	Advantages	Applications
Metal Oxide Nanocatalysts	Calcium Oxide (CaO)	High activity, low cost, easy recovery, efficient biodiesel yield	Transesterification of vegetable oils
	Zinc Oxide (ZnO)	Functions under mild conditions, good catalytic efficiency	Biodiesel production from various oils
	Magnesium Oxide (MgO)	Strong basicity, good thermal stability	Biodiesel production from vegetable oils
Magnetic Nanocatalysts	Iron Oxide (Fe_3O_4)	Easy recovery via magnetic separation, reusable	Transesterification and catalyst recycling
	Cobalt Ferrite ($CoFe_2O_4$)	High stability, easy recovery via magnetism	Biodiesel production, catalyst recovery
Carbon-Based Nanocatalysts	Graphene Oxide (GO)	Large surface area, functional groups, high catalytic activity	Catalyst support for biodiesel production
	Carbon Nanotubes (CNTs)	Enhanced stability, acts as support for other catalysts	Catalyst support in transesterification
Mixed Metal Oxides/Doped Nanocatalysts	CaO-ZnO	Synergistic effects, enhanced catalytic activity	High-efficiency biodiesel production
Biogenic Nanocatalysts	Plant-extracted nanoparticles	Eco-friendly, biodegradable, and sustainable	Eco-friendly biodiesel production

Table No. 3 catalyst use in synthesis of biodiesel its advantage and application

As catalysts to improve the transesterification process, increase efficiency, and lower energy needs, nanoparticles are frequently utilised in the synthesis of biodiesel. Because of their high surface area and catalytic activity, metal oxide nanoparticles such as calcium oxide (CaO), magnesium oxide (MgO), zinc oxide (ZnO), and titanium dioxide (TiO_2) are frequently utilised. Iron oxide (FeO_4) and cobalt ferrite ($CoFeO_4$) are two examples of magnetic nanoparticles that make recovery and reuse simple and increase process sustainability. For distributing metal catalysts, carbon-based nanoparticles like graphene oxide (GO) and carbon nanotubes (CNTs) provide superior support. Furthermore, eco-friendly biogenic nanoparticles and supported metal nanoparticles (such as zinc, silver, and nickel) increase the production of biodiesel while being economical and ecologically benign. By facilitating softer reaction conditions and accelerating reaction speeds, these nanoparticles simplify the manufacture of biodiesel.[1]

Algal biodiesel manufacturing can be improved by the use of nanotechnology, which makes the process more economical, sustainable, and efficient. From the growth of algae to the synthesis of biodiesel, nanomaterials are employed to enhance several phases of the biodiesel production process. For example, by increasing light absorption during photosynthesis, nanoparticles such as zinc oxide (ZnO) and titanium dioxide (TiO_2) are used to promote algal growth. By enabling the quick and effective harvesting of microalgae using magnetic separation techniques, magnetic nanoparticles (such as FeO_4) lower operating and energy expenses. Edible oil sources such palm, sunflower, soybean, olive, maize, rapeseed, safflower, peanut, and coconut oil are the best feedstock for the manufacturing of biodiesel [26]. An overview of the application of nanocatalysts in the production of biodiesel from vegetable oil, waste cooking oil (WCO), and algae oil is shown in Table 4. Table 4 shows that biodiesel yields can be greatly increased by nanocatalysts; the majority of these catalysts' biodiesel yields are above 90%.[1]

Feedstock/oil	Nanocatalyst	Yield	Ref
Plam oil	$CaO\text{-}Al_2O_3$	98.64	11
	$CaO\text{-}CeO_2$	95	12
Rapeseed oil	Li/Fe_3O_4	99.8	13
Soybeen oil	MgAlCe	>90	14
Sunflower oil	$MgO/MgFe_2O_4$	91.2	15
Jatropha oil	MgO-ZnO	83	16
Neem oil	Copper-doped zinc oxide	97.18	17
Waste cooking oil	Copper/zinc oxide	97.71	18
	CaO	96	19
	$CaO\text{-}ZrO_2$	92.1	20
	MgO	93.3	21
	$TiO_2\text{-}MgO$	>85	22
Microalgae Oil	Waste-based calcium oxide	92	23
	Nano-$Ca(OCH_3)_2$ (calcium methoxide)	99	24

Table 4: Biodiesel production from vegetable oil using different nanocatalyst

For biodiesel production to be both economically and environmentally sustainable, nanocatalyst recovery and reusability are essential. [4] Due to their simple recovery through magnetic separation, nanocatalysts especially magnetic ones like iron oxide or cobalt ferrite can be utilised again with little loss of catalytic activity. Non-magnetic nanocatalysts, on the other hand, need more intricate recovery procedures like centrifugation or filtration. Nevertheless, the stability and reusability of non-magnetic nanocatalysts have been improved by developments in nanocatalyst design, such as the creation of porous supports or encapsulating methods. Because nanocatalysts can be recovered and reused, less catalyst is needed, which lowers operating costs and minimises waste. This makes the manufacture of biodiesel using nanocatalysts more economical and environmentally friendly. [1]

Biofuel's safety, renewable nature, and environmental advantages make it a possible substitute for petroleum-based fuels. The production process is intricate, though, and utilises biomass from a variety of sources, including plants, wood, organic waste, and municipal solid waste. High operating expenses for lignocellulosic biomass and the high cost of algal biomass for the manufacture of biodiesel are obstacles. Although its full potential has not yet been realised, nanotechnology is also being investigated for the manufacture of biofuel on an industrial scale. Large-scale biofuel production now uses edible crops like maize and sugarcane, while less biofuel is produced from non-edible sources. Nanotechnology is boosting the quantity of biofuel produced from non-edible sources and speeding up the process.

Current Challenges and Future Perspectives for Biofuel Production

Some researcher told that, "Biofuel's safety, renewable nature, and environmental advantages make it a possible substitute for petroleum-based fuels. The production process is intricate, though, and utilises biomass from a variety of sources, including plants, wood, organic waste, and municipal solid waste. High operating expenses for lignocellulosic biomass and the high cost of algal biomass for the manufacture of biodiesel are obstacles. Although its full potential has not yet been realised, nanotechnology is also being investigated for the manufacture of biofuel on an industrial scale. Large-scale biofuel production now uses edible crops like maize and sugarcane, while less biofuel is produced from non-edible sources. Nanotechnology is boosting the quantity of biofuel produced from non-edible sources and speeding up the process". [10]

Conclusion

The choice of catalyst in biodiesel production via transesterification depends on the desired balance between efficiency, cost, and environmental impact. Homogeneous catalysts provide high activity but face significant separation challenges. Heterogeneous catalysts offer moderate efficiency and ease of separation, while nanocatalysts demonstrate exceptional performance under mild conditions and superior reusability, albeit with higher production costs. Advances in nanocatalysis, particularly magnetic nanocatalysts, show great promise for future biodiesel production, providing an environmentally friendly, scalable, and efficient solution. However, challenges such as cost, synthesis, and environmental risks need continued research and development.

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AI-DRIVEN ANALYSIS OF POETIC THEMES AND INFLUENCE: A COMPUTATIONAL APPROACH

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Abstract

Poetry has played a critical role in shaping human culture, offering deep insights into emotions, social movements, and philosophical ideologies. The research presents an AI driven approach to analyzing poetry by levering Natural Language Processing (NLP) techniques, sentiment analysis, topic modeling, and clustering. The study employs machine learning models, including Latent Dirichlet Allocation (LDA) for theme extraction and K-Means clustering for grouping poets Based on stylistics similarity. Additionally, cosine similarity and graph networks are used to explore poetic influence over time. The results provide novel insights into thematic evolution and poet interconnections, demonstrating the potential of AI in literary studies. Future enhancements include expanding datasets and improving interpretability with advanced deep learning techniques.

Introduction

Literature plays a important role in promoting sustainability by using storytelling, poetry, essays, and other forms of writing to educate, inspire action, and raise awareness about environmental, social, and economic issues. Literature can highlight environmental issues like climate change, deforestation. Literature imparts the value of conservation, ethical consumption, and living in harmony with nature. It will help people to get emotinallly engage and motivate to adapt sustainable practices.

Poetry has been a medium of artistic expression for centuries, reflecting emotions, cultural trends, and historical events. Traditional literary analysis methods, while insightful, are limited in scope and scalability. This research integrates AI and machine learning (ML) techniques to perform large-scale analysis of poetic works, extracting thematic patterns and evaluating poet interconnections. The study answers key questions: What are the dominant themes in poetry across centuries? How do poets influence one another? Can AI model poetic styles effectively? The findings contribute to both digital humanities and computational linguistics.

Objectives:

1. To analyse dominant thematic patterns in poetry across centuries using AI-driven Natural Language Processing (NLP) techniques.
2. To evaluate poet interconnections and stylistic similarities through machine learning models, including clustering and cosine similarity.
3. To automate the large-scale analysis of poetic works, enabling the identification of trends and relationships that traditional methods cannot uncover.
4. To enhance the field of literary studies by integrating AI tools for interactive, efficient, and scalable analysis of poetry.
5. To rise awareness among people about environment, social and economical sustanability study using modern techniques.
6. To help to understand people importance of literature and let them know, there is a need to apply the things which is prescribed in such literarture.

Background and Literature Review

3.1 Traditional Approaches to Poetry Analysis

Historically, Poetry has been analysed using linguistic theories, manual classification, and hermeneutic methods. Scholars such as Eliot (1959) and Jakobson (1960) emphasized rhythm, structure, and meaning in poetic discourse

3.2 Computational Linguistics in Literature

Recent advancements in NLP have enabled automated literary analysis. Blei et al. (2003) introduced LDA for topic modeling, which has been widely used inn text categorization. More recently, transform-based models such as BERT and GPT have improved semantic understanding in literary texts (Devlin et al., 2019). These methods fill the gap between technology, language and literature. Computational Linguistic can evaluate emotions and themes in poetry, novel etc.

3.3 AI in Thematic and sentiment Analysis

Sentiment analysis models like VADER (Hutto & Gilbert, 2014) and Long Former Beltagy et al., 2020) have been applied to poetry for detecting emotional tones. Zero-shot classifiers (Yin et al., 2019 enable flexible theme categorization without predefined labels.

Methodology

The methodology consists of data collection, pre-processing, model applications, and result interpretation

4.1 Data Collection

A dataset of 211 poems from multiple periods (100 CE – 200 CE) was complied, sourced from open access poetry repositories.

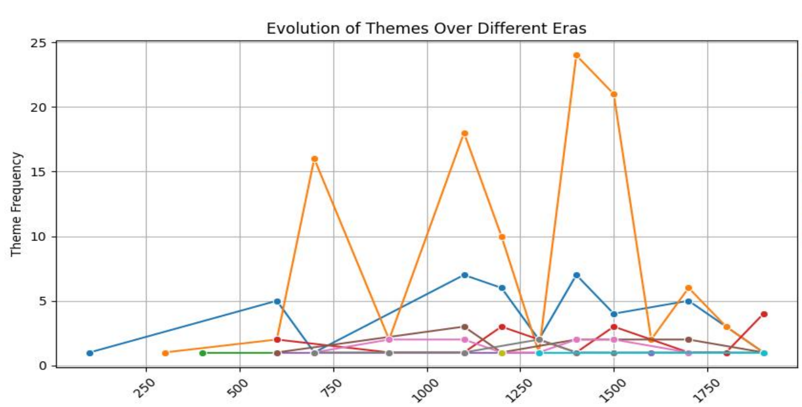
4.2 Pre-processing

Tokenization, stemming, and stop word removal ,Filtering poems with fewer than 20 words, Word embeddings using Word2Vec.

4.3 NLP Models Applied

- **Sentiment Analysis:** Longformer model for emotion classification
- **Theme Classification:** BERT-based zero-shot classifier
- **Clustering:** TF-IDF and K-Means for poet grouping\
- **Similarity Analysis:** Cosine similarity for poet influence mapping

4.4 Thematic Evolution Analysis

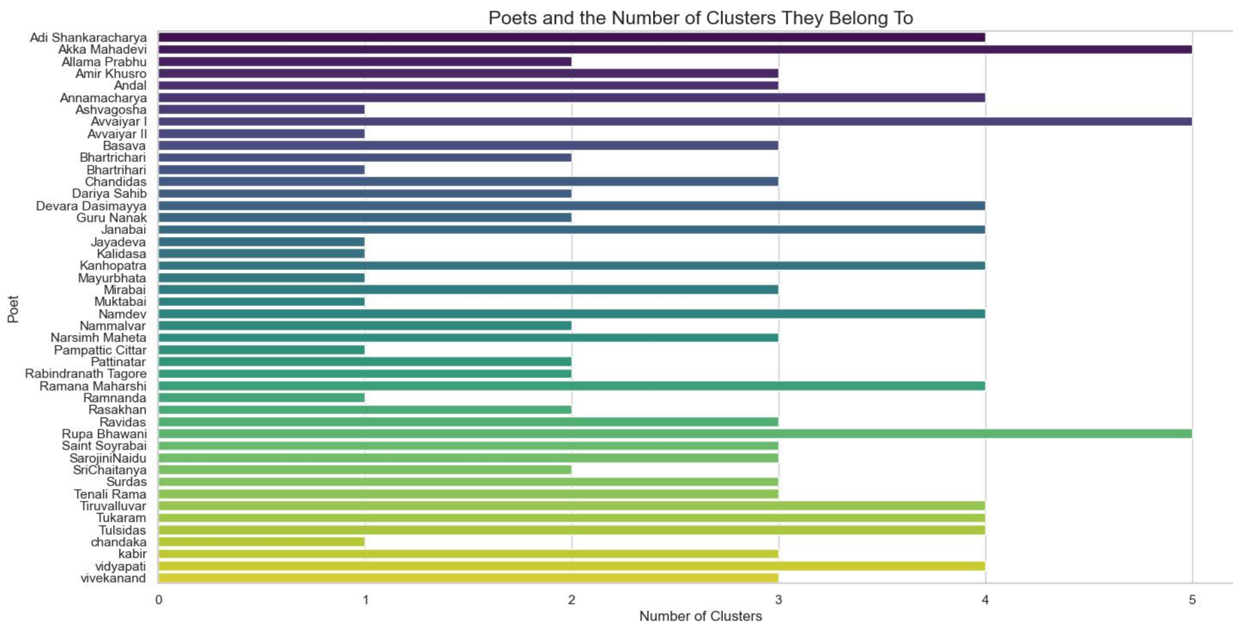


A time series analysis of dominant poetic themes was conducted using stacked area charts

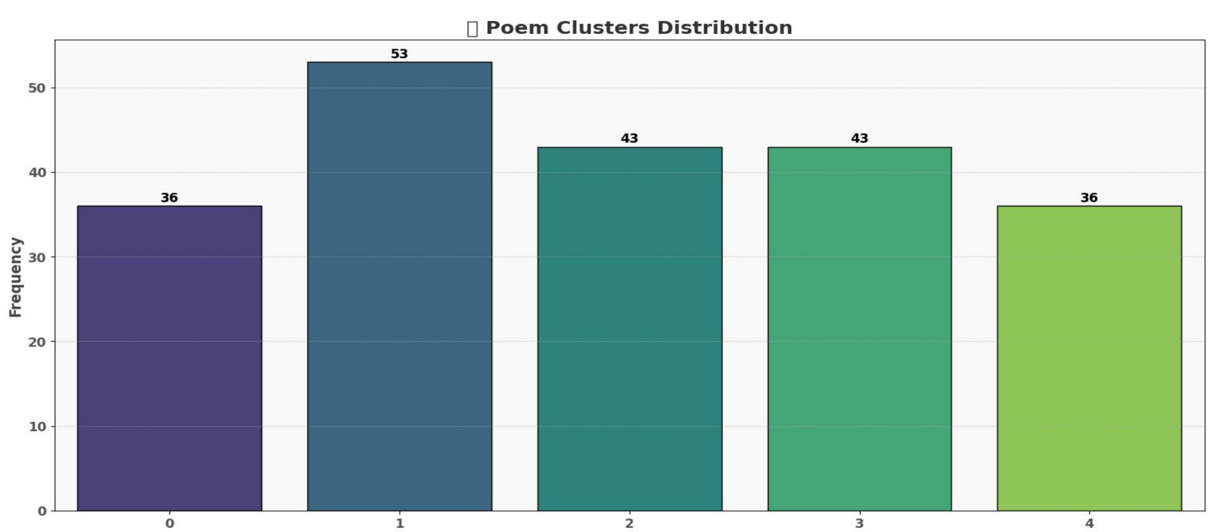
Results

Trend Analysis

The trend analysis reveals that the 1300s saw strong focus on **moral lessons** and **divine justice**, while **devotion to gods** peaked in the 1200s and 1400s. **Philosophy of life** also surged in the 1200s, reflecting intellectual growth. Themes like **heroic legends** and **mythical creatures** had occasional spikes but were less prominent overall. **Celestial beings**, **prophecies**, and **cosmic battles** showed sporadic and minimal interest. Overall, morality, religion, and philosophy were key themes, while niche concepts had limited engagement.



The chart shows poets and their thematic stylistic diversity based on the number of clusters they belong to. **Akkamahadevi** and **Malikarjuna** lead with the highest number of clusters, indicating broad versatility, while poets like **Devara Dasimayya** and **Basavanna** belong fewer clusters, showing a more focused approach. Some poets, such as **Vidyaranyaswamy**, have even fewer clusters, reflecting a narrower thematic scope.



Future Enhancements

Integrating multilingual NLP for non-English poetry analysis.

Use GPT-4 for deeper textual interpretation.

Develop an interactive AI-driven poetry exploration tool.

Conclusion

This research demonstrates the potential of AI in analyzing poetry at scale. BY combining NLP techniques with clustering and network analysis, we gain new insights into poetic evolution and interconnections. Future developments can further enhance literary studies, bridging AI with the humanities to uncover previously unknown relationships between poetic styles and cultural movements.

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AN EMPIRICAL ANALYSIS OF LABOUR PRODUCTIVITY AND CAPITAL-LABOUR RATIO IN INDIAN STATES AND UNION TERRITORIES (2020-21): A LOG-LINEAR REGRESSION MODEL APPROACH FOR SUSTAINABLE DEVELOPMENT

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Abstract

This study examines the relationship between labour productivity and the capital-labour ratio across Indian states and union territories for the year 2020-21 using a log-linear regression model. The analysis reveals a statistically significant positive elasticity of labour productivity with respect to the capital-labour ratio. The regression results indicate that a one percent increase in the capital-labour ratio leads, on average, to a one point fourteen percent increase in labour productivity, with a coefficient of one point one hundred and thirty eight and a highly significant p-value. The model explains eighty five percent of the variance in labour productivity, and the F-test confirms the overall significance of the regression. Hypothesis testing for the regression coefficient strongly rejects the null hypothesis of no effect, underscoring the crucial role of capital intensity in enhancing labour productivity. These findings provide valuable insights into the productivity dynamics in India and emphasize the importance of capital investment in improving labour outcomes.

Keywords: Labour Productivity, Capital Labour ratio, Gross State Domestic Product, State-wise capital expenditure, State-wise Labour Force Participation Rate.

Introduction

Labour productivity is a key determinant of economic growth, reflecting the efficiency of workers in producing goods and services. In the Indian economy, enhancing labour productivity is crucial for accelerating GDP growth, improving income levels, and fostering competitiveness. The capital-labour ratio, which measures the amount of capital available per worker, plays a significant role in boosting productivity. A higher ratio indicates better access to tools, technology, and infrastructure, enabling workers to produce more efficiently. In India, where labour abundance contrasts with limited capital, optimizing the capital-labour ratio is essential for driving industrial output, reducing income disparities, and achieving sustainable economic development.

Research Objective: Understanding the impact of the Capital-Labour ratio on Labour Productivity in India for 2020-21.

Hypothesis:

Null Hypothesis:

Labour productivity elasticity of the capital-labour ratio is zero.

Alternative Hypothesis:

Labour productivity elasticity of the capital-labour ratio is not zero.

Literature Review

Labour productivity is a critical determinant of economic growth and competitiveness, influenced by various factors, including technological progress, human capital, and the capital-labour ratio. Several studies emphasize the role of capital intensity in enhancing productivity levels. “Solow's growth model (1956) highlighted the importance of capital deepening as a driver of output per worker, suggesting that higher investments in capital per labour unit yield substantial productivity gains”. Similarly, “Denison (1967) demonstrated that economies with robust capital accumulation tend to achieve higher productivity growth. In developing economies like India, the relationship between the capital-labour ratio and productivity has been a focal point of policy discussions”. Studies such as

"Goldar (2004) and Krishna and Mitra (1998) found positive elasticities between capital intensity and productivity, underscoring the transformative impact of infrastructure and technology investments". However, regional disparities within India create heterogeneity in the capital-labour dynamic, necessitating localized analyses.

The present study contributes to this literature by empirically estimating the elasticity of labour productivity concerning the capital-labour ratio for Indian states and union territories during 2020-21. By leveraging a log-linear regression model, it adds to the understanding of how capital intensity drives productivity improvements in a rapidly evolving economic context.

Methodology

The production is the function of capital and labour, by using the production equation as $Q = Af(K \times L)$, if we divide this equation with L we get $Q/L = Af(K/L \times 1)$. Here the Q/L is nothing but the Labour Productivity and K/L is the Capital-Labour Ratio, which means that the Labour productivity is the function of the Capital-Labour Ratio. The aim of this study is to understand how the Capital-Labour Ratio affects labour productivity.

For this reason, the exponential regression model is used. $(Q/L) = A(K/L)^{ß_2} e^u$ But such a model can not be estimated by the Ordinary Least Squares (OLS) method. By taking the natural log on both side we get $In\,(Q/L) = InA + ß_2 ln(K/L) + u$ This alternative model can be estimated by the Ordinary Least Squares (OLS) method.Because of this linearity, such models are called Log-linear models.one attractive feature of the Log-linear model is that the slope coefficient $ß_2$ measures the elasticity of regressand with respect to regressor.

$$Here\ (Q/L) = Labour\ Productivity$$

$$(K/L) = Capital - Labour\ Ratio$$

$$ß_2 = Measure\ the\ elasticity\ of\ labour\ productivity\ with\ respect\ to\ the\ capital - labour\ ratio$$

Data collection and Source:

Table No:1 Gross State Domestic Product, State-Wise Capital Expenditure And State-Wise Labour Force Participation Rate Of The Period 2020-21.

Sr.No.	State/Union Territory	(Q) GROSS STATE DOMESTIC PRODUCT 2020-21 (₹ Lakh)	STATE-WISE CAPITAL EXPENDITURE 2020-21 (RE) (₹ Crore)	(K)STATE-WISE CAPITAL EXPENDITURE 2020-21 (RE) (₹ Lakh)	(L)State-wise Labour Force Participation Rate for age 15 years & above at usual status during the period 2020-21 (in %) All India (Rural + Urban) Persons
1	Andhra Pradesh	101437379	32478	3247800	61.1
2	Arunachal Pradesh	3127309	6689	668900	51.4
3	Assam	34017745	26330	2633000	52.7
4	Bihar	58715439	46032	4603200	41.9
5	Chhattisgarh	35026983	14807	1480700	65.2
6	Delhi	78534162	12785	1278500	45.6
7	Goa	7570540	4927	492700	48.5
8	Gujarat	163678141	37647	3764700	56.3

9	Haryana	75850653	23150	2315000	46.9
10	Himachal Pradesh	15667506	9875	987500	71.9
11	Jammu & KashmirU.T.	17020073	40832	4083200	59.0
12	Jharkhand	30071593	12186	1218600	61.6
13	Karnataka	173099141	50230	5023000	56.9
14	Kerala	79957111	20315	2031500	51.3
15	Madhya Pradesh	97628148	43085	4308500	61.4
16	Maharashtra	271168512	101665	10166500	56.0
17	Manipur	3411021	4993	499300	43.4
18	Meghalaya	3471870	2830	283000	63.1
19	Mizoram	1802616	1792	179200	56.5
20	Nagaland	3042511	2708	270800	61.3
21	Odisha	53265168	30136	3013600	56.5
22	Puducherry	3568471	1209	120900	51.6
23	Punjab	53255526	20202	2020200	50.4
24	Rajasthan	101332301	34877	3487700	58.1
25	Sikkim	3180007	1778	177800	72.1
26	Tamil Nadu	180823943	60222	6022200	60.0
27	Telangana	96180037	32645	3264500	60.8
28	Tripura	5441512	2417	241700	55.6
29	Uttar Pradesh	164856708	94788	9478800	50.1
30	Uttarakhand	23466020	10152	1015200	52.3
31	West Bengal	130101677	36498	3649800	54.9

Data Source:

1. Gross State Domestic Product (Current Prices), National Statistical Office, Ministry of Statistics and Programme Implementation, Government of India.

2. State-Wise Capital Expenditure 2020-21 (Re) (₹ Crore) ‘Handbook of Statistics on State Government Finances-2010’ and ‘State Finances: A Study of Budgets’, Reserve Bank of India, various issues.

3. State-wise Labour Force Participation Rate for age 15 years & above at usual status during the period 2017-18 to 2019-20: All India (Rural + Urban). Periodic Labour Force Annual Survey Reports, Ministry of Statistics and Programme Implementation.

Data Note:

1. As of October 2021, India has 28 states and 8 union territories that is total 36. But the Data of Gross State Domestic Product is not available for four union territories: Andaman & Nicobar Islands, Ladakh, Dadra and Nagar Haveli and Daman and Diu, Lakshadweep. Furthermore, the Data of State-Wise Capital Expenditure is not available for five union territories: Andaman & Nicobar Islands, Chandigarh, Dadra and Nagar Haveli and Daman and Diu, Ladakh, Lakshadweep. Therefore, for the study, a dataset of 31 states and union territories is used.

2. State-Wise Capital Expenditure data which was published by Reserve Bank of India in *'Handbook of Statistics on State Government Finances-2010' and 'State Finances: A Study of Budgets', Reserve Bank of India, various issues*, was in Crore Rs. But Gross State Domestic Product data which was published by National Statistical Office, Ministry of Statistics and Programme Implementation, Government of India, Was in Lakh Rs. we know that one crore is equal to hundred lakhs, therefore to convert State-Wise Capital Expenditure in the same unite as Gross State Domestic Product is, the State-Wise Capital Expenditure data is multiplied with hundred.

Data Analysis:

Consider the Log-linear Model:

$$In\ (Q/L) = InA + ß_2 ln(K/L) + u$$

To get the Labour productivity, the data of Gross State Domestic Product (₹ Lakh) is divided by State-wise Labour Force Participation Rate, similarly to get Capital-Labour Ratio the data of State-Wise Capital Expenditure (₹ Lakh) is divided by Labour Force Participation Rate. We have considered the Log-linear model therefore the natural log of Labour productivity and Capital-Labour Ratio is calculated in following Table No:2.

Table No:2 Labour Productivity And Capital-Labour Ratio

(Q/L)	(K/L)	ln (Q/L)	ln (K/L)
1660186.236	53155.48282	14.32244034	10.88097654
60842.58755	13013.61868	11.01604528	9.473751679
645498.0076	49962.04934	13.3777774	10.81901898
1401323.126	109861.5752	14.15292744	11.60697644
537223.6656	22710.1227	13.1941698	10.03056604
1722240.395	28037.2807	14.35913656	10.24129036
156093.6082	10158.76289	11.95821116	9.226091951
2907249.396	66868.56128	14.88271797	11.1104842
1617284.712	49360.34115	14.2962592	10.80690257
217906.8985	13734.35327	12.29182318	9.527655511
288475.8136	69206.77966	12.57236653	11.14485411
488175.211	19782.46753	13.09842966	9.892551346
3042164.165	88277.68014	14.92807972	11.38824258
1558618.148	39600.38986	14.25931018	10.58659424
1590034.984	70171.00977	14.27926658	11.15869054
4842294.857	181544.6429	15.39289931	12.10925687
78594.95392	11504.60829	11.27206278	9.350502955
55021.71157	4484.944532	10.91548314	8.408481407
31904.70796	3171.681416	10.37050886	8.062017141
49633.13214	4417.618271	10.81241388	8.393355977
942746.3363	53338.0531	13.75655253	10.8844053
69156.41473	2343.023256	11.1441261	7.759197364
1056657.262	40083.33333	13.87062096	10.5987159
1744101.566	60029.2599	14.37175012	11.00258739
44105.50624	2466.019417	10.69433991	7.810360558

3013732.383	100370	14.91868986	11.51661864
1581908.503	53692.43421	14.27414259	10.89102738
97868.92086	4347.122302	11.49138432	8.377269365
3290553.054	189197.6048	15.00656621	12.15054728
448681.0707	19411.08987	13.0140676	9.873599824
2369793.752	66480.87432	14.67831348	11.10466958

Regression Statistics	
Multiple R	0.923855491
R Square	0.853508969
Adjusted R Square	0.848457555
Standard Error	0.607201803
Observations	31

The interpretation of the regression analysis is that the Multiple R of 0.9239 indicates a strong positive correlation between the Capital-Labour Ratio and Labour productivity, suggesting that the Log-linear Model has high explanatory power. The R Square value of 0.8535 means that approximately 85.35% of the variation in the Labour productivity can be explained by the Capital-Labour Ratio in the Log-linear model, which is a high level of explanatory power. The Adjusted R Square value of 0.8485 adjusts for the number of predictors in the model, offering a slightly more conservative estimate of how well the Log-linear model fits the data, while accounting for the possibility of overfitting. The Standard Error of 0.6072 indicates the average distance between the observed values and the predicted values; a smaller value would generally suggest better precision of the predictions. Finally, there were 31 observations used in the analysis, providing a relatively adequate sample size for this Log-linear model. Overall, the output suggests a well-fitting model with strong predictive capabilities.

ANOVA				
	df	*SS*	*MS*	*F*
Regression	1	62.29614316	62.29614316	168.9643394
Residual	29	10.69212686	0.368694029	
Total	30	72.98827002		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	1.580735638	0.899952461	1.756465709	0.089565467
ln (K/L)	1.138471164	0.087583945	12.99862837	0

According to ANOVA for this Log-linear model, regression analysis, the degrees of freedom (df) for the regression is 1 because there is only one independent variable that is Capital-Labour Ratio, in the Log-linear model, while the residual degrees of freedom is 29, representing the remaining data points minus the parameters estimated. The total degrees of freedom are 30, which is the sum of the regression and residual degrees of freedom. The Sum of Squares (SS) quantifies the variation, with 62.2961 attributed to the regression and 10.6921 attributed to the residuals, totalling 72.9883. The Mean Square (MS) is calculated by dividing SS by the corresponding degrees of freedom, resulting in 62.2961 for the regression and 0.3687 for the residuals. The F-statistic, which compares the explained variance to the unexplained variance, is 168.9643. This high F-value suggests that the regression model explains a significant portion of the variance in the data, indicating the Capital-Labour Ratio included in the model is highly effective in explaining the outcome.

The Intercept represents the expected value of the Labour productivity when Capital-Labour Ratio is zero, with an estimated value of 1.581. The standard error of the intercept is 0.900, indicating the variability in its estimate. The t-statistic for the intercept is 1.756, and its p-value is 0.0896, which suggests that the intercept is not statistically significant at the conventional 0.05 level. The 95% confidence interval for the intercept ranges from -0.260 to 3.421, which includes zero, further supporting its lack of significance.

For the Capital-Labour Ratio, the coefficient is 1.138, indicating that for every unit increase in Capital-Labour Ratio, the Labour productivity increases by 1.138 units. The standard error of 0.088 reflects the precision of this estimate. These results suggest that Capital-Labour Ratio is a highly impactful and reliable predictor in this Log-linear model

$$In\ (Q/L) = 1.58 + 1.14\ ln(K/L) + u$$

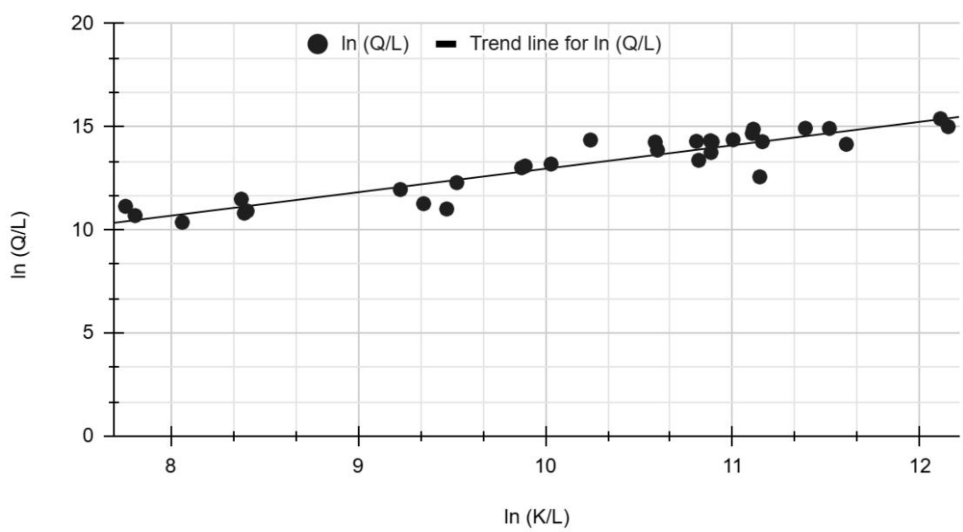

Diagram-1: Line Fit-Plot

From the Log-linear model, we see that in Indian States & Union Territories for the year of 2020-21, the Labour Productivity elasticity of Capital Labour ratio was 1.14. In other words, in the year 2020-21 in Indian States & Union Territories a 1 percent increase in the capital labour ratio led to on an average to about 1.14 percent increase in labour productivity.

Hypothesis testing:

A. Coefficient Significance (t-Test)

Null Hypothesis:

$$H_0: \beta_2 = 0$$

The Labour productivity elasticity of the capital-labour ratio is zero.

Alternative Hypothesis:

$$H_1: \beta_2 \neq 0$$

The Labour productivity elasticity of the capital-labour ratio is not zero.

	Coefficients	*Standard Error*	*t Stat*	*P-value*
ln (K/L)	1.138471164	0.087583945	12.99862837	0

The P-value associated with the *t-Test* is zero. Since the p-value is less than 0.05 acceptance level. Reject the Null Hypothesis that is $H_0: \beta_2 = 0$ and accept the Alternative Hypothesis.

In other words, in the year 2020-21 in India Indian States & Union Territories, a one percent increase in the capital labour ratio led to on an average to about 1.14 percent increase in labour productivity.

B. Overall Model Significance (F-Test)

Null Hypothesis:

$$H_0: \beta_2 = 0$$

The Log-linear regression model is not significant.

Alternative Hypothesis:

$$H_1: \beta_2 \neq 0$$

The Log-linear regression model is significant

F	*Significance F*
168.9643394	0

The p-value associated with the F-Test is zero. Since the p-value is less than 0.05 acceptance level, we reject the null hypothesis and conclude that the regression model is significant. This means that the Capital-Labour Ratio explains a significant portion of the variance in Labour productivity.

Model Validation Tests:

These tests help to ensure that the model is reliable, generalizable, and suitable for inferences. The following tests were conducted to test the validation of the Log-linear model.

1. Residual normality

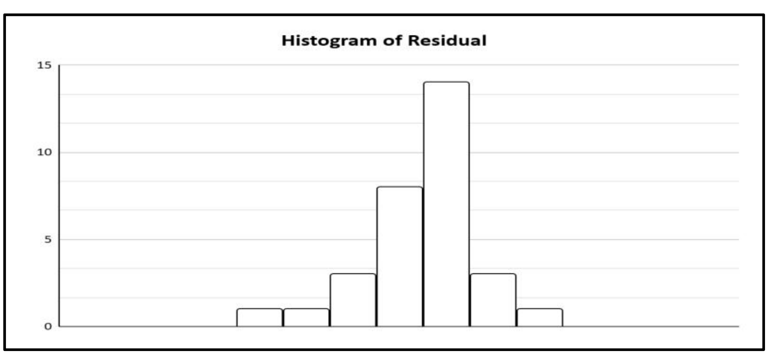

Diagram-2: Histogram of Residuals

A. Residuals Histogram

The residuals from the labour productivity regression appear symmetrically distributed, the distribution closely resembles a bell-shaped curve cantered around zero. This symmetry indicates that the residuals follow a normal distribution.

B. Shapiro Wilk p-value

Shapiro Wilk p-value equals 0.05 of the Log-linear model. We fail to reject the null hypothesis, indicating that the data can be assumed to follow a normal distribution.

2. Homoscedasticity - homogeneity of variance-The White test

The White test yields a p-value of 0.4663 and an F-statistic of 0.784. Since the p-value is greater than the conventional significance level (e.g., 0.05), we fail to reject the null hypothesis of homoscedasticity.

3. Multicollinearity - intercorrelations among the predictors (X_i)-VIF

A VIF value below 2.5 indicates a low level of multicollinearity, suggesting that the Regressor is independent and does not distort the model's estimates.

Conclusion:

The analysis highlights the significant impact of the capital-labour ratio on labour productivity in Indian States and Union Territories during 2020-21. The log-linear regression model shows that a 1% increase in the capital-labour ratio leads to an average 1.14% increase in labour productivity, with the coefficient being highly significant (t-statistic = 12.99, p-value = 0). The F-test confirms the model’s overall significance (F-statistic = 168.96, p-value = 0), indicating that the capital-labour ratio explains a substantial portion of the variance in labour productivity. Model validation tests further support the reliability of the regression. Residuals demonstrate normality (histogram symmetry, Shapiro-Wilk p-value = 0.05), homoscedasticity is confirmed by the White test (p-value = 0.4663), and no multicollinearity issues were detected (VIF < 2.5). These findings underscore the robustness of the model, providing strong evidence for the critical role of the capital-labour ratio in driving labour productivity during the analysed period.

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ASSESSING THE LINK BETWEEN WORK-LIFE BALANCE, JOB SATISFACTION, AND TURNOVER INTENTION IN IT SECTOR: A STRUCTURAL EQUATION MODELING STUDY

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Abstract

The work-life balance (WLB) perspectives, job satisfaction and turnover intention are examined in this paper employing Structural Equation Modeling (SEM) in the context of the IT sector. Computer science workers push their working capacities in their line of duty and most of them may experience lack of personal time off programs that may affect their job satisfaction and organizational commitment. This study seeks to operationalize WLB success and quantify its impact on JS and TI index and test the relative impact of WLB on the two indices among 300 IT employees in different companies. This study established that work life balance factors positively influence job contentment and in turn have a negative influence on turnover intention. The paper gives a real-world advice for policy making in IT organisations for enhancing work-life balance which could positively influence turnover rate and satisfaction level of employees.

Keywords: Work-life balance, job satisfaction, turnover intention, IT sector, structural equation modeling, human resource management

1. Introduction

The IT sector can be considered as one of the fastest and most active industries in the worldwide economic system. But this has been accompanied by high job demands, short innovation cycles, and stiff competition resulting in long working hours stress and difficulty in managing working family responsibilities [1]. New generation has identified work-life balance as significant challenges, especially within the IT industries, employees find it hard to distinguish between work and social lives [2]. In more detail, the work life balance is a situation where work well as personal or family life is not compromised by the other. The existence of such a balance can therefore be received to contribute to improvement in the quality of working environment thus a reduction of turnover rates. IT is an area that must be defended by highly skilled employees and thus the high turnover rates is a danger for profit oriented public sectors [3]. Turnover expenses can really affect the firm badly for the increased expense on recruitment, training, and loss in productivity is incurred whenever replacements are sourced in IT especially.

Job satisfaction as the degree of perceived organizational commitment and EU job satisfaction both positively affect employee retention. From this perspective, research has pointed out a relationship between work-interference with home and work-related demands and job satisfaction where intentions of employees to quit intent in the organization may be enhanced [4]. Turnover intention, defined as the extent to which the employee is passively thinking about leaving the present company, is an antecedent of turnover. It is therefore important that IT companies aspiring to maintain their talent must understand these factors and how they can be controlled [5]. However, prior research has established that the above factors are crucial to determine work-life balance, job satisfaction, and turnover intention of employees in the IT sector However, research that compares and analyzes work-life balance, job satisfaction, and turnover intention within the IT industry is scarce to date. In addition, few of these studies have used powerful statistical techniques which include, Structural Equation Modeling (SEM) in further investigating these relationships. SEM allows the use of multiple relationships between the variables to provide a better understanding of the moderation role of work-life balance on both total job satisfaction and turnover intent [6]. This study intends to fill this gap by utilizing Structural Equation Modeling to establish the correlation between, work to family/ TOTAL WORK CONTENTMENT, satisfaction with job/ JOB SATISFACTION, intentions of leaving job/ TURNOVER INTENTION in Information Technology department. Specifically, the research seeks to answer the following questions [7]:

1. Exploring the factors of work life balance, how does this affect job satisfaction on the employee in Information Technology?
2. To what extent does job satisfaction moderate between work life balance and turnover intention?

3. Possible practical suggestions arising from this study for IT firms are as follows.

Through the answers to these questions, this research provides IT organizations with guidance to formulate practical work-life balance intervention strategies that can help improve the satisfaction level of employees and thus decrease turnover intention that can benefit organization in terms of the stability needed to succeed.

2. Related Work

An investigation has been conducted on WLB, job satisfaction, and turnover intention in general, with many organizations and industries, including the healthcare and educational sectors and the manufacturing companies; however, research investigating the IT sector alone is still scarce [8]. The following section discusses prior literature on these three constructs, their association and the research that is missing, which this study aims to address.

2.1 Work–Life Balance and Job Satisfaction

Employment balance has been studies extensively on how it is instrumental in determining the level of job satisfaction. Work-to-family conflict, which is defined, occurs when demands in the work role interfere with the satisfactory performance of personal roles, which leads to higher job contentment as well as improved health [9]. A study revealed that work arrangements which include telework or flexible working hours greatly enhanced the employees' work and family satisfaction resulting to high job satisfaction. Such results have also been noted, who established that employees with identified that they have more control over balance between work and personal live have higher job satisfaction, as well as lower stress level.

Based on the context of the IT sector, In the process of working, the human resource suffers lots of stress factors such as working hours, stringent deadlines and job pressure which ultimately hampers work-life balance [10]. They also identified the effect of work conflict about personal responsibility on job satisfaction, especially within the context of Information Technology Career employees and per their findings it was seen that poor balance between work and other responsibility produced low satisfaction. In addition, and according, the students should apply the theory of this boundary because the people who can separate the role of work from other roles are likely to be more satisfied with the job.

Nevertheless, although numerous studies stress the importance of the relation between the WLB and JS, only a limited number of researchers have focused these issues using Structural Equation Modeling – SEM, especially in the IT field. The present study aims to remove such deficit by utilising SEM to investigate the impact of work life balance on job satisfaction particular to IT employees.

2.2 Employee Job Satisfaction and Turnover Intention

That turnover intention has a strong relation with job satisfaction has been acknowledged overtime. Many reviews have shown that satisfied employees have low turnover intentions than dissatisfied employees' high turnover intentions [11]. Tailoring and testing the hypothesis in the general area of work, as well as sector-specific studies of the link between job satisfaction and turnover intention, have been by and large positive. From the empirical study conducted by revealed that high job satisfaction reduces the level of turnover intention among the IT employees. Likewise, in a study by noted that job satisfaction was one of the key factors influencing IT employees' tendency to remain with their current employer noted that dissatisfaction on working condition compensation or career advancement leads to higher turnover.

In a meta-analysis work by the authors noted that job satisfaction bears a negative significant relationship with turnover intention [12]. However, in the high-kinetics environment such as in the IT industry factors like time pressure of the project, technological changes, and customer expectations may contribute to stress and dissatisfaction thereby heightening turnover. This active work environment underlines the necessity of specific interventions to increase job contentment, especially about such aspects as work-life conflict.

2.3 Employee's Work Life Balance and its relationship with Turnover Intention

Several works also reveal a positive relationship between work-home interface and turnover intention; this research point out that employees experiencing difficulties in managing work and home demands are more likely to quit their jobs [13]. They noted that work conflict resulted into intention to turnover was established since it increased in organizations with large calls on workers such as IT companies. A key finding proposed by the study was that the level of organizational support directly influences the level of work-life conflict and turnover intention.

Similarly, the confirmed the requirements of work–life balance policies for employees' retention in enterprise, especially in the knowledge-based organizations. Some of them claimed that organisations who provide policies like telecommuting and flexible work schedules for childcare, the general health of the employee can be advanced and hence, turn over intention was curbed. Similarly, it proved that WLB not only affects directly the turnover intention but also moderates other factors on it which are the job stress and burn outs common to the highly demanding sectors like IT.

Although the role of work-life balance as antecedent of turnover intention has become more evident, there seems to be a gap in the literature concerning the relationship between these two variables, particularly in the IT sector and through SEM analysis. Prior research has largely tended to use cross sectional and regression tests that only capture simple associations between work life balance, job satisfaction and turnover intentions. To overcome this limitation, this research uses SEM to capture these relationships in a much more expanded view.

2.4 Theoretical Foundations

In the following section, various theoretical perspectives that have been applied in predicting work-life balance, job satisfaction and turnover intention are discussed [14]. The most widely known theory is Social Exchange which states that if employees believe that they are receiving equal amount of value for things they brought into the organisation and at the same time equal to the value they are giving to organisation regarding the work done as well as personal commitments, it encourages organisational commitment and reduce turnover.

Conservation of Resources (COR) Theory proposed on the second theory discussed here. COR theory postulates that employees have an inherent desire of attempting to maintain employee, temporal, physical, and social capital. When they are employed up, the resources are less effective and instead cause stress and dissatisfaction leading to intention to turnover. Such organizations that offer work-life balance help one's employees to save his/ her energies because the risk of turning down a job is reduced.

2.5 Research Gaps

While extant literature has documented significant evidence of the causal relationship between work-life balance, job satisfaction and turnover intention, there is limited knowledge about how these relationships play out in the context of the IT workers [15]. In addition, a vast majority of previous research works has investigated direct effects model of relationships without paying attention to mediating influence of job satisfaction. Also, few of the previous research attempted to analyze these interactions using methodologies like SEM. The present paper will fill these gaps by using SEM to examine the direct as well as mediated effect of work-life balance on turnover intention through job satisfaction in the context of the IT industry. Through such investigations, this research extends the understanding of work-life balance and job satisfaction for IT organizations to decrease turnover intention and achieve talent retention in the most competitive industry.

3. Methodology

In this section, the method of the study, data collection procedure, instruments for measuring variables and the method of analyzing the data for the assessment of the level of work-life balance, job satisfaction and turnover intention of employees in the IT sector are presented [16]. The main type of analysis in the current study is Structural Equation Modeling (SEM) due to its ability to model multiple dependent relationships without having to meet the assumption of independence and computational efficiency in the present model hypothesis.

3.1 Research Design

The work uses a survey research layout to analyse the relationship between work-life balance and job satisfaction, as well as turnover inclination. The study is cross-sectional whereby data was collected from IT professionals using a structured questionnaire [17]. The study uses Structural Equation Modeling (SEM) to test the hypothesized relationships between the three key variables: , sources: turnover intention, work-life balance and job satisfaction.

SEM is chosen for its capability of capturing the higher order or multiple order interactions between the latent variables to provide an exhaustive explanation of factors motivating the turnover intention in the IT sector.

3.2 Data Collection

Online structured questionnaire was employed for purposes of data collection from the target population, the employees in the IT sector [18]. The survey was conducted among the various companies within the sector with the aid of self-developed questionnaires administering convenience sampling and snowball sampling methods. The specific target population was screened through emails sent to the participants and through LinkedIn corporate network.

Participants were required to meet two inclusion criteria:

1) a person must be working in that sector of IT industry now.
2) Many of the respondents must have worked in their current organisation for at least one year.

The survey was conducted for two months, and data were collected 300 respondents were excluded the questionnaires that contained missing or mismatched information.

3.3 Measurement Instruments

The survey was structured into three sections corresponding to the three primary constructs:

- organizational commitment
- perfect worker model
- work-life balance
- job satisfaction,
- turnover intention.

All the questions given in the data collection instrument were answered on a labelled 5 Likert scale with 1 pointing to strongly disagree and 5 pointing to strongly agree [19].

Work-Life Balance (WLB): The Work-life balance measure was adopted and contains 10 items assessing the employees' work to personal life balance. Examples of 737 sample items are as follows: "I am never pressed for time to attend to my own needs and wants" and "Work has negative impact on personal life."

Job Satisfaction (JS): Perceived job satisfaction Employee job satisfaction was determined by use of the Job Satisfaction Scale that has 8 items derived. These are used to measure the general satisfaction with a person's job, Pay, working conditions and opportunities for promotion. Other sample items are: "I am happy with the quality of work I provide" and "I consider my work as fun".

Turnover Intention (TI): The level of turnover intention was measured using 5 items taken from Turnover Intention Scale. These items capture the respondent's intention to leave his or her current organization by estimating the chances that he or she is contemplating to do so. Some of the examples are ''Many times,' I considered being fired or quitting my job and ''Within the coming year,' I am going to search for another job.'

3.4 Data Analysis

The analysis involved two main phases [20]:

Preliminary Data Analysis: This phase included data preprocessing, where missing values were checked for and where there was need for imputation it was performed. Therefore, preliminary analysis was performed with the use of the descriptive statistics such as the descriptive measure of central tendency and variability, and the correlations between the variables.

Structural Equation Modeling (SEM): In this study, SEM was performed in two stages, Confirmatory Factor Analysis (CFA) and Structural Model Analysis. SEM was selected as the measurement tool because it provides estimates of the relative paths between latent factors and test the fit of the overall model.

3.4.1 Confirmatory Factor Analysis (CFA)

Before estimating the structural model, in order to assess the measurement model's fit, a Confirmatory Factor Analysis was performed. OPA-aligning assessment helps make sure that the variables actually measured in a study truly match the latent constructs that are posited. Key metrics for assessing model fit included:

Chi-square (χ^2)/df ratio: The ratio of χ^2/df less than 3 indicates a good fit of the model is achieved.

Comparative Fit Index (CFI): It is considered as good fit when any value is above 0.90.

Tucker-Lewis Index (TLI): A value equal to and above 0.90 is interpreted as demonstrating a good model fitness.

Root Mean Square Error of Approximation (RMSEA): A value which is less than 0.08 is considered good or acceptable.

3.4.2 Analysis on Structural Model

Subsequently, the structural model was estimated to analyze the pattern between work-life balance, job satisfaction, and turnover intention. The following hypotheses were tested:

- H1: In addition, they showed that work to family conflict has a negative impact on job satisfaction.
- H2: I established that; Employ job satisfaction has a negative relationship with turnover intention.
- H3: They have found that the work to life balance impacts negatively on turnover intention.
- H4: Work life balance has indirect relationship with turnover intention and this relationship is moderated by job satisfaction.

Coefficients from paths were tested for significance at the level of $p < 0.05$ while the fitness of the structural model was tested using the same fitness indices that were used for CFA.

3.5 Mediation Analysis

Besides the main hypotheses that was testing direct effects of work- life balance, job satisfaction and turnover intention, the study run mediation analysis to find out whether job satisfaction has moderated the relationship between work-life balance and turnover intention [21]. To test mediation, the bootstrap procedure was performed with 5,000 resamples. This approach gives more accurate confidence intervals for indirect effects than using conventional characteristic estimates.

3.6 Reliability and Validity

In the study, Cronbach's coefficient alpha was used to test the reliability of the scales adopted and the accepted reliability was set at 0.70, particularly Average Variance Extracted (AVE), where values above 0.50 were deemed to be acceptable. As exhibited in Table 4, discriminant validity was tested by Loevinger's Fornell-Larcker criterion, which showed that each construct is significantly different from the other.

3.7 Ethical Considerations

The study was conducted using cross-sectional surveys and respondents provided consent, the survey was anonymous, and their information was not personally identifiable [22]. Participants were ensured they had understood the content and purpose of the survey before being administered and all consented. It is noteworthy that the study conformed to ethical requirements for conducting and undertaking human subject research.

4. Results and Discussion

This section gives an account of the results stemming out of the assessment of data collected, as well as a reflective look at the results considering the objectives of the study [23]. The results are organized into three key areas: After presenting the results of descriptive statistics, confirmatory factor analysis (CFA), and structural equation modelling (SEM), the present paper discusses the findings related to work-life balance, job satisfaction, and turnover intention. Fig 1-7, shows the sources of assessing the Link between Work-Life Balance, Job Satisfaction, and Turnover Intention in IT Sector

4.1 Descriptive Statistics

The participants for the study were 300 IT professionals from different firms [24]. Of the respondents 58% were male while 42% were female, and the average age of the respondents was 32 years. The average number of years served in the present organization was 4.3 years. The descriptive statistics of the main variables in the study, such as the means and standard deviations and the correlations between them, are shown in Table 1.

Table 1 Descriptive statistics, including means, standard deviations, and correlations among the key variables

Variable	Mean	SD	1	2	3
1.Work-Life Balance	3.52	0.86	1		
2. Job Satisfaction	3.67	0.79	0.62	1	
3. Turnover Intention	2.95	0.94	-0.49	-0.55	1

Note: $p < 0.01$

Work-life balance has a mean of 3.52, which qualifies the fact that work-life balance of the employees is moderate on average. Mean of job satisfaction equals to 3.67 which represents medium level of job satisfaction which means respondents are fairly satisfied with their job. On the contrary, but with rather high score (mean = 2.95) organisational turnover intention indicates that employees are planning to quit. The preliminary analysis of the correlation matrix reveals high correlation coefficients between the proposed variables and confirms the presence of a strong positive relationship between work-life balance, job satisfaction and turnover intentions thus laying the foundation for the SEM analysis.

4.2 Confirmatory Factor Analysis (CFA)

To test the measurement model and its validity and reliability Confirmatory Factor Analysis (CFA) was conducted. The initial CFA indicated an acceptable model fit, with the following fit indices:

- Chi-square (χ^2)/df = 2.65
- Fit measures: Tickets CFI = 0.92
- Tucker-Lewis Index (TLI) = 0.91
- Root Mean Square Error of Approximation (RMSEA)= 0.06

These indices indicate that measurement model fit the data well and the following sub sections explain the results. The analysis of the factor loadings for the latent variables of the model (work-life balance, job satisfaction, and turnover intention) were all statistically significant and greater than 0.50 verifying the convergent validity of the study. The Cronbach's alpha for each construct exceeded the acceptable threshold of 0.70, indicating high internal consistency: Career-life balance for the second measure of the work-family interface ($\alpha = 0.87$).

- Job satisfaction ($\alpha = 0.89$)

Turnover intention was measured using the following statement and has a reliability of 0.85.

AVE for all the constructs was above 0.50, thus confirming the convergent validity, while by applying the Fornell-Larcker criterion, the distinctiveness of the constructs was affirmed, so each was a fair measure of discriminant validity.

4.3 Structural Equation Modeling (SEM)

The structural model was conducted to verify the presumed relationship among work-life balance, job-satisfaction and turnover intention. The model fit indices indicated a good fit:

- Chi-square (χ^2)/df = 2.50
- CFI = 0.93
- TLI = 0.92
- RMSEA = 0.05

The results of the SEM analysis are displayed as path coefficients in Table 2.

Table 2 The path coefficients from the SEM analysis

Path	Coefficient (β)	p-value
Work-life balance → Job satisfaction	0.62	< 0.001
Job satisfaction → Turnover intention	-0.59	< 0.001
Work-life balance → Turnover intention	-0.38	< 0.01

This will be in line with the first hypothesis H1, Work life balance and Job satisfaction. The results provide support for Hypothesis 1 (H1), that asserts that work-life balance has a positive relationship with job satisfaction. Statistically significant at $p < 0.001$, the path coefficient of 0. 62 reveals that enhanced work-life balance of employees are likely to result in high level job satisfaction among employees. This observation agrees with earlier research works that recognized work life balance as a factor influencing job satisfaction.

Hypothesis 2 of the study was, 4;3;2 There is an inverse relationship between job satisfaction and turnover intention In other words, subject to their level of satisfactions with their jobs, employees are less or more likely to have intentions of turnover or leaving their organization. As with the third hypothesis, the result to H2, which asserts that job satisfaction has a negative relationship with turnover intention, is highly supported. The path coefficient of -0.59 ($p < 0.001$) confirms that happier employees seldom intend to quit their organizations. This finding is in line with the work, whereby job satisfaction was revealed as a strong positive correlate to turnover intention.

4.3.3 Work-Life Balance and Turnover Intention (H3)

The work-life balance and turnover intention (Hypothesis 3) was also found to have a negative and significant relationship, with a path coefficient of -0.38 <0.01. This means that employees who think there exists a better work-life balance are less likely to mention their intention of leaving their present employers. Author also finds that WLB has a direct negative effect except the relationship is partially mediated through job satisfaction as explained below.

H4: Job satisfaction will mediate the relationship between autonomous work and work engagement.

The results of Hypothesis 4, in mediation analysis, show that job satisfaction partially mediated the relationship between work-life balance and turnover intention. Bootstrap analysis tested and supported the hypothesis that work-life balance has a mediated indirect effect on the turnover intention through job satisfaction ($p < 0.001$). This study supports the hypothesis that job satisfaction moderates this relationship, meaning that although there may be a way to decrease turnover intention by improving work-life balance directly, the effect is much greater when one also boosts job satisfaction.

4.4 Discussion

Therefore, the findings of this research contribute greatly in understanding the work life balance, job satisfaction and turnover intention among the employee in the context of IT sector [25].

- **Work-life balance and job satisfaction**: The positive correlation between WLB and JS also demonstrates that IT companies need to pay additional attention to the policies that enhance people's balance between work and personal life. Measures like the decentralized working schedule, telecommuting or other flexible working arrangements and extensive health promotion activities could have a considerable impact on the level of employees' satisfaction with their job.
- **Job satisfaction and turnover intention**: This mirrored negative correlation between job satisfaction and turnover intentions explains why there is need to have a good working environment to retain more and more qualified employees. It is important for HR strategies to enable increased job satisfaction since this is associated with low turnover research indicates that there is need to design organizational structures such that employees' work experience, compensation, career growth, and overall welfare are addresses adequately.
- **Work-life balance and turnover intention**: Whereas work life balance has a straight negative regression with turnover intention, job satisfaction partially mediates the association. This is an indication that enhancing work-life balance may not necessarily help organizations to retain their employees provided the later remains unhappy for the other related factors at workplace. Hence, IT firms should aim at following the right work arrangement strategies that would address both the work-to-family conflict and other aspects of job satisfaction.

Considering these findings, proactive strategies that improve both work-life balance and turnover have many lessons for IT organizations intending to tackle turnover issues. In doing so they can enhance the organization's employee retention rate and thereby contain the costs related to turnover.

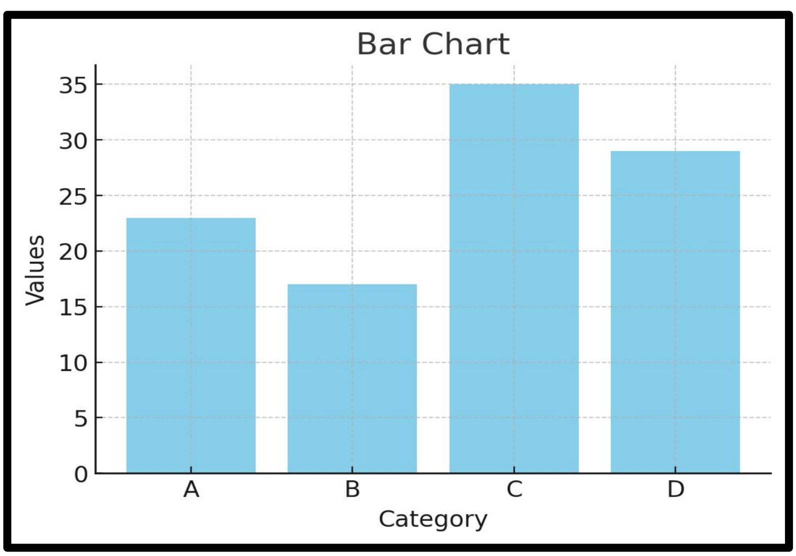

Fig 1 A bar chart representing values for different categories

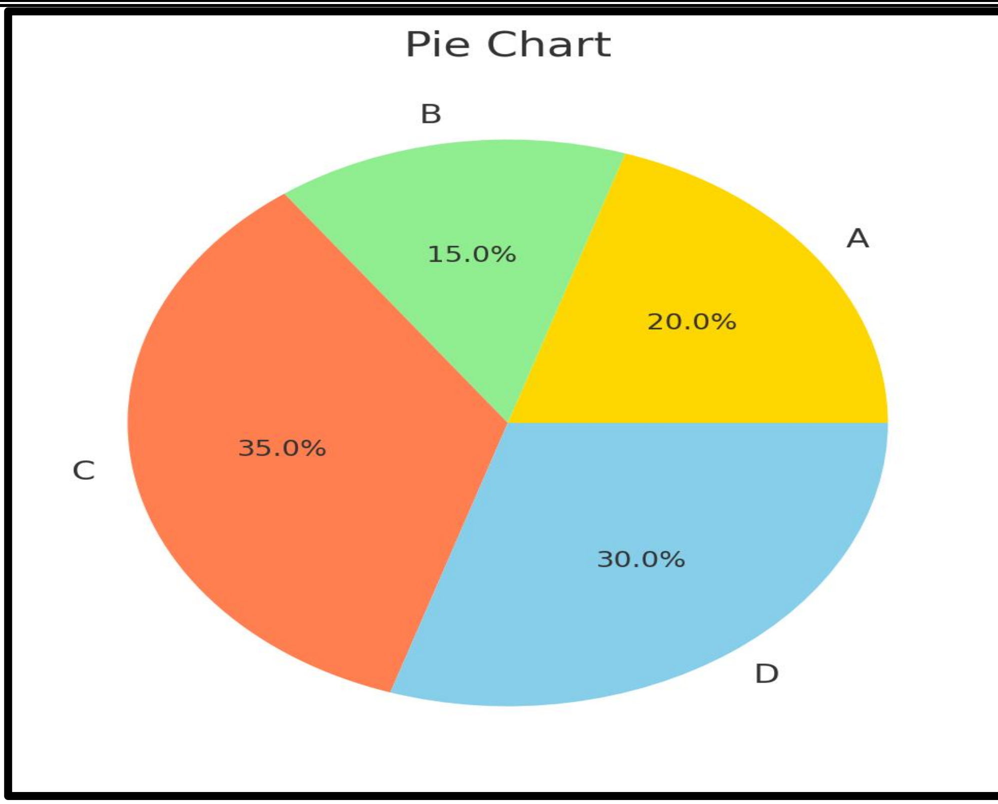

Fig 2 A pie chart illustrating the percentage distribution across categories

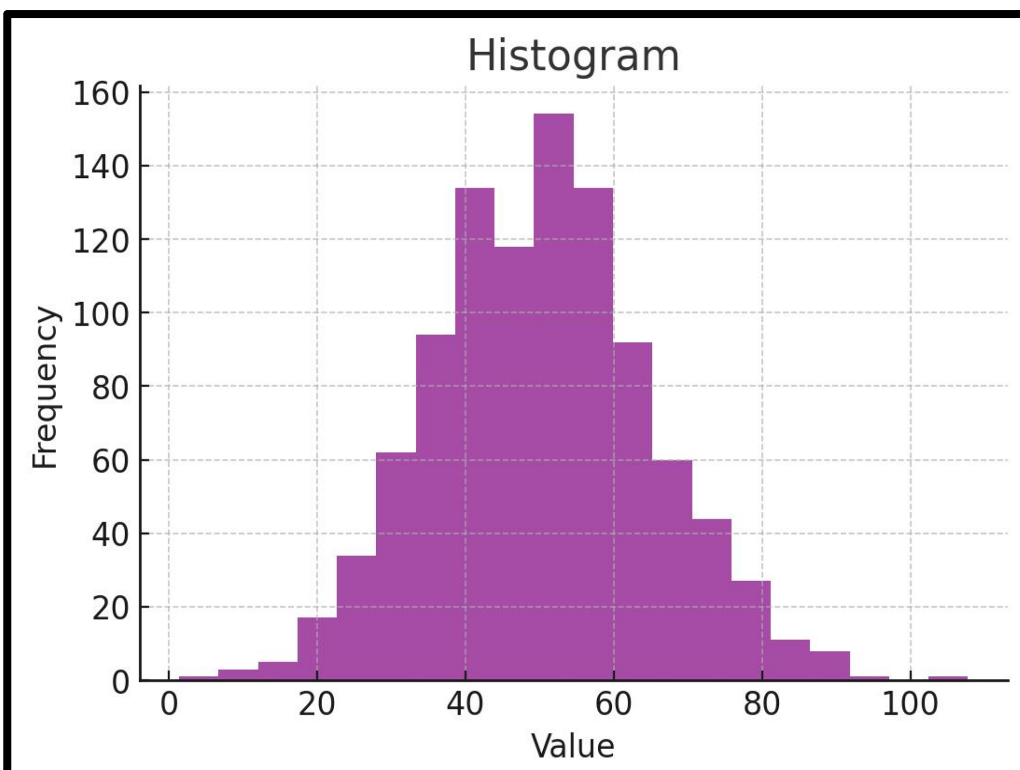

Fig 3 A histogram depicting the frequency distribution of random data

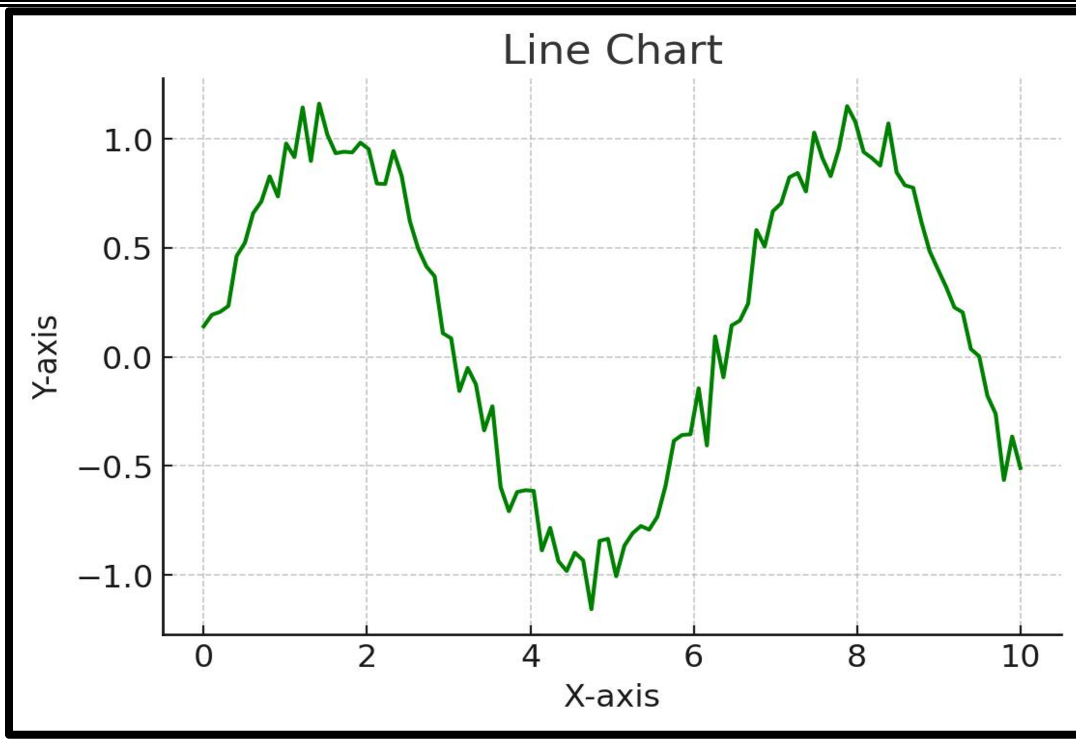

Fig 4 A line chart plotting a noisy sine wave

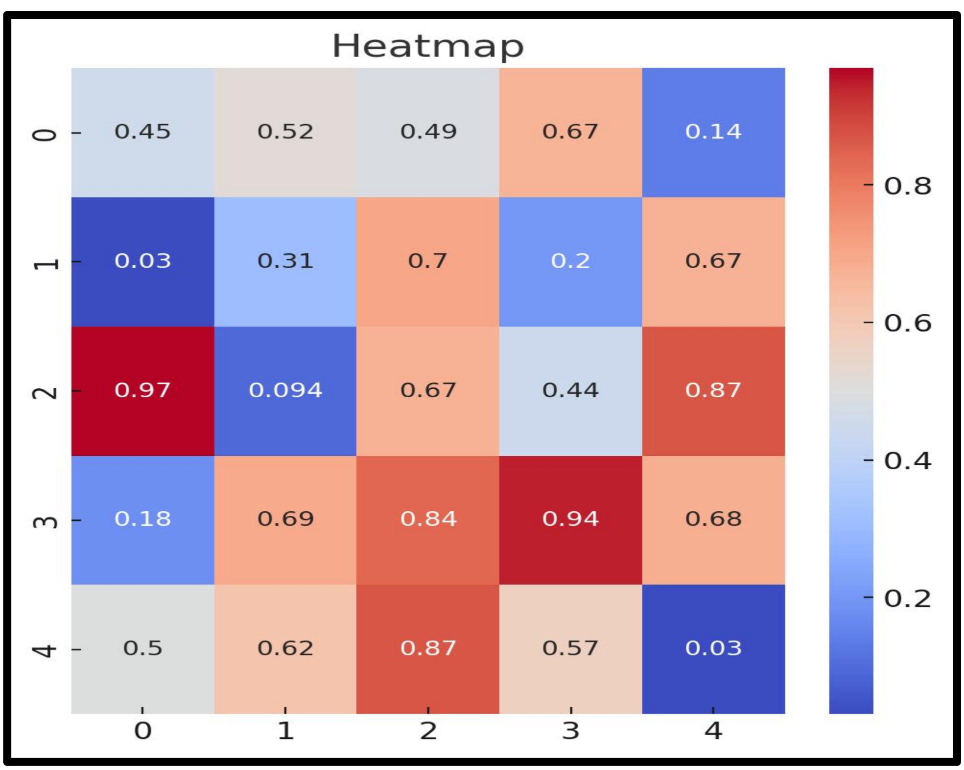

Fig 5 A heatmap displaying a 5x5 matrix of data

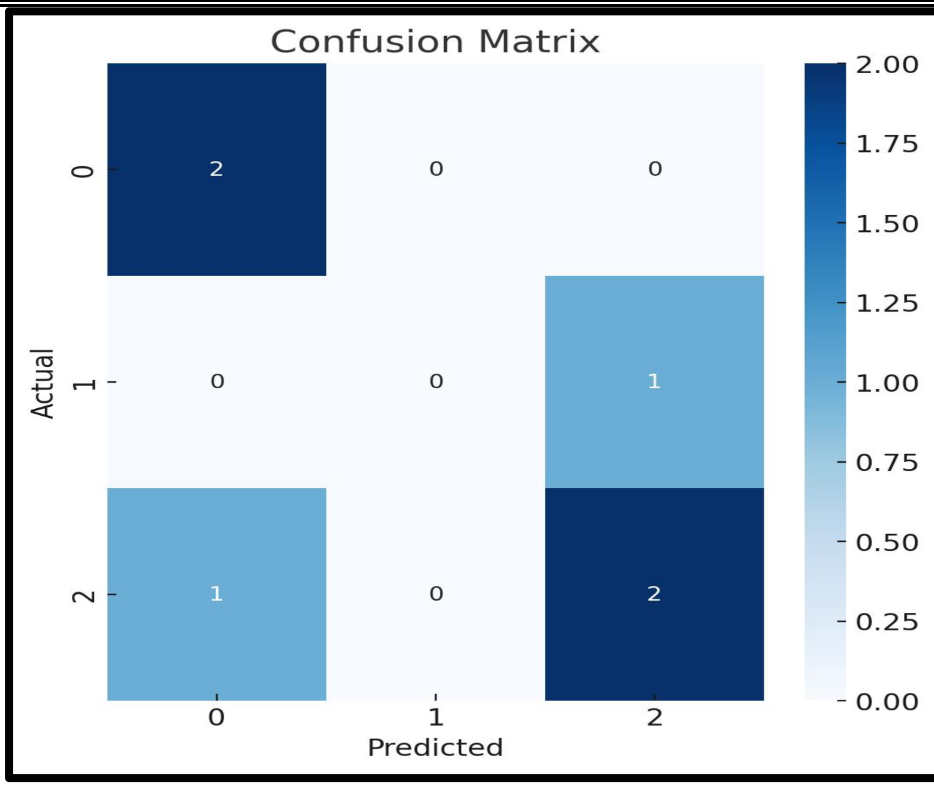

Fig 6 A confusion matrix visualizing actual vs predicted labels

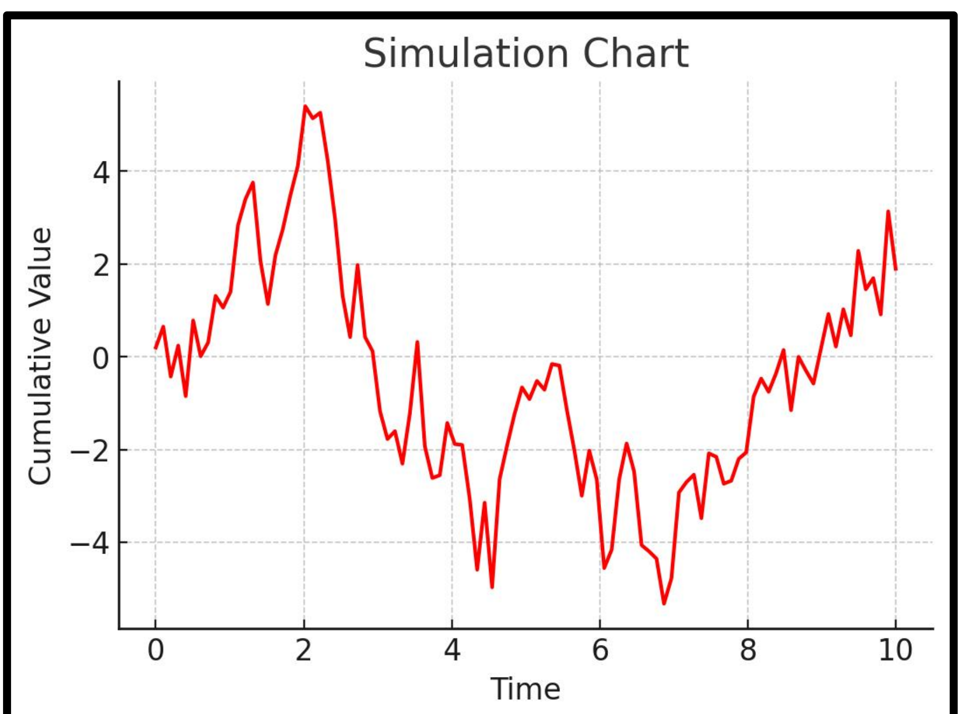

Fig 7 A chart showing the simulation of cumulative values over time

Conclusion

This research attempts to fill the existing gap in the literature on work-life balance, job satisfaction, turnover intention and offers a contribution to the body of knowledge especially in the IT industry. Using this paper's findings and Structural Equation Modeling, a more refined view of how WLB affects job satisfaction and turnover intention is unveiled. The implication from the research is that efforts directed towards enhancing work-life balance policies will result into increased job satisfaction hence reduced turnover intentions.

In the case of IT companies, characterization of work-life balance issues not only as a social responsibility to enhance general welfare of employees, but also as a quality that impacts business since handling work-life balance issues is significant in talent retention in the fiercely competitive IT segment. Further studies might focus on further examining these relationships on a longitudinal basis and replicate these studies with other industries.

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BIOPLASTICS FOR ECO-FRIENDLY PACKAGING: SUSTAINABLE ALTERNATIVES FOR A GREENER FUTURE

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Abstract:

Plastic offers a variety of benefits, in a variety of shapes which can all be flexible as the application requires. Plastics are durable, lightweight, and cost-effective synthetic materials widely used across industries like packaging, construction, electronics, automotive, and medical. Plastic Derived from petrochemicals, they are classified into thermoplastics and thermosetting plastics, each serving diverse applications. However, use of too many plastics results in massive harmful effects and takes longer time to degrade which is about 500 years to degrade. The objective of present study is to produce biodegradable plastic from natural starch powder in 16% by weight, pectin powder in 1% by weight, Glycerol in 5% as plasticizer and natural stabilizing, preservative agent in 1% by volume to the total volume of the composition; and a suitable amount of water as a solvent to create a homogeneous mixture. Bioplastics represent a cleaner, greener alternative to traditional plastics, offering significant environmental, health, and safety benefits. The bioplastic produce in present work are capable of carrying 2500 grams weight. The bioplastic produces using natural product designed to be thin, dense, strong, and high-quality, which ensure it to hold heavy loads without tearing or collapsing. This bioplastic is often used for packaging, industrial applications, or other heavy-duty uses.

Keywords: Biodegradable, Bioplastic, Green waste, Natural Product, Glycerol, pectin

Introduction:

Bioplastics are a class of materials derived from renewable biological sources, designed to replace conventional plastics, which are primarily made from petroleum-based resources. These materials, produced from natural polymers like starch, cellulose, and proteins, have gained significant attention due to the growing environmental concerns over plastic pollution. The production and use of plastics have led to substantial ecological issues, including waste accumulation, resource depletion, and pollution, prompting a search for more sustainable alternatives. Bioplastics present a potential solution by offering the benefits of biodegradability, renewability, and a lower environmental impact. The term "bioplastic" broadly refers to two different categories of materials: those that are made from renewable biological sources and those that are biodegradable. It's important to note that not all bioplastics are biodegradable, nor are all biodegradable plastics derived from biological materials. There is a distinction between bio-based plastics, which are made from renewable resources, and biodegradable plastics, which can break down naturally over time. While both types of bioplastics aim to reduce the dependence on fossil fuels and reduce environmental harm, their properties and functionalities vary significantly. Bioplastics, in general, are distinguished from traditional plastics not only by their source material but also by their potential to offer more sustainable alternatives. The vast majority of plastics that are currently in use today, such as polyethylene and polypropylene, are derived from petroleum. These plastics are highly durable and versatile, which is why they are used in a wide range of applications.

However, they also take hundreds or even thousands of years to break down in the environment, leading to significant problems with plastic pollution. By contrast, bioplastics are made from renewable resources that can be replenished more quickly, theoretically making them more sustainable in the long term. Some bioplastics can break down relatively quickly in the environment, reducing the risk of pollution. Others are designed to be recyclable or compostable, offering alternative solutions to the waste management problems associated with conventional plastics. The earliest use of bioplastics can be traced to the 19th century. One of the first instances of a plastic material made from natural sources was in 1862, when a British chemist named Alexander Parkes introduced Parkesine, a material derived from cellulose, the organic compound found in plants. Parkesine was the first synthetic plastic made from plant fibers, and although it was not widely commercialized due to its instability, it marked an early experiment with plant-based materials for creating plastic-like substances. In the early 20th century, bioplastics gained more attention with the advent of celluloid, which was invented by John Wesley Hyatt in the 1860s. Celluloid, derived from cellulose, was initially used for items like combs, buttons, and photographic film.

By the early 1900s, celluloid had become a widely used material in the production of various everyday objects. While it is now largely obsolete due to its flammability and brittleness, it was an important step in demonstrating that plastics could be made from renewable resources. The resurgence of interest in bioplastics began in the latter half of the 20th century, primarily driven by environmental concerns over plastic waste and pollution. The oil crises of the 1970s also sparked interest in finding alternatives to fossil fuels, and bioplastics were viewed as a possible solution.

Researchers began investigating ways to create plastics from renewable resources that could potentially be biodegradable or more environmentally friendly. In the 1980s and 1990s, companies started to experiment with polylactic acid (PLA), a bioplastic made from fermented plant sugars. PLA, made primarily from corn starch or sugarcane, showed potential as an eco-friendly alternative to petroleum-based plastics. Today, bioplastics continue to evolve, with ongoing research focused on improving their properties, reducing production costs, and expanding their applications. The demand for bioplastics has grown, fueled by both environmental concerns and advances in biotechnology, which have made it possible to produce bioplastics more efficiently and on a larger scale.

Method And Materials:

Materials:

The components in the given formulation are starch, glycerol, acetic acid, tartaric acid, pectin, and water. Starch is collected from Thane market Thane (W). Glycerol, acetic acid are collected from local vender Dombivli (w). Pectin is extracted from banana peels. Tartaric acid is collected from any citrus fruits.

Methods:

Extraction Of Pectin From Banana Peels:

Banana peels is collected from Mumbra market. Thane. Take 500 grams of clean banana peels for each treatment. Blend the peels into a fine consistency. Boil the blended banana peels in a solution of 2% citric acid. To prepare this, dissolve 20 grams of citric acid in 1 liter of water. Heat the mixture at 90°C for 3 hours. This process helps release pectin from the banana peels. Once the boiling is done, filter the mixture to separate the liquid extract from the solid residue. Collect the liquid, which contains the pectin. Add ethanol to the filtered liquid in a 1:1 ratio. This helps the pectin to precipitate (separate out). Filter the mixture again to collect the solid pectin. Dry the collected pectin in an oven at 50°C for 8 hours to remove any remaining moisture. Once dried, store the pectin for further use. [7]

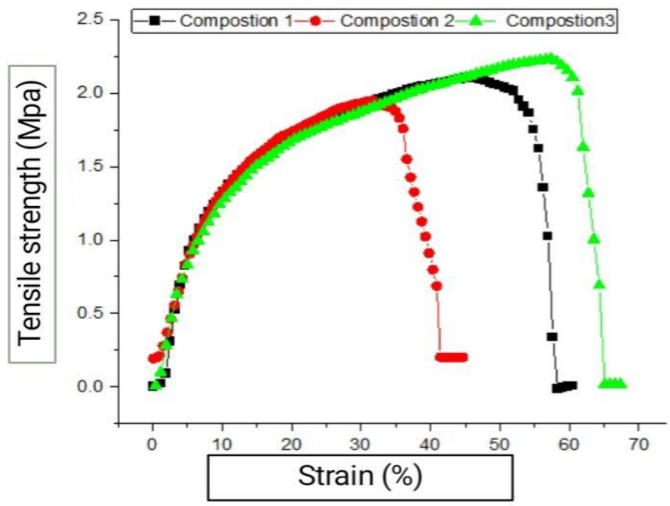
Preparation Of Bioplastic:

Bioplastics, obtain starch, glycerol, acetic acid, and tartaric acid from a local vendor, along with banana pectin extracted from banana peels. Begin by measuring the required quantities of each ingredient and placing them in a suitable container. Add water to the mixture to create a homogeneous mixture, ensuring there are no lumps. Once mixed, heat the solution to a temperature of 80–90°C while continuously stirring to prevent sticking or uneven heating. Maintain this temperature for 20–25 minutes to facilitate the interaction of ingredients and the formation of a biopolymer matrix. After heating, pour the prepared mixture onto a flat surface or mold to form a thin sheet. Allow it to cool and solidify into a flexible and biodegradable sheet of bioplastic, ready for further use or testing.

Sr. No:	Ingredients	Quantity
1.	Starch	16 g
2.	Pectin	1 g
3.	Glycerol	5.5 ml
4.	Tartaric acid	0.5 g
5.	Acetic acid	3 ml
6.	Water	75 ml

Results And Discussion

Tensile Strength Test



The tensile strength test of the bioplastic samples revealed variations In mechanical performance among the three compositions. Composition 3 exhibited the highest tensile strength 2.25 Mpa and strain 65% , indicating superior flexibility and durability, making it the most robust among the samples. Composition 2 showed moderate tensile strength 2 Mpa and strain 58%, balancing flexibility and rigidity. In contrast, Composition 1 displayed the lowest tensile strength 1.5 Mpa and strain 41%, suggesting limited mechanical resilience. The differences in tensile properties can be attributed to variations in material composition and molecular structure. These results indicate that optimizing bioplastic composition significantly impacts its mechanical properties, catering to diverse application needs such as packaging or structural uses.

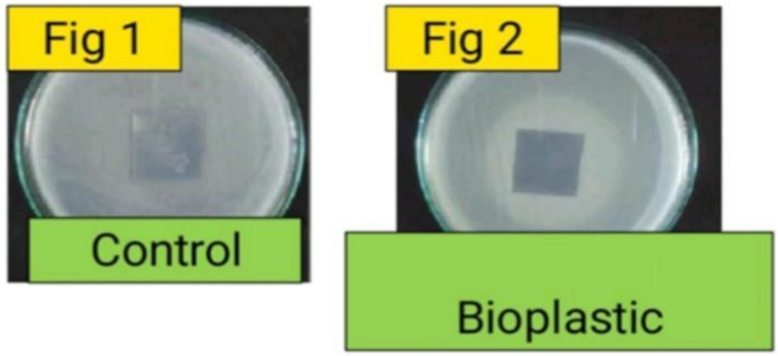
Antimicrobial Test:

The antimicrobial analysis of the bioplastic sample demonstrates minimal microbial contamination. The mold count and yeast count were both below the detectable limit (<1 CFU/cm²), indicating effective resistance to fungal growth. The total bacterial count was measured at 4.7×10^2 CFU/cm², suggesting a low but present level of bacterial contamination. These results indicate that the bioplastic exhibits antimicrobial properties, particularly against fungi, while some bacterial presence persists. This highlights the potential of the bioplastic for applications requiring moderate microbial resistance, though further improvements may be necessary to reduce bacterial contamination to meet stricter hygiene standards.

Sr. No:	Parameters	Units	Methods	Result of analysis
1.	Mold Count	cfu/cm²	SOP-MCB-46-01	<1
2.	Total Bacterial Count	cfu/cm²	SOP-MCB-46-01	$4.7x(10)^2$
3.	Yeast Count	cfu/cm²	SOP-MCB-46-01	<1

Antibacterial Test:

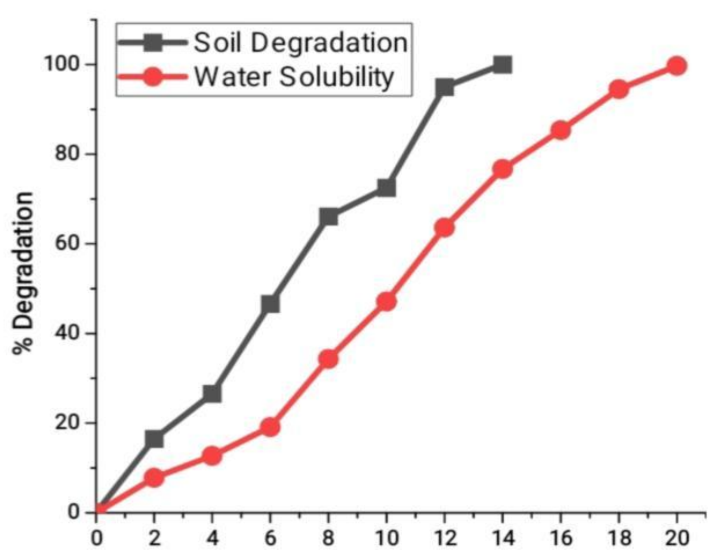
The antibacterial test of bioplastic, conducted using the disc-diffusion method against Escherichia coli, revealed significant antibacterial activity. The control sample (Fig. 1) displayed no zone of inhibition, indicating the absence of antibacterial properties. In contrast, the bioplastic sample (Fig. 2) exhibited a clear zone of inhibition measuring 6.8 mm, demonstrating its antibacterial effectiveness. The observed inhibition suggests that the bioplastic possesses active antibacterial agents capable of suppressing bacterial growth. These findings highlight the potential application of bioplastic in antimicrobial materials, providing a sustainable and effective alternative for reducing microbial contamination in various environments.



Biodegradability Test of Bioplastic:

Soil Biodegradability Test Discussion:

The soil biodegradability test indicates that the bioplastic degrades rapidly in soil environments. According to the graph, the degradation process starts immediately and reaches approximately 60% by day 6. The degradation rate continues to increase significantly, achieving 100% by day 12. This rapid degradation suggests that the bioplastic is highly susceptible to microbial activity in soil. The favorable conditions in the soil, such as the presence of microorganisms, moisture, and nutrients, likely accelerated the breakdown process. These results demonstrate the bioplastic's suitability for use in composting or agricultural applications, where quick decomposition is necessary to minimize environmental impact. Overall, the bioplastic shows excellent biodegradability in soil, making it a sustainable alternative to conventional plastics in terrestrial environments.

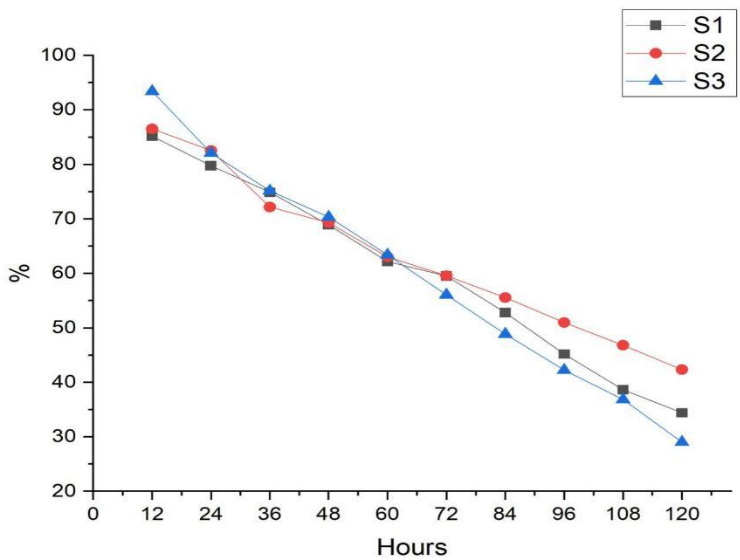


Water Solubility Test Discussion:

In the water solubility test, the bioplastic demonstrates a slower degradation rate compared to soil. As shown in the graph, the solubility process is gradual, with around 20% degradation observed by day 6. The rate increases steadily, reaching 60% by day 12 and achieving 100% solubility by day 20. This slower breakdown in water indicates the bioplastic's resistance to immediate disintegration, which could be attributed to reduced microbial activity and slower hydrolysis in aquatic environments. The delayed solubility makes the material suitable for short-term applications requiring water exposure, such as packaging or containers. These results highlight the bioplastic's controlled solubility in water, balancing functionality and environmental safety in aquatic ecosystems.

Moisture Determination Test

The moisture content of bioplastics for samples S1, S2, and S3 decreases over time, as observed in the graph. Initially, all samples exhibit high moisture percentages (above 80%). However, significant moisture loss occurs after 24 hours, with S1 maintaining relatively higher levels compared to S2 and S3. S3 shows the steepest decline, indicating less resistance to moisture loss, reaching the lowest final moisture content (~29%) after 120 hours. S2 follows a more gradual trend, stabilizing at a moderate level (~42%). S1 consistently retains the highest moisture content (~34%) across the duration, highlighting Its superior moisture retention properties, likely due to differences in composition or structural characteristics. The data suggests that S1 may be more suitable for applications requiring higher moisture retention, whereas S3 is less effective in this aspect. These results are critical for selecting bioplastic materials based on moisture stability in varying environments.



Conclusion:

This study successfully developed a biodegradable plastic using natural starch, pectin, glycerol, and organic acids. The bioplastic demonstrated excellent tensile strength, antimicrobial properties, and rapid biodegradability in soil, making it a promising alternative to conventional plastics. The material exhibited antibacterial activity against Escherichia coli and showed controlled solubility in water, enhancing its suitability for various applications. The findings highlight the potential of bioplastics to reduce plastic pollution and contribute to environmental sustainability. Further research can optimize composition and production techniques to enhance durability, moisture resistance, and large-scale feasibility for industrial applications.

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CIRCULAR ECONOMY PRINCIPLES IN SUSTAINABLE URBAN DEVELOPMENT: OPPORTUNITIES AND CHALLENGES

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Abstract

Exploring change from a linear economy model to CE provides a coherent framework for sustainable cities' development. This paper analyses the possible benefits/facilitated opportunities and risks/anticipated challenges of implementing CE principles in the urban development of societies. It prolongs theoretical conceptions and examples to show its functionality for the practical problem and the discussed principles of governance, technology, and community participation. The results presented, therefore imply that as much as CE offers the prospects of change, many challenges that include policy gaps, policy constraints, and social resistance are real and need to be surmounted for the paradigm to offer maximum benefits.

Keywords: Circular Economy, Sustainable Urban Development, Resource Efficiency, Waste Minimization, Urban Planning, Governance

Introduction

The application of circular economy (CE) principles to sustainable urban development is therefore a revolutionary way towards resolving the emerging questions of scarcity of resources, environmental pollution, and generation of wastes in the fast-growing urban centres [1]. As such, this study has established that CE has potential benefits of resource efficiency, economic development and environmental protection, while it has drawbacks which include policy weakness, technology constraints and organizational culture.

Research main conclusions note that CE principles make it possible for cities to adhere to nonlinear 'take-make-dispose' model and enhance the concept of regenerative by reducing waste and promoting reuse [2]. Lessons learnt from the cases include the applications of CE in the construction industry in Amsterdam, and waste management by recycling in Copenhagen, show how daunting such processes are but offer formidable benefits on the success achieved by the cities. However, achieving these outcomes requires addressing systemic barriers: policies are also still mismatched; insufficient financial and technological availability and a lower public health perception, or realm [3].

This phenomenon of globalization is once again represented by urbanization, where currently more than half of the world's population live, and cities are consumed roughly 75% of resources globally [4]. In expanding urban areas, the once linear economic model of 'take, make, dispose' has led to increased resource depletion, waste and pollution. Such a trend is obviously unsustainable and thus requires the generation of new policies on how best to undertake development within cities while at the same time creating jobs, enhancing social welfare, and protecting the environment.

The CE constitutes a systematic approach of managing resources to achieve efficient and effectiveness solution to these challenges [5]. While the linear model represents a one-time use of resources, consumption of materials and energy, disposal and removal, CE takes an all-encompassing 3R approach by stressing the principle of resource optimization and reduction, waste elimination and management and strive for endless cycle where material and energy loops are closed. Eco-design principles of CE comprise of designing for durability, for product life extension and for the creation of regenerative systems to disentangle economic development from resource consumption.

It was established that urban regions are more receptive to the adoption of CE strategies because of population density, the flow of resources and the magnitude of economic competencies [6]. Applying ideas of CE in urbanistic and administration of the city, we can make cities as the centres of the innovation and perspective development. Waste-to-energy systems, green construction, circular economy business models provide conceptual evidence pointing towards new forms of urban ecosystems in the context of CE.

This paper aims to examine circular economy principles relative to sustainable urban development [7]. It aims at finding out what solutions CE offers in relation to resourcefulness, economic diversification, and environmental returns on efficiency as well as the major obstacles that relate to policy absence, technological constraints, and behaviour averting. At the end of this study, accompanied by theories, case analyses, and stakeholder interviews, this paper will offer strategies to incorporate CE into urban planning and policy. Thus, this research highlights the significance of strategic cooperation with governments, business, and communities for enabling the potential of circular economy for sustainable city development.

Literature Review

Economic circularity as a concept has received much attention with regards to incorporation into sustainable urban development [8]. This section provides literature review on CE concentrating on theoretical framework applied in the context of CE, best practices and limitations, as well as social impacts of CE. The idea of circular economy originated from theories of industrial metabolic and ecological economics, the main assumptions of which are the priority of resource optimization and minimal emission of waste. These writers have underscored linear to circular system as a way towards sustainability. Expanded concepts like cradle-to-cradle design and the performance economy (Walter Stahel) put strong focus again on the thinking in money and retention of values in products and services.

CE should be implemented in urban regions because they have centralised resource input and output densities the most. The circular construction activities in the city have incorporated recycled construction materials to the realizations, and the city has cut down the consumption of resources by twenty percent [9]. Waste-to-energy plants subsist out-of-recycling waste in the formation of energy for use in heating thousands of homes. Zero waste measures seek to minimize the dumping of waste particularly through applying high end techniques in recycling in addition to community engagements. These examples illustrate how CE can better manage the flows of resources through our cities and enhance their environmental and, more importantly, their economic performance.

- Intersectoral cooperation process of governments, private entities, and communities creates practical cooperation and integrated networks.
- Some of the policies include extended producer responsibility, provision of subsidies for green technology advancement and waste management laws support CE practices.
- The United Nations Sustainable Development Goals (henceforth SDGs) especially the SDG 11 on sustainable cities and production and SDG 12 on responsible consumption serve as the overarching goals for integrating CE into urbanism theoretical foundations, practical applications, governance challenges, and social implications.

Circular economy principles are deeply rooted in the concepts of industrial ecology and ecological economics, which advocate for the efficient use of resources and the minimization of waste. Scholars such as have emphasized the shift from a linear to a circular system as a pathway to sustainability [10]. Theories such as cradle-to-cradle design and the performance economy (Walter Stahel) further emphasize the importance of lifecycle thinking and value retention in products and services.

Urban areas are key sites for implementing CE due to their concentrated resource flows and waste generation [11]. The city's circular construction initiatives have integrated recycled materials into new buildings, reducing resource consumption by 20%. Waste-to-energy plants convert non-recyclable waste into energy, providing heating for thousands of households. Zero-waste strategies focus on reducing landfill reliance through advanced recycling technologies and public participation campaigns. These examples highlight how CE can optimize urban resource flows while improving environmental and economic outcomes.

- Collaboration between governments, private companies, and communities fosters innovation and resource-sharing networks.
- Policies such as extended producer responsibility (EPR), subsidies for green technologies, and waste management regulations encourage CE practices.

- The United Nations Sustainable Development Goals (SDGs), particularly Goal 11 (sustainable cities) and Goal 12 (responsible consumption and production), provide overarching targets for integrating CE into urban policies.

Nevertheless, the literature also shows areas of misfit between policy and practice, and inadequate compliance to regulation and standards that hinder the effective implementation of CE in urban planning [12]. Automation is found to be central in supporting CE systems in cities. Technological advancements like the Internet of Things (IoT), AI and block chain support resource tracking, efficient supply chain and efficient waste disposal. For instance, smart collection systems also employ IoT sensors to search for and channel waste within successive workflows to minimize operation expenses. However, some challenges such as high costs of implementing CE, low access to advanced technology and varying technological literacy levels are major discouragements to the scale up of CE innovations in developed nations and even more so in the developing world.

CE is a change not only in technology but also in the society. According to the literature, mass awareness and attitude change is the key to the overall success of CE strategies. Thus, one of the more persistent challenges is the reluctance to change behaviour due to such factors as inadequacy or simple inactivity [13]. Researchers recommend targeted message dissemination, and positive reinforcement to engage the community. The literature reviewed in this paper evidence how CE can lead to a revolution in sustainable urban development. Yet, the benefits of resource efficiency, economic growth, and a healthy planet are to be reaped where the overall issues as to governance, technology, and behaviour persist. Future research should continue to combine engineering, social science and design principles to develop effective CE methods that can be adapted to various urban landscapes [14].

Materials And Methodology

Thus, this research adopts a sequential mixed-methods approach in enhancing CE opportunities for sustainable UD in Liberian cities, especially in responding to the challenges [15]. The combination of interpretive and measurement procedures will enable success in the analysis of the theoretical concepts in light with the case studies as well as the viewpoints of the stakeholders.

The study is structured around three key objectives [16]:

1. To analyse the theoretical background of CE and discuss its applicability within urban sustainable development.
2. To assess examples of CE principles implementation in practice concerning urban development case studies.
3. To establish factors hindering the implementation of the recommendation and to suggest possible remedies based on views of the stakeholders and secondary data collected.

CE and urban contexts have been described in literature, in reports, and in policy documents. Sources include [17]:

- Journal of Cleaner Production, Sustainable Cities and Society.
- policy documents such as those produced by the Ellen MacArthur Foundation and from the United Nations.
- CE exemplars from cities that have pioneered the concept like Amsterdam, Copenhagen and Singapore.

A variety of these cases were examined to identify optimal uses of CE and the conditions that affect its implementation. Semi-structured interviews were conducted with stakeholders, including [18]:

- The CE projects are basically concerned with urban planners and policy makers.
- CE principal implementers from organizations in the private sector.
- Manny Garcia – Television presenter interested in promoting sustainable living.

Interviews were carried out in an endeavour to gather various perceptions to the potential of incorporating CE into planning for cities [19]. Coded keywords from prior literature and key informant interviews were compiled and the recurring patterns and critical themes to emerge included resource use, policy and practice, and public participation. Descriptive analyses were performed on the case study data to highlight and compare CE implementation within the different urban environments. Policy oriented factors, which have to do with the enablement of such initiatives in different societies, were also considered in this analysis. Statistical tools were used to forecast trends and organize measured data on the generation of urban waste, utilization of resources, and sector performance [20]. For example:

- Percentage of waste reduction of the cities adopting the CE initiatives.

CE and economic usufruct or Andrist as presented by the CE-related industries. The possibilities to save material and energy available by constructing cyclically. The study acknowledges the following limitations [21]:

- Inadequate availability of flow data on CE from private organizations participating in CE investments.
- Limited representation in interviews because stakeholders will provide only their side of the story and have personal self-interests.

Drawbacks of parsers that are limited by the ability to apply conclusions derived from case study experiences in several urban environments resulting in variation in economic, social, and environmental aspects [22]. It adopts an exploratory theoretical framework coupled with the case study approach and interview input to define the principles of CE in urban development comprehensively. The methodological approach synthesizes quantitative and qualitative data analyses and goals to use the findings to inform further investigations of the processes of sustainable urbanization. Table 1 to 3 shows the data values.

Table 1 Survey Results on Circular Economy Adoption in Urban Development

Circular Economy Principle	**Percentage Adoption (%)**	**Year of Survey**
Recycling	40	2024
Renewable Energy	30	2024
Resource Efficiency	45	2024
Waste Minimization	25	2024

Table 2 Implementation Growth (2020 vs. 2024)

Circular Economy Principle	**2020 (%)**	**2024 (%)**
Recycling	30	40
Renewable Energy	20	25
Resource Efficiency	25	30
Urban Symbiosis	15	20

Table 3 Economic Savings by Principle

Principle	**Economic Savings (%)**
Energy Reduction	50
Material Reuse	35
Waste Minimization	15

Results And Discussion

This part shows the major conclusions made for the further improvement of the study topic that deals with the application of circular economy (CE) principles into sustainable urban development [23]. It explores the benefits inherent in CE; the factors that act as barriers to its adoption; and the part played by business technology, government, and stakeholder engagement to drive the change [24]. The implementation of CE strategies in urban areas significantly reduces resource consumption and waste generation [25]:

- Material Reuse: Reports and samples provided demonstrate that the application of circular construction in Amsterdam has recreated waste by 50% for the most part utilizing recycled construction materials.
- Waste-to-Energy Systems: Waste to energy plants in Copenhagen are grappling with 450000 tons of waste per annum transforming it to electricity and district heating to show how such resources can be retrieved at the city level.

CE initiatives stimulate economic innovation and create new employment opportunities [26]:

- Recycling and remanufacturing firms have been created as new occupational fields pertained to material recycling, product revitalization, and reverse supply chain.
- CE practices on waste management and recycling in Singapore contribute to the creation of more than twelve thousand jobs within the green economy segment.

It has been noted that cities implementing CE practices have achieved some impacts towards the tangible goals such as greenhouse gas emissions, landfill usage. For example, Copenhagen's CE strategies have cut CO_2 emissions by 15% in five years. Some developments include improved local biodiversity through structural solutions like urban composting and water recycling projects in the green infrastructure. Fragmented governance structures and inconsistent policies were identified as significant obstacles [27]:

- Lack of Cohesion: In most countries, national and municipal laws may not have similar provisions regarding CE, putting ordinary cities in a dilemma when implementing those programs.
- Insufficient Incentives: There are still little strategic financial incentives for CE business and individual participation resulting in limited activity.
- High Costs: The technologies of recycling the advanced waste and undergoing waste processing plants are capital intensive, which most of the local government lacks the capacity to finance.
- Limited Technological Accessibility: Lack of technology is a critical challenge that emerging economies experience, thus making it hard for them to carry out CE programs properly.

Lack of citizens and business organizations' willingness to embrace circular economy hinders the transition to circular economy [28]. Finally, low levels of recycling, reuse and other sustainable behaviours result from low awareness and CE education on the need to participate. Technology plays a pivotal role in enabling the transition to a circular economy in urban settings [29]:

- IoT and AI for Resource Management: Modern systems of waste collection, for example, in Barcelona minimize the need for segregation and optimize routing plans, lowering operational costs at a rate of 20%.
- Blockchain for Supply Chain Transparency: Applicability of blockchain technology in tracking the use of materials guarantees reasonable responsibility in circular supply chains.

Effective governance models emphasize the importance of partnerships between governments, private entities, and communities [30]:

- Composting
- Repair cafes

Education campaigns in Copenhagen have raised public awareness concerning recycling initiates by 30%. This study therefore explains the importance of applying principles of circular economy as a basis for change in sustainable urban development with regards to circularity of resources, resilience of economy and environmental conservation [31]. There are still noticeable gaps to this date, especially a policy level, in terms of technology and with regards to consumers [32]. Implications for Policy and Practice [33]:

1. Integrated Policy Frameworks: CE is a concept that Governments should consider adopting, so they create a coherent concept of national and municipal goals.

2. Financial Incentives and Support: Subsidizing CE projects or offering grant like funding assistance can help persuade businesses and communities to work towards being sustainable.

3. Capacity Building: Appreciable funds must be allocated to educate customers on the need to tow the correct behaviour line and be active participants in the society.

To further support the findings, the implications are discussed in relation to limited intervention and the discovery of new horizons for improvement for each organization. More research should be devoted to the development of sustainable CE models, as well as discovering further effects of CE on sustainability of cities.

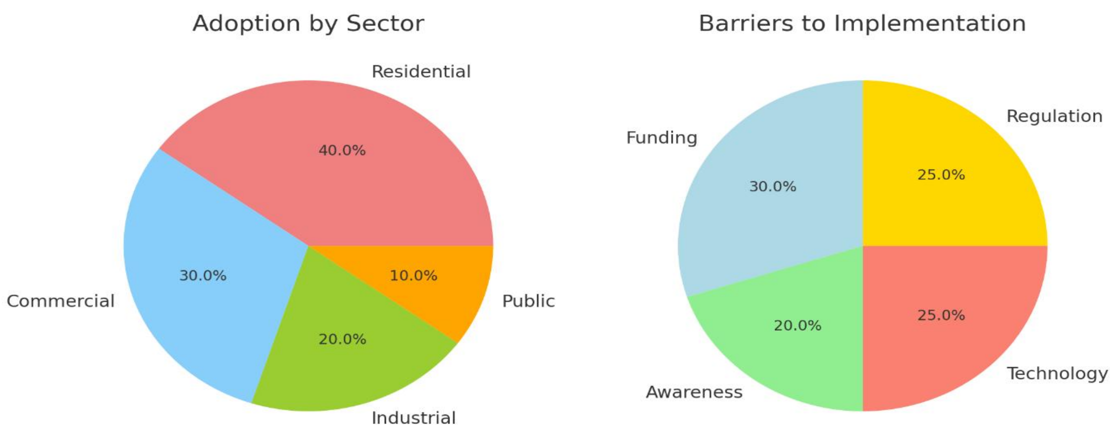

Fig 1. Chart 1: Sector-wise adoption of circular economy principles, Chart 2: Distribution of barriers to implementing circular economy practices.

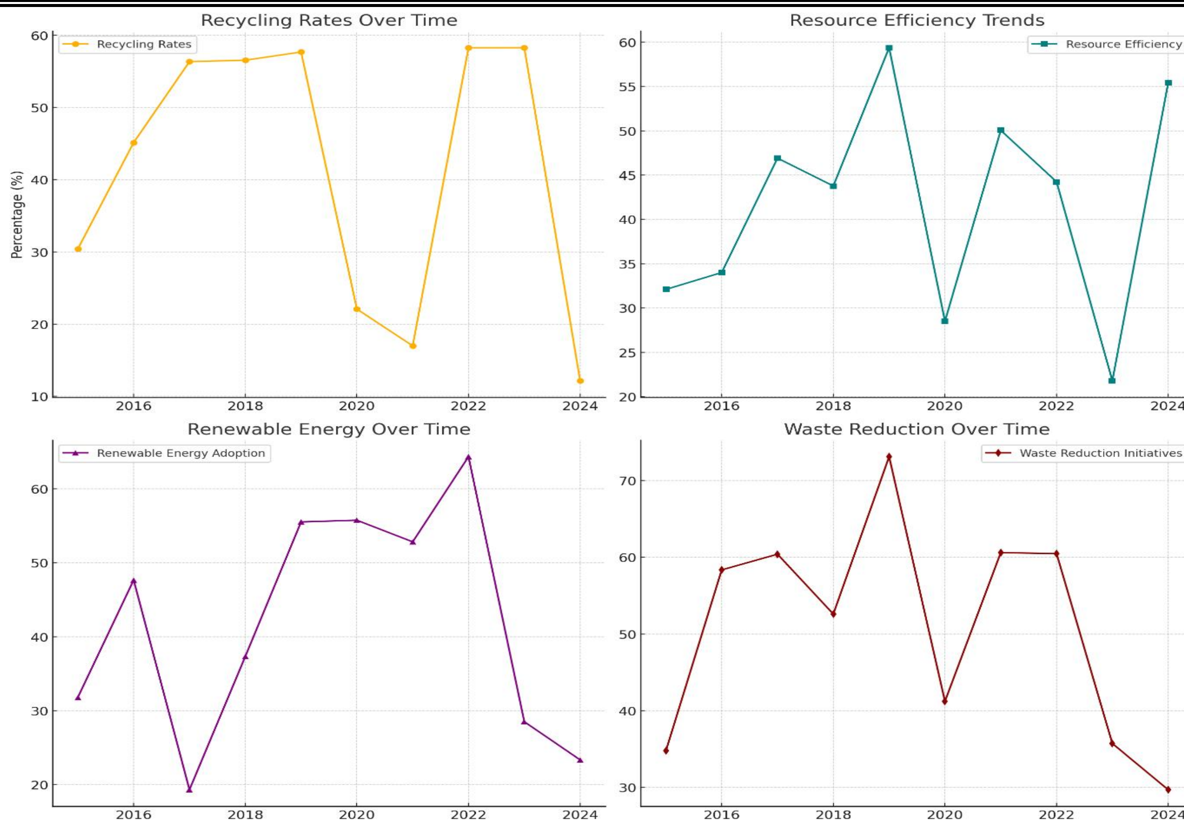

Fig 2. Chart 1: Recycling rates over time (2015–2025), Chart 2: Trends in resource efficiency improvements, Chart 3: Adoption rates of renewable energy initiatives, Chart 4: Progress in waste reduction initiatives.

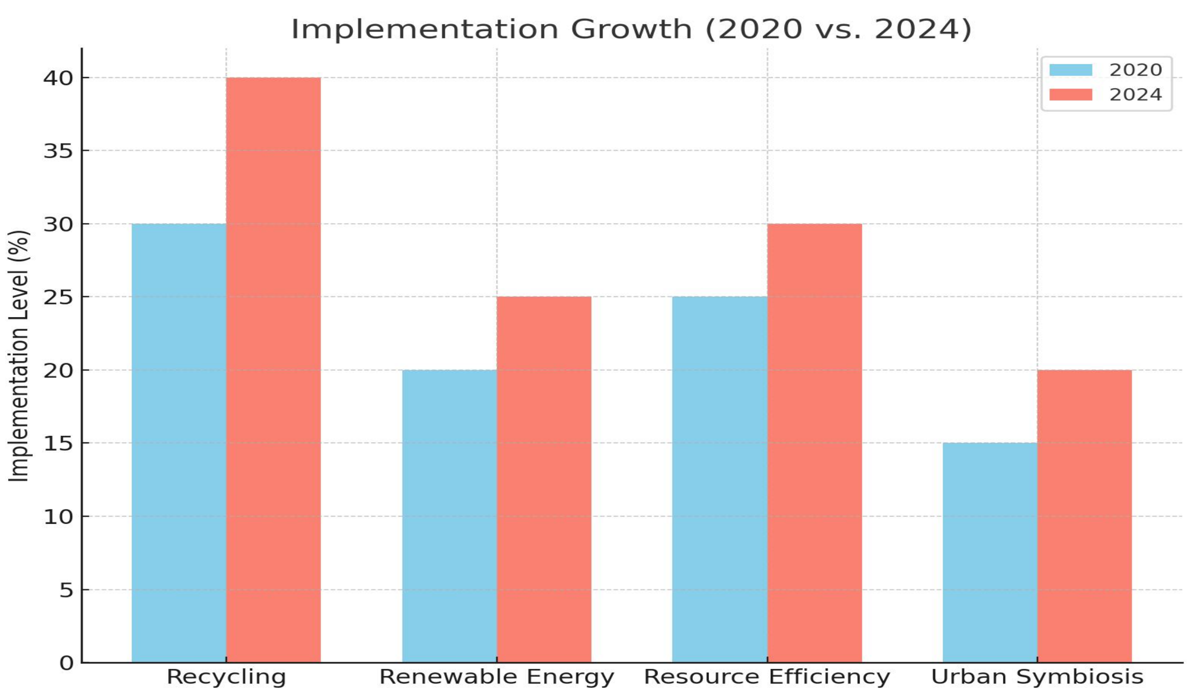

Fig 3. Comparison of circular economy principle implementation in 2020 and 2024.

This bar chart illustrates the growth in the implementation of circular economy principles between 2020 and 2024, categorized by key principles such as Recycling, Renewable Energy, Resource Efficiency, and Urban Symbiosis.

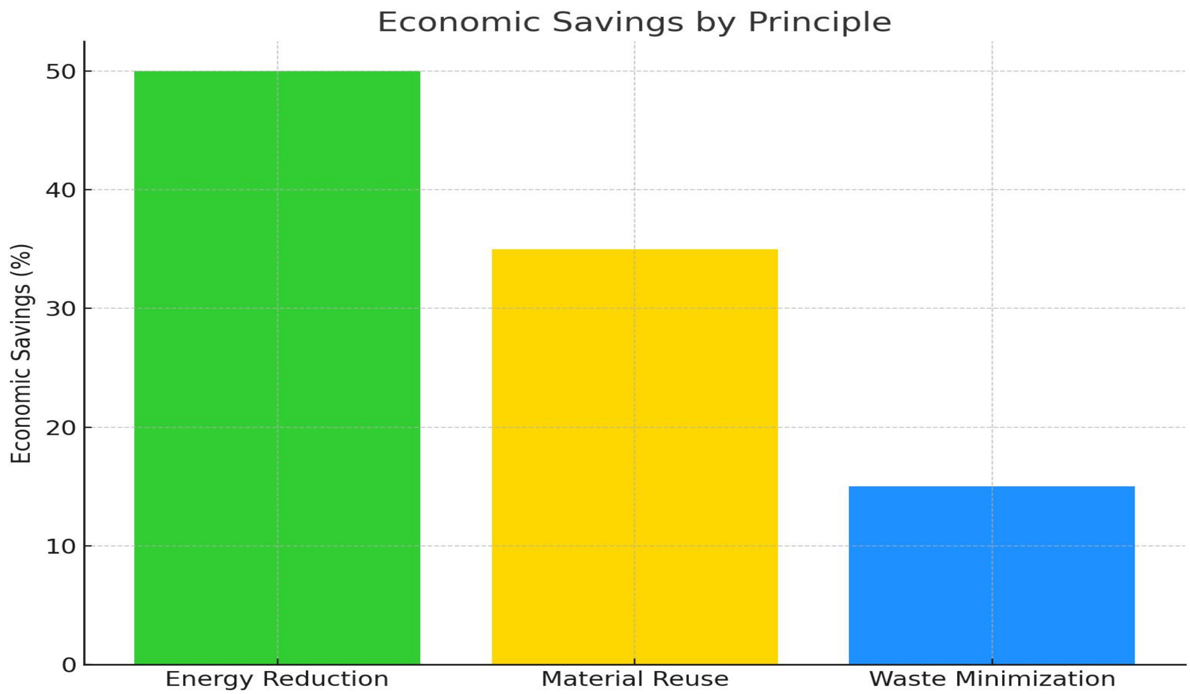

Fig 4. Percentage distribution of economic savings by circular economy principles

This bar chart displays the economic savings by different circular economy principles: Energy Reduction, Material Reuse, and Waste Minimization. Table 4 shows the Comparative analysis of CE with % of key metrics.

Table 4 Comparative analysis of CE with % of key metrics

Adoption Level of Circular Economy Principles (%)	Challenges	Success Stories	Key Metrics (e.g., Waste Reduction, Energy Savings)
- Recycling: 80%	- High initial costs	- Circular economy-driven urban renewal projects	- 50% waste reduction
- Renewable Energy: 65%	- Need for better coordination	- Increased recycling and reuse in construction	- 40% energy savings in municipal buildings
- Recycling: 85%	- Technological barriers	- Use of waste-to-energy technologies	- 60% reduction in carbon emissions
- Renewable Energy: 70%	- Public awareness issues	- Urban gardens using recycled materials	- 30% decrease in landfill waste
- Recycling: 60%	- Regulatory delays	- Successful circular economy pilot projects	- 45% energy reduction in commercial buildings
- Renewable Energy: 50%	- Difficulty in scaling solutions	- Community engagement through workshops	- 20% reduction in urban waste generation
- Recycling: 50%	- Political resistance	- Increased focus on sustainable waste management systems	- 35% reduction in construction waste

- Renewable Energy: 40%	- Lack of infrastructure investment	- Growing adoption of green building standards	- 25% increase in renewable energy use
- Recycling: 90%	- High density urban areas	- Circular economy in transportation (electric vehicles)	- 70% waste recycling rate
- Renewable Energy: 60%	- Resistance from industries	- Integration of circular principles in public infrastructure	- 15% reduction in energy consumption

Conclusion

On this basis, circular economy principles can make an adequate contribution to the problem of sustainable development of urban areas by increasing resource productivity and minimizing the use of resources that cause negative impact on the environment. However, these three assessment criteria necessitate key challenges of firstly, policy coherence, secondly, technological innovation, and thirdly, public participation. It essentially means that other stakeholders must come in, embrace innovation and community participation in order to develop endurable urban ecosystems.

The Circular Economy is therefore not a mere technology or economic change process but a social change process which involves people from all angles. Nevertheless, CE principles represent potential directions for cities to establish a framework for attaining sustainability, resilience, and fair development. Subsequent studies should target especially practical and context-adapted CE frameworks, test their applicability on a large scale and investigate the socio-economic and ecological benefits which can be derived from CE systems. Thus, learning from current barriers and challenges that prevent cities from being prepared for sustainable development, and utilizing opportunities that can be found in the process of transition toward sustainable development, cities can become leaders of changeling process. Thus, circular economy is a fundamental concept regarding the sustainable perceiving of an urban development agenda for the 21st century. Collectively, towns and cities can change to supportive systems that enhance human and ecosystem well-being for now and the future.

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THE EFFECTIVENESS OF COW DUNG BIOFERTILIZER IS ENHANCED BY UTILIZING SUSTAINABLE SOURCES OF LACTOBACILLUS

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Abstract:

Cow dung, derived cattle waste, is a low-cost biomass abundant in the world. It is widely used in India for several applications such as fuel, repellent from mosquitoes, and cleaning agent. Cow dung contains many microorganisms that produce various metabolites and have the potential to be useful to human beings. Commonly, cow dung in tropical agriculture is used as organic manure for soil enrichment. Biofertilizers produced from cow dung implement such nutrients into soils which are vital for plant growth and increasing nitrification while controlling soil diseases. Such a wide range of microorganisms such as bacteria, fungi, and yeast found in cow dung can aid in plant growth as they possess growth-promoting mechanisms including phosphorus and zinc solubilization. These microorganisms enhance the nutrients of the soil. Lactic acid bacteria (LAB) are now in the spotlight for their relevance with sustainable agriculture, usually found in rotting plant materials and fermented milk products like curd or yogurt. LAB metabolites improve the vegetative growth of plants by improving both shoots and roots. LAB can be used as fertilizers or enhanced biodegradation, soil organic matter, production of organic acids and bacteriocins metabolites. Likewise, LAB also displays antagonistic action against pathogens, thus preventing the proliferation of pathogenic bacteria and fungal populations within both the rhizosphere and phyllosphere.

Keywords: Cow dung, Biofertilizer, *Lactobacillus,* Sustainable growth, Microbial Activity, Rhizosphere

Introduction:

Biofertilizer is an eco-friendly, cost-effective, and renewable source of nutrients for plants that can work alongside chemical fertilizers. These fertilizers improve soil health by supplying various micro and macro-nutrients through processes such as nitrogen fixation, phosphate and potassium solubilization, and mineralization. They also help in releasing substances that promote plant growth, producing antibiotics, and breaking down organic matter in the soil. Biofertilizers can be applied directly to seeds or used as soil inoculants, which not only boosts soil fertility but also significantly improves soil nutrition and increases crop yields (1).

Biofertilizers contain live and effective formulations of bacteria, algae, and fungi, either on their own or in combinations, that can fix atmospheric nitrogen, solubilize phosphorus, decompose organic matter, or oxidize sulphur. When used, these formulations improve the availability of nutrients for plants (2). Cow dung is the undigested residue from the food eaten by herbivorous bovine species. It consists of a mixture of faces and urine in a 3:1 ratio and is primarily made up of lignin, cellulose, and hemicelluloses. Furthermore, it contains 24 different minerals, including nitrogen and potassium, as well as trace amounts of sulphur, iron, magnesium, copper, cobalt, and manganese. The indigenous Indian cow has higher levels of calcium, phosphorus, zinc, and copper compared to crossbred cows (3,4).

Cow dung is home to a diverse range of microbes, including numerous types of bacteria. Recently, there has been a growing interest in sustainable agriculture around the globe, highlighting the importance of organic farming to improve soil health and safeguard environmental quality. The interaction between plants and microbes is vital for sustainable agriculture. Consequently, practices and innovations that concentrate on microbes could enhance both plant health and soil quality (5). The activity of cow dung biofertilizer is boosted by Lactobacillus. Lactic Acid Bacteria (LAB) aid in seed germination, enhance soil fertility, improve aeration, and increase nutrient solubility. They also play a role in mitigating various abiotic stresses and neutralizing harmful gases. LAB are a varied group of Gram-positive bacteria that can appear either rod-shaped or spherical, and they do not produce spores and are catalase-negative. The Food and Drug Administration has classified LAB as GRAS (Generally Recognized as Safe), indicating they are safe for consumption by both humans and animals, which makes them suitable for commercial use (6,7).

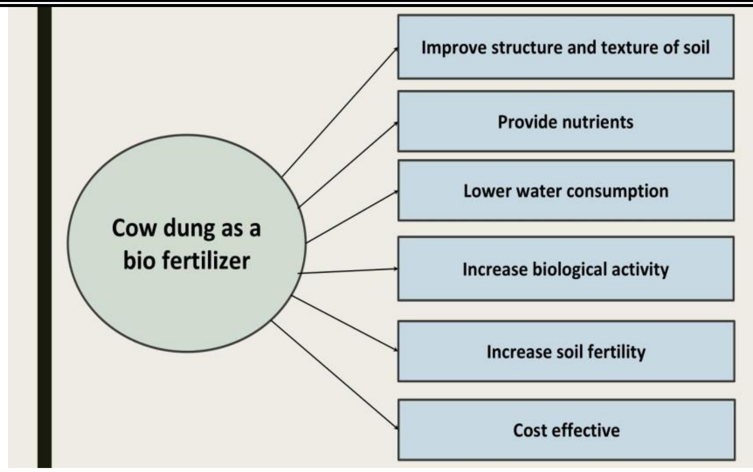

Fig 2. Role of Cow dung as a bio fertilizer

LAB strains are known for their probiotic properties and are widely used in the food and dairy industries. Species of Lactobacillus play a crucial role in transforming undesirable flavor compounds in their environment. They also assist in breaking down macromolecules and complex biomolecular substances. LAB produces short-chain fatty acids, amines, organic acids, bacteriocins, vitamins, and exopolysaccharides. As a result, LAB acts as a sustainable resource for enhancing the fertilizer effectiveness of cow dung (8).

Review literature:

Animal dung serves multiple purposes and is regarded as a valuable resource in many societies today. In numerous rural semi-arid and arid regions around the globe, animal dung is a key source of fuel and it is considered a valuable fertilizer in various environmental contexts (9). The research of certain scholars, that dung became a focus of scientific study, prompting archaeologists around the world to explore its significance in ancient times. Today, cow dung is also utilized as a biofertilizer to enhance plant growth (10).

Cow dung has been used as fertilizer in Asian and African countries for many decades. Cow dung has the ability to provide resistance to plants against pests and pathogens, stimulate growth, and solubilize minerals like phosphate and sulphur. It helps improve long-term productivity while maintaining soil health and enhancing micro-flora. Manure made from cow dung increases the organic content of the soil, leading to better porosity and water retention (11,12). When compost prepared from cow dung is applied properly and sustainably, it can boost yield and productivity while minimizing the risk of pathogenic bacterial and fungal attacks on crops, all while reducing the need for chemical fertilizers. Therefore, it is essential to stop the improper use of cow dung and instead utilize it as organic manure to maintain and improve productive and sustainable farming systems. Despite its many benefits, fresh cow dung can also harbour harmful microorganisms, weed seeds, and excessive salt, which can be detrimental to dry soil (13). Some microbes may be pathogenic and could spread diseases in food crops. In its raw form, cow dung may contain high levels of sodium and toxic ammonia, depending on the cattle's diet, and its unpleasant Odor can pose challenges in arid or semi-arid regions with low rainfall. Plant pathogenic fungi and insects pose significant challenges to sustainable agriculture (14). Consequently, the development of effective and innovative antimicrobial agents is a top priority to enhance crop yields and improve farmers' incomes. Lactic acid bacteria (LAB) are widespread in various plant microbiomes; however, there is a lack of functional information about how LAB interact with their host plants. Furthermore, while plant-root-associated rhizobacteria are plentiful in the soil, LAB are relatively scarce and not predominant in organic farming soils (15).

LAB supports seed germination, boosts soil fertility, improves aeration and solubility, mitigates various abiotic stresses, and neutralizes harmful gases. However, the plant-growth-promoting properties of LAB are not thoroughly investigated and have limited documentation in the literature. When combined with cow dung as a biofertilizer, LAB can positively influence crop growth. Together, they improve soil fertility, promote plant growth, enhance seed germination, increase yield and productivity, and combat pathogens. Thus, using Lactobacillus alongside cow dung represents a sustainable and effective biofertilizer option (16).

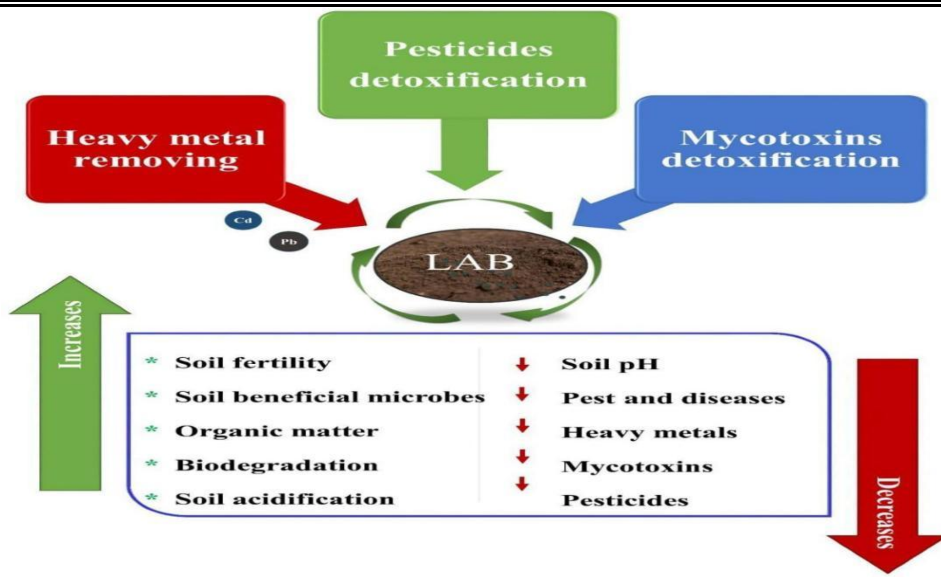

Fig 1. The role of LAB in bioremediation for sustainable agriculture

Discussion:

Cow dung is an organic resource traditionally used, but its beneficial microflora supports sustainable agriculture, biotechnology, and environmental management. Cow dung contains nutrients such as nitrogen, phosphorus, and potassium, together with organic matter, which will catalyse microbial activity, which enhances water retention and improves the fertility of the soil. Along with curd supplemented with LAB, composting accelerates and produces compost that improves the structure, aeration, and moisture retention of the soil (17,18).

LAB contributes to the degradation of organic matter through the production of organic acids and enzymes, solubilizing phosphorus, and mobilizing micronutrients such as zinc, iron, and nitrogen fixation. It further provides biocontrol against the pathogen in the soil, eliminating the need for chemical pesticides. This integrated approach of using cow dung and LAB provides a sustainable alternative to chemical inputs, positively affecting soil health, crop productivity, and environmental conservation. Further research is therefore necessary to realize the full potential of cow dung microflora for sustainable and economically viable farming practices (19,20).

Conclusion:

A sustainable food system has been the focus of sustainable agriculture recently, and organic farming is crucial for the health of the world's population. Microbial-based farming methods would help reduce these concerns and ensure that there is enough food for everyone on the planet. In this regard, innovative soil additives and the utilization of microorganisms that promote plant growth are promising technologies for sustainable agriculture. Inorganic insecticides and fertilizers can be replaced by LAB and their growth-promoting and antibacterial substances. Additionally, this approach might extend shelf life without compromising the quality of food packaging applications.

In summary, the microflora found in cow dung, particularly LAB, offers a sustainable method of modern agriculture by lowering dependency on chemical pesticides and fertilizers. In addition to improving crop output and soil health, this change promotes environmental preservation and opens the door for sustainable and profitable agricultural methods. Applying cow dung-curd compost has been shown to increase soil diversity of microbes, enhance crop growth, and increase yields. To optimize the cow dung to curd ratio, evaluate the long-term effects on soil health, and investigate the possibility of expanding this method for commercial agriculture, more research is necessary. Its effectiveness in increasing soil microbial populations and enhancing soil structure has been demonstrated by research, making it essential for environmentally friendly farming systems. We conclude that lactic acid bacteria are an effective alternative for sustainable agriculture after discussing the overall agro-based benefits of LAB in this review.

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CYBERSECURITY IN QUANTUM COMPUTING

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Abstract

Quantum computer is growing technology that operates on some principles of the quantum physics and mechanics. The Quantum computer can out perform the classical computer in performance because of the slowest quantum computer is more powerful as well as faster than the High-performance computers.

As Quantum computer are faster because of the quantum properties it will change the way of protecting the sensitive data or System that need to be protected. Quantum computer can break the most of the encryption's methods that are meant to provide security in less time (or quickly) as compare to classical computer(or Super Computer). Every technology is built they have two faces of implementations that might be for good purpose to enhance human's life or that technologies can misused by peoples.

The experts of quantum computer field they suggest to get ready to for the Quantum computer before it will used for commercially and build Strong encryption methods that called or named as the Post Quantum Cipher Suites. Post Quantum Cipher Suites contain multiple encryption security method to protect digital assets and its complex algorithm that even quantum computers cannot crack immediately. For instance, quantum advancements accelerate, proactive adaptation is essential to safeguarding digital assets (Cryptocurrency, Bonds and Shares) and maintaining the integrity of global cybersecurity infrastructure.

Keyword: Quantum Computer, Cybersecurity, Superposition, Encryption, Post Quantum Cyptography

Introduction

Quantum computing brings about a paradigm shift in computational power by enabling the solution of problems that were previous unlearnable by classical computers, and much more quickly. These computers are theoretically able to perform computations at a staggering pace, employing quantum mechanics principles concerning superposition and entanglement. That said, the development comes with a slew of challenges and can serve as a springboard especially in cybersecurity, where robust encryption of data is a necessity.

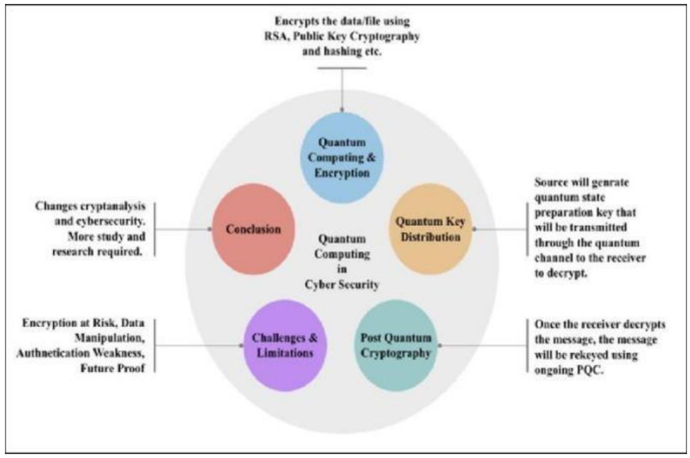
Presently, cybersecurity surviving stands on advanced encryption standards, the likes of RSA and ECC which most classical computers cannot crack. It offers digital security by securing much encryption of data. Yet, with quantum computers, all these encryption techniques could be broken and create an imminent threat to digital security.

Throughout the discussion, this article explores the impacts of quantum computing on cybersecurity, as well as the threats to digital security presented by it. For an unarguable reality of the impact, the area in which such threats would become actual serving as well as the development of encryption standards to resist them are also discussed. As quantum computing is still in its primitive development phase and cybersecurity threats keep on changing, the article is meant to help researchers, policymakers, and indeed the experts in cybersecurity both appreciate with and find ways for eliminating the perils surrounding quantum technology.

Quantum Computer : An Overview

Quantum computing is a new way of processing informaion, which is based on quantum mechanics. A quantum computer is an executive device that can work on information provided in increments of 1 or 2. Closed systems use qubits that can represent both 0 and 1 simultaneously, while equally binary qubits are used or can be temporarily entangled; if one qubit has a specific state, then so does the other qubit, no matter the distance apart. This is why quantum computers can compute so many calculations at the same time -- a great deal more than classical computers.

Quantum supremacy is when quantum computers could do certain calculations that are so overpowering that classical ones can hardly or inefficiently handle. The objective is not yet fully achieved; there were some milestones that have been crossed. In 2019, Google announced that quantum supremacy was achieved when it finished a task in 200 seconds that would otherwise take the world's most powerful supercomputer around 10,000 years.

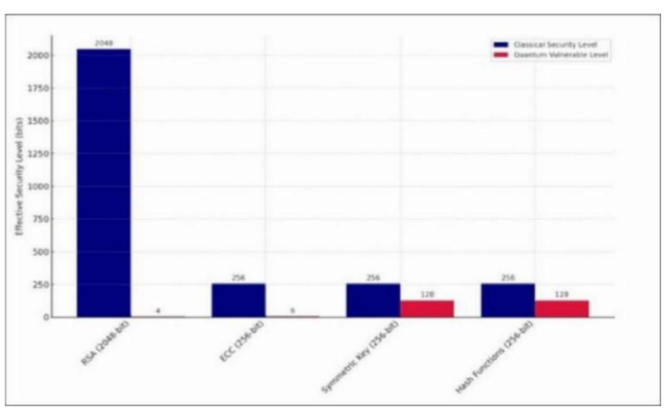


Quantum computing could have tremendous bearing on various fields like drug discovery, material science and system simulations. But the way it can break the current encryption schemes is a great threat to cybersecurity and work on new encryption schemes capable of resisting this cannot wait.

Current Cybersecurity Framework And Their Quantum Vulnerabilities

Modern cybersecurity depends largely upon cryptographic algorithms to shield Internet communications and data from unauthorized intruders. Two commonly used protocols are RSA and ECC. RSA stands for Rivest, Shamir, and Adleman, they are three inventors. This algorithm is based on the logic, as it is extremely hard to factor large numbers, and now most commonly uses digital signatures and encryption. Another approach, ECC, is one that employs the algebraic properties of elliptic curves. These systems are secure against classical computers due to the fact that it would require an enormous amount of computation to break them.

The emergence of quantum computing completely jeopardizes the current cryptographic system. A quantum computer can calculate numbers much faster than a classical one by exploiting principles from quantum mechanics. Hence, RSA and ECC are no longer secure by this new means of calculation. Shor's quantum algorithm, invented in 1994, renders both RSA and ECC useless for quantum situations by breaking them quickly.



Grover's algorithm, which is also a quantum-based one, accelerates unstructured search, conceivably reducing the effective key length of symmetric cryptographic systems by half, thereby softening the security of these systems. Although less harmful than Shor's algorithm, it nonetheless poses risks to the security of such systems. In light of this, the adoption of post-quantum cryptocurrencies by the National Institute of Standards and Technology (NIST) is taken upon as a relevant quest, bringing its development to a standard stage to be implemented to counter any quantum attacks.

This shift will be a great technical and strategic challenge. Existence systems must be changed, and new institutions will have to operate under a global standard that will be the determiner of integrity in digital security. This includes the vast involvement of research, development, and implementation to ensure a seamless conversion into a secure post-quantum era.

Quantum Computering ‘s Threat To Cybersecurity

Quantum computing is the powerful computational ability that many believe will be able to solve very difficult problems. However, the other concern is that it would be screaming from the rooftop with very alarming messages about breaking the encryption standards that safeguard the computer world. This chapter dissects the threats to cybersecurity that could be posed by the advent of quantum computing. It further presents some insight into possible vulnerabilities to cryptographic protocols in a quantum world.

Shor’S Algorithm And Cryptographic Vulnerability

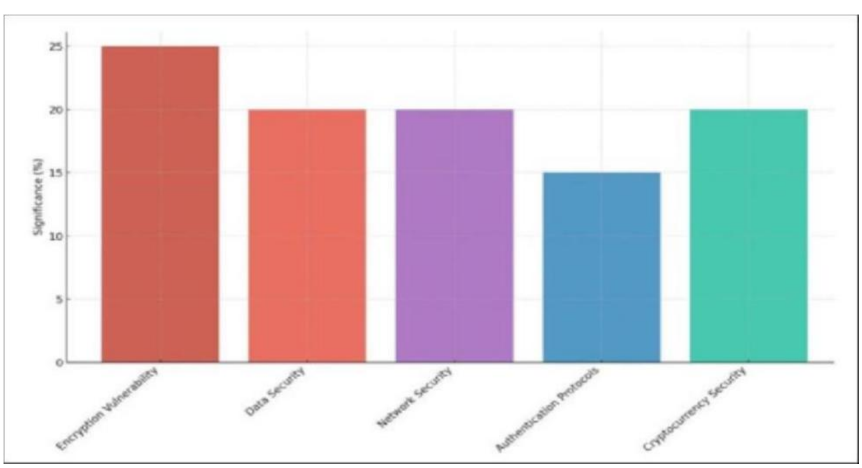
Shor's algorithm is central to the quantum threat to encryption. It can factor large numbers and compute discrete logarithms in polynomial time, which is impossible for classical computers with large enough numbers. This makes cryptographic protocols like RSA, ECC, and Diffie-Hellman, which secure most digital communication systems, vulnerable. Shor's algorithm could potentially break these systems, putting the confidentiality and integrity of digital data at risk.

Grover’S Algorithm And Symmetric Cryptography

Shor’s algorithm represents a more direct threat to systems such as asymmetric cryptography systems, whereas Grover's algorithm provides an indirect and also significant threat to symmetric systems such as block ciphers or hash functions. Grover’s algorithm is programmable to speed search rates, undermining the security of symmetric keys by half. In other words, symmetric key size would have to be doubled to retain the same security in the quantum era.

Quantum Computing And Data Privacy

Quantum computing is a threat to the current encryption-oriented system, as well as the possibility of a severe threat to data privacy in the coming years. Data encrypted now could be at risk should its cryptographic base be broken by a quantum computer. This implies that in case of a long-term retention, even data currently encrypted could face exposure from distant quantum threats. The latter is a serious cause for concern for sensitive data including government secrets or personal information.



Preparing For The Quantum Threat

The constantly growing quantum threat requires a proactive cybersecurity in order to transition to quantumsafe cryptographic algorithms to make sure that digital systems are safe in an age dominated by quantum technology, that is, to come up with new cryptographic methods, set standards, and update current digital infrastructures to conform to and effectively handle the new technologies.

Quantum-Resistant Cryptography

As quantum computing jeopardizes the security of current cryptographic systems, quantum-resistant cryptography is now the cybersecurity priority. Post-Quantum Cryptography (PQC) ensures safety in cryptography that can defeat the threats of quantum computing. This section presents status-based progress reports on quantum-resistant crypto with research, development, and standardization aimed at making sure that the digital communication infrastructure is not vulnerable to quantum attacks..

Post-Quantum Cryptography (Pqc)

Post-Quantum Cryptography (PQC) consists of cryptographic systems that can withstand quantum computing attacks. It was because of methods like Shor's and Grover's algorithms that were able to disrupt and undermine conventional cryptography. But that will be different for post-quantum schemes which rely on mathematical problems difficult for quantum computers to solve. Leading examples among PQC are lattice-based, hash based, multivariate polynomial-based, and code-based cryptography. Those cryptographic systems are designed to ensure confidentiality and secrecy in the quantum age.

Lattice-Based Cryptography

This technique is a young one and promising for PQC research. It is based on a mathematical structure called lattice and reaching toward the difficulty of lattice problems that are difficult for both classical and quantum computers. Among the several schemes, the Learning With Errors (LWE) problem has been gaining attention for its high security and ability to provide advanced features, like homomorphic encryption (FHE).

Strategic Approaches To Mitigating Quantum Threats

As quantum computing approaches, it's important to create strategies to address its cybersecurity risks. These include developing quantum-resistant cryptographic standards, encouraging global cooperation, and ensuring a smooth update of existing digital systems.

1. Enhancing Cybersecurity Policies And Frameworks

Preparation for the quantum era also involves updating cybersecurity strategies to include quantum-resistant instruments. It is important for the government and organizations to probe into their security performance and identify areas that necessitate improvement so as to handle risks posed by quantum computing. The settlements will include updating encryption standards, protecting critical infrastructure, and employing the use of quantum-safe protocol for digital communication.

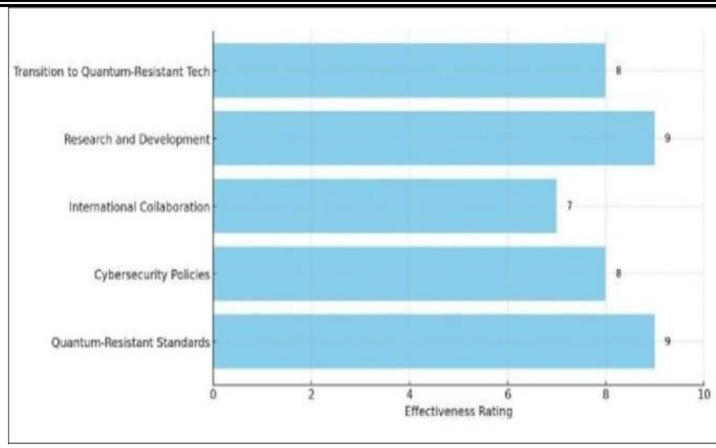
2. Promoting International Collaboration And Information Sharing

Tackling quantum threats requires global cooperation and sharing of information. By working together, countries can share research, best practices, and resources to develop quantum-resistant solutions faster. International partnerships and agreements can help coordinate responses to quantum risks, ensuring a unified approach to securing digital infrastructures worldwide.

3. Preparing For A Transition To Quantum-Resistant Technologies

The shift to quantum-resistant technologies will be a complicated process that requires careful planning.

Organizations should begin by assessing quantum risks to identify weaknesses and develop transition plans. This includes updating cryptographic systems, training staff on quantum-safe practices, and working with vendors and partners to ensure the supply chain is ready for the change to quantum-resistant standards.



- **Potential Uses Quantum-Resistant Encryption:** Developing and implementing encryption methods that are secure against quantum computing attacks, ensuring the protection of sensitive information in the quantum era.
- **Secure Communications:** Utilizing quantum key distribution (QKD) for secure communications, a method that uses the principles of quantum mechanics to create virtually unbreakable encryption keys.
- **Enhanced Authentication:** Quantum-based authentication uses the unique features of quantum entanglement to create stronger security for identity checks, making it much harder for anyone to fake or tamper with the process.
- **Quantum Key Distribution (QKD):** Quantum mechanics can be used to create super-secure communication channels that are almost impossible for anyone to listen in on, making data transmission much safer.
- **Enhanced Threat Detection:** Quantum computers can quickly analyze large amounts of data, helping to detect cyber threats and weaknesses much faster and more efficiently than traditional computers.

Conclusion

Quantum computing is a big change, especially in cybersecurity. It poses a threat to current security systems based on encryption. At the same time, it sparks innovation in creating new solutions for a post-quantum world. Key steps to address this include developing quantum-resistant security standards, improving cybersecurity frameworks, encouraging global cooperation, and boosting research. Ongoing research and discussions across fields, along with better education, will help us prepare for the future. As the quantum age approaches, it’s crucial for countries, industries, and experts to work together to protect our digital world, adapting to new challenges and vulnerabilities.

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LEAPFROGGING DIGITAL TRANSFORMATION FOR FINANCIAL INSTITUTES FOR A SUSTAINABLE FUTURE: CONFLUENCE OF 5G GENERATIVE AI AND FINTECH INNOVATION

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Abstract

Generative AI and 5G are now a reality in Financial Services Sector. This paper focuses on the levers of Generative AI (GenAI) that would give financial institutions the most value. Early, and more importantly right, adoption of GenAI and associated technologies like 5G will be key to gain and retain value. In this value unlocking from GenAI, there are multiple dimensions i.e. strategic road map, talent, operating model, use cases, technology, data, risk and controls, adoption and change management. This paper goes deep into selecting the right use cases for initial trial and future value adds, which gives long-term, governance driven, enterprise level roadmap. The GenAI use cases focus on sustainability through Environmental, Social, Governance (ESG), data-stewardship and privacy considerations.

Keywords: 5G, Banking, Financial Services, Fintech, Generative AI, Insurance, Sustainability.

Introduction

Innovation in Banking and Insurance will move faster with adoption of 5G and GenAI becoming mainstream. While presently industry leaders are talking of GenAI and 5G, they are looking for the right use cases which will give them value at scale. FinTechs are at the forefront of building a positive spiral of data – both real-time and historical and derive insights through AI and GenAI. The GenAI models, with right guardrails, are ingesting organisational data to give insights. They are becoming mature with 5G led alternate data, faster than ever before. Thus, multidimensional use cases are emerging, and progressive financial institutes are moving towards the same. However, financial institutes are trying to understand the aspects of governance, explainability, hallucination and cultural change that need to be brought in.

Objectives

The objective of this paper is to analyse the

1. Approach to be taken by financial institutes for adopting GenAI and 5G for getting optimal value
2. Sustainability considerations related to Environmental, Social, Governance (ESG), data-stewardship and privacy which leads to selection of right use cases

Principles And Guidelines For Genai Adoption

The approach to adopting GenAI and 5G would need to be incremental but disruptive. The financial institutes are still trying to identify the right use case and more importantly do not want to commit to large investment as this area is still evolving. However, financial institutes cannot go slow on adoption as otherwise they will get disrupted. Thus, they should create a long-term roadmap to disrupt the status quo but start with right use cases and then follow the incremental approach. The use cases can be for financial inclusion, operational efficiency, core capability enhancement, personalised customer engagement or information security enhancement.

Literature Review

Development of different language representation model like BERT (**B**i-directional **E**ncoder **R**epresentations from **T**ransformers) in 2019 and other models enabled pre-training deep bidirectional representations from unlabeled text by jointly conditioning on both left and right context in all layers. The trust and reliability of the models also paved move from AI to GenAI with significant approach towards pre-training on huge sets of data. [1], [2].

Explainable AI (XAI) played a key role in further helping researchers and users of GenAI understand discriminative models better, thereby paving its path towards usage in application and business domain. Using scenario-based design and question-driven XAI design approaches helped explainability of the AI model outputs, thereby users understand and relate to the GenAI outputs. [3], [4].

Considering evolution of AI and GenAI, the financial services businesses started adopting GenAI. The McKinsey Global Institute (MGI) estimates that across the banking sector, GenAI could add between $200 billion and $340 billion in value annually, or 2.8 to 4.7 percent of total industry revenues [5], largely through increased productivity. The right mix of strategic road map, talent, operating model, technology, data, risk and controls, adoption and change management plays a key role in the success. [6].

However, the use cases are equally or more important to select so that right adoption is taken into account.

Recommendations And Use Cases

The use cases a play very important roles in selecting, prioritizing and deriving business value. Based on guidelines and principles laid out, guardrails considered around ESG, privacy and data-stewardship, the following recommended use-cases would enable value added adoption cycle:

1) Financial inclusion at scale:

- Based on experience from other countries, 5G adoption is first driven by B2B use cases. While 5G is reducing data divide, GenAI is democratising capabilities in remote locations. Banks can roll out mobile branch, mobile ATMs with augmented capabilities. Earlier banks rolled out mobile branches but had very limited capabilities. 5G can enable complex services with teleporting a branch staff for complex transactions, assist customer for ATM/Kiosk operations, physical form filling. It can also enable multi-skilling of a staff with remote specialist. While 5G enabled devices would not be available with new to bank (NTB) customers but B2B2C model will enable financial institutes to increase geographical presence with 5G enabled remote operating model. Union Bank of Philippines has already rolled out banking kiosks on mobile van even at remote locations. Multi-lingual, device agnostic GenAI Bot is reaching remote locations with 5G.
- Bank and insurance companies would gain maximum once they adopt inclusion-based use cases. Inclusion typically comes with higher commercial and operating cost, however 5G will eliminate those risks while driving inclusion. Real-time alternate data streamed through 5G will help financial inclusion but with lower cost. Many construction workers go through tough working conditions leading to sudden deteriorating health conditions like falls and fainting. IoT data streams supported by GenAI Bot and Videos can help take preventive actions and/or provide quick response.

2) Improvement in Cost to income ratio (CIR) for Banks and lower Combined ratio (COR) for insurance companies:

- Banks and insurance companies have large firm loans and firm equipment loans. However, managing those portfolios lead to very high operating expenses. Use of drones, GenAI based video and image processing can be leveraged by Banks to reduce survey cost. Crop insurance can be better managed with drones and 5G is making it a reality. 5G has enabled better triangulation of different available data. IoT data from soil, drones can help farmers reduce waste, predict pest attacks, understand weather conditions, and thereby increase yields. GenAI Bots would suggest proactive actions to farmers, and this will help the Banks and insurance companies better manage risk.
- Marine and cross-border shipments are now taking longer due to geo-political tension and diversion of cargo ships away from Suez Canal. The freight is under higher risk and insurance companies can look at better usage of IoT data for better loss management. This can enable them to take preventive actions during long haul shipments and reduce claims ratio.

3) Enhancing core capabilities of financial institutes – better risk management:

- 5G can capture data from different IoT devices and drones which can enable better risk management for Banks. Banks can real-time monitor business loans by tracking inventory, agri loans through crop monitoring, warehouse monitoring & management. A proactive and early warning-based risk management would enable reducing NPAs in banks.
- Cash management poses a significant risk to banks especially w.r.t. operational risks. Centralized cash van tracking can be enabled through 5G and IoT leading to an early alert.
- Insurance companies can track shipment of perishables by monitoring temperature, ambient conditions and proactively engage in remedial actions with logistics service providers.
- Fraud prevention with inclusion of alternate data sources will get enabled by leveraging real-time data including GPS, geo-tagging, ATM usage, velocity of transactions, drone video capture, video analytics and other data and analytics capabilities.

4) Customer engagement getting more personalised:

- 5G enables ultra-low latency which can enable customer engagement at a different level. With availability of customer behavioural data, device data, location data etc. multiple on the spot innovative products can be offered once augmented with GenAI. With purchases of financial services moving from planned to automated and consent driven, financial institutes can make multiple micro-offers which are highly personalised and relevant for the customer. Dynamic insurance top ups, loan top ups based on travel location during a holiday, special rates for agri-loans based on usage of farm equipment, construction equipment preventive maintenance support by financial institutes in tie-up with original equipment manufacturers etc. are examples where 5G and GenAI would play together. This would make the customer engagement deeper. Sora from OpenAI can help create campaigns for micro-segments with videos so personalised that customers would get super engaged, personalised content to engage with.
- Customer consent for enabling innovative customer engagement is paramount. Customers are willing to provide consent, provided data is used for customer benefit and purpose is pre-established. The Data Protection and Data Privacy Act (DPDP Act 2023) in India, GDPR regulations in EU gives a right framework to support consent driven innovation. GenAI and 5G has fuelled innovative customer engagement further once done within the right framework.

There are many other use cases of GenAI and 5G, be it in human resource management, digital marketing, legal, procurement or finance, are horizontal use cases and is relevant for financial institutes as well.

Conclusion

The value of GenAI and 5G enabled use cases for financial institutes is not just internal but gives immense potential for external monetization. The GenAI models are attuned to general purposes today and lacks benefits of plethora of data that the large financial institutes have. The historical and ongoing availability of data with large financial institutes would make the models more accurate. The outputs of these models, which is trained with real historical data would make the large financial institutes take benefit and monetize the GenAI models. While we are at a primitive age of 'data as a service', the financial institutes would derive maximum value from these models. A smaller financial institute, who does not have sufficient data, may be coming to large financial institutes to gather insights.

In Summary, financial institutes are the adopters of GenAI and 5G at scale to generate tangible external and internal stakeholder value. A calibrated approach with potential to scale is necessary. The established players would benefit the most by augmenting core internal capabilities and monetizing the same.

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A REVIEW : E-COMMERCE AND ENVIRONMENTAL IMPACT: OPPORTUNITIES FOR SUSTAINABILITY

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Abstract

Sustainability is the most important environmental topic of today's time. Now consumers are having high demand for eco friendly product that ensures sustainable e-commerce. The frequent connection shipping, high rate of interest and non-recyclable packaging are causes of negative impact on e-commerce. Because of that e-commerce business are having a great challenges. It also true that e-commerce is rapidly growing and widely accepted by people. However, the challenges are how to maintain growth of e-commerce in the market for long run considering the environmental impact. According to the survey, two out of three customers found convince online shopping by adopting sustainability policies. Only one out off four customers has decided to deny firms that do not follow sustainability practices. Sustainable e-commerce are very crucial and its findings indicate that most European countries have adopted e-commerce sustainability policies while few countries are still on process to adopt.

Introduction

Digitalization has had a major impact on domestic and international commerce. Boosted by the COVID-19 pandemic, more people and businesses are going online to look for the goods and services they wish to purchase.

"E-commerce "refers to all transactions in which goods or services are ordered over a computer network. Any economic entity, whether a business, household, government unit or non-profit institution, can engage in e-commerce as a buyer or seller.

Ecommerce transactions often cross international borders, with the seller being in a different economic territory from the buyer. Business-to-business (B2B)

E-commerce plays an important role in global value chains and often involves electronic data interchange and online versions of traditional transactions for goods, which are then sold to consumers through retail outlets. B2C e-commerce involve "pure play" e-commerce enterprises that only sell through their single online presence (such as Alibaba or eBay) to consumers, as well as sales by traditional bricks-and-mortar firms that operate through an additional online sales channel. Consumer-to-consumer (C2C)

The shift to e-commerce brings both opportunities and challenges. It can transform economic processes, trade and consumption patterns and open up new trade and business opportunities for entrepreneurs and small businesses that would otherwise have a limited geographic footprint. E-commerce can improve export opportunities and offer better access to suppliers abroad. Consumers also stand to benefit from access to greater choice, convenience and lower prices. At the same time, various factors – including obstacles relating to ICT infrastructure and services, trade logistics, payment solutions and legal frameworks – pose critical challenges to engaging in and benefiting from e-commerce, especially in low-income countries ,

the growth of international e-commerce may expose local firms to increased import competition and there by impact on employment and growth prospects.

E-commerce has potential implications for environmental sustainability that are both positive and negative. For example, under certain conditions, buying a product online can be more energy efficient than driving to a physical store to purchase the same product and can lead to reduced GHG emissions.

1. Literature review

1.1. Why is sustainable e-commerce important?

Why is it important to care about the environment by using compostable, recyclable, and reusable packaging materials? Statistics show that due to the growth of e-commerce a third of the world is filled with garbage. A recent study shows that the high growth of e-commerce globally has led to unprecedented environmental impacts. One of study stated that more than 3 billion tons of waste end up in landfills every year. Most come from packaging materials which are plastics, nylons, and cardboard boxes that result on land, water, or air pollution. Steps and action need to be taken to address packaging materials in e-commerce platforms so that retailers offer sustainable packaging materials.

Therefore, there is a need for collaboration between the producers and retailers in ecommerce platforms, to source their packaging materials from suppliers who comply with sustainability statements, values, and missions. Manufactures must produce packaging materials that are in align to the 3Rs: recycle, reduce, and reuse. Recent research has shown that companies and retailers who are ecologically friendly have secured a larger market share of consumers who are already paying a higher price for sustainable products.

1.2. Right policies in place guarantee sustainable e-commerce

It is of great importance that retailers have policies stipulating sustainability or sustainable e-commerce in their mission, vision, and core objectives. Similarly, should let all stakeholders know that will partner with suppliers, manufacturers, and logistic supply providers who are compliant with green standards and sustainability. Retailers who ensure this will be opening their doors to customers who are keen on supporting sustainable e-commerce. There will be large market share for retailers who offer more durable and high-quality and eco-friendly products. According to this research consumers value much more online stores that are aligned to sustainability policies in the conduct of their businesses. Similar study by Wang argues that e-commerce platforms that offer customers with products that are eco friendly to their health are the most embraced enterprises. Therefore, customers become loyal to such brands. In return retailers who care about the wellbeing and economic value of their customers stay in the business in long term.

1.3. What do consumers pay attention to while shopping online?

This study discusses various ways that e-commerce can become more sustainable. Most customers demand for eco-friendly products on environmental impacts. Poor products that do not meet the standards shortens lives, compromises future generations and impacts people negatively both socially and health-wise. In addition, there is a great concern about the high levels of shipments of products from different parts of the world to various destinations through e-commerce platforms. Customer would like to buy food from the e-commerce firms with sustainability trademarks and have a good reputation due to concern of their healthy. This means huge emissions of carbon dioxide which pollute the environment daily, that cause climate change and contribute to respiratory pollution from smog and air pollution

1.4 Making e-commerce more environmentally sustainable

Reducing the impact of warehouses and distribution centre

There are multiple ways to reduce the environmental footprint of warehouses and distribution centers. One approach is to use renewable energy sources, such as solar photovoltaic panels, to power operations. Several e-commerce companies are already taking action. The redesign of warehouses from large, traditional centers to micro hubs or micro fulfillment centres that link suburban warehouses to final delivery points present additional opportunities for reducing energy consumption and transportation use. At the same time, this can also create in efficiencies that include generating more aggregate energy consumption across multiple sites and higher overall inventory levels. Integrating e-commerce warehouses into dense, mixed-use urban other development challenges ,including adverse health and environmental effects on the local population

By adopting sustainable practices and optimizing logistics, e-commerce warehouses can bring down their carbon footprint and help to protect the environment.

1.5 Minimizing the impact of product packaging and waste

E-commerce packages have been found to use up to seven types of packaging materials, including envelopes, cardboard boxes, plastic bags, woven bags, tape and buffer materials such as bubble wrap. In particular, single-use packaging materials such as card board boxes, plastic air pillows and bubble wrap are often not recycled, leading to an increase in packaging waste and environmental pollution. E-commerce reportedly used approximately 950 million tons of plastic packaging globally in 2019

Amazon India has taken steps to achieve complete elimination of single- use plastic, including by replacing plastic packaging material, such as bubble wraps and air pillows with “paper cushion”. The company has also introduced 100 per cent plastic- free and biodegradable paper tape, which is used to seal and secure customer shipments (Amazon,2020).

Unilever’s Easy Green e-commerce sustainability partnership with Lazada aims to reduce the use of plastic packaging materials in delivery parcels. It entails using carton boxes and recycled shredded paper instead of plastic fillers (Unilever,2022). These alternative packaging solutions are provided as “eco” (plastic-reduced) and “zero” (plastic-free options)

Conclusion

Sustainable e-commerce is the backbone of the sustainability and growth of online businesses . Therefore, to retailers and customers of e-commerce cannot separate sustainable e-commerce from environmental sustainability. If online stores support policies that govern sustainable commerce, then without no doubt online business will flourish, presenting a greater opportunity for business growth. It is absolutely that everyone desires a sustainable life that will be enjoyed if the three dimensions of sustainability are practiced. However, retailers and consumers must focus their minds on sustainable business solutions. only retailers who adopt technology-driven and sustainable solutions and are courageous enough to be responsible to lead the way in sustainable businesses will ultimately make profits in the long term. Most of the sustainable e-commerce solutions for retailers lie in businesses’ ability to make profits and have a long-term impact on their customers on eco-friendly environment. By using recyclable packaging materials, prioritizing sustainable e-commerce hilanthropy, and environmentally friendly business practices. Such as practicing green technology in production and distribution, charity donations, and support for projects to reach needy communities in areas of sustainability. For example, telling customers that if they buy a pair of sustainable shoes, they will protect environment for long life and contribute $1 to donations that support children without shoes, and thus increase social interactions in society.

A green environment and eco-friendly products are the desire of every consumer. there is a high demand for healthy and less harmful products among consumers. Research shows that sustainable e-commerce can be the solution to the environmental issues suffocating the world, ranging from pollution and climate change through green policy initiatives that are implemented to see sustainability become a priority. Designing eco-friendly and durable products, and packaging them in the right size of the right material, which is recyclable, reusable, and decompose is an attempt to achieve e-commerce sustainability.

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ENHANCING PHOTODEGRADATION OF ORGANIC DYES THROUGH VISIBLE LIGHT DRIVEN PHOTOCATALYTIC ACTIVITY OF ZNFE$_2$O$_4$ NANOPARTICLE

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Abstract:

The increasing environmental concerns associated with the discharge of toxic organic dyes from industrial processes have prompted the need for effective and sustainable methods of wastewater treatment. Zinc ferrites nanoparticles ($ZnFe_2O_4$) were synthesised by green methods using temple waste flower i.e. *Tagetes erecta* flower (yellow Marigold) extract. Zinc ferrites nanoparticles ($ZnFe_2O_4$NPs) as a photocatalyst use for the use of light energy to break down contaminants. The physio chemical properties of synthesized $ZnFe_2O_4$ NPs were characterized using UV-visible spectroscopy, fourier transform infrared spectroscopy (FTIR), Scanning Electron Microscopy (FEG-SEM) and X-ray diffraction (XRD) techniques. The photocatalytic activity of the $ZnFe_2O_4$NPs compound was examined to assess its effectiveness in degrading the methylene blue dyes under visible light irradiation. SEM analysis confirmed the presence of a spherical and porous agglomerate morphology. The infrared spectra showed absorption bands between 450 and 550 cm^{-1}, indicating the presence of the ferrite phase. The optimal temperature for synthesizing the $ZnFe_2O_4$ NPs to enhance the photocatalytic degradation performance of the methylene bule dyes was found to be 600 °C. This temperature showed a more significant effect for the methylene blue dye, in comparison to the $ZnFe_2O_4$ NPs synthesized at other temperatures, due to the formation of secondary phases and smaller crystal sizes.

Keywords: Organic Dyes, waste water, Tagetes erecta, and crystal sizes

Introduction:

The increasing environmental concerns associated with the discharge of toxic organic dyes from industrial processes have prompted the need for effective and sustainable methods of wastewater treatment.[1] Toxic organic dyes which use in textile or industries for dying process, can have detrimental effects on both aquatic ecosystems and human health. In aquatic environments, they can decrease the penetration of sunlight in water, which harms the ecosystem [2], [3]. In humans, harmful substances like heavy metals and aromatic compounds present in these dyes can cause genetic mutations, cancer, and damage to various organs, including the kidneys, liver, brain, and reproductive and central nervous systems. Photodegradation, a promising technique for the removal of these dyes, involves the use of light energy to break down contaminants[4]. Metal nanoparticles, due to their unique physical and chemical properties, have emerged as highly efficient photocatalysts for enhancing the photodegradation process[5]. Various treatment methods have been employed to remove toxic organic dyes from wastewater. These techniques aim to eliminate the dyes and minimize their harmful effects on the environment. Common methods include: Adsorption[6], Advanced Oxidation Processes (AOPs), Biodegradation, Coagulation and Flocculation and Membrane Filtration. A key drawback of these methods is that they primarily result in physical changes to the dyes. As a result, the dye's structure may be altered, leading to the creation of secondary waste that requires additional treatment using other techniques. The present study explores the role of $ZnFe_2O_4$ nanoparticles, in promoting the degradation of organic dyes under visible and ultraviolet light irradiation. The mechanism of photodegradation, which involves the generation of reactive oxygen species (ROS) such as hydroxyl radicals and superoxide anions, is discussed in detail[7]. Factors influencing the efficiency of nanoparticle-based photocatalysis, including surface area, crystallinity, doping, and morphology, are critically examined[8]. Additionally, the potential for improving the stability and recyclability of these photocatalysts for real-world applications in wastewater treatment is evaluated. Some investigations used different photocatalysts based on Fe2O3 as photocatalysts have been published with other metal like ZnO [9][10], [11], TiO_2 [12], $Fe_2V_4O_{13}$[13], Ti_3C_2/TiO_2 [14], TiO_2 @MoS[15] etc used for the degradation of various pollutants. Zinc ferrite nanoparticles are considered highly promising photocatalysts because of their remarkable physiochemical properties, efficient charge carrier separation, and strong ability to degrade contaminants under visible light**.** The photocatalytic performance of zinc ferrite can be affected by various factors, including the synthesis method, temperature, particle size, morphology, dielectric properties, and the presence of impurities. Therefore, the synthesis method plays a crucial role in determining the material's properties, its particle size and its photocatalytic performance. Biosynthesis using flower extract and metal salt reactions in solution is a straightforward process that is time-efficient and energy-saving. This method, ideal for nanoparticle preparation, offers better control over the homogeneity and composition of the products compared to other techniques which produces nanometric and crystalline materials[16], [17] Although numerous studies on photocatalytic investigations have been published, this work focuses on synthesizing $ZnFe_2O_4$ nanoparticles via the bio-reduction method using *Tagetes erecta* flower (yellow Marigold) extract in solution. After reducing the metal salt *Tagetes erecta* flower (yellow Marigold) extract, the samples were heat-treated at temperatures ranging from 400°C to 600°C, with a lower ignition temperature of 400°C. The aim was to assess the photocatalytic degradation of methylene blue dyes, commonly used in the textile industry. A detailed discussion of the obtained results is provided below.

Material and Methods:

The reagent Zinc nitrate hexahydrate [$Zn(NO_3)_2 6\ H_2O$], Ferric nitrate Nona-hydrate [$Fe\ (NO_3)_3 9H_2O$], Methylene blue dyes of analytical grade are directly used for synthesis without further purification. Waste *Indian Tagetes erecta* flower (Marigold yellow) were collected from the local nearby temples.

Synthesis of $ZnFe_2O_4$

Yellow marigold flowers were gathered, dried in an oven at 100°C for 48 hours, and then powdered. Appx. 5.0 g sample of the powder was mixed with 100 ml of distilled water and heated on a hot heating plate to boil at 200°C for 1 hour. After boiling, the flower extract was obtained. The extract was then cooled and filtered using filter paper. The resulting extract was referred to as the *Tagetes erecta flower* (Marigold yellow) aqueous extract.

$Zn(NO_3)_2 6\ H_2O$ (1.00 g) and $Fe\ (NO_3)_3 9H_2O$ (1.00 g) were taken in a 1:1 ratio and dissolved separately in 10 ml of distilled water. The two solutions were then combined in a beaker, and 100 ml of plant extract was added. The mixture was stirred continuously for 5 hours at 60°C. the above solution is then reduced to1/3 by heating at 100°C. The resulting solution were calcined at 400-600°C for 4 hours in a muffle furnace. The obtained $ZnFe_2O_4$ powder was characterized, and its photocatalytic activity was analysed.

Characterization:

The physical characterization of the synthesized nanoparticles was examined using UV–visible double beam Spectroscopy , X-ray diffraction (XRD) [BRUKER D2 Phaser], fourier transform infrared spectroscopy (FTIR), Scanning Electron Microscopy (FEG-SEM).

Photocatalytic Activity:

The photodegradation using $ZnFe_2O_4$ nanoparticles, synthesized through green methods, was evaluated under visible light irradiation evaluate against Methylene Blue (MB) dye. The photodegradation process took place in a photoreactor. A 50 mg sample of the $ZnFe_2O_4$ nanoparticles as photocatalyst was added to a quartz beaker containing 5 ppm of MB dye in 250 mL of aqueous solution. To achieve adsorption/desorption equilibrium, the reaction mixture was kept in the dark for 10 minutes. Afterward, the mixture was exposed to 300 W tungsten visible light at room temperature. Samples were taken at 10-minute intervals initially, and its absorption are measured to determine the degradation percentage of the dye. The residual dye concentration was measured by examining the absorbance at 670 nm. The photodegradation was calculated using the following formula [18], [19]:

Percentage of degradation $= \frac{(Co - Ct) \times 100}{Co}$

Where Co is the initial absorbance of the 5 ppm of MB dye solution, and C_t is the absorbance of the dye solution after time *t* in minutes.

Results and Discussion:

UV-Visible analysis

Figure 1 displays the UV-Visible spectrum of $ZnFe_2O_4$ nanoparticles synthesized from *Tagetes erecta flower* (Marigold yellow) extract, measured in the wavelength range of 350–450 nm. The spectrum reveals a broad absorption band cantered around 405 nm, which can be attributed to the π-π* transition within the conjugated system of the molecules. The optical band gap of the prepared samples was determined using diffused reflectance spectra obtained from a UV-Visible spectrophotometer and is shown in the figure 2. The incorporation of $ZnFe_2O_4$ nanoparticles conveys important development in the optical response of the compound. The significant decrease in the optical band gap $ZnFe_2O_4$ nanoparticles (i.e., 2.95 eV) makes it a more responsive photocatalyst, which supports the generation of electron-hole pair and resultantly the advanced hydroxyl radicals

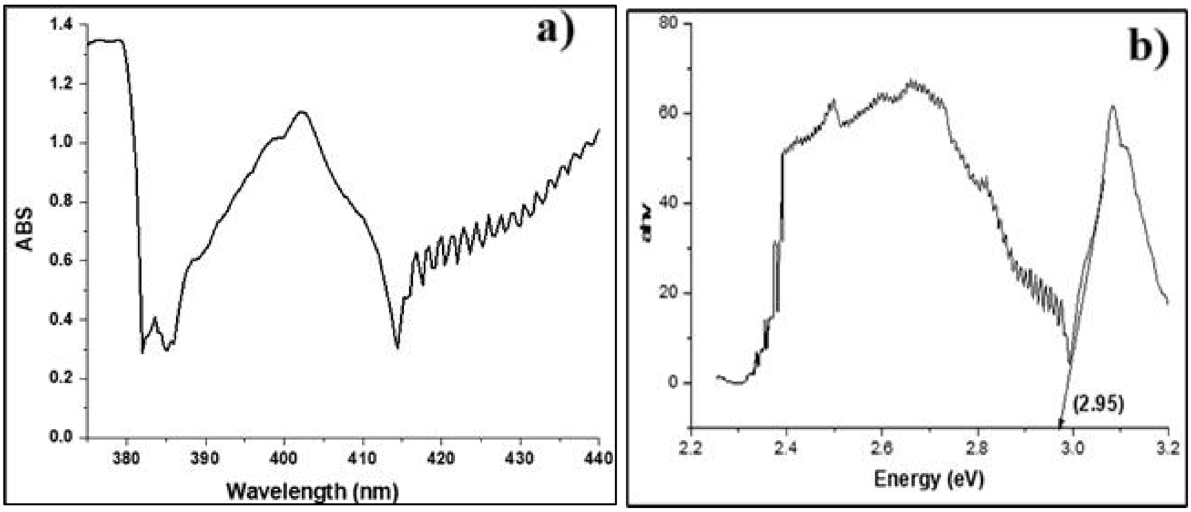

Fig. 1(a) UV-Visible spectrum and (b)Band gap of $ZnFe_2O_4$ NPs synthesized from *Tagetes erecta flower*

FTIR Analysis:

FTIR spectrum of of $ZnFe_2O_4$ nanoparticles and *Tagetes erecta flower* (Marigold yellow) extract is shown in figure 2.

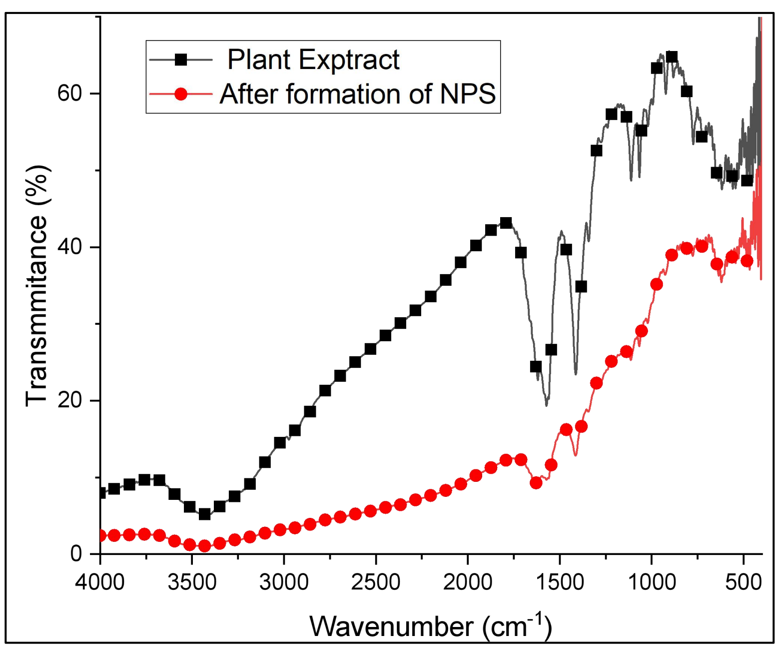

Fig. 2 FTIR spectrum of *Tagetes erecta flower* (Marigold yellow) extract and $ZnFe_2O_4$ nanoparticles

The FTIR spectrum was recorded in the range from 4000–400 cm^{-1}. Peaks below 1000 cm^{-1} was assigned to metal-oxygen complex. The tetrahedral and octahedral vibrational bands of $ZnFe_2O_4$ nanoparticles were noted in between 400–600 cm^{-1}. $ZnFe_2O_4$ nanoparticles, *Tagetes erecta flower* (Marigold yellow) extract shows the peaks at 3423 cm^{-1}, 2848 cm^{-1}, 1574 cm^{-1}, 1411 cm^{-1}, 1109 cm^{-1}, 1066 cm^{-1}, 922 cm^{-1}, 770cm^{-1}, 616 cm^{-1}. These detected peaks could be due to the various functional groups present in the extract. The broad peak at 3423 cm^{-1} was allocated to –OH hydroxyl group. The small peak at 1574 cm^{-1} was identified as –C=C– group due to the flavonoids and amino acids. The wide peak at 1411 cm^{-1} could be related to the methylene group. The peak at 1066 cm^{-1} was due to C–O–C group. –OH, – C=C–, C–O–C functional groups were presented in plant materials used for synthesis of $ZnFe_2O_4$nanoparticles. The above peak intensity was decreases that prove the reduction of metal salt and formation of nanoparticles as shown in figure 2.

X-ray diffraction (XRD) Analysis:

The crystalline structures and phase transformations resulting from thermal treatments were identified using the X-ray diffraction technique. The analysis of the results was performed by comparing the JCPDS crystallographic patterns. The optimization of the samples treated at 400, 500, and 600^0C by using the XRD data. This aimed to verify the percentage of the phases and crystallite size.

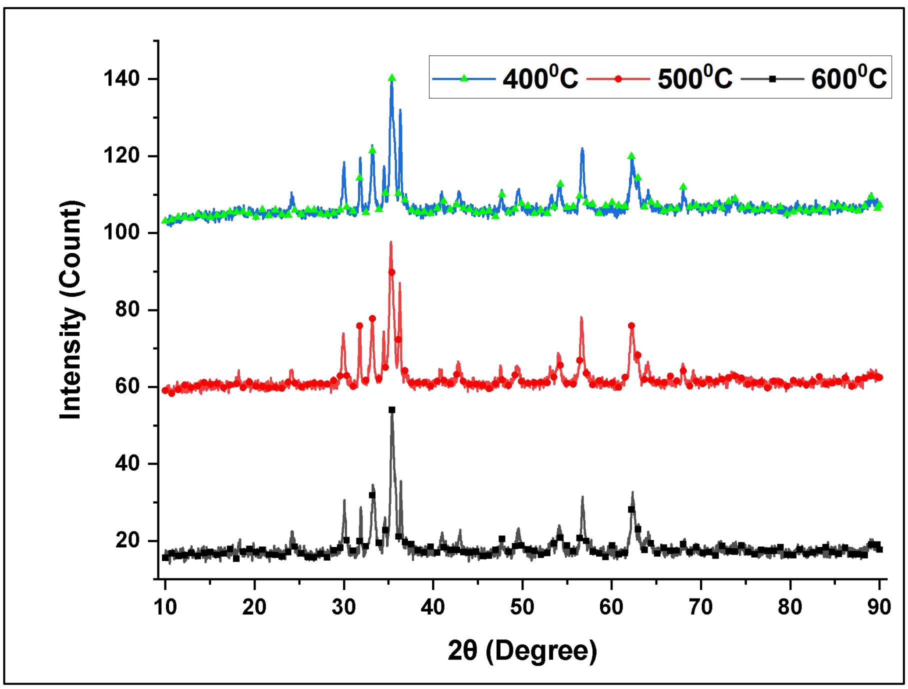

Fig 3. $ZnFe_2O_4$ nanoparticles synthesized at 400, 500, and 600^0C

The crystal size of the $ZnFe_2O_4$ samples was calculated using the Scherrer equation as follow:

$$D = \frac{0.9\lambda\lambda}{\beta Cos\,\theta}$$

Here, D is the average diameter of the crystallites (nm), which is assumed in a spherical shape, l is the wavelength of the electromagnetic radiation (nm), b is the width at half height (FWHM) of the most intense peak of diffraction in radians and q is the diffraction Bragg angle given in degrees.

The XRD patterns of the zinc ferrite samples heat-treated at different temperatures are shown in Fig. 3 All results show the presence of the $ZnFe_2O_4$ phase with a cubic structure.

The XRD pattern of the sample showed prominent diffraction peaks at 2θ values of 30.1°, 31.92°, 35.52°, 37.29°, 56.68°, 63.26°, 65.05°, 69.02°, corresponding to the (220), (311), (222), (400), (422), (511), (440), (620), and (533) respectively crystallographic planes of the cubic phase of the material. The relative intensities of the peaks indicated a high degree of crystallinity, while the broad peak widths suggested the presence of small crystallites with a mean size of approximately 20 nm.

SEM Analysis:

SEM Analysis is a technique used to examine the surface structure and composition of materials at very high magnifications of the sample and can be used to observe the surface features such as topology, morphology, size distribution and chemical composition. Figure 4 show the SEM image of synthesised $ZnFe_2O_4$ nanoparticles. The analysis revealed nanoparticles of regular size some signs of agglomeration. The nanoparticle was varied from 60 to 80 nm.

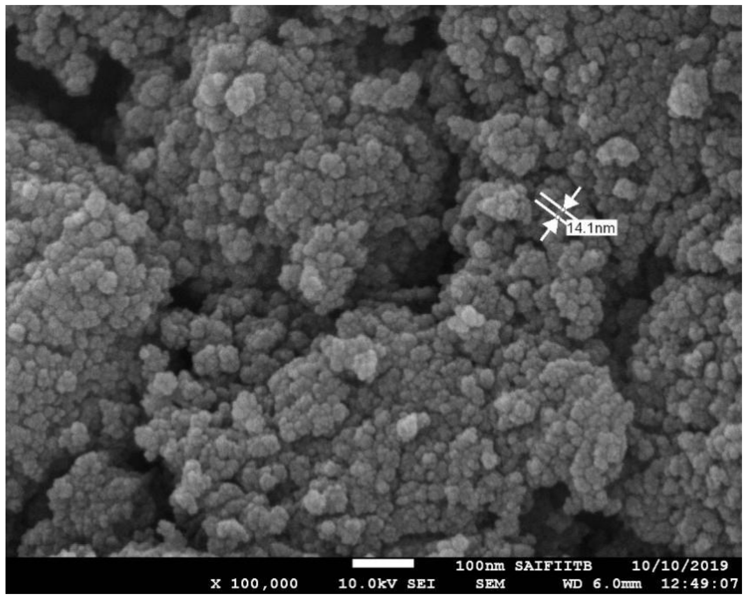

Fig 4. SEM image of $ZnFe_2O_4$ Nanoparticles

Photocatalytic study:

The photocatalytic efficiency of $ZnFe_2O_4$ nanoparticles was evaluated by examining the specific decolorization of Methylene Blue (MB) into inorganic species under visible light, using it as a model reaction. This choice was based on the fact that MB's absorption peaks fall within the visible region, allowing its decolorization to be easily tracked through UV-Visible spectrophotometry by measuring the reduction in absorbance at λmax (670 nm), along with a less defined peak at 670 nm. The photocatalytic degradation of MB is significant due to its toxicity as a pollutant. Figure 5 presents time-dependent UV-Visible spectra of MB decolorization, which show the reaction completion within 75 minutes. Additionally, the spectra were not notably affected by the surface Plasmon resonance peak because a minimal amount of catalyst was used. The factors influencing the photocatalysis of MB, the possible degradation mechanism, and the reuse of $ZnFe_2O_4$ nanoparticles are also discussed. The complete disappearance of the blue color confirms the reaction's completion. The photocatalytic decolorization of MB using $ZnFe_2O_4$ nanoparticles demonstrates excellent degradation efficiency, as the presence of the photocatalyst helps the reaction overcome the activation energy barrier. Figure 5 shows the degradation of Methylene Blue dye over time. Under visible light, MB was degraded by up to 80% after 60 minutes using $ZnFe_2O_4$ nanoparticles as the catalyst. The relatively small quantity (0.5 g) of $ZnFe_2O_4$ nanoparticles and the shorter reaction time contributed to increased degradation efficiency. Moreover, the $ZnFe_2O_4$ nanoparticles can be filtered and reused in subsequent degradation processes.

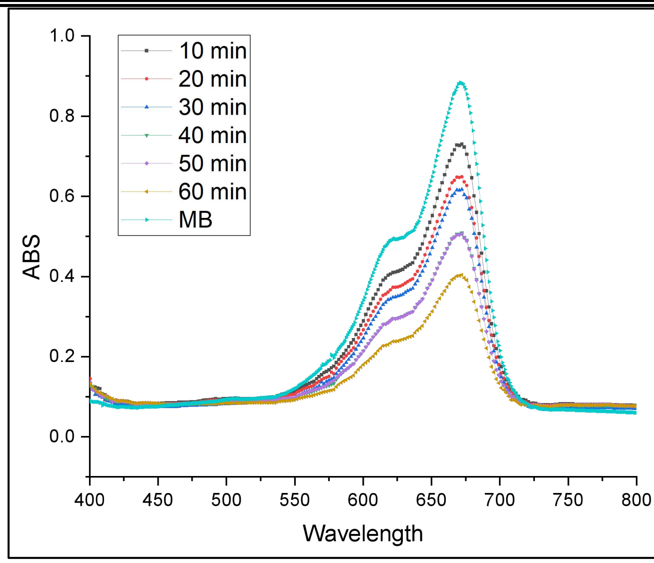

Fig 5. Photocatalytic degradation of MB in presence of $ZnFe_2O_4$ nanoparticles

Conclusion:

In this study, we synthesized zinc ferrite nanoparticles due to their excellent photocatalytic activity. The $ZnFe_2O_4$ nanoparticles were synthesized using a green method, utilizing the plant source Tagetes erecta flower (Marigold yellow) and calcination at 600°C. XRD analysis revealed the particle size to be 20 nm. The synthesized $ZnFe_2O_4$ nanoparticles exhibited a size distribution ranging from 60 to 80 nm. These nanoparticles were found to be non-toxic and environmentally friendly. The prepared $ZnFe_2O_4$ nanoparticles demonstrated significant photocatalytic activity for the degradation of Methylene Blue dye. Under visible light, MB was degraded by up to 80% within 60 minutes using the synthesized $ZnFe_2O_4$ nanoparticles as the photocatalyst.

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FACTORS INFLUENCING STATE-WISE SDG COMPOSITE INDEX OF INDIA: A COMPREHENSIVE STUDY

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Abstract

The SDG Index introduced in 2015 by United Nations are used for the purpose as an indicator for countries status various purpose including investments in Sustainable development industries, tourism etc. Further the countries index depends on state wise (regional) composite index which also helps the investor to guide in which state it can do sustainable investment. This study explores the relationship between key socio-economic factors of India and its State-wise Sustainable Development Goals (SDG) Composite Index, using data for the year 2023-24. The objective is to understand how land area, population, Gross State Domestic Product (GSDP), and per capita income influence the SDG performance across Indian states. This study is done on basis of maximum accurate statistical data available of 21 states out of 28 states and 8 Union territories of India. It has employed the Karl Pearson and Spearman's Rank correlation coefficient to assess the strength and direction of the relationship between these variables and the SDG composite index.

The XY scatter plot further supports these observations, highlighting the contrasting effects of economic and demographic factors on the achievement of SDGs. underscores the complex interaction between economic growth, demographic pressures, and sustainable development, offering valuable insights for policymakers to tailor strategies that address state-specific challenges in achieving the SDGs.

The findings reveal intriguing insights into the dynamics of state-level SDG performance. Land area**,** population**,** and per capita income exhibit a negative correlation with the SDG Composite Index, suggesting that larger states and higher populations might struggle with achieving sustainable development goals, potentially due to resource strain and socio-economic disparities. In contrast, GSDP shows a positive correlation, indicating that economically prosperous states tend to perform better on the SDG index, possibly due to their ability to invest in infrastructure, education, and healthcare.

Keywords: SDG Composite Index, Correlation, GSDP, Per Capita Income, Population, Land Area, India State wise Composite Index. State wise, Sustainable Development.

Acronyms:

UN	United nations
SDG	Sustainable Developmental Goals
UNDESA	United Nations Department of Economic and Social Affairs
UNSD	United Nations Statistics Division
IAEG	Inter-agency and Expert Group
UNSC	United Nations Statistical Commission
GSDR	Global Sustainable Development Report
GDP	Gross Domestic Product.
GSDP	Gross State Domestic Product
SDG	Sustainable Developmental Goals
SDG CI	Sustainable Composited Goal Composite State wise Index

Introduction

The UN Department of Economic and Social Affairs. Timeline for development of Sustainable Developmental Goals (SDG). 9

Table 1: Time line of Sustainable Developmental Goals

Sr. No.	Month/Year	Place	Agenda
1	June 1992	Earth Summit in Rio de Janeiro, Brazil,	Agenda 21, a comprehensive plan of action 175 countries participated. 12
2	September 2000	Millennium Summit in at UN Headquarters in New York	to reduce extreme poverty by 2015. elaboration of eight Millennium Development Goals (MDGs)
3	2002	Johannesburg South Africa	Declaration and the Plan of Implementation by including more emphasis on multilateral partnerships. . 6
4	June 2012,	Rio de Janeiro, Brazil	"The Future We Want" in which they decided, inter alia, to launch a process to develop a set of SDGs to build upon the MDGs and to establish the UN High-level Political Forum on Sustainable Development. 7
5	2013	United Nations Headquarters in New York	General Assembly set up a 30-member Open Working Group to develop a proposal on the SDGs. . 8
6	January 2015	United Nations Headquarters in New York	A landmark year for multilateralism and international policy shaping 9
7	March, July, September & December 2015	United Nations Headquarters in New York and in Paris.	Sendai Framework for Disaster Risk reduction, Addis Ababa Action Agenda on Financing for Development, Transforming our world: the 2030 Agenda for Sustainable Development, UN Sustainable Development Summit, Paris Agreement on Climate Change with 17 SDGs at its core, at the UN Sustainable Development Summit. 12

The 17 Goals adopted by UN sustainable goals are as follows:

Table 2 : 17 Goals of SDG

SDG 1	No poverty.	SDG 9	Industry innovation and infrastructure.
SDG 2	Zero hunger.	SDG 10	Reduced inequalities.
SDG 3	Good health and wellbeing.	SDG 11	Sustainable cities and communities.
SDG 4	Quality education.	SDG 12	Responsible consumption and production.
SDG 5	Gender equality.	SDG 13	Climate action.
SDG 6	Clean water and sanitation.	SDG 14	Life below water.
SDG 7	Affordable and clean energy.	SDG 15	Life on land.
SDG 8	Decent work and economic growth.	SDG 16	Peace justice and strong institutions.
		SDG 17	Partnerships for the goals.

Sources: 12

The above SDG are given point maximum 100 based on Quantitative factors and combining each SDG a combined Composite indicator is calculated for each state.

Literature Review

The Sustainable Development Goals (SDGs) are a universal call to action to end poverty, protect the planet, and ensure that all people enjoy peace and prosperity by 2030 12. The SDG Index is a composite measure that tracks the performance of countries and regions in achieving these goals (Bissio, 2019). Several studies have explored the factors influencing the SDG Index, including population, land measurement, Gross State Domestic Product (GSDP), and per capita income.

1. **Population and SDG Performance:** Population size can significantly impact a state's SDG performance. Larger populations may strain resources and infrastructure, making it challenging to achieve sustainable development goals 13 . Conversely, smaller populations might have better resource management but face challenges in economic growth. 13

2. **Land Measurement and SDG Performance:** Land measurement is crucial for sustainable development as it determines the availability of resources and the potential for development projects. States with larger land areas may have more resources but also face greater challenges in managing these resources sustainably.

3. **GSDP and SDG Performance:** GSDP is a primary indicator of economic health and productivity. States with higher GSDP are generally better positioned to invest in sustainable development initiatives4. However, economic growth must be balanced with environmental and social considerations to achieve the SDGs

4. **Per Capita Income and SDG Performance:** Per capita income reflects the standard of living and economic stability of a state. Higher per capita income often correlates with better access to education, healthcare, and other essential services, contributing to SDG achievement.

Table 3 : Summarised form Indicators on SDG Composite Index.

Sr.No.	Factors	Indicators
1.	State wise SDG Composite State Index	Determines the availability of resources and the potential for development.
2.	Gross State Domestic Product (GSDP)	Economic health and productivity, reflecting a state's capacity.
3.	State wise Population,	Opportunities and challenges, influencing the demand for resources.
4.	State Wise Per capita income	Indicates of the standard of living and economic stability.
5.	State wise Land Area	1. Size determines the availability of resources. 2. Larger states often face significant challenges related to infrastructure, resource management, and governance

Materials and Methodology

This study and analysis are based on Secondary data the sources are as follows:

Table 4: Type of Secondary data and Sources

Sr.No.	Type of Secondary data	Source
1.	Composite State wise Data	Niti Aayog Report 2023-24 1

2.	Population Data	Wikipedia Population State wise Data of India 14
3	Land measurement	Government of Bihar 4
4.	Per capital Income	Ministry of Statistics Programme and Implementation. 5

To assess the correlation between the SDG Composite Index and factors, three statistical tests were employed:

1. Karl Pearson's Correlation Coefficient,
2. Spearman's Rank Correlation Coefficient with repeated ranks, and
3. Graphical Method analysis using XY scatter diagrams.

Assumptions:

1) **Population Data Accuracy:** The official census in India is conducted every ten years last census was held on (2011) (Census India 2011, 2025) The available estimated population data used in the analysis is based on estimates and projections. The most recent census data may not capture recent demographic changes, impacting the accuracy of the correlation analysis.

2) **Per Capita Income Estimates:** The per capita income data from Ministry of Statistical Programme and Implementation is for the year 2022-23, it is assumed that the State wise rank as in previous year will remain same for the year 2023-24 and may not be material changes in account for recent economic developments or adjustments.

Hypothesis

The following hypothesis is being applied to test the correlation between state wise SDG Composite Index with State wise Factors.

Table 5: Hypothesis

Factors – State wise	Hypothesis
1. Population and SDG CI	❖ **(H_0):** There is no significant correlation between population and SDG Composite Index. ❖ **(H_1):** There is a significant correlation between population and SDG Composite Index.
2. Land Measurement and SDG CI	❖ **Null Hypothesis (H_0):** There is no significant correlation between land measurement and SDG Composite Index. ❖ **(H_1):** There is a significant correlation between land measurement and SDG Composite Index.
3. Per Capita Income and SDG CI	❖ **(H_0):** There is no significant correlation between per capita income and SDG Composite Index. ❖ **(H_1):** There is a significant correlation between per capita income and SDG Composite Index.
4. Gross State Domestic Product (GSDP) and SDG CI	❖ **(H_0):** There is no significant correlation between GSDP and SDG Composite Index. ❖ **(H_1):** There is a significant correlation between GSDP and SDG Composite Index.

(H_0): Null Hypothesis (H_1): Alternate Hypothesis

Table 6: Details of State wise data for comprehensive study

Sr. No.	**State**	**State Wise SDGCI 2023-24** (Aayog, 2024)	**Land Measurement Area (km2)** (Goverment, 2015)	**States wise at constant Price Year 2023-24* `. In Lakhs Crore** (Aayog, Indian Climate and energy Dash Board, 2025)	**Per capita Income 2022-23*** (MOSPI, 2023)	**Estimated Population 2022-2023 in Lakhs** (Wikipedia, India State wise Population Data, 2024)
1	Rajasthan	67	342,239	8.45	156,149	810.25
2	Madhya Pradesh	67	308,252	6.60	140,583	865.79
3	Maharashtra	73	307,713	24.11	242,247	1263.85
4	Uttar Pradesh	67	240,928	14.23	*9,418	2356.87
5	Gujarat	74	196,024	*15.74	293,909	715.07
6	Karnataka	75	191,791	14.23	301,673	676.92
7	Andhra Pradesh	74	162,975	8.21	219,518	531.56
8	Odisha	66	155,707	5.21	150,676	462.76
9	Chhattisgarh	67	135,192	3.22	133,898	301.8
10	Tamil Nadu	78	130,058	15.71	273,288	768.6
11	Telangana	74	112,077	7.93	308,732	380.9
12	Bihar	57	94,163	4.65	*56,124	1267.56
13	West Bengal	70	88,752	9.04	141,373	990.84
14	Jharkhand	62	79,716	2.85	*7,589	394.66
15	Assam	65	78,438	4.25	118,504	357.13
16	Himachal Pradesh	77	55,673	1.43	*18,521	74.68
17	Uttarakhand	79	53,483	2.13	233,565	116.37
18	Punjab	76	50,362	4.96	173,873	307.3
19	Haryana	72	44,212	6.34	296,685	302.09
20	Kerala	79	38,863	6.35	*34,445	357.76
21	Tripura	71	10,491	0.46	21,014	41.47

* Includes Estimated figures

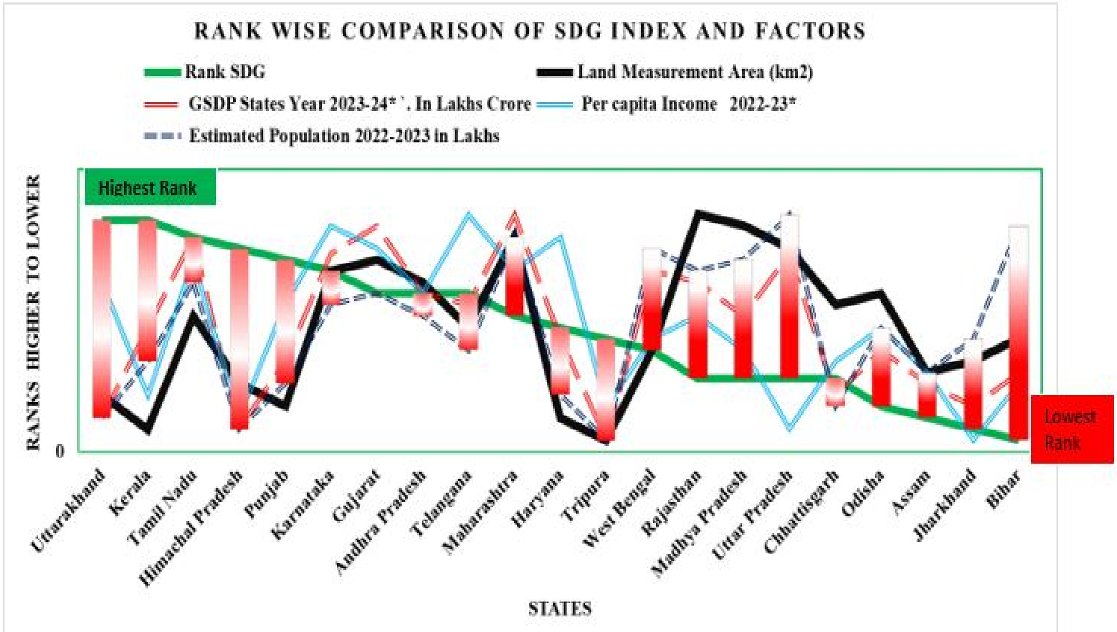

Figure 1: Line chart of Ranks based on Table 7 Higher to Lower SDG CI with all Factors

From Figure 1, We can observe the SDGCI rank in state of Uttarakhand starting with green line of SDG CI is in top and Black line of land measurement is in Bottom which means lower the land area, higher is the SDG rank. Similarly, the Per capita income of Karnataka and Telangana states is higher, however SDCI is lower. Rajasthan State with highest land area having lower SDGCI. In other word the gradient bars indicating the gap with SDGCI of each state.

Table 7: Ranks of Table 6

Sr. No.	States	Rank of SDGCI for the year 2023-24	Rank Population year 2022-23*	Rank Land Measurement	Rank Per capita Income	Rank of GSDP for the year 2023-24*
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Ranks	**R1**	**R2**	**R3**	**R4**	**R5**
1	Uttarakhand	1.5	21	17	14	19
2	Kerala	1.5	13	20	19	11
3	Tamil Nadu	3	6	10	20	3
4	Himachal Pradesh	4	22	16	9	20
5	Punjab	5	16	18	18	14
6	Karnataka	6	8	6	11	5
7	Telangana	8	12	11	7	9
8	Andhra Pradesh	8	10	7	3	8
9	Maharashtra	10	2	3	17	1
10	Haryana	11	18	19	1	12

11	Tripura	12	23	21	4	21
12	West Bengal	13	4	13	16	6
13	Gujarat	8	9	5	10	2
14	Uttar Pradesh	15.5	1	4	21	4
15	Rajasthan	15.5	7	1	5	7
16	Madhya Pradesh	15.5	5	2	13	10
17	Chhattisgarh	15.5	17	9	8	16
18	Odisha	18	11	8	15	13
19	Assam	19	15	15	6	17
20	Bihar	21	3	12	12	15
21	Jharkhand	20	14	14	2	18
	r (Correlation Coefficient)		**-0.29**	**-0.28**	**-0.31**	**0.16**

1. r Correlation Coefficient $= \frac{\Sigma (xy) - \Sigma (x).\Sigma (y).}{\sqrt{\left(\Sigma x^2 - \Sigma (x)^2\right)}.\sqrt{\left(\Sigma y^2 - \Sigma (y)^2\right)}}$ $REF\ \_Ref190110364\ \backslash r\ \backslash h\ 16$

2. Spearmans Rank correlation Co-relation coefficient formula for repeated ranks

$$R = 1 - 6\ \frac{\Sigma\ (D_n{}^2) + \left(\frac{1}{12}(m_1{}^3 - m_1)\right) + \left(\frac{1}{12}(m_2{}^3 - m_2)\right) + \left(\frac{1}{12}(m_3{}^3 - m_3)\right) .....}{(N^3 - N)}\ 17$$

$$D_n{}^2 = \left(Rank\ 1(R1) - Rank\ n\ (Rank2,3,4)\right)^2\ m_1 = 2, m_2 = 2, m_3 = 4\ repeated\ ranks\ in\ SDG\ Index$$

Table 8: Calculation of Rank Correlation Coefficient of each factor

Particulars	**Workings**	**Solution**
1. Colum (3) and (4)	$1 - 6\ \frac{\Sigma\ 1{,}944.50 + \left(\frac{1}{12}(2^3 - 2)\right) + \left(\frac{1}{12}(2^3 - 2)\right) + \left(\frac{1}{12}(4^3 - 4)\right)}{(21^3 - 21)}$	-0.27
2. Colum (3) and (5)	$1 - 6\ \frac{1957.5 + \left(\frac{1}{12}(2^3 - 2)\right) + \left(\frac{1}{12}(2^3 - 2)\right) + \left(\frac{1}{12}(4^3 - 4)\right)}{(21^3 - 21)}$	-0.28
3. Colum (3) and (6)	$1 - 6\ \frac{2008.50 + \left(\frac{1}{12}(2^3 - 2)\right) + \left(\frac{1}{12}(2^3 - 2)\right) + \left(\frac{1}{12}(4^3 - 4)\right)}{(21^3 - 21)}$	-0.31
4. Colum (3) and (7)	$1 - 6\ \frac{\Sigma\ 1287.50 + \left(\frac{1}{12}(2^3 - 2)\right) + \left(\frac{1}{12}(2^3 - 2)\right) + \left(\frac{1}{12}(4^3 - 4)\right)}{(21^3 - 21)}$	0.16

Correlation Rule:

r/R = 1 Perfect Positive Correlation, r/R = - 1 Perfect Negative Correlation, r/R > 0.50 high Positive Correlation, r/R > - 0.50 High Negative Correlation, r/R < 0.50 low Positive Correlation,r/R < 0.50 Low Negative Correlation, r/R = 0 no Correlation

The analysis of the above Table 8 are as follows:

1. **SDG Index with Population (R = - 0.27):** There is a negative low correlation may be due to the increased demand for resources and infrastructure challenges.
2. **SDG Index with Land Measurement (R = - 0.28):** A negative low correlation exists may be due to resource management, impacting their SDG performance.
3. **SDG Index with Per Capita Income (R = - 0.31):** The negative low correlation could be due to unequal distribution of wealth and resources within the state.
4. **SDG Index with GSDP (R = 0.16):** There is low positive correlation suggests the ability to invest in sustainable development initiatives.

Analysis Limitations

1. **Reliability on Data sources:** The data for land measurement and per capita income GSDP were based on estimated figures, which may not be as reliable or comprehensive as official sources.
2. **Temporal Variation:** The analysis is based on data from the years 2022-23 and 2023-24. Changes over time in these factors could affect the results.
3. **Urban and Rural analysis :** The current analysis does not distinguish between urban and rural areas within each state. Urban and rural populations have different characteristics and challenges that can impact SDG performance.
4. **Other Influencing Factors:** This study has not considered other variables such as education, healthcare, infrastructure, and environmental policies could also significantly impact SDG performance.

XY Scatter Chart of State wise Composite SDG Index with other Factors and analysis.

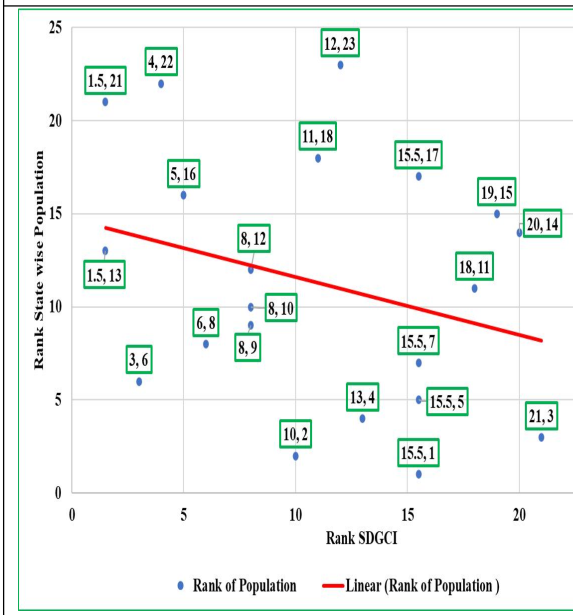

Figure 2: XY Chart SDGCI and Population

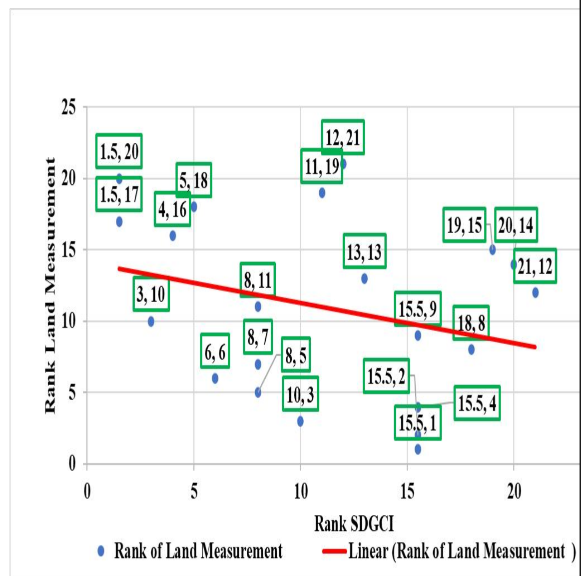

Figure 3: XY Chart SDGCI with Land Measurement

Fig. 2: The red coloured trend line sloping downward indicates low negative correlation.	Fig. 3 The red coloured trend line sloping downward indicates low negative correlation.

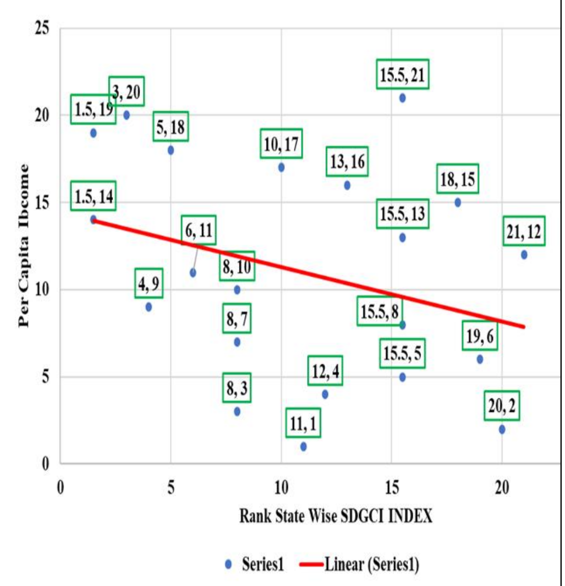

Figure 4: XY Chart of SDGCI and Per capita Income

Fig. 4 The red coloured trend line sloping downward indicates low negative correlation.

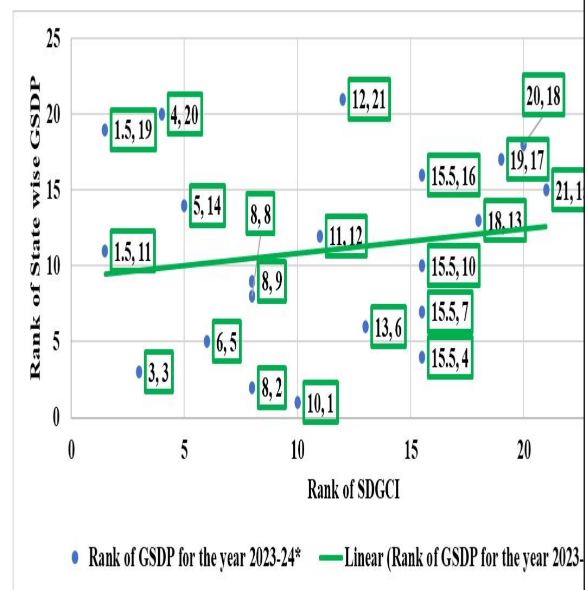

Figure 5: XY Chart of SDGCI and GSDP

Fig. 5 The green coloured trend line sloping upward indicates low positive correlation.

Conclusion and Future Directions:

From all above three test we derive following conclusions :

Table 9: Summary of Analysis.

Factors – State wise	Conclusion
1. Population and SDG Index	We reject **(H_0)** and accept alternate hypothesis stating there in Negative correlation between state wise Population and SDG Index
2. Land Measurement and SDG Index	We reject **(H_0)** and accept alternate hypothesis stating there in Negative correlation **(H_1)** between state wise Land Measurement and SDG Index.
3. Per Capita Income and SDG Index	We reject **(H_0)** and accept alternate hypothesis stating there in Negative correlation **(H_1)** between state wise Per Capita Income and SDG Index.
4. Gross State Domestic Product (GSDP) and SDG Index	We reject **(H_0)** and accept alternate hypothesis stating there in Positive correlation **(H_1)** between state wise GSDP and SDG Index.

(H_0) : Null Hypothesis, (H_1) Alternate Hypothesis.

1. **Policy Recommendations:** The findings suggest that states with larger populations and land areas face unique challenges in achieving SDGs. Policymakers should focus on resource management, infrastructure

development, and equitable distribution of resources to address these challenges. Tailored policies that consider the specific needs of urban and rural areas can help bridge the gap in SDG performance.

2. **Promoting Economic Growth:** The positive correlation between GSDP and SDG performance highlights the importance of fostering economic growth while ensuring it aligns with sustainable development principles. Investments in industries that promote green technology, renewable energy, and sustainable practices can drive economic growth while enhancing SDG outcomes.

3. **Enhancing Per Capita Income:** Strategies to improve per capita income, such as skill development, job creation, and promoting entrepreneurship, can lead to better SDG performance

4. **Attracting Investment:** Creating an enabling environment with clear policies, regulatory frameworks, and incentives for sustainable investments can make states more attractive to investors looking to support sustainable development projects.

5. **Future Research Directions:** This study identifies the need for further research to explore additional factors influencing SDG performance, such as education, healthcare, and environmental policies. Longitudinal studies that track changes over time can provide deeper insights into the effectiveness of various interventions and strategies. It should address the limitations identified, including the use of more reliable data sources, analyzing temporal variations, and considering urban-rural distinctions.

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GREEN ACCOUNTING: AN ESSENTIAL STEP TOWARDS SUSTAINABLE DEVELOPMENT

Case Study: Bharat Petroleum Corporation Limited (BPCL)

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Abstract:

'Environment' has immense importance in our life. In order to protect the environment, all sectors of the economy are making collective efforts, which will lead to achieving sustainable development in future. "Green Accounting is one of the recent trends in the commerce field. Green Accounting is also termed 'Environmental Accounting'. 'Green accounting' considers various environmental costs and benefits which are the result of all actions of protecting and depleting the environment. This type of accounting attempts to showcase environmental cost and benefits into a financial performance statement. Policy makers should take green accounting into consideration as in present computation of Gross Domestic product the same is ignored. One of the vital agendas of green accounting practice is to make Business aware and manage the traditional business goals and environmental goals.

Key Terms: Green Accounting, Sustainable Development, Environmental Cost

Introduction:

The term Green Accounting started gaining importance when Professor Peter Wood used 'Green accounting' for the first time. 'Green accounting allows computation of income for a nation by taking into consideration the economic damage and depletion within the natural resources base of the economy.' It has gained power in the present era. India's former Environment Minister Mr. Jairam Ramesh insisted on the introduction of Green Accounting Practices in India. Unfortunately, till date there have been no concrete arrangements made in this direction. This study attempts to understand the process of environmental protection and corporate sectors' practices towards sustainable development goals.

Objectives:

1. To study and understand Green accounting concept and relevance of green accounting in sustainable development.
2. This study attempts to study BPCL practices under Green accounting objectives.

Differences between Traditional Accounting and Green Accounting

Traditional Accounting	Green Accounting
Traditional Accounting aims to figure out financial profits of an organization and focus on Profit Maximisation.	Green Accounting aims to improve environmental performance.
Traditional Accounting data is Primarily of Quantitative Nature.	Green Accounting data is both qualitative and Quantitative in Nature.
Traditional Accounting is governed by Accounting Standards and various corporate acts.	Various environmental legislations are in existence to back up Green Accounting Concept, but No Specific regulatory mechanism is introduced till date.

To analyze the financial performance of an organization, 'Financial Auditing' is conducted.	Environmental Auditing is conducted.
Financial Accounting and Auditing are Statutory.	Green Accounting is non-statutory.

Chart 1.1 : Relationship Between Green Accounting and Traditional Accounting (i.e Cost Accounting and Financial Accounting)

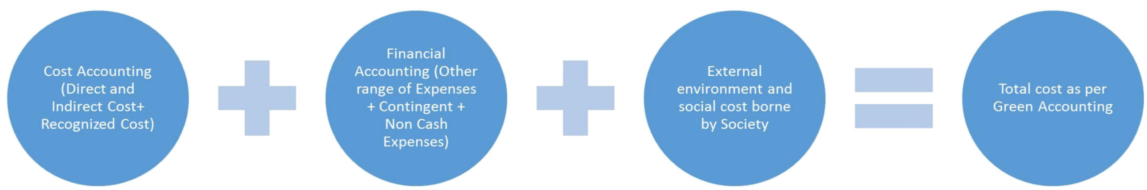
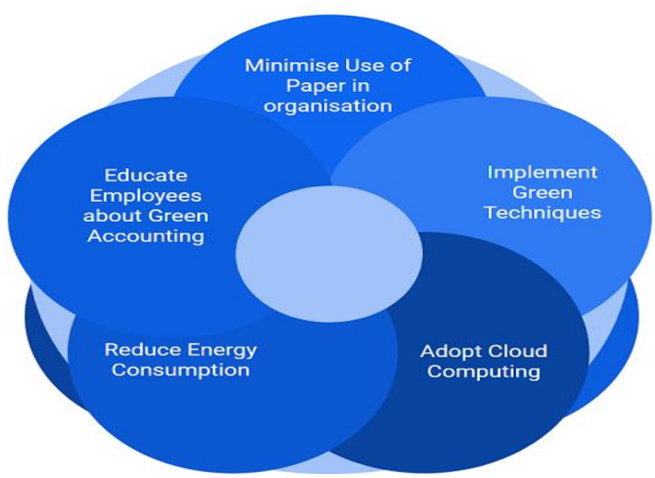


Chart 1.2 Basic Steps to Implement Green Accounting



Types of Green Accounting

There are three types of Green Accounting

1. Environmental Management Accounting (EMA)

Environmental Management Accounting consists of both economic and environmental information. EMA approach guides businesses to evaluate the environmental factors and adopt strategies in an organization accordingly.

2. Environmental Financial Accounting (EFA)

Environmental Financial Accounting deals with environmental transactions which will have an impact on the financial performance of an organization. In this approach financial risk and gain with respect to environmental factors are analyzed.

3. Environmental National Accounting

This type involves green accounting with respect to natural resources and green costs at national level.

Green Gross Domestic Product (i.e. GGDP):

This concept focuses on the costs of degradation of an environment and Its Prevention. GGDP is an economic growth index with the effects of development on the environment factored into Nation's GDP. GGDP is also termed as Environmental Domestic Product (EDP).

Calculation of Green Gross Domestic Product Requires following elements to be deducted from GDP:

1. Net Natural Capital Consumptions
2. Resources Depletion
3. Environmental Degradation
4. Protective and Retrospective Environmental Initiative

I.e. GGDP = GDP - (Net Natural Capital Consumption + Resources Depletion + Environmental Degradation + Protective and Retrospective environmental initiative

Formula:

EDP = Net Exports + FC + NAPEC + NANPEC + NANPN

Here,

EDP = Environmental Domestic Product

FC = Final Consumption

NAPEC = Net Accumulation of Produced Economic Assets

NANPEC = Net Accumulation of Non- produced Economic Assets

NANPN = Net Accumulation of Non-Produced Natural Assets

Research Methodology

The data of this research is collected through secondary sources like published annual sustainability reports of BPCL newspapers, websites, magazines etc.

Case Study: Bharat Petroleum Corporation Limited (BPCL) Financial Year 2021-22

Bharat Petroleum Corporation Limited (BPCL) implemented a Health, Safety, Security & Environment Management system in 2007, which was further strengthened in the year 2011. BPCL has adopted a systematic approach to manage its operations in such a way that health and safety risks associated with it are As Low as Reasonably Practicable Level (ALARP Level) in accordance with other business goals, values and policy.

BPCL Strategic Safety objectives consists of:

- Unlocking possibilities for a sustainable future.
- People, Assets and Environment with no harm.
- Design, Operate and Maintain Assets to minimize risks to a level which is As Low as Reasonably Practicable.

Steps taken by BPCL under Green Accounting

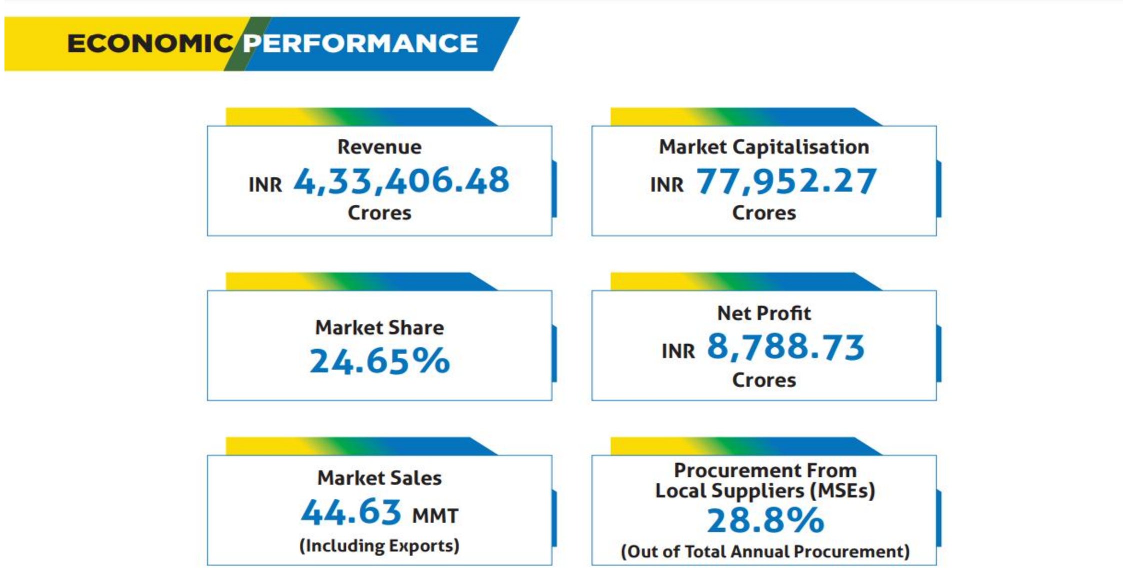
1. As the key infrastructure of oil and gas industries are in coastal areas, this sector is most vulnerable to climate changes. BPCL along with other industry members took part in a study on climate change for the oil and gas sector through The Energy and Resources Institute (TERI). This study aided in developing short term and long-term action plans to deal with climate change issues. BPCL has implemented recommendations suggested in the study.

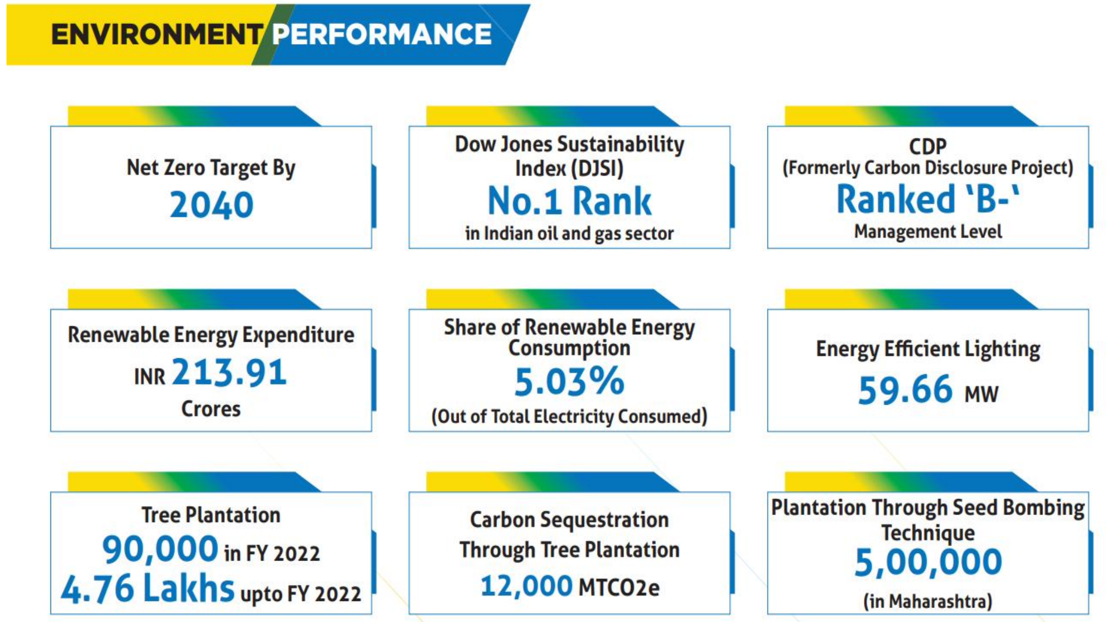
2. BPCL installed Mumbai Refinery Non-Intrusive wireless corrosion monitoring system of M/s. Emerson. Multiple technical studies were carried out by BPCL to improve existing process.

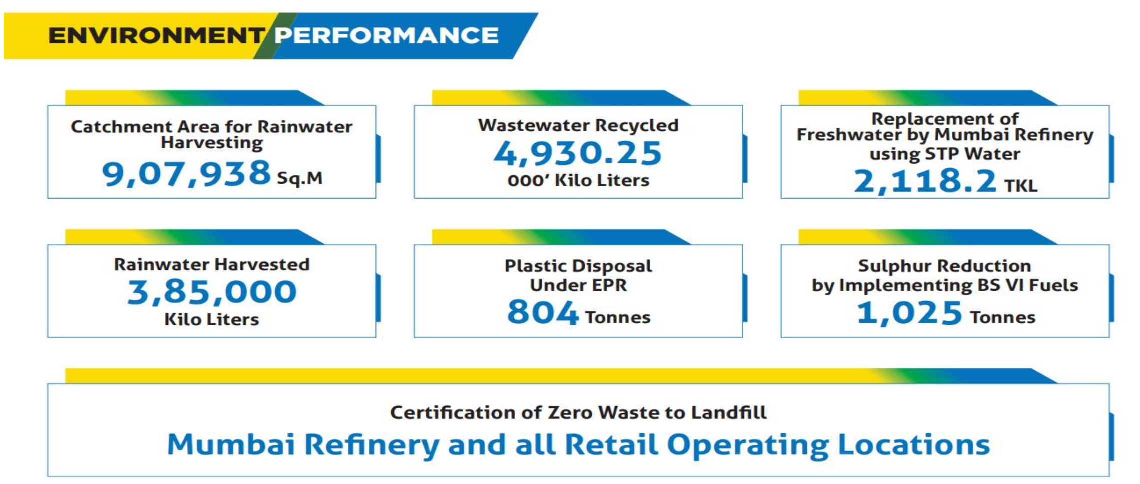
3. AIMS (Meridiam) Software Upgrade to latest version & implementation of new modules has been initiated. Implementation and software configuration is in progress Provision of Electrical Heat Tracing (EHT) to Bitumen delivery headers viz. VG10 & VG40 for steam saving Reconfiguration of Naphtha splitter in ISOM unit for fuel saving Processing of return kerosene in Diesel Hydrodesulfurization (DHDS) unit and stoppage of return kerosene to Diesel Hydrotreater (DHDT) to increase DHDT feed preheat for fuel saving Reduction of steam consumption in DHT complex by bypassing DHT lean amine cooler APC Implementation in Amine Treatment Units & Sour Water Stripper units (viz. SWS4, DHDS ATU & Old SWS) for steam saving Diversion of Splitter overhead gasses in Continuous Catalytic Reformer (CCR) to furnace burners reducing flaring.

4. BPCL has taken various steps for Energy Conservation. Mumbai and Kochi Refinery are both certified for Energy Management System, ISO 50001: 2011.

Highlights from BPCL Sustainability Report 2021-22







Observations

1. Green Accounting awareness is required.
2. Statutory provisions and policies should be framed at national level
3. It should be made compulsory to administer ecological standards at organizational level.
4. The significance of Environmental cost accounting should be spread through all levels of organization. Every single employee and worker should be aware of Green Accounting.

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RESEARCH PAPER: GREEN CLOUD COMPUTING: SUSTAINABLE PRACTICES FOR REDUCING ENVIRONMENTAL IMPACT

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Abstract

Cloud computing has changed the way businesses and individuals use digital services. However, as the need for cloud services grows, so does the environmental impact of cloud data centers, which are major energy consumers and contribute to carbon emissions. This paper explores the concept of green cloud computing, focusing on sustainable practices that can reduce the environmental footprint of cloud-based services. We examine energy-efficient hardware, renewable energy adoption, resource optimization, and carbon offsetting strategies that are shaping the future of sustainable cloud computing. Furthermore, we assess the role of various stakeholders, including cloud service providers, governments, and end- users, in driving this shift toward more sustainable cloud ecosystems. Keywords Green Cloud Computing, Sustainability, Energy Efficiency, Carbon Emissions, Renewable Energy, Data Centers, Environmental Impact, Resource Optimization, Sustainable Practices.

1. Introduction

The rapid rise of cloud computing in recent years has offered organizations worldwide scalable and cost-effective solutions. However, this growth has also brought significant environmental challenges. Data centers, which form the backbone of cloud services, are energy-demanding facilities that use large amounts of electricity for both operation and cooling. As the environmental consequences of these activities become more apparent, there is an increasing call for more eco-friendly cloud computing practices, often termed "green cloud computing." These practices aim to reduce energy consumption, optimize resource efficiency, and lower the carbon footprint of cloud infrastructures. This paper looks into various sustainable practices being adopted to lessen the environmental impact of cloud computing, such as utilizing energy-efficient hardware, incorporating renewable energy sources, and developing software that maximizes resource efficiency. Through this examination, we aim to showcase how the cloud computing industry can contribute to broader global sustainability efforts.

2. Environmental Impact of Cloud Computing

2.1 Energy Consumption in Data Centers

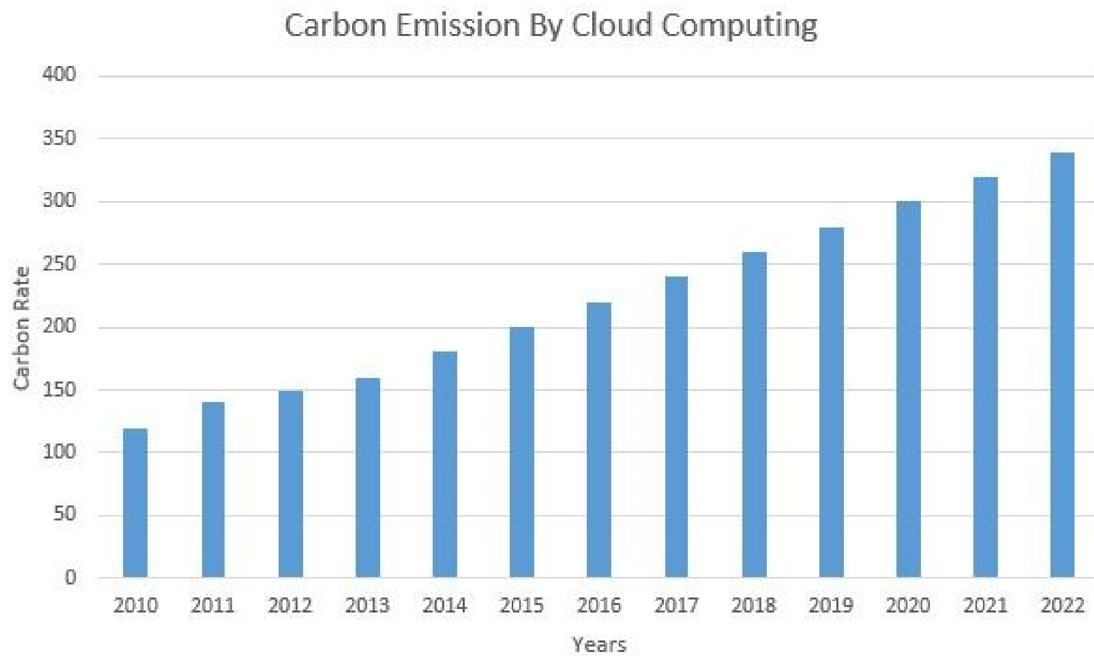
Data centers are crucial to cloud services, housing the servers and storage systems that support a wide range of applications, from email services to data analytics. These facilities are highly energy-intensive, consuming large amounts of electricity to power the servers and maintain cooling systems. With the growing global demand for cloud services, the number of data centers has increased, leading to a rise in overall energy consumption. The International Energy Agency (IEA) reported that data centers were responsible for roughly 1% of global electricity use in 2020, and this figure is expected to grow in the future.

2.2 Cooling Requirements

Maintaining the ideal temperature for servers is another significant source of energy consumption. Traditional cooling methods, which rely on air conditioning or water-based cooling systems, are often inefficient, requiring large amounts of energy to maintain stable operating conditions.

2.3 Carbon Emissions

The carbon footprint of cloud services is largely dependent on the energy sources used to power data centers. While many cloud providers have made significant strides in adopting renewable energy, a large portion of cloud infrastructure is still powered by fossil fuels. This reliance on non-renewable energy contributes to the carbon emission associated with cloud computing.



"Green Cloud Computing Practices" Green clouds computing incorporates a variety of sustainable practices aimed at reducing the energy consumption, environmental impact, and carbon emissions of cloud-based services. Below are some of the most significant practices currently being adopted in the industry.

1. Energy-Efficient Hardware

The hardware used in data centers plays a crucial role in overall energy consumption. Green cloud computing encourages the use of energy-efficient servers, storage devices, and networking equipment. Companies like Intel, AMD, and NVIDIA have developed processors with lower power consumption, reducing the amount of electricity needed to run servers. In addition, the use of solid-state drives (SSDs) instead of traditional hard disk drives (HDDs) can lower energy usage due to their faster read/write speeds and reduced heat generation.

2. Virtualization and Resource Optimization

Virtualization plays a crucial role in cloud computing by enhancing energy efficiency. Through the virtualization of physical hardware, cloud service providers can make better use of server resources, reduce the number of physical servers needed, and cut down on energy consumption. This approach not only increases the overall efficiency of the infrastructure but also lessens its environmental impact. Moreover, dynamic scaling, which adjusts resources according to actual demand, further improves energy efficiency by preventing both excess resource allocation and underuse.

3. Renewable Energy Integration

One of the most efficient ways to reduce the carbon footprint of cloud services is by using renewable energy sources like solar, wind, and hydroelectric power to supply data centers. Major cloud providers, including Google, Microsoft, and Amazon, have made commitments to power their data centers entirely with renewable energy. This shift helps reduce dependence on fossil fuels and lessens the environmental impact of cloud services. Cloud providers can also establish power purchase agreements (PPAs) with renewable energy suppliers to ensure a reliable flow of clean energy.

4. Carbon Offset Programs

Cloud providers can also reduce their environmental impact through carbon offset programs. These programs focus on funding initiatives that reduce or prevent greenhouses gas emission, like reforestation project or renewable energy initiatives. By compensating for the emissions generated by their data centers, cloud providers can work toward achieving carbon neutrality. Some organizations also track their emissions and report them transparently, allowing customers to make informed decisions about their cloud service providers.

Challenges in Implementing Green Cloud Practices While green cloud computing offers several benefits, the implementation of sustainable practices is not without its challenges.

High Initial Costs Adopting energy-efficient hardware, renewable energy sources, and other sustainable practices often involves high upfront costs. For many cloud providers, the transition to greener technologies requires significant investments in new infrastructure and technologies. However, the long-term operational savings from reduced energy costs can help offset these initial investments.

Energy Demand Growth

As the demands for cloud services continues to rise, so does the need for more data center. While it is possible to reduce the energy consumption of individual data centers, the overall energy Demand may still grow. This could pose a challenge in the quest for sustainable cloud Computing, as increasing energy demands may outpace the adoption of renewable energy Sources.

Scalability and Reliability

Ensuring the scalability and reliability of cloud services while adopting green practices can be challenging. For instance, renewable energy sources like solar and wind can be intermittent, which may affect the reliability of cloud services. Cloud providers need to invest in energy storage systems and backup power solutions to maintain high uptime and service availability.

Case Studies of Green Cloud Computing Initiatives

Google has been a pioneer in green cloud computing, reaching carbon-neutral status in 2007. Since 2017, the company has committed to powering its data centers entirely with renewable energy. Its infrastructure is built with energy efficiency in mind, incorporating advanced cooling technologies and AI-driven energy optimization. Additionally, Google actively engages in carbon offset programs to further minimize its environmental footprint.

Microsoft's Sustainability

Microsoft has set a goal to become carbon negative by 2030, meaning it intends to remove more carbon from the atmosphere than it releases. The company is making substantial investments in renewable energy, energy-efficient data centers, and carbon removal projects. Additionally, Microsoft aims to equip its customers with the tools and data needed to monitor and reduce their own environmental impact through the Azure cloud platform.

Amazon Web Services (AWS) and Renewable Energy Amazon Web Services (AWS), the cloud computing arm of Amazon, has made substantial progress in its efforts to reduce its carbon footprint. AWS operates its data centers with 100% renewable energy as of 2025 and is investing in sustainable infrastructure, including wind and solar projects. AWS also provides customers with tools to track their energy consumption and optimize their own carbon footprints.

Governments and regulatory organizations are key players in advancing green cloud computing practices. Policies that offer incentives for using renewable energy, such as tax breaks for clean energy projects or renewable energy certificates, can motivate cloud providers to adopt more sustainable technologies. Furthermore, governments can implement mandatory reporting requirements for energy use and carbon emissions in the tech sector, fostering greater transparency and accountability.

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INNOVATIONS DRIVEN BY THE INTERNET OF THINGS TO REDUCE CARBON FOOTPRINTS IN SUSTAINABLE SMART CITIES

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Abstract:

The creation of smart cities has been transformed by the incorporation of the Internet of Things(IoT) into urban planning, which makes it possible to find sustainable solutions to major environmental problems. Reducing the carbon impact brought on by urbanization is one crucial area of attention. Smart grids, intelligent transportation systems and energy – efficient infrastructure are examples that are essential to reaching this objective. This research examines how IoT technologies can reduce carbon emissions, with a focus on how they can be used in sustainable urban settings. This research explores how IoT has the ability to turn cities into carbon – neutral ecosystems by examining recent research and case studies.

Keywords: IoT, Smart Cities, Carbon Foodprint, Sustainability, Renewable Energy.

Introduction:

Recent decades have seen a sharp expansion in urbanization, which has raised greenhouse gas emissions and greatly accelerated climate change. A possible way deal with these issues is through smart cities, which are defined by the incorporation of cutting – edge technologies like the Internet of Things. Real – time data gathering, analysis, and response are made possible by IoT technologies, which promote effective resource management and less environmental impact. This study explores the ways in which IoT can specifically help to reduce carbon emissions in smart cities, taking into account both technical developments and practical issues.

Objectives:

The objective of this paper are to:

- Analze the potential of IoT technologies in reducing carbon emissions in urban areas.
- Explore specific IoT applications in energy management, transportation and infrastructure.
- Highlight successful case studies and best practices for IoT implementation in smart cities.
- Identify Challenges and propose strategies for enhancing IoT adoption to achieve sustainability goals.

1. IoT Technologies to Reduce the Carbon Footprint:

IoT technologies have emerged as a transformative force in minimizing the carbon footprint of urban environments. By enabling smart solutions in energy management, transportation and infrastructure. IoT plays a pivotal role in achieving sustainable urban development. This section delves into key IoT technologies and their applications in reducing carbon emissions.

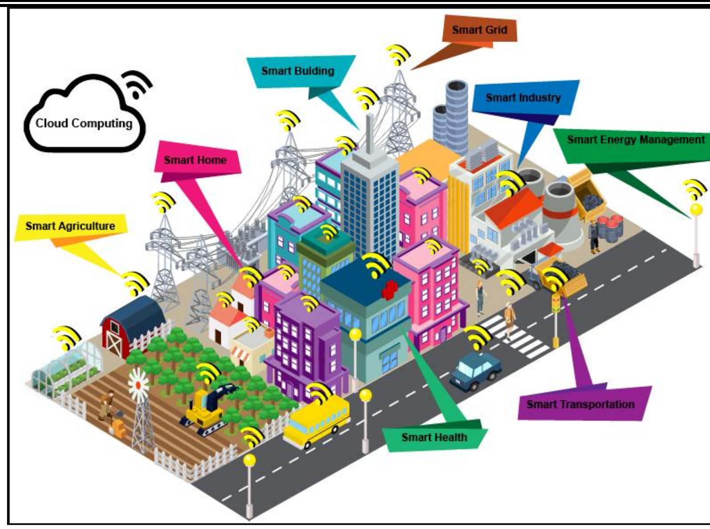

Figure1. IoT Technologies to Reduce Carbon Footprint

Smart Energy Management with IoT:

Energy consumption is a primary source of greenhouse gas in cities. IoT-enabled smart grids optimize energy distribution by integrating renewable energy sources, reducing energy loss and ensuring efficient usage. For instance, smart meters collect real-time data on energy consumption, allowing users and utility providers to identify inefficiencies and adopt energy-saving measures. IoT-powered devices, such as smart thermostats and lighting systems, adapt to user behavior and environmental conditions, significantly lowering energy usage in residential and commercial buildings. Studies have shown that implementing IoT-based energy management systems can reduce energy consumption by 20-30%, directly impacting carbon emissions.

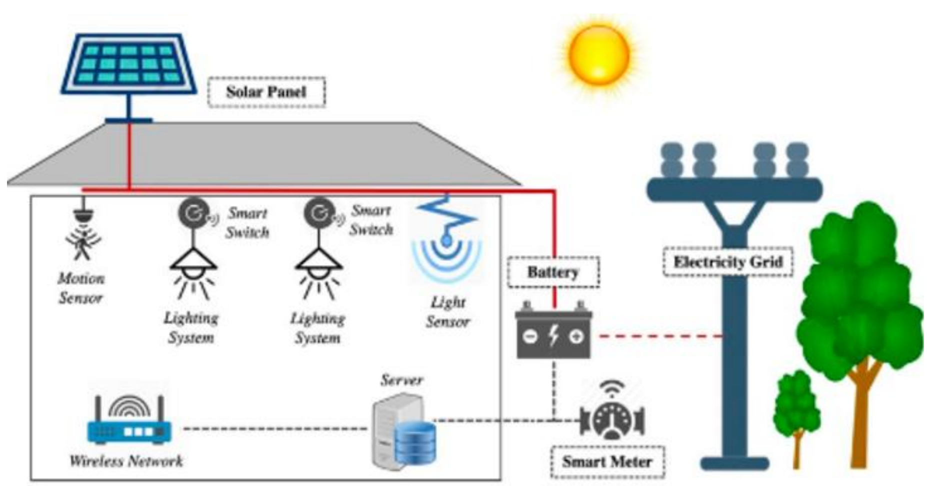

Figure2. Smart Energy Management with IoT

Intelligent Transportation Systems:

Transportation accounts for a significant portion of urban carbon emissions. IoT technologies facilitate intelligent transportation systems(ITS) by optimizing traffic flow, reducing congestion and promoting eco-friendly mobility options. IoT sensors embedded in roads and traffic lights enable real-time traffic management, minimizing idle times and fuel consumption. Additionally, IoT applications in public transportation improve scheduling and efficiency, encouraging greater use of buses and trains over private vehicles. Shared mobility platforms, powered by IoT, further reduce the number of vehicles on the road. These advancements collectively contribute to a reduction in transportation-related emissions.

Figure3. Intelligent Transportation Systems[5]

IoT in Urban Infrastructure:

Urban infrastructure, including buildings, water systems and waste management, significantly influences a city's carbon footprint. IoT sensors in smart buildings monitor parameters such as temperature, humidity and occupancy, enabling automated adjustments to optimize energy use. For example, IoT-based HVAC systems can adapt to real-time conditions, reducing unnecessary energy expenditure. Similarly, smart water systems powered by IoT detect leaks and optimize water usage, conserving this vital resource. IoT also transforms waste management by enabling real-time tracking of waste collection and disposal, ensuring efficient recycling and reducing methane emissions from landfills.

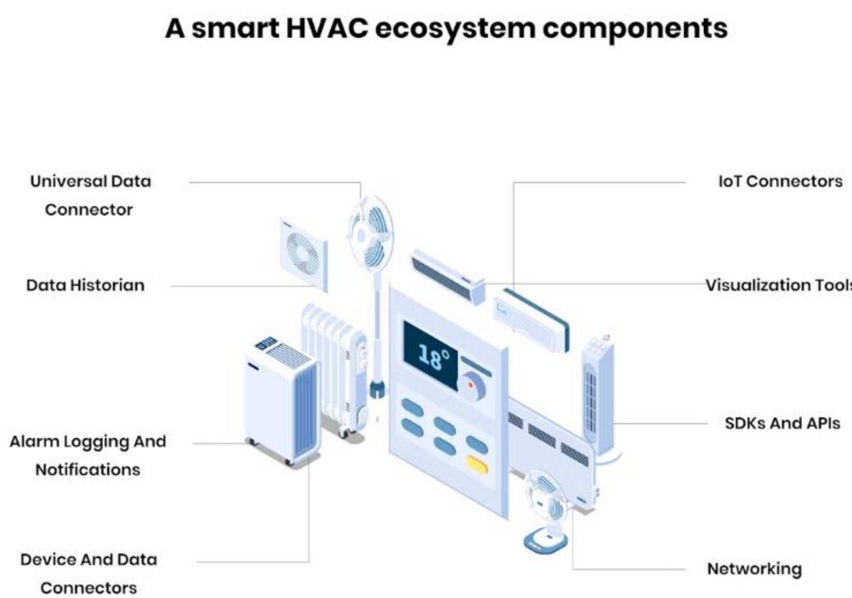

Figure4. Smart HVAC system[6]

IoT in Waste Management:

Waste management in urban areas can benefit significantly from IoT technologies. IoT-enabled waste bins equipped with sensors monitor fill levels and optimize waste collection routes, reducing fuel consumption and emissions from collection vehicles. Additionally, IoT systems can track and sort waste materials, promoting recycling and reducing landfill use. Smart waste management systems have been implemented in cities like seoul and Amsterdam, showcasing their potential to enhance sustainability.

Figure 5. IoT based Waste Management System[7]

IoT for Air Quality Monitoring:

IoT plays a crucial role in monitoring and improving urban air quality. Distributed IoT sensors collect real-time data on air pollutants, enabling authorities to implement targeted measures to mitigate pollution. For instance, smart air quality monitoring systems can identify high-emission zones and suggest traffic diversions or industrial regulations. Cities like London and Beijing have adapted IoT-based air quality monitoring to combat pollution and improve public health.

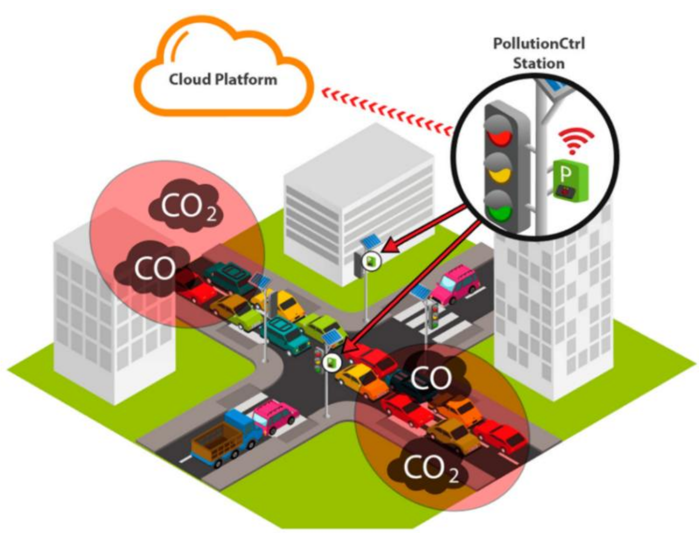

Figure 6. IoT based Air Quality Monitoring System[8]

Case Studies and Example:

Several cities worldwide have demonstrated the effectiveness of IoT technologies in reducing carbon footprints. In Barcelona, smart street lighting powered by IoT has led to a 30% reduction in energy consumption. Singapore's smart city initiatives leverage IoT for water and energy efficiency, significantly cutting resource wastage. These examples underscore the scalability and adaptability of IoT solutions in various urban contexts, showcasing their potential to drive sustainability.

Figure7. Smart Street Lighting in Barcelona[9]

Figure8. Singapore – Smart City using IoT Technologies[10]

Challenges in implementing IoT for Sustainability:

Despite its potential, IoT implementation faces the following challenges.

Technical Challenges:

Implementing IoT in smart cities presents several technical challenges that need urgent attention. One of the foremost issues is interoperability, as devices from different manufacturers often fail to communicate effectively due to varying standards and protocols. This lack of uniformity complicates large-scale IoT deployments and hinders seamless integration. Another critical challenge is limited network bandwidth, especially in high-density urban areas where the number of IoT devices can overwhelm existing infrastructure. As IoT systems heavily rely on continuous data transfer, these bandwidth limitations can lead to latency and reduced system efficiency. Moreover, data security and privacy concerns present a major barrier, with IoT devices being susceptible to cyberattacks. Addressing these challenges necessitates advancements in network technologies like 5G, the development of universal IoT standards, and robust cybersecurity frameworks that can protect data integrity and user privacy.

Socioeconomic Barriers:

In addition to technical challenges, socioeconomic factors also limit the widespread adoption of IoT in reducing carbon footprints. The high initial costs associated with IoT deployment, including device installation and maintenance, can deter investment, particularly in developing regions. This economic barrier is exacerbated by the digital divide, where access to IoT technologies and supporting infrastructure is unevenly distributed. Regions with limited connectivity and resources may struggle to implement IoT solutions, further widening the sustainability gap. Public-private partnerships and government incentives, such as subsidies for IoT infrastructure or tax breaks for green initiatives, are crucial to overcoming these financial barriers. Additionally, fostering awareness and building trust among stakeholders, including citizens, is essential to ensure the acceptance and effective utilization of IoT technologies for sustainable urban development.

Conclusion:

IoT-driven innovations hold immense potential to minimize carbon footprints and promote sustainability in smart cities. By optimizing energy use, enhancing transportation systems and improving urban infrastructure, IoT technologies can significantly reduce greenhouse gas emissions. However, addressing the associated challenges is crucial for realizing the full potential of these technologies. Collaborative efforts between governments, industries and academia will be instrumental in advancing IoT adoption for sustainable urban development. Future research should focus on developing energy-efficient IoT devices, integrating artificial intelligence for predictive analytics and exploring block chain for secure and transparent data management. Additionally, longitudinal studies are needed to assess the long-term impacts of IoT on carbon emissions in smart cities.

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INNOVATIVE E-LEARNING APPROACHES FOR SUSTAINABILITY EDUCATION: CURRENT TRENDS AND FUTURE DIRECTIONS

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Abstract

Sustainability education has evolved into an essential component of modern education, preparing students to face the world's complex environmental, social, and economic concerns. E-learning platforms have emerged as a promising method for advancing sustainability education, as they provide flexibility, accessibility, and scalability. The latest e-learning trends for sustainability, including essential platforms, pedagogical methodologies, and technology advances like gamification, virtual reality, and artificial intelligence.

Literature Review:

E-learning platforms for sustainability education highlight significant advancements and concerns. Major themes in the current literature include the application of cutting-edge technology, innovative pedagogical strategies, and challenges to effective implementation.

1. **Technology's Role in Sustainability Education:** Studies show that progress in technology has greatly expanded the scope and efficiency of sustainability education. Digital tools, smartphone apps, and virtual learning environments are making high-quality education on sustainability issues accessible to people all over the world. "The potential of artificial intelligence (AI) to customise learning experiences and modify content to meet the needs of individual learners is one example that Khalid and Ahmed (2019) address"**.** Additionally, to improve engagement and retention, systems such as Quizlet and Kahoot! use gamified quizzes and AI-driven adaptive learning. Mobile applications like "Sustaina" and "Good On You" provide students with access to sustainability information and practical guidance in a user friendly format, encouraging behavioral changes through technology.

2. **Pedagogical Methods:** The efficiency of e-learning platforms is largely dependent on pedagogy. Researchers **like Brown et al. (2021)** stress the value of experiential and participatory learning in sustainability education. According to **Deterding et al. (2011),** gamification has been shown to be successful in capturing students' attention by introducing game-like features like challenges and prizes. The use of microlearning strategies, which divide difficult sustainability subjects into digestible units, is another noteworthy trend, as **Johnson and Taylor (2022)** describe. Initiatives such as the Ministry of Education's **SWAYAM** platform have played a significant role in offering free online courses on environmental education and sustainability in India. The classes frequently include case studies on regional environmental concerns, including waste management or water conservation in rural India or waste management in urban areas.

3. **Barriers to Implementation:** Despite advances in technology, there are still obstacles to overcome. According to **Smith et al. (2020),** "the digital divide restricts access to e-learning platforms in rural and low-income communities". Furthermore, cultural relevance and content localisation are frequently disregarded, which lowers the efficacy of sustainability education in a variety of circumstances. **Patel and Green's (2021)** assessment emphasises "the necessity of region-specific curriculum that tackle regional sustainability issues".

4. **Collaborative Learning and Community involvement:** Research also emphasises how crucial it is to promote community cooperation and involvement in e-learning for sustainability. A case study by **Williams and Harper (2020)** discusses how platforms such as "Future Learn" have been successful in establishing peer-to-peer learning settings. These methods enhance the learning process by encouraging students to exchange different viewpoints and work together to develop solutions.

Methodology:

Designing an E-Learning Platform for Sustainability Education:

Key features to include in the platform:

- Course structure (modules, assessments, interactive content).
- Multi-language support to provision to different followership.
- Integration with social media for community engagement.
- Data-driven insights to track learning progress and impact.

Technological Tools to Enhance Learning:

- Use of gamification, simulations, and virtual reality to make sustainability concepts more engaging.
- Incorporating multimedia content such as videos, podcasts, and live webinars to create a dynamic learning environment.

Collaboration and Partnerships:

- Partnerships with educational institutions, NGOs, governments, and industry leaders to provide credible content.
- Input from sustainability experts and activists for real-world insights.

Current Trends in E-Learning for Sustainability Education

1. **Integration of Sustainable Development Goals (SDGs):** Information on e-learning platforms is becoming more and more in line with the SDGs of the UN. A thorough approach to sustainability that takes into account its social, economic, and environmental facets is ensured by this integration. For example, platforms such as edX and Coursera provide courses on subjects including climate action, sustainable cities, and renewable energy, frequently in partnership p with renowned universities and organisations.
2. **Gamification and Interactive Learning:** Increasing the effectiveness and engagement of sustainability education, gamification has become a prominent trend in e-learning. To encourage active learning, platforms incorporate features like leaderboards, interactive simulations, badges, and quizzes. Through gamified activities, such as the "EcoChallenge" app, users are encouraged to develop sustainable behaviours while fostering a sense of community and competition.
3. **Virtual reality (VR) and augmented reality (AR):** These modern technologies are revolutionising learning about sustainability. Through virtual reality (VR) apps, users can virtually explore ecosystems, comprehend the effects of deforestation, or model sustainable city planning. Through a practical viewpoint, these immersive encounters improve comprehension.
4. **Microlearning and Modular Courses:** Microlearning meets the needs of contemporary learners by offering brief, targeted courses. Bite-sized classes on sustainability subjects are available on platforms like Udemy and Khan Academy, which simplify and make difficult ideas more approachable.
5. **Community-Based Learning and cooperation:** Through discussion boards, group projects, and live webinars, e-learning platforms are encouraging peer-to-peer learning and cooperation. Community-driven learning is emphasised by platforms such as Future Learn, which allow people from a variety of backgrounds to exchange ideas and solutions.

E-learning platforms provide several key benefits for sustainability education:

1. **Wider Reach:** E-learning enables access to education for individuals in remote or underserved areas, overcoming geographical barriers.
2. **Convenience:** Learners can engage with course content at their own pace, anytime and anywhere, offering flexibility that accommodates different schedules and lifestyles.
3. **Capacity:** E-learning platforms can support a large number of students simultaneously, reducing the need for physical classrooms and the associated resources.
4. **Affordability:** By cutting down on costs like travel, accommodation, and printed materials, e-learning offers a more cost-effective alternative to traditional face-to-face learning.

Challenges of E-Learning Platforms for Sustainability Education

While e-learning platforms offer significant benefits for sustainability education, they also present some challenges:

1. **Reduced Interaction**: The lack of face-to-face interaction on e-learning platforms may limit the personal connection and collaboration that can enhance the learning experience.
2. **Technical Challenges**: Issues like poor internet connectivity or video quality can disrupt the learning process, especially in areas with limited access to reliable technology.
3. **Engagement and Motivation**: Without interactive or relevant course materials, it can be difficult to keep learners motivated and engaged, leading to reduced participation and success.
4. **Assessment and Feedback**: E-learning platforms may face difficulties in accurately assessing learner progress and providing timely, personalized feedback, which is crucial for effective learning.

Best Practices in Designing and Implementing E-Learning Platforms for Sustainability Education

1. **Include interactive and multimedia content**: To engage students and encourage active learning, use interactive and multimedia content, such as games, simulations, and videos.
2. **Encourage online communities:** Encourage collaboration and interaction among students by using social media groups and online discussion platforms to create online communities.
3. **Give learners timely and useful feedback:** Make use of peer review and automated grading methods to give students timely and useful feedback.
4. **Include case studies and real-world examples:** To highlight important ideas and encourage applied learning, use case studies and real-world examples.

Future Directions

1. **Adaptive Learning Technologies:** By using artificial intelligence, adaptive learning systems can customize the learning experience to meet individual needs and progress. These technologies can recommend personalized content, offer instant feedback, and identify areas where learners need improvement, leading to better educational outcomes.
2. **Open Educational Resources (OER):** OERs are essential in making education more accessible. With organizations like UNESCO advocating for free, high-quality materials, the expansion of OER repositories is crucial. Efforts should focus on increasing their availability and encouraging their adoption by educators and institutions.
3. **Collaborative Partnerships:** Collaborations between governments, universities, non-profits, and the private sector can improve the quality and accessibility of e-learning. These partnerships can support the development of interdisciplinary courses, funding for technology infrastructure, and the creation of locally relevant content.

4. **Blended Learning Models:** Blending online learning with offline experiences can address some e-learning challenges. Virtual courses can be paired with hands-on workshops, field trips, or community projects, offering practical, real-world learning opportunities.

5. **Emphasis on Behavioural Change:** Future e-learning initiatives should focus on encouraging behavioural change. Integrating elements of psychology and behavioural science into course design can help learners apply theoretical knowledge to sustainable practices in their everyday lives.

6. **Improved Data Analytics:** Data analytics can offer valuable insights into learner engagement, course effectiveness, and areas for improvement. By leveraging these insights, course content and delivery methods can be refined to enhance learning outcomes and student participation.

Case Studies

1. edX and SDG Academy:

SDG Academy, hosted on edX, offers a wide range of courses aligned with the UN's SDGs. Courses like "The Age of Sustainable Development" by Jeffrey Sachs provide learners with in-depth knowledge of global sustainability challenges and solutions. The platform's collaboration with world-class educators ensures high-quality content.

2. Eco Challenge Platform:

Eco Challenge engages learners through gamified sustainability tasks, encouraging them to adopt eco-friendly habits. Users track their progress, share experiences, and compete with peers, fostering a sense of accountability and community.

3. Tata Power's "Jigyasa" E-learning Platform

Jigyasa is a unique e-learning platform initiated by Tata Power, one of India's largest electricity providers. The platform is aimed at promoting environmental consciousness and sustainability practices among school children, with a special focus on clean and green energy.

Conclusion

E-learning platforms have the potential to promote sustainability education and prepare learners to address the complex environmental, social, and economic challenges facing the world. By incorporating interactive and multimedia content, fostering online communities, providing timely and effective feedback, and incorporating real-world examples and case studies, e-learning platforms can promote effective learning and improve learner outcomes. Future directions, such as artificial intelligence, virtual and augmented reality, mobile learning, and gamification, offer exciting opportunities for innovation and improvement.

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INNOVATIVE METHODS TO GLOBAL SUSTAINABILITY: THE USE OF VIRTUAL REALITY (VR) AND AUGMENTED REALITY (AR) IN ENVIRONMENTAL STUDIES

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Abstract

In today's world, these VR and AR technologies have grabbed the attention of scholars as well as educationists, as they allow the incorporation of scientific data into an interactive and visually engaging format. This paper elaborates on the use and application of AR and VR in the field of climate studies such as visualizing climate change impacts, biodiversity conservation, disaster management, and sustainable urbanization. These concepts can greatly change the attitude of scholars towards the environment and technology, and support in abundance to tackle global sustainability problems. Furthermore, this study outlines international environmental development policies and suggests deep learning and machine intelligence solutions that mitigate accessibility, economic and skills limitations these concepts pose.

In education, traditional educational levels are able to learn ar and Vr and communication and the movement of tradition. The students can be involved in historical events, natural systems, and the strong scientific theories. These tools increase emotions, promote unity in weaknesses, and include qualities as the interpretation of a time of time.

They store such challenges such as suitable for itself as due to lack of standards, setting basic standards, and lack of values. However, progress and beatings are always being used.

Introduction

1. Entering a New Decade of Solutions in Environmental Problem

We live in a 21st century that necessities creative validated answers to climate change, deforestation, domain and biodiversity dilemmas as an emerging urgent sources. Although the insights from traditional tools have been fundamental, it will require more immersive and meaningful ways that reflect the complexity and immediacy of these challenges. And that is where Virtual Reality (VR/AR) comes as a crosswalk from massive data complexity to human comprehension.

2. Unexplored Potential

VR (and AR) have been mostly used in gaming and entertainment for a while already when it comes to the broader context of environmental studies; they are still brand-new applicative tools. To go one step further and unlock this dormancy, this paper addresses key inquiries of what VR and AR can contribute on research about environment and learning? In what way have they gone on to the rest? And how can we solve these hurdles of the technological and ethical in more depth such measures

Literature Review

Technological Evolution in the Immersive Domain
Immersive technologies have come a long way, from crude VR goggles in the 80s to cutting-edge head-mounted displays (HMDs) and AR enabled smart phones we use today. Right now they offer hyper-realistic 3D spaces and data in real-time tools, both accessible but also transformational for environmental sciences.

Cutting-Edge Applications

1. Climate Change Experience Download VR in which you experience increasing sea levels and melting glaciers as seen from the windows on your computer. They allow the public and decision makers to wrap their heads around what can happen if we fail to act.

2. Biodiversity Conservation: AR apps designed for sustainable use encourages interaction with the digital ecosystems creating a more authentic relationship among people and nature, fostering conservation or caring life experience.
3. Disaster Management: Radiotherapy training simulations would deal with flood drills and earthquake preparedness of the emergency responder for the case of disaster.
4. Efficient urban development : AR technologies are able to provide the actual status of environment for urban construction; it is a breakthrough.

Scholarly Gaps in Research

Still, there are big gaps. Very few studies address the sustained impact of VR/AR intervention in environmental education, and issues around data privacy, cost and technical feasibility are still scarcely researched.

Methodology

A Multi-Disciplinary Approach

The study uses a qualitative research design, cases and literature in environmentalism, technology and education for sustainable development framework. The said research design goes through the following steps of research:

1) Objectives Explanation
2) Literature Review
3) Case Studies Identification
4) Analyse Thematically
5) Insights & Recommendations

Data Collection

Secondary Sources: Peer-reviewed articles, industry reports and conference proceedings.

Situations: Different fantastical projects- VR coral reef explorations, AR biodiversity apps

Analytical Lens

This qualitative research is analyzed in form of thematic analysis and identifies the key patterns and insights relating to innovation, accessibility, impact.

Research Design

This paper uses a qualitative research methodology to examine case studies and extant literature for applications and implications of VR and AR in environmental studies. Below is the process for research design:

- **Mermaid**

graph TD

A[Identify Research Objectives] --> B[Conduct Literature Review]

B --> C[Select Case Studies]

C --> D[Analyze Data Thematically]

D --> E[Conclusion and Recommendation]

Including this flowchart helps elucidate the research design steps and make it easy for readers to trace the methodology.

This qualitative research paper focuses on case studies and existing literature to evaluate applications and implications of VR and AR in environmental studies.

Data Collection

Secondary Sources: Peer-reviewed journals, conference proceedings, and reports from environmental organizations.

Case studies: Projects and initiatives using VR and AR on environmental issues like climate simulations on VR and AR-based biodiversity applications.

Data Analysis

Using thematic analysis will help to pick out recurring patterns and insights.

For example, the technology of AR and VR is always acquired, learning, work, work, and communication in the world of Digital.

Results

Advances in Environmental Research

1. Immersive Data Visualization:

VR allows for more realistic simulations of real phenomena (e.g., deforestation and ocean acidification) as done in the case of (e.g., Feature Photo)

AR provides in-the-moment overlays for increased fieldwork with GPS and other environmental data.

2. YOP (Enhanced Awareness)

Nothing can beat the ability of VR to generate empathy in a very specific content through immersive experiences. E.g. users can "walk" in endangered rainforests or get to dive into coral reefs.

AR-based interactive trails keeps the attention of young audience, mixing education in entertainment.

Enhanced Decision Making

OR Policy Simulators: Policymakers run simulations of what scenarios might result from climate policies.

in AR, means urban planners can visualize sustainable development in 3D and run different scenarios.

Challenges Identified

- Cost Barriers: High price of hardware and software stop many to have access.
- For researchers, training has a long way to go before anything will actually be adopted by educators.

Issues and Concerns:

There is a host of ethical issues regarding data privacy in the digital realm.

Discussion

A Paradigm Shift in Environmental Studies:

The incorporation of VR and AR stands for a paradigm shift in environmental research. These technologies allow:

1. Multisensory Learning

Besides static maps or charts, VR/AR platforms provide dynamic and interactive experiences which enhance the knowledge of the users as compared with conventional learning system.

2. Accessible globally

Virtual/ Augmented experiences can be accessed from anywhere in the world that have what it takes for online.

3. Old stand-bys – Visuals/VR/AR Technologies

Static maps and 2D charts Immersive 3D simulations

Non-Interactive Learning Experience Mixed Interactive, Experiential learning

4. Fringe reach

Wide range of access — the digital society (global from your phone)

Overcoming Challenges

Affordability

Open-source and subsidized hardware can help to reduce the cost in terms of infrastructure and running.

Training

Workshops & online tutorials that provide the needed pedagogical knowledge to educators.

Ethical Frameworks

Formalizing solid protocols will safeguard data privacy and equal access and use systems programmers are accountable for.

Future Directions in Environmental Policy

The Dream of Innovation

1. AI Integration

The combination of VR/AR and AI to expound insights in real-time & predictive models will change climate research 2025 or earlier

2. Longitudinal Studies

Assessing the long-term effect of these technologies on behavior and policy will validate their value.

3. Regionalised solutions

Creating region-based VR/AR applications will solve locality-specific environmental problems, such as desertification in Africa or glacier retreat from the Arctic.

Beyond the Horizon

Environmental Studies will be Technology colliding with empathy in the next era. VR and AR are not tools, they are bridges connecting human experience to the immediacy of ecological urgency.

Conclusion

A Call to Action

VR and AR have the power to change environmental studies. These tools make data easier to see, get people involved, and help us make better choices. This can speed up our progress toward a world that lasts. But to make this happen, we need to work together to solve problems like high costs, lack of know-how, and unequal access.

The Road Ahead

As VR and AR get better, we need to use them in environmental studies in new, fair, and lasting ways. With these tools, we can turn big hard-to-grasp issues into clear pictures. This can push people to act and help keep our planet healthy for years to come.

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INTERDISCIPLINARY SYNERGY FOR SUSTAINABLE DEVELOPMENT: A COLLABORATIVE APPROACH THROUGH HUMANITIES, COMMERCE AND SCIENCE

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Abstract:

Sustainable development is a complex concept that aims to meet present needs without compromising the ability of future generations to meet their own. Traditionally associated with environmental sciences, sustainability has expanded to encompass economic, social, and cultural dimensions. This research explores the potential of a collaborative approach to sustainable development, drawing from humanities, commerce, and science. By integrating the strengths of these disciplines, the study aims to demonstrate how interdisciplinary cooperation can foster innovative solutions to the complex challenges of sustainability.

The Humanities, through the exploration of ethics, philosophy, and cultural understanding, provide a framework for valuing human well-being, social justice, and equitable access to resources. Commerce contributes by examining sustainable business practices, corporate social responsibility, and the role of market forces in promoting long-term environmental stewardship. Science, with its focus on technology and research, offers practical solutions through innovation, environmental protection, and resource management.

This collaborative approach fosters a holistic understanding of sustainable development goals, ensuring that economic progress does not come at the expense of social equity or environmental health. By highlighting case studies where these fields intersect, this research demonstrates the efficacy of cross-disciplinary partnerships in driving sustainable policies and practices. The research highlights that economic progress must align with environmental responsibility and social inclusion to achieve true sustainability. Ultimately, the study aims to establish a comprehensive model for sustainable development goals that integrates human values, economic growth, and scientific advancement to create a more sustainable and equitable world for future generations and to promote holistic progress.

Introduction

The concept of sustainable development emerged prominently with the 1987 Brundtland Report, which defined it as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Over time, this definition has evolved to encompass three interdependent pillars: environmental sustainability, economic viability, and social equity. Achieving these goals necessitates a multidisciplinary approach where humanities, commerce, and science converge to provide comprehensive solutions.

Sustainable development is a concept that encompasses the long-term preservation of the planet's natural resources, the protection of human societies, and the promotion of economic prosperity. It is fundamentally concerned with meeting the needs of the present without jeopardizing the ability of future generations to meet their own needs. While often associated with environmental issues, sustainable development is a multifaceted concept that touches upon economic, social, and cultural dimensions. This paper explores how a collaborative approach, drawing from the Humanities, Commerce, and Science, can provide innovative solutions to the complex challenges of sustainability. Each of these disciplines offers unique insights and perspectives that, when integrated, can drive holistic and effective strategies for achieving sustainable development.

The Role of Humanities in Sustainable Development

1.1 Ethical Foundations and Moral Responsibility

The Humanities encompass disciplines such as philosophy, ethics, history, sociology, anthropology, and cultural studies. While seemingly distinct from the technical aspects of sustainability, the Humanities play a crucial role in shaping the values, beliefs, and social structures that influence human behavior and decision-making. At the heart of sustainable development lies the need for social justice, ethical responsibility, and an understanding of the intricate relationships between individuals, communities, and the environment. By providing a moral and ethical framework, the Humanities guide sustainable development towards equity and long-term environmental stewardship.

Ethical theories such as utilitarianism, deontology, and environmental ethics offer essential guidelines for policymakers and individuals to make decisions that balance human needs with ecological preservation. The concept of "intergenerational justice" underscores the moral obligation to safeguard natural resources for future generations, a principle deeply embedded in philosophical discourse. Thought leaders such as Arne Naess, with his deep ecology theory, advocate for a paradigm shift in values—moving from resource exploitation to stewardship, emphasizing that humans are intrinsically connected to nature rather than separate from it.

1.2 Cultural Awareness and Social Inclusivity

Cultural diversity is a cornerstone of sustainable development. Understanding different cultural perspectives fosters social cohesion, promotes inclusive practices, and enhances community-driven sustainability initiatives. The Humanities facilitate cross-cultural dialogue, helping societies navigate conflicts, embrace diversity, and cultivate a global sense of responsibility. Cultural sensitivity ensures that sustainability efforts are relevant, respectful, and effective in diverse communities.

Cultural studies highlight how societies perceive and engage with sustainability. Indigenous knowledge systems, for instance, emphasize the deep interconnection between humans and nature. These long-standing traditions offer valuable insights into sustainable practices honed over centuries, often aligning with modern conservation principles. By integrating these perspectives, sustainable development becomes more inclusive and adaptable, fostering solutions that are locally relevant and globally impactful.

1.3 Education and Advocacy

Education is a powerful catalyst for sustainable development. Humanities-driven curricula can raise awareness about environmental and social sustainability issues, inspire critical thinking, and empower individuals to become proactive change agents. Literature, art, and media serve as compelling platforms for advocacy, transforming complex sustainability concepts into relatable narratives that resonate with diverse audiences.

Philosophical inquiries into environmental ethics have been particularly influential in shaping sustainability discourse. Questions regarding human responsibility toward nature, non-human life, and future generations are central to ethical considerations. Scholars argue for a shift in values from mere resource consumption to a more conscientious and balanced coexistence with nature.

Furthermore, real-world examples reinforce the importance of integrating traditional wisdom with modern conservation efforts. In India, several tribal communities, such as the Kadars, Garasia, Gond, Apatani and Baiga, actively preserve forests through sustainable practices. These communities exemplify how indigenous stewardship can harmonize ecological conservation with human livelihood, demonstrating effective models of sustainability rooted in cultural traditions.

Key Tribal Contributions to Forest Conservation in India:

- **Sustainable Resource Utilization:** Tribes like the Kadars in South India practice mindful collection of forest products such as honey, firewood, and medicinal herbs, ensuring resources naturally replenish over time.
- **Sacred Groves:** Many tribal communities designate specific forest areas as sacred groves, where logging and other destructive activities are strictly prohibited, helping protect biodiversity and threatened plant species.
- **Rotational Farming:** The Gond and Baiga tribes of Madhya Pradesh practice "Utera" farming, a method where the next crop is sown before harvesting the current one, optimizing soil moisture and ensuring land productivity.

- **Community-Based Conservation:** Some tribal groups have designated portions of forest land as "Community Conserved Areas," managed collectively by local communities, fostering participatory environmental stewardship.
- **Beliefs and Totems:** Traditional tribal beliefs often prohibit the hunting of certain animals, reinforcing wildlife protection through cultural norms and spiritual significance.

By recognizing and integrating such indigenous knowledge systems, sustainable development efforts can be both scientifically robust and culturally grounded. A truly holistic approach to sustainability must blend ethical considerations, cultural awareness, and education, ensuring an equitable and resilient future for all.

The Contribution of Commerce to Sustainable Development

Commerce, often seen as the driving force of economic growth, plays a critical role in shaping sustainable development through the promotion of responsible business practices and the adoption of sustainable economic models. In addition to environmental concerns, commerce also addresses social sustainability. Fair trade, ethical labor practices, and community investment are vital aspects of sustainable business models. By supporting initiatives that prioritize social equity and human rights, businesses can contribute to the creation of more inclusive and just societies.

2.1 Economic Growth and Resource Management

Commerce is the engine of economic development, influencing how resources are produced, distributed, and consumed. Sustainable commerce focuses on creating economic value while minimizing environmental impact and promoting social well-being. This involves adopting practices such as sustainable supply chain management, ethical sourcing, and circular economy models that reduce waste and promote resource efficiency.

The rise of the circular economy is a key development within the field of commerce that supports sustainability. Unlike the traditional linear model of "take, make, dispose," the circular economy emphasizes the reuse, repair, refurbishment, and recycling of materials, thereby reducing waste and the consumption of finite resources. By encouraging companies to rethink the life cycle of products and materials, the circular economy fosters a more sustainable and regenerative approach to business.

2.2 Corporate Social Responsibility (CSR) and Sustainable Business Practices

CSR has become a cornerstone of modern business strategy. Companies are increasingly held accountable for their environmental and social impacts, prompting them to integrate sustainability into their core operations. CSR initiatives may include reducing carbon footprints, supporting community development, and ensuring fair labour practices. Businesses that embrace sustainability often experience enhanced brand reputation, customer loyalty, and long-term profitability.

As key actors in the global economy, businesses are both contributors to environmental degradation and potential agents of positive change. In recent years, the concept of corporate social responsibility (CSR) has gained prominence, pushing companies to consider the social, environmental, and ethical implications of their operations.

One of the most significant contributions of commerce to sustainability is the development of green business practices. This includes the adoption of sustainable supply chains, resource-efficient production methods, and the promotion of environmentally friendly products and services. For example, companies in the renewable energy sector, such as Tesla and Vestas, are playing a pivotal role in reducing global reliance on fossil fuels and advancing clean energy solutions. Similarly, businesses in the fashion industry, such as Patagonia, are increasingly embracing sustainable sourcing, fair trade practices, and waste reduction strategies.

2.3 Sustainable Finance and Green Economics

Sustainable finance involves investing in projects and companies that prioritize environmental, social, and governance (ESG) criteria. Green bonds, impact investing, and socially responsible investing (SRI) are examples of financial mechanisms that support sustainable development. By directing capital towards sustainable ventures, commerce can drive large-scale environmental and social transformations.

3. The Role of Science in Sustainable Development

3.1 Technological Innovations and Environmental Solutions

Science and technology are essential to addressing many of the challenges posed by sustainable development. Science provides the empirical foundation for understanding and addressing sustainability challenges. From renewable energy to sustainable agriculture, waste management, and climate modeling, scientific innovation offers practical solutions to environmental and resource management issues. One of the most significant areas where science contributes to sustainability is in the development of clean technologies. The transition from fossil fuels to renewable energy sources, such as solar, wind, and hydroelectric power, is central to combating climate change and reducing global greenhouse gas emissions.

In addition to energy, scientific advancements are playing a key role in sustainable agriculture. Precision farming, for instance, uses technology to optimize resource use, reduce waste, and increase food production without compromising environmental integrity. Biotechnology is also advancing sustainable agriculture by developing drought-resistant crops and reducing the need for chemical pesticides and fertilizers. These innovations help ensure food security while minimizing the environmental footprint of farming practices.

Furthermore, the field of environmental science has been instrumental in understanding the impacts of human activity on the planet. Research on biodiversity loss, ecosystem degradation, and climate change has led to the development of strategies aimed at mitigating environmental harm. Conservation science, for example, focuses on protecting endangered species and preserving natural habitats, while climate science informs policies and actions related to global warming.

3.2 Evidence-Based Policy Making

Effective sustainability policies rely on scientific data and analysis. Environmental monitoring, climate research, and ecological studies provide critical insights into the state of the planet and the impact of human activities. Science informs policy decisions on issues such as carbon emissions, biodiversity conservation, and water resource management, ensuring they are grounded in factual evidence.

3.3 Public Awareness and Scientific Literacy

Promoting scientific literacy is essential for fostering a society that values and supports sustainable practices. Public understanding of scientific concepts related to climate change, energy conservation, and health risks can drive behavioral changes and encourage community participation in sustainability initiatives.

However, scientific innovation alone is not enough to ensure sustainable development. It is essential that science, commerce, and the humanities collaborate to translate scientific discoveries into practical, ethical, and economically viable solutions. In this way, science serves as the foundation upon which sustainable development can be built, but it must be integrated with social, economic, and cultural considerations to achieve long-term success.

The Need for Interdisciplinary Collaboration

The challenges of sustainable development are inherently complex, spanning environmental, economic, and social domains. To address these challenges effectively, it is crucial to adopt an interdisciplinary approach that combines the strengths of the Humanities, Commerce, and Science. The traditional siloed approach, where disciplines work in isolation, often leads to fragmented solutions that fail to consider the broader implications of sustainability.

For instance, environmental policies that focus solely on technological solutions may overlook the cultural and social dimensions of sustainability, such as public acceptance and behavioral change. Similarly, business practices that prioritize economic growth without considering environmental and social impacts may lead to unsustainable practices in the long term. A collaborative approach ensures that solutions are not only scientifically sound and economically viable but also ethically and socially responsible.

One of the most promising examples of interdisciplinary collaboration in sustainability is the concept of sustainable development goals (SDGs) adopted by the United Nations in 2015. The SDGs emphasize the interconnectedness of economic growth, social inclusion, and environmental protection, and they provide a comprehensive framework for addressing global sustainability challenges. Achieving these goals requires the collective efforts of governments, businesses, communities, and individuals, with contributions from all sectors of society, including the Humanities, Commerce, and Science.

4. Interdisciplinary Synergy: Bridging Humanities, Commerce, and Science

4.1 Integrated Education and Curriculum Development

Educational institutions play a critical role in promoting interdisciplinary approaches to sustainability. Curricula that integrate humanities, commerce, and science encourage students to think critically, understand complex systems, and develop holistic solutions. Programs in sustainability studies, environmental management, and global development often reflect this interdisciplinary model.

4.2 Collaborative Research and Innovation

Cross-disciplinary research fosters innovative solutions to sustainability challenges. For example, addressing climate change requires scientific expertise to understand environmental processes, economic analysis to assess costs and benefits, and ethical considerations to guide policy decisions. Collaborative projects that bring together researchers from diverse fields can generate comprehensive and effective strategies.

4.3 Policy Development and Governance

Sustainable development policies benefit from the integration of ethical principles, economic strategies, and scientific evidence. Policymakers can draw on humanities to ensure social justice and cultural relevance, commerce to promote economic viability, and science to provide empirical support. This holistic approach enhances policy effectiveness and public acceptance.

5. Case Studies of Collaborative Approaches

5.1 The Paris Agreement on Climate Change

The Paris Agreement exemplifies a global effort to combat climate change through interdisciplinary collaboration. Negotiations involved scientific assessments of climate risks, economic analyses of mitigation strategies, and ethical considerations of equity and justice. The agreement's success lies in its ability to balance these diverse perspectives and foster international cooperation.

5.2 Sustainable Urban Development in Copenhagen

Copenhagen's approach to sustainable urban development integrates environmental science, economic planning, and cultural values. The city's focus on renewable energy, green transportation, and inclusive public spaces reflects a comprehensive strategy that addresses environmental, social, and economic dimensions of sustainability.

5.3 Corporate Sustainability at Patagonia

Patagonia, an outdoor apparel company, demonstrates how businesses can lead in sustainability. The company integrates scientific research on environmental impact, ethical principles in corporate governance, and sustainable business practices. Its commitment to environmental activism and sustainable production has set a benchmark for corporate responsibility.

6. Challenges and Opportunities in Interdisciplinary Collaboration

6.1 Communication Barriers and Disciplinary Silos

One of the main challenges in interdisciplinary collaboration is the difference in language, methodologies, and priorities across disciplines. Overcoming these barriers requires effective communication, mutual respect, and a willingness to integrate diverse perspectives.

6.2 Balancing Competing Priorities

Sustainability initiatives often involve trade-offs between economic growth, environmental protection, and social equity. Finding a balance that satisfies all stakeholders can be complex. However, interdisciplinary approaches can help identify synergies and innovative solutions that address multiple objectives simultaneously.

6.3 Opportunities for Innovation and Impact

Despite these challenges, interdisciplinary collaboration offers significant opportunities for innovation and impact. By leveraging the strengths of humanities, commerce, and science, societies can develop resilient systems capable of adapting to changing conditions and emerging threats.

Conclusion

Sustainable development is a multifaceted challenge that requires a collaborative approach across disciplines. The humanities provide ethical guidance and cultural understanding; commerce drives economic growth and resource management; and science offers technological solutions and empirical insights. By fostering interdisciplinary synergy, we can create comprehensive strategies that promote environmental sustainability, social equity, and economic prosperity. This holistic model is essential for addressing the complex and interconnected challenges of the 21st century, ensuring a sustainable future for generations to come.

Ultimately, sustainable development is not a goal that can be achieved by any one discipline alone. It requires the combined efforts of all sectors of society, working together to create a world that is not only prosperous but also just, equitable, and environmentally resilient.

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ISRO'S ROLE IN SUSTAINABLE DEVELOPMENT: A JOURNEY FROM SPACE EXPLORATION TO SOCIETAL IMPACT

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Abstract

The Indian Space Research Organization (ISRO) has played a pivotal role in the development of India's space capabilities and has significantly contributed to the country's sustainable development. Founded in 1969, ISRO's mission has always been to harness space technology for improving the socio-economic status of the country.

Over the years, ISRO has not only contributed to global space exploration but also applied its technological advancements to Earth's sustainability challenges, such as climate monitoring, disaster management, and environmental conservation. This paper provides a comprehensive review of ISRO's contributions, focusing on its role in promoting sustainability through space-based applications.

It also discusses various orbital types, such as Low Earth Orbit (LEO), Medium Earth Orbit (MEO), Geosynchronous Orbit (GEO), and others, that ISRO employs for different missions. Additionally, the paper covers the different launch vehicles developed by ISRO, including the Satellite Launch Vehicle (SLV), Polar Satellite Launch Vehicle (PSLV), Geosynchronous Satellite Launch Vehicle (GSLV), and the most powerful, GSLV Mk III.

The paper traces the history of Indian satellites from the launch of Aryabhata in 1975 to the recent advancements in missions like Chandrayaan-2 and the Mars Orbiter Mission (Mangalyaan). By examining these technological developments, ISRO's contributions to sustainable development are outlined, highlighting how its space-based solutions have addressed challenges in sectors such as agriculture, communications, disaster response, and environmental protection.

1. Introduction

The Indian Space Research Organization (ISRO) was founded in 1969 by Dr. Vikram Sarabhai with the goal of advancing India's space technology to aid national development. Over the decades, ISRO has achieved remarkable milestones, from launching India's first satellite, Aryabhata, in 1975 to establishing itself as a key player in the global space community. ISRO's journey is not just about space exploration, but also about utilizing space technology to tackle sustainable development challenges such as climate change, disaster management, and agriculture. ISRO's initiatives in these areas have positively impacted social, economic, and environmental sustainability, positioning India as a leading force in space-based applications for global development.

2. History of Indian Satellites

ISRO's satellite program began in earnest with the launch of Aryabhata in 1975, India's first satellite, which was launched with Soviet assistance. Aryabhata was designed for scientific studies, including X-ray astronomy and solar research. Over the years, ISRO has developed and launched several other satellites, gradually becoming self-reliant in satellite technology.

Table 1: Key Indian Satellites from 1975 to 2024

Year	Satellite Name	Purpose
1975	Aryabhata	Scientific research in space and solar studies
1983	Rohini	Earth observation and remote sensing
2003	INSAT-3C	Communications, broadcasting, and weather data
2008	Chandrayaan-1	Lunar exploration, first Moon mission
2013	Mangalyaan (Mars Orbiter Mission)	Interplanetary mission to Mars
2023	Chandrayaan-2	Lunar exploration and scientific data collection

Figure 1: Illustrative image of Aryabhata, India's first satellite launched in 1975

3. ISRO's Contribution to Sustainable Development

ISRO's space technology has contributed to sustainable development in several crucial sectors, such as agriculture, climate monitoring, disaster management, and communication. Through the use of Earth observation satellites, ISRO provides real-time data that is essential for managing natural resources, monitoring climate change, and supporting agriculture. These contributions not only benefit India but also assist other countries in meeting their sustainability goals.

Agriculture:

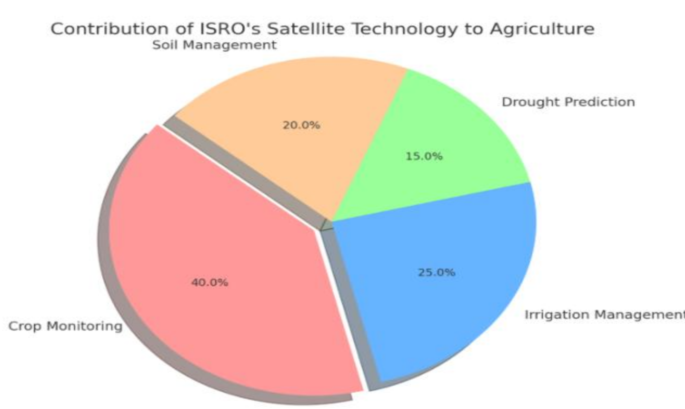
ISRO's remote sensing satellites, such as Oceansat-1, Cartosat-2, and RISAT, provide valuable data for crop health monitoring, soil moisture levels, and early warning systems for droughts. This data is used to enhance agricultural productivity, improve food security, and make farming practices more sustainable.

Crop Monitoring: 40%

Irrigation Management: 25%

Drought Prediction: 15%

Soil Management: 20%



Pie Chart 1: *Contribution of ISRO's Satellite Technology to Agriculture*

Disaster Management:

ISRO's Earth observation satellites play a crucial role in disaster management by providing real-time data to predict and monitor natural disasters like floods, cyclones, and earthquakes. The INSAT and GSAT satellites help in issuing early warnings, thereby saving lives and minimizing damage.

Environmental Monitoring:

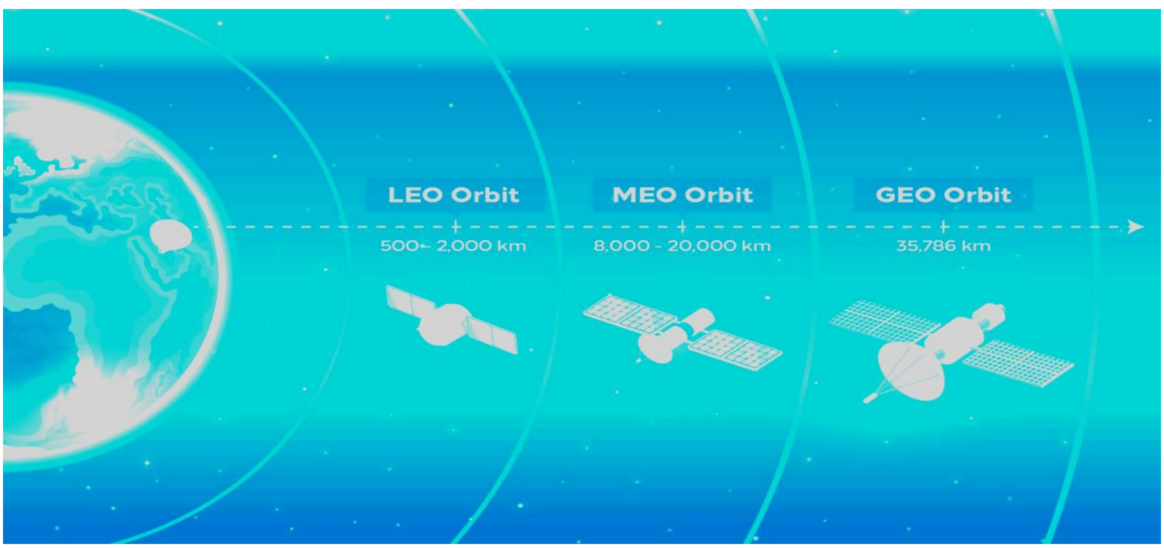
ISRO has contributed to monitoring environmental changes such as deforestation, pollution, and water resource management. Satellites like Cartosat-2 and RISAT provide detailed images of forest cover, water bodies, and urban sprawl, which help in environmental protection and sustainability initiatives.

"YUVIKA: ISRO's Initiative to Foster Interest in Space Science and Technology Among Youth"

Indian Space Research Organization is organizing a special programme for School Children called "Young Scientist Programme" "YUva VIgyani KAryakram", YUVIKA, to impart basic knowledge on Space Technology, Space Science and Space Applications to the younger students in emerging trends in space science and technology amongst the youngsters, who are the future building blocks of our nation. ISRO has chalked out this programme to "Catch them young". The programme is also expected to encourage more students to pursue in Science, Technology, Engineering and Mathematics (STEM) based research /career

4. Types of Orbits Used by ISRO Satellites

ISRO's satellites are placed in various orbits depending on the mission objectives. The following are the primary types of orbits used by ISRO:



ISRO has launched satellites into various types of Earth orbits that contribute to sustainable development by supporting environmental monitoring, communication, navigation, and disaster management. The key types of orbits used by ISRO for such purposes are:

1. Low Earth Orbit (LEO)

Altitude: 180 km – 2,000 km

Contribution to Sustainable Development:

LEO is used for Earth observation satellites, which provide high-resolution imagery for climate monitoring, agriculture, disaster management, and environmental protection.

Example: **RISAT (Radar Imaging Satellite)** series, **Cartosat** series, which provide data for SDG 13 (Climate Action), SDG 2 (Zero Hunger), and SDG 11 (Sustainable Cities and Communities).

2. Medium Earth Orbit (MEO)

Altitude: 2,000–35,786 km

Contribution to Sustainable Development:

MEO satellites are typically used for navigation and regional communication.

Example: **NavIC (Navigation with Indian Constellation)**, ISRO's regional satellite navigation system, contributes to SDG 9 (Infrastructure) by providing accurate navigation for transportation and logistics.

3. Polar Sun-Synchronous Orbit (SSO)

Altitude: 600–800 km (typically in LEO)

Contribution to Sustainable Development:

In SSO, satellites pass over the same region of Earth at the same local solar time, making them ideal for consistent Earth observation, environmental monitoring, and resource management.

Example: **EOS (Earth Observation Satellite)** series and **Oceansat** satellites, which contribute to SDG 14 (Life Below Water), SDG 15 (Life on Land), and SDG 13 (Climate Action).

4. Geostationary Orbit (GEO)

Altitude: ~35,786 km

Contribution to Sustainable Development:

Satellites in GEO stay fixed over a specific location on Earth. These are primarily used for communication, weather monitoring, and broadcasting services.

Example: **INSAT** and **GSAT** series, which contribute to SDG 9 (Industry, Innovation, and Infrastructure) and SDG 11 (Sustainable Cities and Communities) through weather forecasting and telecommunication services.

5. Geosynchronous Transfer Orbit (GTO)

Altitude: Transition orbit that takes satellites into higher orbits (GEO).

Contribution to Sustainable Development:

Satellites are launched into GTO before being transferred to GEO for communication and meteorological purposes.

Example: **GSAT** and **INSAT** series, which contribute to SDG 9 (Infrastructure) and SDG 13 (Climate Action) through weather prediction and communication services.

6. Highly Elliptical Orbit (HEO)

Contribution to Sustainable Development:

Though ISRO has not primarily focused on HEO for many of its missions, this type of orbit can be used for long-duration Earth observation and communication over polar regions, which can aid in Arctic and Antarctic climate monitoring (supporting SDG 13: Climate Action).

ISRO's use of these orbits supports sustainable development goals by providing essential data and services for environmental monitoring, disaster management, communication, and infrastructure development.

ISRO's Launch Vehicles

ISRO has developed a range of launch vehicles to send satellites into various orbits. The development of these vehicles has been a major achievement in terms of technological innovation and self-reliance.

ISRO (Indian Space Research Organisation) has developed a series of launch vehicles to send satellites and payloads into different orbits and support various missions, including communication, Earth observation, navigation, and interplanetary exploration. Here is a detailed overview of ISRO's key launch vehicles:

1. Satellite Launch Vehicle (SLV)

- **Introduction:** India's first experimental satellite launch vehicle.
- **First Flight:** 1980 (SLV-3)
- **Payload Capacity:** ~40 kg to Low Earth Orbit (LEO)
- **Purpose:** Primarily used for launching small payloads into low Earth orbit.
- **Notable Achievements:** Launched **Rohini-1** satellite, India's first satellite placed into orbit by an indigenous rocket.

2. Augmented Satellite Launch Vehicle (ASLV)

- **Introduction:** Designed to overcome the limitations of SLV.
- **First Flight:** 1987
- **Payload Capacity:** ~150 kg to LEO
- **Purpose:** Small satellite launches to low Earth orbit.
- **Notable Achievements:** Carried the **SROSS** series of satellites for remote sensing and other applications.

3. Polar Satellite Launch Vehicle (PSLV)

- **Introduction:** The workhorse of ISRO for launching satellites into polar and geosynchronous orbits.
- **First Flight:** 1993
- **Payload Capacity:**
  - Up to 1,750 kg to Sun-Synchronous Polar Orbit (SSO)
  - Up to 3,800 kg to Geosynchronous Transfer Orbit (GTO)
- **Purpose:** Launching Earth observation satellites into Sun-synchronous polar orbits and communication satellites to GTO.
- **Notable Achievements:**
  - Launched **Chandrayaan-1** (India's first Moon mission) in 2008.
  - Launched **Mars Orbiter Mission (Mangalyaan)** in 2013.
  - Launched **104 satellites in a single mission** in 2017, a world record.

4. Geosynchronous Satellite Launch Vehicle (GSLV)

- **Introduction:** Developed to launch heavier communication satellites into geosynchronous transfer orbit (GTO).
- **First Flight:** 2001
- **Payload Capacity:**
  - Up to 2,500 kg to GTO
  - Up to 5,000 kg to Low Earth Orbit (LEO)
- **Purpose:** Primarily for launching communication satellites.
- **Notable Achievements:** Launched the **GSAT** series of communication satellites.

- **Variants:** GSLV Mk I, Mk II, and Mk III (Mk III has higher payload capacity).

5. GSLV Mk III (LVM-3)

- **Introduction:** ISRO's most powerful launch vehicle, capable of carrying heavy payloads into space.
- **First Flight:** 2014 (Experimental), 2017 (Operational)
- **Payload Capacity:**
  - Up to 4,000 kg to GTO
  - Up to 10,000 kg to LEO
- **Purpose:** Launching large communication satellites, interplanetary missions, and crewed missions (as part of ISRO's **Gaganyaan** program).
- **Notable Achievements:**
  - Launched **Chandrayaan-2** (Moon mission) in 2019.
  - Used in **Gaganyaan** (India's crewed space mission).

6. Small Satellite Launch Vehicle (SSLV)

- **Introduction:** Developed to meet the growing demand for launching small satellites, especially for commercial purposes.
- **First Flight:** 2022 (SSLV-D1)
- **Payload Capacity:**
  - Up to 500 kg to Sun-Synchronous Polar Orbit (SSO)
  - Up to 300 kg to Geosynchronous Transfer Orbit (GTO)
- **Purpose:** Low-cost, quick turnaround launch vehicle designed to carry small satellites into LEO and SSO.
- **Notable Achievements:** First SSLV mission launched **EOS-02** (Earth Observation Satellite).

7. Reusable Launch Vehicle (RLV)

- **Introduction:** ISRO's experimental vehicle for developing reusable space technology.
- **First Flight:** 2016 (RLV-TD HEX-01, a scaled-down version)
- **Payload Capacity:** Still in development, aiming to reduce the cost of launching satellites.
- **Purpose:** To develop a fully reusable space vehicle for launching satellites with reduced costs and increased efficiency.
- **Notable Achievements:** Successfully conducted multiple test flights, including the landing demonstration and hypersonic flight experiment.

Comparative Table of ISRO's Launch Vehicles:

Launch Vehicle	First Flight	Payload Capacity	Orbit Type	Notable Missions
SLV	1980	40 kg to LEO	LEO	Rohini-1
ASLV	1987	150 kg to LEO	LEO	SROSS series
PSLV	1993	1,750 kg to SSO,	SSO, GTO	Chandrayaan-1, Mars

		3,800 kg to GTO		Orbiter Mission, Cartosat
GSLV	2001	2,500 kg to GTO, 5,000 kg to LEO	GTO, LEO	GSAT series
GSLV Mk III (LVM-3)	2017	4,000 kg to GTO, 10,000 kg to LEO	GTO, LEO	Chandrayaan-2, Gaganyaan
SSLV	2022	500 kg to SSO, 300 kg to GTO	SSO, GTO	EOS-02
RLV	In development	Reusable vehicle	LEO, GTO (future goal)	Test flights

These launch vehicles represent the backbone of ISRO's efforts in space exploration and satellite deployment, contributing to both India's space missions and global space applications.

6. Future Prospects and Conclusion

ISRO’s continued advancements in space technology promise even greater contributions to sustainable development. The future missions such as Gaganyaan (India’s first crewed mission), Chandrayaan-3 (Moon exploration), and Aditya-L1 (solar mission) will further enhance India’s capabilities in space technology, while continuing to address environmental, agricultural, and communication challenges on Earth.

"The Gaganyaan Mission: India's Journey to Human Spaceflight"

The Gaganyaan project aims to launch a 3-member crew into a 400 km orbit for a 3-day mission and safely return them to Earth, landing in Indian sea waters. It leverages Indian industry, academia, and international technology.

In conclusion, ISRO’s technological advancements, particularly in satellite systems and launch vehicles, have been crucial for India’s growth and global sustainability efforts. As the agency moves towards further space exploration and increased international cooperation, its role in achieving the UN’s Sustainable Development Goals (SDGs) will continue to grow.

The paper concludes by discussing ISRO's future trajectory, its potential for further advancements, and its continued importance in global sustainability efforts.

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ENHANCING BIO-PRESERVATION FOR SUSTAINABLE DEVELOPMENT EXECUTED WITH THE HELP OF PROBIOTIC LACTOBACILLUS

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Abstract:

Food preservation has always been a big problem, hence several methods have been devised to extend food's shelf life, such as non-thermal methods, heat treatments, and chemical additions. These days, bio preservation is increasingly acknowledged as a sustainable method that may effectively replace food preservation. Bio preservation is the process of using controlled microbes or their metabolites to promote food safety and shelf life. The use of chemical preservatives may be replaced by this biological approach. Lactic acid bacteria are the most crucial application in food bio preservation. numerous studies have demonstrated that lactic acid bacteria can neutralize mycotoxins.These characteristics are significant as they open up the possibility of replacing chemical and physical preservation methods with a biological approach that utilizes lactic acid bacteria and their metabolites. The paper further examines how biopreservation can influence the sensory characteristics and the food quality itself.

Keywords: Probiotic, Lactobacillus, Bio preservation, Shelf life

Introduction:

The term probiotic refers to non-harmful living microorganisms that are believed to provide health benefits to humans and animals when consumed in sufficient amounts (1). The most commonly used genera are bacteria, particularly lactic acid bacteria (LAB), with *Bifidobacterium* and *Lactobacillus* being the most prominent (2). *Lactobacilli* are part of the LAB group, which is a diverse collection of catalase-negative, Gram-positive, non-spore-forming bacteria that can be either anaerobic or aerotolerant. They are typically coccobacilli or rod-shaped and are primarily known for producing lactic acid as the main byproduct of carbohydrate fermentation (3). Strategies for food bio preservation to extend shelf life while ensuring safety, and health improvement initiatives. Lactic acid bacteria (LAB) strains isolated from household curd have demonstrated intrinsic antimicrobial properties against various gastrointestinal pathogens. The antagonistic effects of curd bacteria have been observed against *E. coli, Bacillus subtilis, Staphylococcus aureus, B. cereus, Salmonella typhi, Shigella* and *Pseudomonas* aeruginosa. Curd can serve as a potential food bio preservative for various food products, because curd is a most valuable source for probiotic bacteria is *Lactobacillus* (4).

Review of literature:

Probiotics have been used since before microorganisms were discovered. Egyptian hieroglyphs show fermented milk products, and Tibetan nomads have long preserved milk for their lengthy travels by using fermented yak milk (5). The health benefits of eating fermented milk products were first recognized by scientists in the 1800s, but the causes of these benefits were not then known. Although Louis Pasteur recognized the yeasts and bacteria that contribute to fermentation, he did not link these microorganisms to any particular health advantages (6). When it was found that the bacteria employed as yogurt starters, *Lactobacillus bulgaricus* and *Streptococcus thermophilus*, could not colonize the human body, the notion that yogurts were the best source of probiotics was called into question in the 1930s (7).

Increased consumer demand for natural food products, free from chemicals, has opened the eyes of researchers to look into the possibility of bio-preservatives as alternatives to synthetic food additives. Among such bio-preservatives is curd, or yogurt, which has gained significant promise because of its microbial and biochemical profiles. This review discusses the scientific basis, applications, and potential of curd in food preservation (8). In the 1930s, the belief that yogurts were the best source of probiotics was challenged when it was discovered that the bacteria used as yogurt starters, *Lactobacillus bulgaricus* and *Streptococcus thermophilus*, could not colonize the human intestine. Instead, a different strain, *L. acidophilus*, was introduced to milk, as it does not produce high levels of acid that cause curdling and was found to effectively colonize the human colon (9). *Lactobacillus* has been used as a probiotic in yogurt and curd for many years. The role of Lactic acid bacteria (LAB) in agriculture, nutrition, and clinical practice is diverse. LAB naturally produces bacteriocins that help in food bio preservation, acting as a defence mechanism against pathogens and spoilage microorganisms. Probiotics, which are beneficial microorganisms, provide health advantages when consumed in adequate amounts. Similar to LAB, probiotics support and enhance the human immune system (7).

Different applications with potential for curd preservation have been shown to be productive. Against dairy products such as cheese and butter, curd prevents spoilage while at the same time increasing probiotic content (8). On meat and poultry, curd-based marinades reduce the microbial load; increase tenderness; and flavour, thus providing a natural substitute for a number of chemical preservatives (9). Similar results are observed for fruits and vegetables coated with curd, as they show a decrease in microbial spoilage and increased shelf life. Probiotic beverages produced from curd provide preservation along with health benefits. These applications respond to the consumer's increasing demand for clean-label and chemical-free food products while improving gut health by delivering probiotics (10).

Lactobacillus has also proven to have an excellent biocontrol capacity in farmlands with a strong impact on fruit diseases, caused by fungal, bacterial, and viral microorganisms. With the release of lactic acid, bacteriocins, and hydrogen peroxide as antimicrobial compounds, *Lactobacillus* represses detrimental pathogens in a totally natural and safe alternative to conventional pesticides (11). Lactic Acid Bacteria (LAB) improve aeration, boost nutrient solubility, improve soil fertility, and facilitate seed germination. They also contribute to neutralizing toxic gasses and reducing a variety of abiotic stressors. The diverse group of Gram-positive bacteria known as LAB can be spherical or rod-shaped, are catalase-negative, and do not generate spores. Because they are safe for both human and animal consumption, LAB has been categorized as GRAS (Generally Recognized as Safe) by the Food and Drug Administration, making them appropriate for commercial use (12).

The application of *Lactobacillus* as a biocontrol agent is based on its ability to outcompete harmful microorganisms for nutrients and space on the fruit surface, as well as its production of various antagonistic metabolites. These antimicrobial substances could inhibit the growth of pathogens that cause diseases, such as Gray Mold, anthracnose, and bacterial spot, among others, and are commonly associated with fruits such as grapes, apples, and tomatoes. Studies have shown that *Lactobacillus* is effective in the reduction of severity of these diseases, thus enhancing fruit quality and shelf life (13).

For instance, species of *Lactobacillus* have been successfully used to control fungal infections on grapes, in which the production of lactic acid by the bacterium lowers the pH of the fruit surface and makes it inhospitable to fungal growth. Furthermore, production of bacteriocins by *Lactobacillus* strains has been established to inhibit the growth of specific pathogens, such as Botrytis cinerea, the Gray Mold causative agent. The use of *Lactobacillus* has also been reported to be an effective postharvest treatment, extending the shelf life of fruits by reducing spoilage caused by bacterial infections (14).

One of the significant advantages of using *Lactobacillus* for biocontrol is its safety for humans, animals, and the environment. Unlike chemical pesticides, *Lactobacillus* is a naturally occurring microorganism and poses no toxicity to non-target organisms. Furthermore, its use aligns with the growing demand for sustainable agricultural practices that minimize the environmental impact of farming. This makes *Lactobacillus* a desirable choice for organic farming (7).

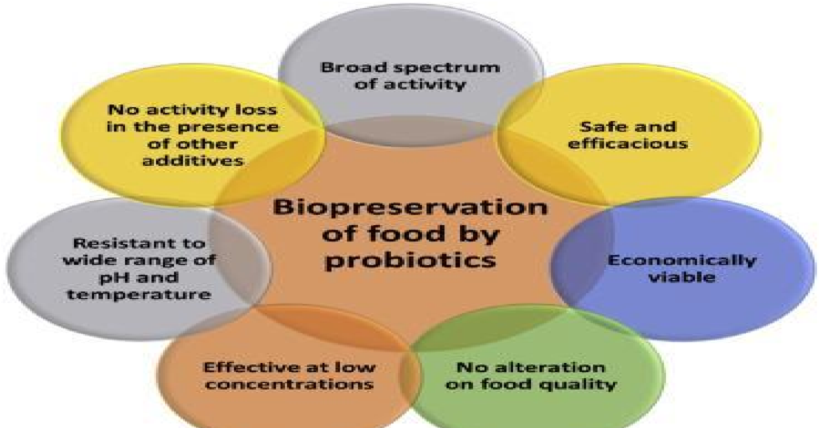

Fig 1 : The role of probiotics in the biopreservation of food

While *Lactobacillus* presents great promise, applying it as a biocontrol agent is not without challenges. The foremost challenge would be its stability and effectiveness under several environmental conditions. *Lactobacillus* strains are often less effective in extreme weather or when applied to fruits that have not been handled and stored properly. Further, large-scale fruit production poses a great challenge in the scalability of *Lactobacillus*-based biocontrol systems (15). Another challenge facing the widespread adoption of *Lactobacillus* in agriculture is regulatory issues surrounding the approval and commercialization of biocontrol agents. Despite all these challenges, the future of *Lactobacillus* as a biological control agent in fruit production appears bright. Ongoing research is focusing on overcoming these limitations through genetic modification and better application techniques for more robust strains. This could be integrated with other biocontrol agents and agricultural practices for further enhancing its efficacy and providing a sustainable solution to fruit diseases . As the demand for sustainable agricultural practices increases, the application of *Lactobacillus* in integrated pest management systems is going to be one of the useful tools for fruit growers looking for environmentally friendly alternatives to chemical pesticides (14, 15).

Discussion:

Lactobacillus species are increasingly recognized as effective natural preservatives since they can prevent spoilage and pathogenic microorganisms through lactic acid production, antimicrobial compounds such as bacteriocins, and competitive exclusion. Such probiotics are commonly used for preserving fermented foods, including dairy products, vegetables, and meats, resulting in longer shelf life and higher safety (16). One widely used bio preservation method is fermentation. Curd is an excellent choice among fermented milk products for isolating probiotic *Lactobacilli*, serving as an effective vehicle for delivering these beneficial bacteria to consumers. Various curd *Lactobacilli*, such as *L. fermentum* and *L. casei*, have been identified through physiological and biochemical characterization. Additionally, a chick isolate of *L. fermentum* was identified using phenotypic characterization. *Lactobacillus probiotics* from curd act as effective bio preservatives due to their microbial activity. In curd, *Lactobacillus* naturally grows through fermentation, making it a sustainable source of probiotic *Lactobacillus* for bio preservation (17).

The application of *Lactobacillus* as biopreservatives has significant advantages over synthetic preservatives and could be very appealing. Some drawbacks that come in the form of limited antimicrobial activity, temperature sensitivity, and competition with microbes limit their applications effectively. Continued research in strain optimization and combined preservation (18). Increased consumer demand for natural food products, free from chemicals, has opened the eyes of researchers to look into the possibility of bio-preservatives as alternatives to synthetic food additives. Among such bio-preservatives is curd, or yogurt, which has gained significant promise because of its microbial and biochemical profiles. This review discusses the scientific basis, applications, and potential of curd in food preservation (19).

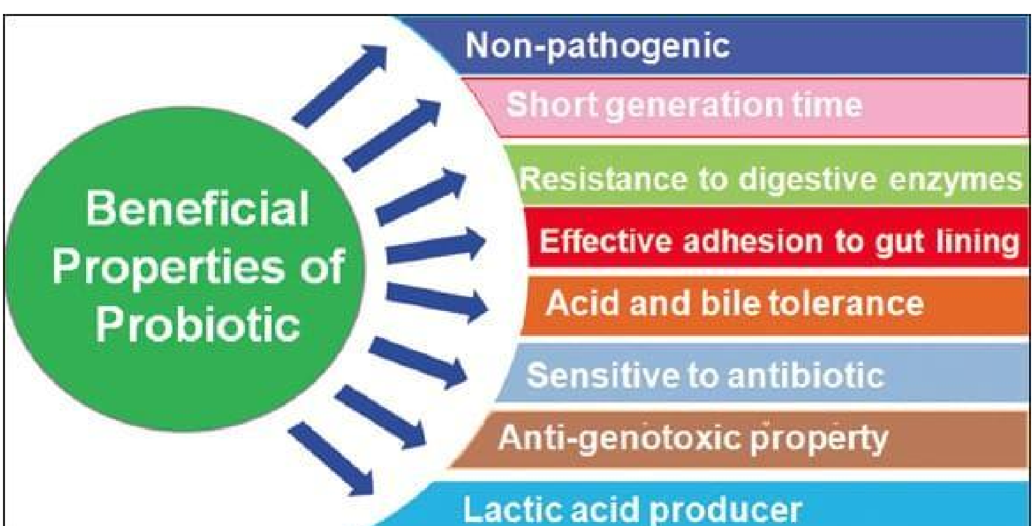

Fig 2 : The beneficial properties of probiotics

Conclusion:

Curd is an eco-friendly and low-energy food made from locally sourced milk and cultures, made through traditional methods. It contains helpful bacteria like *Lactobacillus, Lactobacillus* bio-preservatives arise from their naturally safe and healthy properties, which produce acids and natural chemicals that stop harmful bacteria from growing. Curd is full of nutrients, including probiotics, vitamins, and minerals, making it good for both preserving food and improving health. It keeps food safe hence making them the best alternatives for synthetic preservatives. Further improvement of strains and development of combined preservation methods will increase their applicability to food products.

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PHYTOCHEMICAL ANALYSIS & ANTIMICROBIAL ACTIVITY OF LEAF EXTRACT OF AVICENNIA ALBA COLLECTED FROM CHINCHANI-TARAPUR VILLAGE, PALGHAR, MAHARASHTRA

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Abstract:

Mangroves are best, not waste. *Avicennia alba* is an example of mangroves. As population and urbanization increases, mangroves present in the coastal region are destroyed by considering it as a waste. But these mangroves play an important role in environmental sustainability.

To determine their importance, phytochemical analysis of leaves extract of *Avicennia alba* prepared in five different solvents that is distilled water, ethanol, methanol, chloroform and petroleum ether was carried out. There is presence of alkaloids, flavonoids, tannins, phenols, terpenoids, saponin, steroids, oxalic acid, glycosides, proteins & carbohydrates in all five extracts.Only anthraquinone was absent. As use of antibiotics increases day by day, the majority of bacteria become resistant to antibiotics. Therefore it is necessary to find alternatives to antibiotics. Therefore, antimicrobial activity of leaves extract of *Avicennia alba* was done against gram positive (*Staphylococcus aureus*) and gram negative (*Escherichia coli)* by agar cup method. Extract prepared in distilled water, ethanol, methanol & chloroform were highly effective against gram positive organisms as compared to gram negative organisms. Out of five extracts, methanolic extract was more effective against both types of microorganisms.

Key words: Avicennia, Phytochemicals, Antimicrobial activity.

Introduction:

Avicennia alba is an example of black mangrove and it belongs to the family Acanthaceae(Mitra S.et.al 2022).They mostly found the intertidal areas between land and sea of tropical and subtropical regions where they play an important role in environment sustainability. They are evolutionarily adapted to combat against hostile environmental conditions such as low oxygen, high salinity, and temperature(Vidya Padmakumar 2022). The adaptive features are endowed with novel secondary metabolic pathways and bioactive compounds to sustain in harsh conditions. The novel metabolites are a rich source of the wide range of bioactive compounds and natural products. It includes terpenoids, alkaloids, phenolics, saponins, flavonoids, and steroids. The bioactive and natural compounds may serve as therapeutic precursors and industrial raw materials. To date, several mangroves' plants have been examined and recognized as a potential source of novel natural products for exploitation in medicine. In fact, most of isolated compounds are novel and showed promising biological activities such as gastroprotective, cytotoxic, antioxidant, antibacterial, antifungal, antiviral, enzyme activation and inhibition, immunosuppressive, anti-inflammatory, antifeedant effects. (N. Dhabhate,2018).

Mangrove species with medicinal values are frequently used as herbal remedies by local communities in some countries including India. Traditionally, mangrove plants have been used medicinally in diverse cases like to treat infections, relieve pain and purify blood and as antioxidants. Avicennia alba bark and seeds are used as a fish poison and resin used in birth control, ulcer treatment, skin diseases and also used to cure tumors (Surya Shekhar Das, 2020).

As the population increases day by day, Mangrove forests are used for coastal development, agriculture, industrial development and for dumping garbage by considering it as a waste land. Therefore it is necessary to determine its constituents which are very important in medicines & industries. Due to the increased use of antibiotics, bacteria become resistant to antibiotics. Thus, it is necessary to find alternatives to antibiotics.Mangroves may work as an alternative to antibiotics in future.

Materials & Methods:

Sample Collection & processing : Leaves of *Avicennia alba* were from Chinchani Tarapur village (located at 19.87°N & 72.7°E),Taluka/ District- Palghar, Maharashtra, India.Leaves were washed & shed dried at room temperature.Dried leaves were grinded to fine powder.

Extract preparation: Extracts were prepared by using 15 grams of dried powder & 300 ml of solvents (Distilled water, methanol,ethanol, chloroform & Petroleum ether), through soxhlet extraction method.Then extracts were dried by evaporation & stored in refrigerator for further use.

Phytochemical analysis: Phytochemical analysis of five extracts was carried out by standard method (Shaikh and Patil, 2020).

1. Alkaloids: 1ml of extract was mixed with 1% HCL. Heated gently and added a few drops of Wagner's reagent. Development of reddish brown precipitate indicates positive test.
2. Flavanoids: 1 ml of extract was mixed with a few drops of 10% lead acetate solution. Formation of yellow coloured precipitate indicates presence of flavonoids.
3. Tannins & Phenols: 1 ml of extract was mixed with 5% lead acetate solution. Development of dark green / bluish black colour indicates positive test.
4. Terpenoids: 2ml chloroform was mixed with 5mL plant extract, (evaporated on water bath). Add 3mL of conc. H_2SO_4 (boiled on water bath), formation of a grey coloured solution indicates presence of terpenoids.
5. Saponins: 1 ml of extract was mixed with 1 ml of distilled water. Kept in a water bath. Persistence of froth indicates presence of saponins.
6. Steroids: Salkowski test was performed in which 1ml of extract mixed with 2 ml of chloroform & 2 ml of conc. H_2SO_4. If chloroform layer appear red & acid layer shows greenish yellow fluorescence, steroids are present.
7. Glycosides:1 ml of extract mixed with glacial acetic acid , few drops of 5 % $FeCl_3$ & conc. H_2SO_4. Formation of Reddish brown colour at junction of two liquids indicates presence of glycosides.
8. Oxalic acid: 1ml of extract was mixed with 1% $KMnO_4$ & dilute H_2SO_4. The disappearance of $KMnO_4$ colour indicates the presence of Oxalic acid.
9. Anthraquinones: Borntrager's test was performed in which 1 ml of extract was mixed with 5 ml of Chloroform. Then it was filtered. Filterate was mixed with equal volume of 10% ammonia solution. Development of pink/ violet/ red colour indicates presence of anthraquinone.
10. Proteins & amino acids: Extract was mixed with 5 % $CuSO_4$ & 0.5 ml Folin Ciocalteu reagent. Purple colour indicates presence of proteins.
11. Carbohydrates: 1 ml of extract was mixed with Benedict's reagent. Kept in a boiling water bath for 10-15minutes. Development of yellow/ orange/ red precipitate indicates the presence of carbohydrates.

Antimicrobial activity: Agar cup method was performed to determine antimicrobial activity of plant extracts.Gram positive culture *Staphylococcus aureus* (MTCC 96) & Gram negative culture Escherichia coli (MTCC 739) were used.Culture was swabbed on sterile Muller & Hinton agar. Wells were punched on the media by using Sterile cork borers. 0.1 ml of leaf extracts were added in the wells. Plates were kept for prediffusion for 30 minutes at 4°C & then incubated at 37°C for 24 hours.Solvents used for extract preparation were run as controls. Zone of inhibition was measured after incubation.

Results & Discussions:

Phytochemical analysis & antimicrobial activity of five extracts *Avicennia alba* prepared in distilled water, methanol, ethanol, chloroform & petroleum ether was performed. The results obtained are presented in table 1 & 2 respectively. There is presence of alkaloids, flavonoids, tannins, phenols, terpenoids, saponin, steroids, oxalic acid, glycosides, proteins, amino acids & carbohydrates in all five extracts.Only anthraquinone was absent. R A

Zerubabel Michael (2022) has reported that chloroform and methanolic extracts of A. alba stem and leaves collected from Corangi mangrove forests, Kakinada, Andhra Pradesh, India possessed different phytochemical constituents like terpenoids, flavonoids, glycosides, carbohydrates, alkaloids and tannins. Surya Shekhar Das (2020) from West Bengal, India showed that Avicennia alba methanolic extract contains alkaloids, phenolics, flavonoids, tannins, diterpenes, triterpenes, sterols, saponins and carbohydrates but lacks glycosides, proteins and reducing sugars. Aqueous, methanolic, ethanolic & chloroform extract showed a zone of inhibition against *S.aureus*.While aqueous, methanolic & ethanolic extract showed a zone of inhibition against *E.coli*. Extract prepared in distilled water, ethanol, methanol & chloroform were highly effective against gram positive organisms as compared to gram negative organisms.Varahalarao Vadlapudi et. al. (2009) from Andhra Pradesh, India have reported Methanolic extracts showed the most significant Zone of inhibition against Gram positive S. mutans. Out of five extracts, methanolic extract was more effective against both types of microorganisms.

Table1: Phytochemical analysis of *Avicennia alba* extracts.

Sr. No.	Phytocemical	*Avicennia alba*				
		Aqueous Extract	Methanolic Extract	Ethanolic Extract	Chloroform Extract	Petroleum Ether extract
1	Alkaloids	+	+	+	+	+
2	Flavonoids	+	+	+	+	+
3	Tannins & Phenols	+	+	+	+	+
4	Terpenoids	+	+	+	+	+
5	Saponins	+	+	+	+	+
6	Steroids	+	+	+	+	+
7	Oxalic acid	+	+	+	+	+
8	Glycosides	+	+	+	+	+
9	Anthroquinones	-	-	-	-	-
10	Proteins & Amino acids	+	+	+	+	+
11	Carbohydrates	+	+	+	+	+

Note: ‘+’ indicated Present ; ‘-’ indicated Absent

Table 2: Antimicrobial Activity of *Avicennia alba* extracts.

Sr. No.	*Avicennia alba* extract	Zone of Inhibition (in mm)	
		S.aureus	*E.coli*
1	Aqueous	5 mm	3 mm
2	Methanolic	7 mm	7 mm
3	Ethanolic	5 mm	4 mm

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4	Chloroform	4 mm	-
5	Petroleum ether	-	-

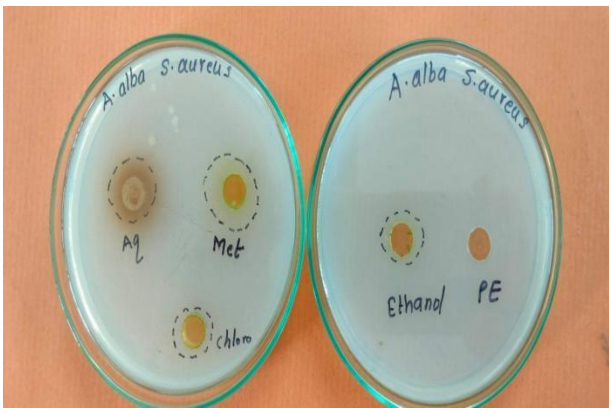

Figure 1: **Antimicrobial activity of *Avicennia alba***

Extracts against *S. aureus*

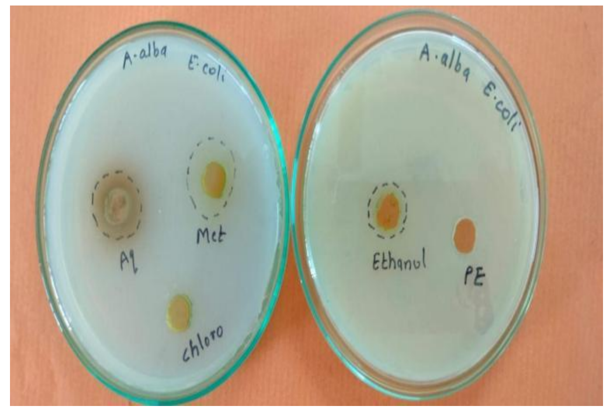

Figure 2: **Antimicrobial activity of *Avicennia alba***

Extracts against *E.coli*

Conclusion: Present study showed that Aqueous, methanolic, ethanolic, chloroform & petroleum ether extract of *Avicennia alba* are rich source of phytochemicals namely; alkaloids, flavonoids, tannins, phenols, terpenoids, saponin, steroids, oxalic acid, glycosides, proteins & carbohydrates. Methanolic extract of *Avicennia alba* showed highest antibacterial activity against both Gram positive as well as Gram negative microorganisms.Therefore, methanol is a better solvent for extract preparation than other solvents.

Acknowledgements: We thank Mangrove cell , Mumbai & the Department of Biotechnology, Sonopant Dandekar college, Palghar.

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PREPARATION AND EVALUATION OF PLANT-BASED SHAMPOO CONTAINING CUO NANOPARTICLES

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Abstract:

Plant based shampoo preparation is eco-friendly as well as easy method. It is free from various side effects that arise from regular use of chemically prepared shampoo due to the fact that it contains naturally occurring herbs. Plant-based shampoo was prepared by using extracts of herbal ingredients such as reetha, shikakai, neem, hibiscus, onion, and curry leaves. To increase the effectiveness of prepared shampoo, copper oxide nanoparticles are added to it. The synthesis of copper oxide nanoparticles (CuO NP's) by green method is environmentally friendly, economical and non-toxic. The prepared nanoparticles were characterized by different techniques, such as SEM, XRD and UV. The formulation was estimated for anti-fungal activity, foam stability, skin irritation, pH, percent solid content, and dirt dispersion tests. Based on the outcome, we can conclude that the plant-based hair shampoo preparation approach is environment friendly, safe and cost-effective.

Keyword: shampoo, copper oxide nanoparticles, herbal, anti-fungal

Introduction:

Nanoscience is the study of structures and molecules at nanoscales, typically between 1 and 100 nm, and the technology that applies this knowledge to real-world things is called nanotechnology [1][2]. In cosmetic nanoscale versions use to give better UV protection, deeper skin penetration, longer-lasting benefits, improved colour and finish quality, and so on. Shampoo is now widely used by large population to wash their hair. One of the primary purposes of the shampoo's is to eliminate material from the hair, which can include sweat, sebum residue, dust, cosmetic residue from hair care products, and other foreign objects[3]. A shampoo is a mixture of surfactants, or surface-acting agents that can be supplied in liquid, powder, or solid form. When applied, these surface-active agent help remove oil, skin debris, and dirt from the hair and scalp without hurting the skin, scalp, or hairs[4]. There are many different types of shampoos available today, including synthetic, herbal, medicated, and non-medicated varieties, Synthetic shampoo contains various chemical ingredient that potentially have detrimental effects, including dryness of hair, split ends, premature greying of hair, irritation to skin and eye. Therefore, many people are getting attracted towards the herbal products due to their fewer side effects and no long-term problems. Number of medicinal plants with good benefits on hairs have been used for centuries in shampoo formulation. These herbs can be used as extract, powders, crude form, or derivative[5]. It is difficult to make a safer, softer shampoo than synthetic shampoo with just one natural ingredient. Like synthetic shampoo, it must also have significant foaming, detergency, and solid content. Because of this, we carefully considered creating a pure natural cleanser using a proven method and a widely utilized plant material for hair cleaning.

Materials and methods:

Chemicals and collection of plants for nanoparticles:

0.1M Copper (ll) chloride dihydrate [$CuCl_2 \cdot 2H_2O$] Solution was prepared in distilled water. 0.170 gram of copper (ll) chloride compound in 100 ml distilled water.

Fresh neem (*azadirachta indica*) leaves are collected from vande mataram college campus, Dombivli (W) and washed with distilled water and then dried in oven. 10g of leaves powder and 100 ml of distilled water was kept on reflux for 1 hour at 100^0c. After the reflux solution is filtered.

Synthesis of CuO nanoparticles:

10 ml of 0.1M copper chloride solution was slowly added into 100 ml of leaves extract solution with continuous stirring on magnetic stirrer for 2 hours, and the solution was kept for settling for overnight. After that, solution was kept in heating plate near to dryness at 350°C for 5 hours.

Material and methods for plant-based shampoo:

Chemicals and Collection of ingredients:

Sodium benzoate and coco betaine was taken from college, Dombivli (W).

Plant parts use in the preparation of shampoo and its application Aare shown in table No1. Neem leaves, curry leaves, and hibiscus flowers were collected from the college campus. Remaining all other herbal ingredients were purchased from local market, Ulhasnagar.

Table No.1 Plant Name and application of plant parts use in the preparation of Shampoo

Sr. No	Plant name	Botanical name	Part use	Uses
1.	Neem	Azadirachta indica	Leaves	Anti-dandruff activity and antibacterial
2.	Shikakai	Acacia concinna	Pod	Surfactants, makes hair clean
3.	Reetha	Sapindus mukorossi	Fruits	Detergent, Battles scalp infections
4.	Curry leaves	Murraya Rutaceae	Leaves	Stop hair loss, and anti-microbial activity
5.	Hibiscus	hibiscusrosa-sinensis	Flowers	Hair growth, strength to hairs
6.	Onion	Allium cepa	Pulp	Encourage hair growth, and remove dandruff
7.	Coconut oil	Cocos Nucifera oil	Oil	Seal hair moisture
8.	Castor oil	Ricinus communis	Oil	Provide moisture to scalp

Preparation of extracts:

Neem and curry leaves and hibiscus flowers collected and washed several times with distilled water, then separately kept in oven to dry and converted into fine powder. With the help of weighing machine exact 5 gm of powder separated and added into 100ml of distilled water respectively. The solution was kept for reflux for 1hr at 100^0C. The extraction was cooled, filtered by normal filtration method. Extracts of remaining ingredients (like reetha & shikakai) was also prepared by the similar method.

Synthesis of plant-based shampoo:

The plant extracts were added in different quantities to produce a shampoo, whose formula is indicated in the table no.2. Decoction of reetha, shikakai, neem, curry leaves and hibiscus extract were prepared and 0.5g of sodium benzoate as well as coco betaine were added carefully while continuously slow stirring on magnetic stir. 0.1g of the prepared CuO nanoparticles and 0.5 g of xanthan gum were added into the shampoo and stirred for 10 min. The pH of the mixture was adjusted using citric acid.

Table No.2 Quantities use in the preparation of shampoo

Sr. no.	Ingredients	Quantity
1.	Reetha	15ml

Figure No.1

2.	Shikakai	15ml
3.	Neem leaves	20ml
4.	Curry leaves	20ml
5.	Hibiscus flowers	10ml
6.	Onion	10ml
7.	Sodium benzoate	0.5g
8.	Coco betaine	10ml

Prepared Shampoo

Characterisation of CuO nanoparticle's:

UV-Vis Spectral Analysis:

An UV-Vis spectrophotometer was used to carry out the spectroscopic analysis (LABMAN). The samples were analysed in 1 cm path length. samples were scanned from 600 to 700 nm wavelength. The baseline correction was done using distilled water as a reference.

XRD (X-ray Diffraction) analysis:

The XRD data is used to determine the crystallinity and purity of nanostructures. XRD patterns are caused by X-ray diffraction on the system's multiple crystallographic planes.

Characterisation of shampoo:

The formulations were subjected to established protocols for quality control tests, which included such as pH, dirt dispersion, foam volume, foam stability, and, antimicrobial, antifungal, skin irritation, percentage of solid content.

PH: A digital pH metre was used to measure the pH of herbal shampoo formulations. After calibrating the device, an exact amount of prepared herbal shampoo was taken in distilled water, and the pH of the mixture was measured at room temperature. Solution of citric acid was added to achieve neutral.

Skin irritation: To determine whether or if there is skin inflammation, this test is performed on human volunteers' skin. After mixing distilled water with shampoo, the skin was treated. For half hour, the applicant was allowed to stay in contact.

Anti-fungal Activity: To produce the potato dextrose agar medium, 1.5 g of Agar, 20 g of potato infusion, and 2 g of dextrose were mixed and dissolved in 100 mL of double distilled water. For 15 min, the dissolved medium was ramped at 12°C and 15 lbs pressure. After that, the medium was poured into 100 mm Petri dishes. These Petri plates were filled with the fungal strain (Aspergillus niger), and the wells were sliced and shampooed with and without NP's. After that, the plates were incubated at 28°C for 72 hours. The zone of inhibition was computed using a method akin to that used for bacterial cultivation [6].

Foam stability: The ability to produce foam was evaluated using the cylinder shaking method. A graduated 100 ml cylinder was filled with 20 ml of the 1% shampoo solution and 10 ml of water, the cylinder was then covered with a hand and shaken ten times while the findings were noted. Following a minute of shaking, the total foam volume was determined. Following the shaking, the amount of foam was measured right away, and for four minutes, measurements were made every minute[5].

Percentage Of Solid Content: After 4 g of plant-based shampoo was added, an evaporating dish that was dry and clean was weighed. Weighing the shampoo carefully beforehand, we just put the evaporating dish on the hot plate until the liquid part evaporated. Once the shampoo had dried, the weight of the solids alone was determined [7].

Observation & calculation:

1. Weight of empty petri plate (A)= 34.356 gm
2. Weight of plate after evaporation (B)= 35.156 gm
3. Weight of sample = (B) – (A) = 35.156 – 34.356 = 0.8 gm
4. Total solid content = 0.8 gm
5. Therefore, percentage of solid content = (B – A)/ 4 x 100 = 0.8 gm / 4 x 100 = 20%

Results and Discussion:

UV-Visible spectrophotometer: The sample teste was conduct in labmen UV spectrometer. The fig. no 2 shows the UV Vis absorption spectrum of CuO nanoparticles, which shows a prominent peak at 640 nm that formation the formulation of CuO nanoparticles was confirmed by this method. The absorption maximum was noted in the range 600-700 nm for CuO nanoparticles.

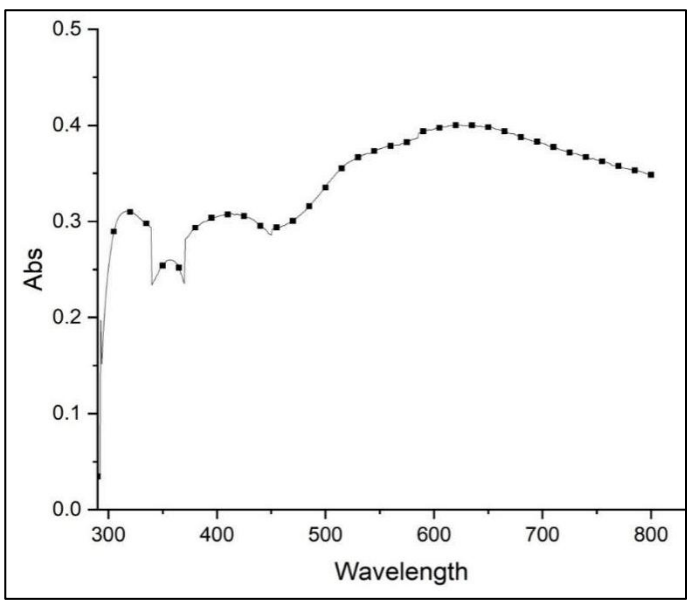

Figure No.2 UV-Vis spectra of CuO nanoparticles

X-ray Diffraction (XRD) analysis: Fig. No.3 shows the X-ray diffraction pattern, that reveals the formation of CuO nanoparticle powder. There is a clear broadening of the XRD peaks, indicating the presence of particles in the nanoscale range. From analysis of the XRD, we were able to ascertain the peak intensity, position, full-width at half maximum (FWHM), and width data. The location of the diffraction peaks has two values. The intensity of the following Peaks is as follows 2.75470, 2.53290, 2.52700, 2.32560, 2.31390, 1.96360, 1.86970, 1.71410, 1.62370, 1.58260, 1.41960, 1.41960, 1.41160, 1.38020 are in good agreement with those powder CuO nanoparticles obtained from the International Centre of Diffraction Data card (JCPDS), which confirmed formation of crystalline structure. It also confirms that the synthetic nanopowder was free of impurities because it is attribute-free.The Debye-Scherrer formula was used to calculate the average crystallite Size of CuO nanoparticles is 90 nm [8], [9].

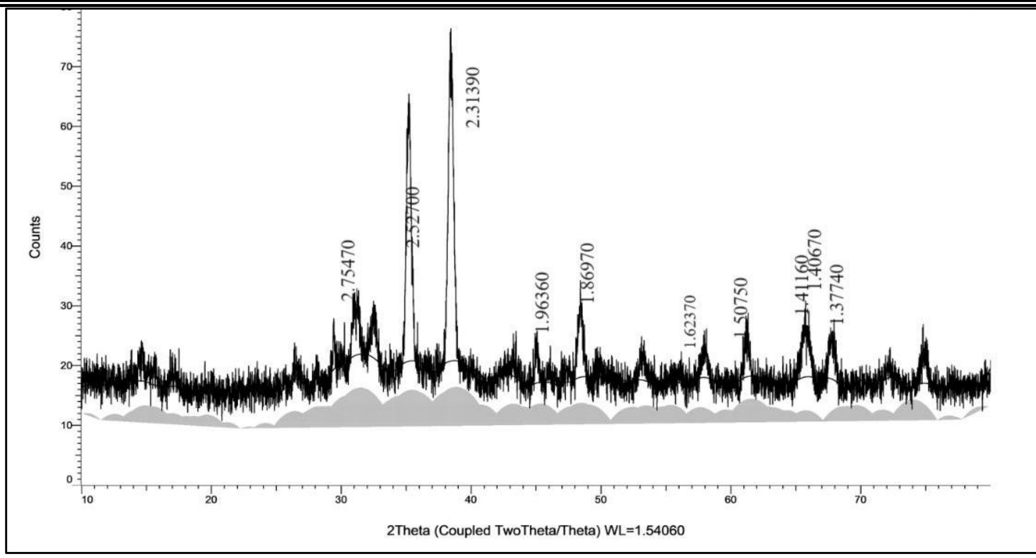

Figure No.3 XRD Spectrum of CuO nanoparticles

SEM (Scanning Electron Microscope):

The size and surface morphology of the produced nanoparticles were verified by the scanning electron microscope (SEM). Fig. No. 3 shows the SEM pictures of CuO nanoparticles synthesised by green method.

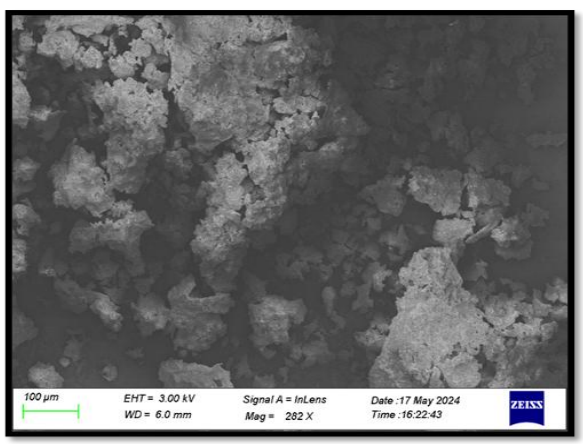

Figure No 4. SEM image of NP's

The average size of synthesised CuO nanoparticles are 100nm, a major distribution. Agglomerations reduced as particle size grew, as expected, because increasing particle size has a linear effect on size. SEM photos of CuO nanoparticles show when the aggregation of particles is related to an attempt to reduce surface free energy

It was found that the medicinal plants used to make herbal shampoo were a rich source of innovative medications. These plants included Neem, Reetha, Shikakai, Curry leaves, Hibiscus and others whose effects on hair development and conditioning have been documented. Numerous quality control factors were examined, including pH, percentage of solid contents, foam stability and ability, antimicrobial, antifungal, dirt dispersion, and physical appearance. Every parameter produces a positive outcome. The current study's findings show that incorporating these medications' active components into shampoo results in more stable, aesthetically acceptable products.

- **pH:** A digital pH metre was used to measure the pH of prepared shampoo formulations. After calibrating the device, A precise quantity of prepared herbal shampoo was mixed with distilled water, and the pH of the mixture was measured at room temperature. The pH of shampoo was raised to 5 Most shampoos have little to no acidity or are neutral.

- **Skin Irritation Test:** The skin of human volunteers is used for this test; the skin was treated with a solution of the prepared shampoo in water, and it was left in contact for half hour. The prepared shampoo was safe to use because the applied region showed no signs of irritation, redness, itching, or inflammation.

- **Anti-Fungal Activity:** The antifungal activity was measured using the Agar well diffusion method. This approach allowed the test organisms set in the petri plates to interact with the media by diffusion of CuO NP's. The Zone of inhibition will be evenly circular because to the confluent lawn of development, as shown in fig. No. 5. Zone of inhibition, which is expressed in millimetres and indicates the sample's level of antimicrobial activity against the selected pathogen, is measured. The Antifungal activity was analysed using fugal pathogen such as *Aspergillus niger* (*A. niger*).[10]

Table No 3. Zone of inhibition in mm by prepared herbal Shampoo

Sr.no.	Samples	Fungus	ZOI (in mm)
1.	With NP's	*A. niger* ATCC6275	17 mm
2.	Without NP's	*A. niger* ATCC6275	14mm

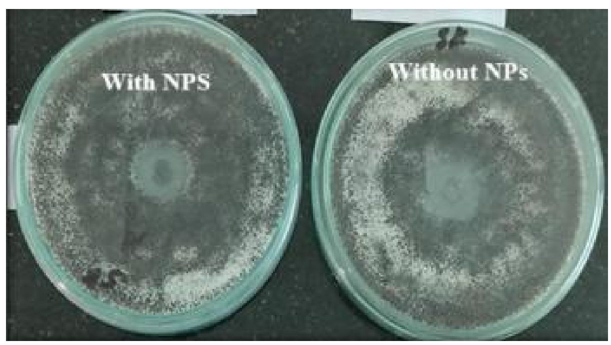

Figure No. 5 Anti-fungal activity of shampoo against fungus (*A. niger*)

Dirt Dispersion Test:

An essential factor in assessing how well a shampoo cleans is its ability to disperse dirt. Because dirt or ink that gets stuck in the foam and resurfaces on the hair during cleaning, shampoos that concentrate the ink in the foam are considered to be of inferior quality. 10ml of distilled water are placed in a test tube, and two drops of shampoo are added. After adding one drop of India ink, the test tube is stopped and given 10 shakes. The amount of ink in the foam is observed and categorized as none, light, moderate, or heavy. The amount of ink in the froth was assessed during the Indian ink dirt dispersion test, and it was determined to be modest.

Stability of foam Test: The cylinder shaking method was used to assess the capacity to create foam. Figure No.6 shows the Foam stability test in a measuring cylinder. A graduated 100 ml cylinder was filled with 20 ml of the 1% shampoo solution and 10 ml of water. The cylinder was then covered with a hand and shook ten times while the results were recorded. Following a minute of shaking, the total foam volume was determined. Over the course of five minutes, the foam volume did not vary, indicating that the foams that were created have good stability.

Solid Content: A shampoo appears good if it has a suitable percentage of solid components and is easy to apply and rinse from the hair. A lack of solids causes the shampoo to quickly wash out of the hair. On the other hand, It will be difficult to work the shampoo into the hair or remove it if it contains an excessive amount of solids. The designed shampoo was found to contain 20% solids.

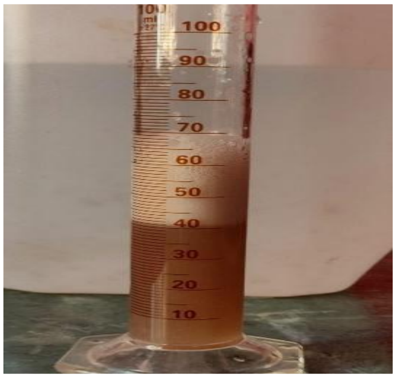

Figure No.6 Foam stability test in a measuring cylinder

Figure No.7 Solid content plate

Conclusion:

In the present work, we found that the bio-reduction of Cu ions by the leaf extract of the neem plant has been useful source for synthesis of copper oxide nanoparticle. By this method, obtained copper oxide nanoparticles have uniform shape as well as well-defined dimensions. The process of synthesizing copper oxide nanoparticles using green chemistry has numerous benefits, including the capacity to scale up the process easily and its economic sustainability, etc. The present study was carried out with the aim of preparing plant-based shampoo containing copper oxide nanoparticles, they can enhance the benefits of active ingredients in order to improve the action of shampoo. All the ingredients used for the preparation of shampoo are safer than marketed commercial and the characterization showed ideal results. The formulations were tested for various tests and shows non skin irritation, a little acidic pH which beneficial to shampoo, good foam stability, good cleansing action, 20% solid content and shows positive antifungal activity against fungus. At the end, the plant-based shampoo formulation incorporating copper oxide nanoparticles has antifungal activity, which opens the door to a new line of medicinal goods.

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PUBLIC CLOUD AND CRYPTOGRAPHY IN SUSTAINABLE GROWTH OF IT INFRASTRUCTURE

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Abstract: Cloud computing is widely used and highly versatile, offering a range of services such as storage, software, infrastructure, and more, all available on-demand. It enables businesses to innovate and strengthen technological partnerships, enhancing marketing strategies, simplifying processes, and boosting security. Additionally, it helps improve stakeholder engagement and enrich consumer experiences. The pay-as-you-go model of cloud computing significantly reduces costs by only charging for the resources used. A key advantage is scalability, allowing businesses to easily adjust resources based on demand. Despite its accessibility, security remains a primary concern, especially with the growing popularity of public clouds. This research paper explores how cryptography and encryption techniques can address some of these security challenges.

Keywords: Cloud computing, Public cloud, encryption, cryptography, cloud security

1. Cloud Computing:

Cloud computing enables computing services to be delivered via web-based platforms, allowing both businesses and individuals to utilize third-party IT infrastructure remotely. It facilitates online storage, social networking websites, web-based business applications, and internet-based email services. Users can access their data and applications from any device any time through internet connection. Cloud services provide a range of capabilities, including data storage, network connectivity, processing power, and specialized software tools.

The concept of cloud computing has evolved over time, tracing its roots back to early computing systems that enabled remote time-sharing of resources. While cloud technology has significantly advanced, concerns remain regarding the variety of applications and services it offers. In many cases, the devices and applications involved do not require any unique hardware or extraordinary functionality, making cloud computing a highly accessible and versatile solution.

Public Cloud :

"Google Cloud Storage" offers a wide range of services for both individual users and large IT enterprises. Many companies provide their own cloud solutions to cater to customer needs. Among these, some cloud services are freely available and easily accessible. Public cloud, in particular, is widely used due to its convenience and accessibility. However, this extensive usage also raises security concerns, as a large number of users rely on cloud storage. Additionally, the growing adoption of cloud services is driven by its pay-as-you-go model and the fact that it requires no specialized technical expertise.

The following components elaborate the idea about service models of cloud computing.

1.1 Features of Cloud Computing:

Following are the important features of cloud computing.

- **Suitable for Distributed Infrastructure**: Cloud system operates on a framework like as creating virtual machines through hypervisors. In which it includes all the features of networking and allows user to share physical resources. It can also be utilized for scalable storage solutions. Instead of the deployment model, cloud computing facility is designed to accommodate the required number of users efficiently.
- **Dynamic Provisioning**: Automatic allocation of cloud service is based on real-time demand through software automation. Resources can scale up or down as needed, ensuring optimal performance, reliability, and security while meeting fluctuating workload requirements.
- **Network Accessibility**: Cloud computing enables seamless access to services through an internet connection. Users can connect via various devices, including desktop computers mobile phones, laptops, using standard APIs. Cloud services support a wide range of applications, from essential business tools to advanced smartphone applications.

- **Managed Metering**: Cloud computing incorporates metering mechanisms for tracking, optimizing, and billing resource usage. Services are scalable and available from virtually any location, with users charged based on actual consumption, ensuring cost efficiency and flexibility.

1.2 Service Models:

Cloud service models are as below

- **Software as a Service (SaaS):** It allows consumers to use cloud-hosted applications or services without managing the underlying infrastructure. It allows users and businesses to store data in the cloud without managing physical storage infrastructure. Large amount of data can be stored and accessible for users.
- For example : "Amazon s3, Google cloud storage, Microsoft Azure, IBM cloud, oracle cloud."
- **Platform as a Service (PaaS):** PaaS provides a platform for users to develop, deploy, and manage applications in the cloud. Users don't have control over the underlying operating systems, network access, or infrastructure but can build and run applications within the provider's environment, often with some constraints on application deployment.
- **Infrastructure as a Service (IaaS):** This model grants users greater control over computing resources, including system processes, storage, networking, and applications. Unlike SaaS and PaaS, consumers manage their virtualized infrastructure while the cloud provider handles hardware maintenance.

1.3 Cloud Computing and Cryptography:

Cryptography is the practice of securing data by converting it into an unreadable format to protect it from unauthorized access. It involves the use of secret codes to ensure that only the intended recipient can decrypt and access the original content, making it a fundamental technique for secure communication.

In the realm of cloud computing, cryptography plays a vital role in ensuring data security during storage, transmission, and processing. This section provides an overview of the history and methodologies of cryptography, along with a summary of various encryption techniques used to enhance security in cloud environments.

Encryption for cloud computing :

Encryption is a crucial security measure in cloud computing, ensuring data confidentiality and integrity by transforming readable data into an unreadable format. Below are some widely used encryption techniques in cloud computing.

1. Symmetric Encryption (Private Key Encryption)

- For encryption and decryption single key is used.
- Faster than asymmetric encryption but requires secure key management.
- **"Example Algorithms**: AES (Advanced Encryption Standard), DES (Data Encryption Standard), 3DES (Triple DES)."

2. Asymmetric Encryption (Public Key Encryption)

- Two keys are used, in which public key for encryption and a private key for decryption.
- It provides good security as compare to symmetric encryption but is slower.
- **"Example Algorithms**: RSA algorithm (Rivest-Shamir-Adleman), ECC (Elliptic Curve Cryptography)."

3. Homomorphic Encryption

- It enables computations to be carried out directly on encrypted data without requiring decryption.
- It is useful for secure data processing and privacy-preserving cloud applications.
- **"Example Algorithms**: Paillier Cryptosystem, BGN Cryptosystem."

4. Attribute-Based Encryption (ABE)

- Encrypts data based on user attributes, allowing access control policies.
- Used in access control mechanisms for cloud storage.
- **“Types**: Ciphertext-Policy ABE (CP-ABE) and Key-Policy ABE (KP-ABE).”

5. Format-Preserving Encryption (FPE)

- Maintains the original structure of the data while encrypting it.
- It is commonly used in financial transactions and database security.
- **“Example Algorithms**: FF1 (NIST-approved format-preserving encryption method).”

6. Searchable Encryption

- It allows users to find encrypted data without decrypting it.
- Useful for secure cloud-based data retrieval.
- **“Example Techniques**: Order-Preserving Encryption (OPE), Searchable Symmetric Encryption (SSE).”

7. End-to-End Encryption (E2EE)

- Ensures data is encrypted on the sender’s side and only decrypted by the recipient.
- Used in secure messaging apps and cloud storage services.
- **“Example Protocols**: TLS (Transport Layer Security), Signal Protocol.”
- Each of these encryption techniques plays a very critical role in protecting cloud stored data, it also ensuring secure communication, and preventing unauthorized access from users.

2. Literature Review

2.1 “S. Bleikertz, S. Bugiel, H. Ideler, S. Nürnberger, and A.-R. Sadeghi introduced the concept of secret key principles in their research paper, *"Client-controlled Cryptography-as-a-Service in the Cloud."* They applied these principles to virtual machines within a specialized client-controlled CaaS architecture for cloud computing. The authors emphasized the critical importance of utilizing actual hardware security components. Their research demonstrated that the design effectively isolates all cryptographic operations within a secure crypto-domain, referred to as DomC, which is closely integrated with client workloads. This approach ensures the successful separation of key management and storage, offering enhanced security for cloud customers.”

2.2 “The research paper *"Cloud Computing—An Approach with Modern Cryptography"* by S. Sanyal and P. P. Iyer explores cloud security concepts through the use of public key values. They propose a secure and effective solution utilizing 128/192/256-bit cipher keys for data encryption and decryption, leveraging the multi-key AES encryption technique. Their findings indicate that, when compared to RSA, AES significantly enhances cloud computing security. Additionally, AES is versatile, suitable for both private and public cloud environments, as well as virtual machines, providing a robust encryption solution across various cloud settings.”

2.3 “A research paper titled *"Key-Insulated Symmetric Key Cryptography and Mitigating Attacks Against Cryptographic Cloud Software"* by Y. Dodis, W. Luo, S. Xu, and M. Yung explores key-insulated symmetric key cryptography as a mechanism to minimize the impact of looping attacks on integrated cryptographic software. The authors highlight the feasibility of symmetric key cryptography within a key-insulated framework and present a proof-of-concept implementation using a kernel-based virtual machine environment.”

2.4 “In the research paper *"Enhanced Security Framework to Ensure Data Security in Cloud Computing Using Cryptography,"* M. Sudha examines cloud security concerning data integrity, confidentiality, and authentication. The study proposes a security model that incorporates hyper crypto-encryption, utilizing both asymmetric and symmetric cryptographic algorithms to enhance data protection in cloud computing.”

2.5 “The paper *"Enhancing Security in Cloud Computing Using Public Key Cryptography with Matrices"* by B. Goswani and D. S. Singh introduces an NP-complete class by solving equations over a ring of integers. Their proposed algorithm enhances public encryption agreements and has potential applications in securing cloud computing services at the server level.”

3. Objectives Of The Research:

- To find the use of cloud computing is secure or not.
- To find cryptography is how much useful in cloud computing
- To find how much people use these services
- To what are specific components that need to be secured
- To find which service is best for security
- To find how services do accessible and how it can keep our information securely.

4. Discussion:

Cloud computing introduces challenges related to data control, the impact of software systems on natural resources, and the delegation of data access control. Based on the literature review, cryptography emerges as a crucial solution to address these concerns, offering applications in proofs of irretrievability, homomorphic encryption, private information retrieval, Broadcast encryption, knowledge and zero-knowledge proofs.While cloud computing has significantly expanded its benefits across various sectors, its full potential cannot be realized without robust security measures, encryption techniques, and well-defined security policies. However, implementing security across multi-cloud environments introduces additional challenges, particularly in performance optimization. A key concern is the efficient management of cryptographic encryption using large keys at minimal cost—a problem that remains an ongoing area of research.

Beyond security and performance, availability is also a critical factor. Security is the most significant concern when compared to other cloud computing factors. This is particularly relevant in scenarios where end users, such as individuals at home, upload data from their personal devices to the cloud.

Ultimately, cloud computing security remains an evolving field, with no perfect or complete solution. However, extensive research and real-time implementations have led to highly efficient and effective security solutions, continuously shaping the future of secure cloud computing.

5. Conclusion:

Based on the surveyed research, we suggest an alternative approach where a third-party entity functions as a gateway between the client and the cloud. Although advancements have been made in cloud security, no single cryptographic implementation has emerged as a definitive solution. A collaborative approach that integrates cryptographic algorithms with security policies could enhance cloud security. However, we believe that this development alone is insufficient. This "crypto box" or an upgraded system could serve as an encryption/decryption mechanism, facilitating secure cryptographic session agreements between the client and server. This approach could strengthen cloud security by ensuring seamless and secure data exchanges.

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GREEN SOFTWARE TESTING PRACTICES: APPROACHES AND BENEFITS

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Abstract

The global shift towards sustainability has led to a growing emphasis on reducing the environmental impact of all industries, including the software sector. Green Software Testing is a developing field focused on optimizing software testing practices to reduce energy consumption, lower carbon footprints, and ensure more efficient use of resources throughout the testing process. This paper explores Green Software Testing, focusing on various methodologies used to improve testing efficiency, reduce environmental impact, and enhance business outcomes. By examining the strategies employed by organizations to integrate sustainability into their testing processes, this paper highlights both the environmental and economic advantages of adopting Green Software Testing practices.

1. Introduction

Background

Recently, the software industry has been criticized for its impact on global energy use and carbon emissions.With the increasing reliance on digital solutions and IT infrastructures, it is estimated that the sector accounts for nearly 4% of total global emissions. The energy consumption involved in software testing, in particular, can be significant, as it often requires large amounts of computational power and physical hardware.

The push for sustainability in software development is becoming more prominent as industries and governments seek to reduce the environmental footprint of their activities. Green Software Testing is part of this broader movement, aiming to make software testing more energy-efficient and environmentally friendly. Traditional software testing processes, especially those involving manual testing and resource-intensive infrastructure, can be wasteful and inefficient. Green Software Testing aims to minimize these inefficiencies, providing a more sustainable approach to the testing phase of the software lifecycle.

Objective of the Paper

This paper aims to explore Green Software Testing practices, presenting an overview of key strategies employed to optimize the energy usage and resource consumption during software testing. The paper also highlights the benefits that organizations can achieve by adopting these practices, including reduced costs, improved operational efficiency, and a positive environmental impact. Furthermore, the paper addresses the challenges companies face when implementing Green Software Testing, and it discusses potential future trends in the field.

2. Understanding Green Software Testing

Defining Green Software Testing

Green Software Testing refers to the incorporation of sustainable practices in the software testing process, with the goal of minimizing the consumption of energy and resources while maintaining the effectiveness of the testing procedures. It involves applying methods such as reducing hardware usage, automating testing tasks, optimizing test execution, and using virtualized environments. Green Software Testing strives to minimize the environmental impact of testing activities without sacrificing test quality, efficiency, or coverage.

The central objective is to optimize resource consumption by using fewer computing resources, lowering power usage, and taking advantage of modern tools and technologies that help conserve energy while enhancing the testing process.

The Role of Software Testing in Sustainability

Software testing is crucial for maintaining the quality, reliability, and performance of software products. However, it can require significant resources, especially when managing complex test cases, large systems, or a high level of parallel processing. As the software industry grows, so does the environmental cost of testing, which typically involves substantial amounts of energy for running tests, storing test results, and maintaining infrastructure.

Green Software Testing addresses this by optimizing the test execution process, reducing the hardware required, and decreasing the overall energy consumption associated with testing activities. By integrating green practices, organizations can reduce the negative environmental impacts associated with software testing, while simultaneously driving greater efficiency and innovation.

3. Approaches to Green Software Testing

Green Software Testing involves a variety of approaches, all aimed at reducing energy consumption and optimizing the overall testing process. Below are some of the most commonly used methods.

Optimizing Test Execution

Test execution is one of the most energy-intensive parts of software testing, especially when large test suites or repeated tests are involved. To reduce the energy consumption during test execution, several techniques can be applied:

- **Limiting unnecessary test executions**: By reducing the number of test runs, unnecessary computations can be avoided. For example, focusing on high-priority test cases that are more likely to expose defects can reduce the need for exhaustive testing.
- **Off-peak scheduling**: Scheduling tests during periods of low demand helps balance the load on hardware resources and reduces strain during peak usage times. This can lower electricity consumption and optimize the use of computing power.
- **Parallel test execution**: Running tests in parallel across multiple machines or cores allows for faster execution times and ensures that resources are used efficiently. This method minimizes idle time for hardware, which can help conserve energy.

Leveraging Test Automation and Virtualization

Automation has long been a key to increasing efficiency in software testing. By automating repetitive tasks and processes, companies can streamline testing workflows while minimizing human effort. Automation, combined with other green practices, contributes significantly to energy efficiency:

- **Automating repetitive tests**: Automated testing facilitates the fast execution of repetitive test cases, leading to a reduction in the time and resources required for manual testing.
- **Virtualized test environments**: Virtualization tools, such as Docker and virtual machines, enable the creation of isolated testing environments that can share resources more efficiently. These tools reduce the need for multiple physical servers, helping to decrease hardware requirements and energy consumption.

By using cloud services, virtualized environments can dynamically scale, providing resources as needed without unnecessary over-provisioning, ensuring efficient energy use.

Cloud-based testing

Cloud-based testing solutions provide a way to reduce energy consumption in software testing. Instead of depending on extensive on-site data centers, organizations can take advantage of cloud infrastructure to execute tests on-demand, cutting down on the need for physical hardware.

- **Energy-efficient data centers**: Leading cloud service providers have made significant investments in energy-efficient data centers. Many cloud platforms are now powered by renewable energy sources, making cloud testing a more sustainable option compared to on-premise solutions.

- **Resource optimization**: Cloud services provide the flexibility to run tests in a distributed manner, enabling tasks to be allocated to different regions, further optimizing resource use and reducing the environmental footprint.
- **Elastic scalability**: Cloud platforms allow organizations to scale resources according to demand, ensuring that only the necessary computing power is used during testing, thus enhancing energy efficiency.

Optimizing Test Environments

Efficient test environments are crucial for minimizing energy consumption during testing. By optimizing the hardware and configuration of test environments, organizations can achieve better energy efficiency:

- **Energy-efficient hardware**: Choosing hardware designed for low energy consumption, such as processors optimized for performance-per-watt, can contribute to a greener testing environment.
- **Consolidating test environments**: Virtualizations enables multiple testing environments to run on a single physical machine, reducing the need for additional servers and lowering the associated energy consumption.
- **Improved server management**: Proper configuration of servers, such as turning off unnecessary services or managing CPU and memory resources, can reduce the energy required to run tests.

Efficient Test Design

Efficiently designed tests can significantly reduce the environmental impact of testing by minimizing unnecessary tests and optimizing the overall testing process:

- **Test prioritization**: By prioritizing the most critical test cases—those that are most likely to expose issues—organizations can focus on areas of higher risk and importance, reducing the need for exhaustive testing.
- **Test optimization tools**: Using tools that optimize the test design process, such as AI-based test case generation or machine learning-driven test selection, can help testers identify the most relevant tests, reducing unnecessary repetitions.

4. Benefits of Green Software Testing

Reduced Carbon Footprint

One of the primary advantages of adopting Green Software Testing is the reduction of the carbon footprint associated with testing activities. By optimizing resource usage and reducing energy consumption, organizations can significantly lower their emissions, contributing to sustainability goals and reducing environmental impact.

Cost Savings

By reducing the energy consumption required for testing, organizations can also save on costs associated with running physical servers, maintaining infrastructure, and paying for electricity. Additionally, cloud services and virtualized environments can help further reduce operational costs, as companies only pay for the resources they actually use.

Enhanced Efficiency

Green Software Testing can increase overall efficiency within testing workflows. Through automation, parallel test execution, and optimized test designs, companies can reduce testing time, increase test coverage, and improve productivity without sacrificing resource efficiency.

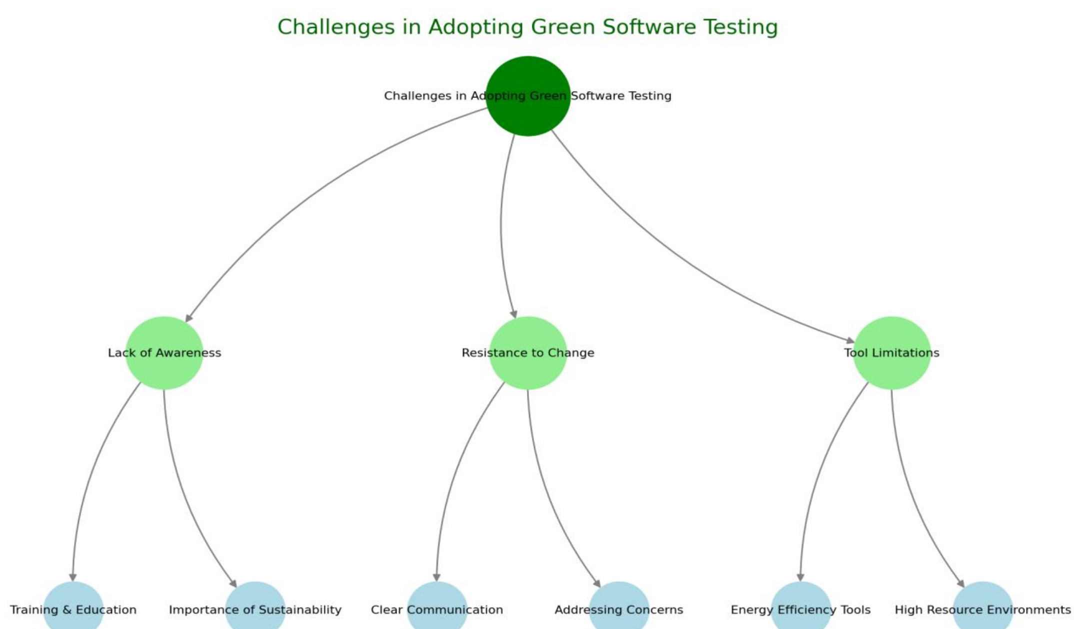
Positive Brand Image

Sustainability is becoming a key concern for customers, and organizations that adopt Green Software Testing practices can differentiate themselves by demonstrating their commitment to reducing their environmental impact. A positive reputation for sustainability can attract customers, build brand loyalty, and increase market share.

Regulatory Compliance

As governments introduce more stringent environmental regulations, organizations that adopt Green Software Testing practices will be better positioned to comply with these mandates. By proactively reducing energy consumption and carbon emissions, businesses can avoid potential penalties and legal challenges.

5. Challenges in Adopting Green Software Testing



Lack of Awareness

Many professionals in the software industry may not be aware of Green Software Testing practices or how to implement them effectively. Training and education are essential to ensure that testing teams understand the importance of sustainability and how to incorporate green practices into their workflows.

Resistance to Change

Transitioning to greener practices may encounter resistance, particularly in organizations where traditional testing processes have been in place for years. Overcoming resistance requires clear communication of the long-term benefits, as well as addressing any concerns about potential complexity or costs.

Tool Limitations

While many tools for test automation and optimization are available, some may not be designed with energy efficiency in mind. This can limit their effectiveness in achieving green testing goals, especially in environments that require significant computational resources.

6. Future Trends in Green Software Testing

Integration with Green Software Development

The future of Green Software Testing is closely tied to the broader adoption of green software development practices. As software developers increasingly focus on building sustainable applications, testing will naturally evolve to align with these objectives.

AI-Driven Optimization

Artificial intelligence and machine learning are expected to become increasingly important in streamlining software testing. AI can analyze past data to identify the most relevant tests, reducing unnecessary ones and enhancing the overall efficiency of the testing process.

Sustainable Testing Frameworks

The development of standardized frameworks for Green Software Testing will provide a common set of practices and guidelines for organizations. These frameworks will help companies adopt and implement green testing methodologies with greater ease.

7. Conclusion

Green Software Testing is a critical practice for organizations seeking to reduce their environmental impact while maintaining high standards of software quality. By optimizing the testing process through automation, virtualization, and cloud-based solutions, companies can reduce energy consumption, save costs, and improve productivity. Although challenges remain, the future of Green Software Testing looks promising, as emerging technologies and increasing awareness continue to drive the adoption of sustainable practices across the software development lifecycle.

Certainly! Here are some references you can use to support your research paper on Green Software Testing. These sources provide valuable insights into sustainable software practices, green testing, and related fields:

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