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Cow dung as bio e3- economy, employment and environment. A review

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Abstract
This review highlights the importance of cowdung towards economy, employment and environment. Cow dung, one of the most abundant versatile resource has been used in household as a fuel, household material, mosquito repellent and cleaning agent for many centuries. It has been valorised through multiple technological pathways, including anaerobic digestion for biogas/CBG, composting and vermicomposting, briquetting, biochar production, paper and packaging industries, and eco-friendly construction materials. Economical, conversion of cowdung into biogas, organic fertilizers and compressed biofuels find a good cost effective alternative over fossils fuels and opens the door for carbon credits. In terms of employment it provides job opportunities in rural areas, through schemes like GOBAR-DHAN and Godhan Nyay Yojana especially for women's groups and young entrepreneur. Environmentally, it helps reduce methane release, enhance soil fertility, recycle nutrients, and lower pollution from open dumping and associated health risk. Environmental benefits include methane mitigation, soil fertility enhancement, nutrient recycling, and reduction of open dumping and associated health risks. This study gives step by step Plan for the use of cowdung to be more useful on large scale for jobs, green energy, organic farming and solution of climatic change.

Keywords: Cow dung, Bio-economy, employment generation, environmental sustainability, biogas, organic fertilizer, waste valorization, rural development, renewable energy, climate change mitigation

1. Introduction

Cow dung, an abundant, easily available and low cost bioresource, has long been integral to sustainable development by simultaneously addressing the three pillars of the E3 framework Economy, Employment, and Environment. For a very long time, it has been a part of rural life. It is commonly used as a fuel for cooking, while smoke generated from burnt cow dung used a natural mosquito repellent, and the ash left behind used as a cleansing agent. Cow dung itself used as house building material. It serves as a natural fertilizer for improving soil health and increases crop production. It contains wide variety of microorganism producing various metabolites that are beneficial to humans. Beyond these practical uses, it has a special place in culture and traditions, and even holding ritualistic and medicinal value (Gupta *et al*., 2016; Chaubey *et al*., 2022) [1, 2]. In recent decades, technological advancements have expanded its applications well beyond traditional uses. It is now considered as a vital resource for renewable energy generation through biogas and compressed biogas (CBG) production, soil fertility improvement, and effective agent as pollution control. These multifaceted values, thereby redefining it from low value agricultural waste to a valuable raw material for green technologies (Sahdev *et al*., 2024; Ratminingsih & Jumadi, 2021) [76, 36]. Economically, cow dung utilization reduces dependence on fossil fuels and chemical fertilizers that are environmentally harmful. It producing value-added outputs such as biogas for household and industrial energy need, compressed biogas (CBG) as a clean transportation fuel, biochar for soil amendment, briquettes as an alternative to coal, biogas power plants for electricity production, and organic fertilizers. These vast applications contribute for lower production costs, generate new income streams, and enhance energy security (Schott *et al*., 2023; Albalate-Ramírez *et al*., 2022) [8, 9]. As published, for example, in rural areas of Bangladesh people used cowdung as fuel, compost, fish feed, biogas, and fertilizer. Sustainable

Development Index (SDI) for waste management in dairy farm was 0.73, while bio-slurry waste management had a score of 0.81, showing much greater satisfaction. Biogas plants saved 8.50 kg firewood, 0.29 kg petroleum gas, and 1.67 kg chemical fertilizer per day. More than 90% households met FAO's sustainable agriculture score yelding a cost-benefit ratio of 3.34 (Shaibur *et al*., 2025) [2]. Cowdung through conversion to compressed biogas, organic fertilizers, and promoting of organic farming practices presents an opportunity for income generation ad environmental sustainability. Government initiatives like GOBAR-DHAN and Godhan Nyay Yojana show positive impacts for both farmer livelihoods and environment (Sahdev *et al*., 2024) [76], DOI:10.46609/ijsser.2024.v09i09.034). Environmentally, if not properly managed, cow dung release harmful gases like that leads to air pollution and climate change, Instead, through anaerobic digestion, it is converted into useful resource like biogas for cooking, lighting, and generating electricity and biofertilizers for improving soil health and crop productivity. Biogas replace LPG, kerosene, gasoline, and generate power or drive pump help in reducing pollution, reliance on fossils fuels and energy scarcity **(**Ratminingsih & Jumadi, 2021; Shaibur *et al*., 2025) [36, 2]. It also enriches soil fertility through organic matter and microbial populations, while cow urine supplements nitrogen and minerals, together reducing reliance on chemical inputs and supporting organic farming practices (Patra & Bharti, 2024) [35]. Moreover, dung harbors plant growth-promoting bacteria that enhance phosphate solubilization, siderophore and IAA production, antifungal activity, and crop yields, with studies confirming improved growth in pea plants (Sagar *et al*., 2025) [7]. Both Cow Dung and cow urine are valuable resources. It contain essential macronutrients such as nitrogen (N), phosphorus (P), and potassium (K), organic matter, and microbes while cow urine in nitrogen, urea, and minerals. Both act as natural fertilizers and pesticides, fostering organic farming, reducing chemicals dependency, lowering costs, and promoting sustainable agriculture (Patra & Bharti, 2024, DOI:10.18805/BKAP696) [35].

Emerging cow dung valorization technologies such as composting, vermicomposting, pyrolysis, gasification, briquetting, and co-digestion with agricultural residues further enhance its scope of utilization. These methods not only generate valuable by-products like organic fertilizers, biochar, bioenergy, and renewable fuels but also manage waste efficiently. Innovations like calcium-enhanced UASB reactors making cowdung valorisation more efficient achieving both energy (via higher methane yields) and nutrient retention (via enhanced phosphorus capture) **(**Schott *et al*., 2023) [8]. Cowdung can be converted into biofuel by blending it with agricultural waste. This process increases its gross calorific value (from 3066 to 3600 Kcal/kg), raises volatile matter (60% to 68%), and reduces ash content (19% to 11%) making it a cleaner and sustainable alternative to fossils fuel for domestic and industrial use (Anwar *et al*., 2024) [13]. Community-level initiatives, such as biodigester projects in Indonesia, have showing dual ecological and economic advantages. These projects substituting LPG, reduce dependence on fossils fules and generating organic fertilizer for local agricultural practices (Damayanti *et al*., 2024) [12]. Beyond energy, cow dung-derived biochar help to store carbon for long term, improved soil health, and support climate resilience (Shyam *et al*., 2025) [14]. New approaches such as microbial fuel cells and nanoparticle synthesis further show its potential in advanced materials and renewable energy (Kushwaha *et al*., 2024; Selim *et al*., 2023) [74, 15]. Overall, cow dung is a versatile source bridges traditional practice with modern innovation. It is used as as fuel, fertilizer, building material, and in cultural practices for centuries. Now, Today, it is transform into biogas, biochar, organic fertilizers, and raw material for advanced technologies like microbial fuel cells and nanomaterials. By aligning with the E3 framework, cowdung helpful in many ways by creating rural employment, ensures economic prosperity, protects the environment by reducing waste, lowering pollution, and cutting greenhouse gas emissions, carbon neutrality, and climate change mitigation, thereby establishing itself as an important foundation for the circular bio economy and promoting agriculture worldwide.

2. The E3 Framework for Cow Dung Valorization

2.1. Economic perspective

2.2. Employment opportunities

2.3. Environmental sustainability

The E3 Framework for Cow Dung Valorization focusing on Economy, Employment, and Environment highlights the multifaceted benefits of utilizing cow dung as a sustainable bioresource. Economically, cow dung can be converted into biogas, organic fertilizers and compressed biofuels, a good alternative over costly fuels. We can use organic fertilizer and enhance farmer income by using it. With heavy production (in millions of tons), valorization offers vast potential for energy generation and soil enrichment. Cow dung plays a vital role in the economic pillar of the E3 Framework, offering renewable energy and low-cost agricultural inputs. Optimization studies shows methane yield improvements of up to 26.5% with strong model accuracy ($R^2 = 0.968$) in biogas digesters (Obileke *et al*., 2022) [16]. Blending cow dung with agricultural biomass enhanced its calorific value (3066-3600 Kcal/kg), with this calorific value it become volatile matter with low reduced ash content, which makes it an efficient fuel alternative (Anwar *et al*., 2024) [13]. By increasing the consumption of Biogas we can substitute LPG, kerosene, and electricity, easing energy costs (Ratminingsih & Jumadi, 2021) [76], while in Indonesia, it has the potential to generate 5,580 kW/day of electricity (Apriantika *et al*., 2022) [19]. Pilot plants further confirm its cost-effectiveness by producing both energy and nutrient-rich slurry for farming (Gedefaw, 2015) [33]. Moreover, cow dung and urine reduce reliance on chemical fertilizers through their nutrient content (Patra & Bharti, 2024) [35], and co-composting produces humus-rich compost with economic value (Oladipo & Okon, 2018) [22]. Together, these applications highlight cow dung's economic potential in reducing fuel dependency, improving soil productivity, and supporting rural incomes.

In terms of employment, proper management and processing of cow dung create rural job opportunities through schemes like GOBAR-DHAN and Godhan Nyay Yojana, while new business using cow dung can be started like cow dung based paints and numerous organic products. It encourages rural entrepreneurship and youth interest in developing new products.

The E3 Framework for Cow Dung Valorization emphasizes more on its potential to generate rural employment by converting cattle waste into energy, fertilizers, medicines, pesticides, paper, composites, and eco-friendly products (Fasake & Dashora, 2021) [24]. Livestock waste recovery models in the Global South show that biogas, compost, and aquaculture feed can enhance livelihoods while addressing environmental risks (Taron *et al*., 2025) [25]. In India, where most of the rural population depend on livestock, cow dung valorization supports hybrid farming systems and enables income generation through manure, bioenergy, and ayurvedic products (Mandavgane & Kulkarni, 2020) [30]. Government schemes such as GOBAR-DHAN and Godhan Nyay Yojana it strengthens farmer earnings and promote organic farming (Sahdev *et al*., 2024) [76]. Innovative products item like cow dung-based paints also play a important role in generating rural entrepreneurship opportunities while supporting sustainability goals (Kumar & Upadhyay, 2023; Nandkumar, 2022) [28, 29]. A case study of a dung-urine biorefinery reported a Sustainability Index of 0.69, confirming its social, economic, and environmental viability (Sustainable Industrial and Environmental Bioprocesses, 2020).

Environmentally, Valorization reduces methane emissions, manages organic waste, and promotes renewable energy through biogas and bio-hydrogen production. It also improves soil fertility with bio-fertilizers, supports eco-friendly pest control, and enables sustainable material substitution for bricks, plastics, and other resources. Thus, the E3 approach positions cow dung as a vital contributor to sustainable development and rural prosperity.

From an environmental perspective, cow dung valorization plays a dual role: mitigating pollution while enabling eco-friendly resource recovery. Unmanaged cow dung often causes air, water, and soil contamination, unpleasant odour, and disease spread (Ratminingsih & Jumadi, 2021; DOI:10.2991/ASSEHR.K.210305.012) [76]. However, when processed, it generates positive externalities, such as reducing dependence on fuelwood and fossil fuels, thereby conserving forests and lowering greenhouse gas emissions (Dikshit & Birthal, 2010) [32]. Biogas technology transforms cow dung into renewable energy while producing nutrient-rich slurry that serves as organic fertilizer, minimizing chemical inputs and improving soil health (Gedefaw, 2015) [33]. Similarly, cow dung microflora enhances soil biodiversity, nutrient cycling, and pest resistance, strengthening organic farming systems and supporting climate-resilient agriculture (Banerjee *et al*., 2023) [69]. Valorization methods such as anaerobic digestion, composting, pyrolysis, and co-digestion reduce methane release from open manure decomposition, contributing to climate change mitigation (Ounnar *et al*., 2019) [34]. These processes also provide sustainable alternatives to unsustainable disposal practices, aligning with the eco-efficiency principle of the E3 framework. Overall, cow dung valorization under the Environment pillar of E3 emphasizes waste-to-resource transformation that reduces methane emissions and environmental pollution, conserves forests and land by replacing fuelwood, enhances soil fertility and microbial health, contributes to renewable energy generation, and promotes sustainable, low-carbon rural ecosystems. Thus, cow dung, when professionally managed, becomes not an environmental liability but a key bio-resource for sustainable development (Patra & Bharti, 2024; Ratminingsih & Jumadi, 2021) [35, 76].

3. E3 Impacts of Cow Dung Utilization

3.1. Economic Benefits: Cow dung valorization demonstrates significant economic potential through its applications in energy, industry, and construction. It serves as a low-cost raw material for paper, packaging, and bio-based products, reducing reliance on wood, lowering production costs, and providing eco-friendly alternatives to plastics (Sahdev *et al*., 2024) [76]. Recent studies also highlight its role in producing high-value materials such as type I cellulose nanofibrils, offering cost-effective and sustainable pathways for biopolymers and advanced applications in textiles, food, packaging, and healthcare (Dai *et al*., 2025) [38]. Government schemes like GOBAR-DHAN and Godhan Nyay Yojana further support compressed biogas and organic fertilizers, enhancing farmers' income and aligning with circular economy models (Sahdev *et al*., 2024) [76].

3.2. Employment Generation: Cow dung utilization fosters rural employment opportunities in energy, processing, and manufacturing. Thermochemical conversion pathways such as pyrolysis and gasification create demand for skilled labor in renewable energy generation, syngas, and bio-oil production (Constantinescu *et al*., 2024; Kim *et al*., 2024) [37, 41]. In addition, construction applications involving dung-based plasters and bricks promote entrepreneurship and skill development among rural communities, generating substantial income through locally available resources (Kulshreshtha *et al*., 2022) [42]. These valorization pathways collectively strengthen rural livelihoods by offering diverse employment streams across multiple sectors (Sahdev *et al*., 2024) [76].

3.3. Environmental Outcomes: Environmentally, cow dung valorization contributes to significant reductions in greenhouse gas emissions over 90% in certain applications while mitigating waste and pollution, improving soil health, and supporting renewable energy production (Sahdev *et al*., 2024) [76]. Thermochemical approaches such as pyrolysis, gasification, hydrothermal liquifaction, and combustion produce bioenergy and biochar, with potential integration of carbon capture technologies for further emission control (Guo *et al*., 2020; Kiehbadroudinezhad *et al*., 2025) [39, 40]. The use of microbial aggregates in cow dung for water-resistant earthen blocks offers eco-friendly construction solutions, while biochar improves soil quality and supports sustainable agriculture (Kulshreshtha *et al*., 2022) [42]. Collectively, these outcomes position cow dung valorization as a driver of environmental resilience and resource conservation

4. Policy and Financial Support

Government policies and financial support play a central role in promoting cow dung valorization which directly strengthen the Bio-E3 framework—Economy, Employment, and Environment. Through energy and fertilizer policies, schemes like GOBAR-DHAN, Godhan Nyay Yojana, the National Biogas and Manure Management Programme (NBMMP), and SATAT provide subsidies and aid for biogas and compressed biogas (CBG) plants, reducing fossil fuel dependence while producing clean energy and organic manure (Honoured, 2019; Sahdev, Jain, & Aggarwal, 2024; Yadav & Sircar, 2021; Mishra, 2016) [76, 50, 47]. Carbon credit markets and green finance further boost economic viability, enabling farmers to earn income from carbon trading, though higher carbon prices are needed for wider adoption (Cariappa *et al*., 2024) [46]. At the same time, skilling initiatives such as Suryamitra, Varunmitra, TPSDI, and SCGJ train youth for green jobs, while community participation and women's self-help groups enhance adoption and empower rural households (Bajaj *et al*.; Schott *et al*., 2024; Shrestha *et al*., 2024; Yasmin & Grundmann, 2019) [45., 53, 54]. Together, these measures reduce energy poverty, improve sanitation, promote organic farming, and create livelihoods, making cow dung valorization a driver of sustainable development. Other policies and schemes Supporting Cow Dung Valorization and Their Impacts are listed in below table 1

Policy / Scheme	Purpose / Impact	References
GOBAR-DHAN	Supports biogas and organic fertilizer production, enhances farmer income, reduces waste	Honoured, 2019; Sahdev, Jain, & Aggarwal, 2024 [76]
Godhan Nyay Yojana	Promotes cow dung collection, valorization, and rural livelihoods	Sahdev, Jain, & Aggarwal, 2024 [76]; Yadav & Sircar, 2021 [50]
National Biogas and Manure Management Programme (NBMMP)	Provides subsidies for biogas plants and manure management	Mishra, 2016; Sahdev, Jain, & Aggarwal, 2024 [47, 76]
SATAT (Sustainable Alternative Towards Affordable Transportation)	Encourages compressed biogas (CBG) production for clean fuel	Sahdev, Jain, & Aggarwal, 2024 [76]
Rashtriya Kamdhenu Aayog Initiatives	It works to conserve and develop cows and their breeds. Strengthens cow-based projects, promotes natural farming, enhancing indigenous breeds and promoting scientific, economic, and environmental benefits and organic products	https://dahd.gov.in/sites/default/files/2024-10/LS68.pdf
UP Gaushala Self-Reliance Program	Makes cow shelters self-sufficient, encourages cowdung and urine utilization for energy, manure and eco-friendly agricultural practices.	https://economictimes.indiatimes.com/
Madhya Pradesh Rural Livelihoods Project (MPRLP)	Integrates cow dung valorization with rural development, boosting agricultural, making biogas work for poor communities and livelihood enhancement	https://en.wikipedia.org/wiki/Madhya_Pradesh_Rural_Livelihoods_Project

6. Challenges

Although, Cow dung valorization in India has shown vast potential for economic growth, employment generation, and environmental sustainability yet it has faces multiple challenges. Cowdung is used as a fuel or fertilizer, but its improper disposal and leftover creates environmental hazards and dirty enviroment in rural areas (Kushwaha *et al*., 2024; Shaibur *et al*., 2024) [74, 60]. Cowdung mixed with waste contains many impurities that create a hurdle for the biogas plant to work properly. Biogas plants can be dangerous because they carry serious risks such as fires explosions, toxic gas leaks, and poor slurry management, which can endanger both workers and ecosystems (Stolecka & Rusin, 2021) [61]. Cowdung is transformed into biogas by the process of anaerobic digestion is always found not easy technical issues occurs like leftover material (digestate) need treatment, process work best at use on farms. The process works best at certain temperatures, optimal C/N ratio, and microbial balance that has to maintained (Samoraj *et al*., 2022; Hamzah *et al*., 2023; Nekhubvi, 2022) [63, 64]. The therapeutic potential of cowdung has been neglected, scientists and industries have not explored on this, so that it can be useful in medicine or health products due to it bioactive properties (Raja *et al*., 2021) [67].

7. Future Prospects of Cow Dung Valorization

The future of cow dung valorization in India holds significant promise if supported by good policies and new technologies. On economic scale use of cowdungfor energy have shown good economic benefits. Community-based energy models projects show that these systems can be economically feasible and replicable, save money for rural families and reduce the need for fossil fuels (Ceglia *et al*., 2022; Jessica *et al*., 2011) [71, 73]. Also these models provide local employment in bioenergy production, forest management, and renewable energy infrastructure (Jessica *et al*., 2011) [73]. With proper government policy subsidies, small and medium biogas plants can grow, reducing transportation and generating income for farmers (Brahmi *et al*., 2024) [70]. Making products like compressed biogas, biofertilizers, and biochar from cow dung can create new businesses and increase farmers' income (Sahdev *et al*., 2024; Kushwaha *et al*., 2024) [76, 74]. The green economy is sharpened as products like compressed biogas, biofertilizers, and biochar are made from cowdung (Sahdev *et al*., 2024; Kushwaha *et al*., 2024) [76, 74]. Dairy cooperatives help farmers to sell cowdung at fair prices and offer jobs for people in collecting, processing, and distributing products (Rath & Joshi, 2020) [75]. New biogas technologies like nanobubble systems and microbial electrolysis for generating energy from waste to create skilled jobs in running plants, developing technology, and turning waste into energy (Sher *et al*., 2024; Goldfarb *et al*., 2022) [79, 72]. Cow dung is offers important environmental benefits. It reduces greenhouse gas emissions and support clean energy by converted into biogas, biomethane, hydrogen, and organic fertilizers (Sher *et al*., 2024; Saboohi & Hosseini, 2025) [79, 77]. Cow dung and its natural microbes plays a key role in improving soil health, increasing pest resistance and reduce the need for chemical fertilizers (Banerjee *et al*., 2023) [69]. Community biogas projects provide long-term environmental advantages by protecting forests, improve cooking conditions, and recovering valuable resources (Shaibur *et al*., 2021) [78].

Conclusion

Cow dung, a traditionally undervalued bioresource, has emerged as a cornerstone of sustainable development through its contribution to the *Bio-E3* framework Economy, Employment, and Environment. Its multifaceted applications, ranging from biogas and biofertilizer production to eco-friendly construction materials and organic farming, highlight its immense potential for circular bioeconomy advancement. Economically, cow dung valorization offers cost-effective and renewable alternatives to fossil fuels and chemical fertilizers while generating additional income for farmers and entrepreneurs. Employment-wise, initiatives such as GOBAR-DHAN and Godhan Nyay Yojana have demonstrated its role in empowering rural communities, particularly women and youth, by creating green jobs and small-scale business opportunities. Environmentally, cow dung utilization mitigates greenhouse gas emissions, enhances soil fertility, and contributes to waste management and climate change adaptation. Despite challenges like improper waste segregation, limited technical expertise, and safety concerns in biogas operations, the future remains promising with government support, technological innovation, and public participation. Integrating cow dung valorization into national energy and agricultural policies can strengthen rural livelihoods, promote renewable energy, and advance India's commitment to sustainable development and carbon neutrality. Thus, cow dung serves not merely as waste, but as a vital agent for economic growth, environmental restoration, and rural transformation.

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