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BIO-WASTE TO BIO-ENERGY: A PERSPECTIVE FROM INDIA

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Abstract:

Present crises of climate change, environmental degradation, poverty, food security, and energy optimization are critical challenges linked with the linear model of the economy based on continuous extraction of natural resources, dependency on fossil fuels, and unsustainable production & consumption. Due to the growing population rate and economic development, an enormous amount of bio-waste is being generated in India; on the other hand, globally, to reduce greenhouse gas (GHG) and climate change mitigation, the demand for bio-energy is increasing rapidly. Diverse types of bio-waste generated in India are causing long-term environmental pollution and biodiversity loss; on the other hand, research data reveals that bio-waste has enormous potential in supplementing virgin resources and energy generations. In the early civilization, bio-wastes were either dumped or burnt off in the open environment leading to environmental degradation, increased concentration of GHG, and incurred a considerable amount of economic cost. The globally accepted circular economy principle for bio-waste utilization holds the promise for providing sustainable long-term solutions towards bio-waste valorisation and supplementing virgin resources and non-renewable energy, respectively. Utilization of diverse category bio-waste with the circular economy principle helps to reduce the volume of the waste dump and is used as raw materials for other fields of applications such as bio-energy, bio-chemical, and bio-fuel. This paper describes the present state of the arts of recycling and valorisation opportunities of bio-waste for bio-energy generation through the circular economy principle, leading to replenishing the depletion of natural resources, reducing the dependency on fossil fuel, reducing global warming, and helping to integrate global sustainability.

Key Words: Bio-Waste, Greenhouse Gas, Environmental Degradation, Bio-Energy, Natural Resources & Circular Economy

List of Abbreviations and Symbols:

Abbreviation	Explanation
DNES	Department of Non-Conventional Energy Sources
GDP	Gross domestic product
ICAR	Indian Council of Agricultural Research
IEA	International Energy Agency
IREDA	Indian Renewable Energy Development Agency
LCA	Life cycle assessment
NMAET	National Mission on Agricultural Extension and Technology
NPIC	National Programme on Improved Cook Stoves
PPP	Power Purchase policies
UN	United Nation

1. Introduction:

Worldwide among the agricultural country, India is one of the significant bio-economy based country (Patel et al., 2020; Singh, 2017), consisting of the diverse category of crop species and livestock, including indigenous and exotic with covering 21 broad agro-ecological regions (Singh, 2017), and 15 wide agro-climatic zones (Balasubramanian, 2013) respectively. In India gross arable land area of 159.7 million hectares, annual GDP 17.32% of total India's GDP during 2017-2018 (Bisht and Thakur, 2019), employment engagement 48.9% during 2011-2012 (Bisht and Thakur, 2019), and forest cover around 24% of its total geographic area. Thus, a massive amount of bio-waste residues available in India as around 686 million metric tons annually (Panwar et al., 2019), which is 23 Giga-watt of energy equivalent (Singh and Setiawan, 2013), and forest waste residues around 59.68 million tons annually (Bisht and Thakur, 2019). Table 1 presents the generation of bio-waste residues in the Indian context.

Table 1: Bio-waste residues availability in India

Bio-Waste Residues	Quantity	References
Agricultural surplus dry biomass	145.02 million tons annually	Bisht and Thakur, 2019
Agriculture Residues (gross)	686 million tonnes	Panwar et al., 2019
Bagasse	181Mt by 2040	Kapoor et al., 2020
Biomass Generation	89 119.1 Kt/ Year	Bisht and Thakur, 2019

Biomass residue of straw	552.3 MT by 2040	Kapoor et al., 2020
Forest surplus dry biomass	59.68 million tons annually	Bisht and Thakur, 2019
Lignocellulosic agro-residue biomass	686 million tonnes	Kapoor et al., 2020
Oil cakes	6.3% of oil cakes of global in 2013–14	DES, 2013
Projected biogas potential of crop residues	103 and 172 billion m^3/year in 2040	Kapoor et al., 2020
Straw residues	100 Mt per year	Kauldhar and Yadav, 2018
Total agriculture residues	552.3 MT	Gupta and Dadlani, 2012; Hiloidhari et al., 2014

The quantity of bio-waste generated in India is a very prospective input for recycling and utilization in energy generation and other industrial applications; however, in India, the potential of the large quantity of bio-waste is still not utilized (Kapoor et al., 2020; Bisht and Thakur, 2019).Table 2, Table 3, and Table 4 summarized the state-wise and crop-wise surplus bio-waste and forest residues (bio-waste) in India.

Table 2: State-wise availability of surplus agricultural biomass in India

State	Bio-Mass Generation (Kt/ Year)	Bio-Mass Surplus (Kt/ Year)
Andhra Pradesh & Telangana	43 893.2	6956.4
Arunachal Pradesh	400.4	74.5
Assam	11 443.6	2346.9
Bihar	25 756.9	5147.2
Chhattisgarh	11 272.8	2127.9
Goa	668.5	161.4
Gujarat	29 001	9085.5
Haryana	29034.7	11342.9
Himachal Pradesh	2896.9	1034.7
Jammu & Kashmir	1591.3	279.6
Jharkhand	3644.9	890
Karnataka	34 167.3	9027.2
Kerala	11 644.3	6352.1
Madhya Pradesh	33 344.8	10 329.3
Maharashtra	47 624.8	14 789.6
Manipur	909.4	114.4
Meghalaya	511.1	91.6
Mizoram	61.1	8.5
Nagaland	492.2	85.2
Orissa	20 069.5	3676.8
Punjab	50 847.6	24 842.9
Rajasthan	29 851.3	8645.7
Sikkim	149.5	17.8
Tamil Nadu	22 507.6	8900
Tripura	40.9	21.1
Uttar Pradesh	60 322.2	13 737.9
Uttarakhand	2903.2	638.4
West Bengal	35 989.9	4301.5
Manipur	909.4	114.4
Total	511041	145026.6

(Source: Bisht and Thakur, 2019; Hiloidhari et al., 2014)

Table 3: Crop wise bio-mass generation and surplus bio-mass for electricity generation in India

Crop	Residues	Bio-Mass Generation (Kt/ Year)	Bio-Mass Surplus (Kt/ Year)
Arecanut	Fronds	788.5	276
	Husk	212.3	74.3
Arhar	Stalks	5120.2	822
	Husk	614.4	306.4
Bajra	Stalks	12 039.4	1919.5
	Cobs	1986.5	939.9
	Husk	1805.9	431.3
Banana	Residue	11 936.5	4176.7

Barley	Stalks	563.2	57.5
Berseem	Stalks	71.6	57.3
Black pepper	Stalks	29.1	17.4
Cardamom	Stalks	43.6	34.9
Cashew nut	Stalks	148.2	36.1
	Shell	41.2	10
Castor seed	Stalks	1657.2	733.8
	Husk	41.4	20.7
Casurina	Wood	211.8	180
Coconut	Fronds	7278.9	3633
	Husk & pith	3184.8	1592.4
	Shell	1322	938.8
Coffee	Pruning & wastes	1457.6	1166.1
	Husk	133.4	13.3
Coriander	Stalks	188.3	18.8
Cotton	Stalks	31 357.1	16 576.9
	Husk	10 789.1	4828.7
	Bollshell	10 789.1	4828.7
Cow gram	Stalks	48.5	4.85
Cumin seed	Stalks	182.6	146.1
Dry chilly	Stalks	268.6	28.8
Dry ginger	Stalks	5.3	0.53
Eucalyptus	Residue	162.8	138.4
Gram	Stalks	5440.6	1014.2
Groundnut	Stalks	13 148.2	2066.9
	Shell	1972.2	1200.2
Guar	Stalks	233.3	163.3
Horse gram	Stalks	191.3	19.1
Jowar	Cobs	5043.5	1912
	Stalks	2042.7	2042.7
	Husk	2017.4	959.11
Kesar	Stalks	9.4	7.8
Kodo millets	Stalks	3.13	2.54
Linseed	Stalks	86.3	8.9
Maize	Stalks	23 421.3	4547.11
	Cobs	3536.4	1319.12
Meta	Leaves	40.1	4.04
Moong	Stalks	671	67.4
	Husk	91.5	25.11
Moth	Stalks	17.8	1.81
Mustard	Stalks	6999	3173.12
	Husk	1674.9	1591.5
Niger seed	Stalks	94	6.7
Oilseeds	Stalks	1143.1	118.6
Onion	Stalks	66.5	7.4
Paddy	Straw	149 969.1	30 594.6
Husk	Husk	19 995.9	12 944.4
Peas & beans	Stalks	27.4	3.77
Sweet potato	Stalks	12.8	1.31
Tapioca	Stalks	3959	2769.8
Tea	Sticks	909.8	582.6
Til	Stalks	1207.7	282.8
Tobacco	Stalks	204.8	20.8
Turmeric	Stalks	32.3	16.5
Wheat	Stalks	93 361.7	16 176.6
Total		**4911 54**	**136428.1**

(Source: Cardoen et al., 2015; Bisht and Thakur, 2019)

Table 4: State-wise forest bio-mass generation and surplus bio-mass potential for electricity generation in India

State/Uts	Biomass Generation (Kt/ Year)	Biomass Surplus (Kt/ Year)
Andhra Pradesh & Telangana	1013.2	685.5
Andhra Pradesh & Telangana	1013.2	685.5
Arunachal Pradesh	7161.8	5207.6
Assam	2804.1	1850.4
Bihar	664.9	443.3
Chhattisgarh	11204.5	7473.3
Goa	180.7	119.5
Gujarat	1520.2	1072.8
Haryana	58.9	38.1
Himachal Pradesh	1864.4	1864.4
Jammu & Kashmir	3304.2	2180.1
Jharkhand 3	3305.2	2202.8
Karnataka	7840	5174.6
Kerala	2110.8	1421.7
Madhya Pradesh	8058.2	5374.9
Maharashtra	7580.9	5123.7
Manipur	1044.3	689.4
Meghalaya	1434.1	946.5
Mizoram	1037.7	684.11
Nagaland	760.8	502.4
Orissa	9282.4	6027.1
Punjab	282.8	186.9
Rajasthan	2838.6	1873.7
Sikkim	436.7	288.4
Tamil Nadu	3506.9	2314.8
Tripura	635.2	419.4
Uttar Pradesh	3255.8	2181.1
Uttarakhand	4542.8	3044.5
West Bengal	1388.8	921.4
Manipur	1044.3	689.4
Total	**89 119.1**	**59 680**

(Source: Rajagopal et al., 2017; Bisht and Thakur, 2019)

The availability of a massive amount of surplus bio-wasteresources in India could reduce dependence on fossil based energy resources. Ministry of new and renewable energy (MNRE), Govt. of India launches various favorable policies and programs to promote renewable energy sources, primarily through the utilization of bio-waste as feedstocks for the development of bio-energy sources in India (Prasad et al., 2020; Kapoor et al., 2020, Bisht and Thakur, 2019; Heidari et al., 2019; Kumar et al., 2015). Year-wise development, policy formation, and program for the development of the bio-energy sector in India has been presented in Table 5

Table 5: Development scenario ofthe bioenergy sector in India

Year	Activity Name	Activity
1981	Programs/ installations	The national biogas development program, Commission for additional sources of energy
1982	Organization	DNES set up under the ministry of energy
1984	Organization Set Up	"Gasification action research centre set up at IITD,IISC Banglore, Ankur and NARI"
1985	Programs	National awareness programme on improvement of Cook stoves (NPIC)
1986	Programs	National program on gasification technology
1987	Organization Set Up	IREDA Set Up
1992	Organization Set Up	Department of non-conventional energy sources(DNES) becomes ministry of non- conventional energy sources (MNES)
1993	Organization Set Up	National programme on promotion of biomass power
1994	Policy	"Single part tariff for bagasse generation power with 1993-1994as base year"
1995	Organization Set Up	First cogeneration plant installed (18.68 MW)
1998	Policy	Power purchase policies (PPP) in 14 states

2001	Organization Set Up	Rural electrification programme (VEP)
2002	Regulation	Maharashtra electricity regulatory commission (MERC) tariff order for bagasse cogeneration
2003	Act Program Organization Set Up	Electricity act Establishment of national CDM authority Village electrification programme (VEP) modified to village electrification (RVE)
2005	Organization Set Up	First time cogeneration and combustion project registered under CDM
2006	Policy	National tariff policy
2007	Organization Set Up	Implementation of gasifier based project projects under clean development mechanism (CDM)
2008	National Plan Regulation	National Plan on climate change CERC open access regulation for inter-state transmission
2010	Policy	Renewable energy certification mechanism
2012	Regulation Organization Set Up	Formation of central electricity regulatory commission (CERC) terms and conditions for tariff determination regulations Grid-connected power from gasifier plant sale to third party in Gujrat

(Source: Ghosh, 2016; Bisht and Thakur, 2019)

Kapoor et al., (2020) "emphasized that despite having the potential of biogas production, 29-48 billion m^3/ year in India using only 2.07 billion m^3/year". The recycling and reuse of waste biomass as an input resourcefor bio-energy generation has several benefits. It reduces the dependency on fossil fuels, reduces environmental impacts, and provides future energy security. The vast potential of bio-energy resources in India is still not utilized (Kapoor et al., 2020; Bhuvaneshwari et al., 2019; Hiloidhari et al., 2014). In India, several initiatives have been taken towards utilizing bio-waste as an input resource for gasification (non- bagasse) based electricity generation plants; Table 6 summarizes India's state-wise bio-energy installed capacity.

Table 6: State-wise grid-connected bio-energy installed capacity in India

Rank	**State/Uts**	**Installation (MW)**	**Rank**	**State/Uts**	**Installation (MW)**
1	Uttar Pradesh	2127.91	12	Bihar	121.22
2	Maharashtra	2081.4	13	Uttarakhand	120.5
3	Karnataka	1619.8	14	Madhya Pradesh	105.35
4	Tamil Nadu	921.55	15	Gujarat	65.3
5	Andhra Pradesh	477.18	16	Orissa	58.6
6	Punjab	322.1	17	Meghalaya	13.8
7	West Bengal	319.92	18	Himachal Pradesh	7.2
8	Chhattisgarh	228.5	19	Jharkhand	4.3
9	Haryana	199.66	20	Chandigarh	2.5
10	Telangana	158.1	21	Kerala	0.72
11	Rajasthan	121.3			

(Source: Bisht and Thakur, 2019)

Under that MNRE mission 2022, Govt. of India set the expected target of 10 GW by 2022; details of sector-wise electricity generation hasbeen presented in Figure 1.

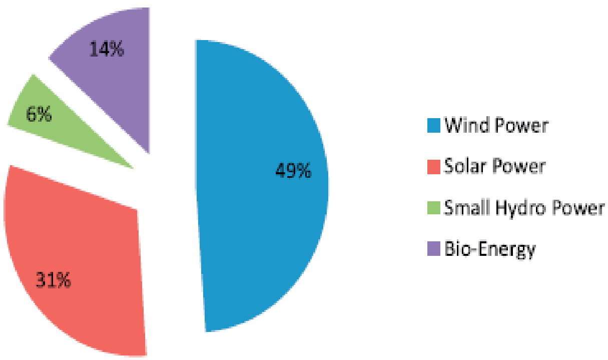

Figure 1: The MNRE missions 2022, Govt. of India, set the expected target 10 GW by 2022
(Source: Bisht and Thakur, 2019)

2. Bio-Waste to Bio-Energy: Present State of the Arts towards Valorization of Bio-Waste:

Population growth, Global warming, sustainability issues, and depletion of fossil fuel is the significant challenges faced by the global community. To mitigate these issues and reduce the dependency on fossil based energy, renewable energy is one of the best ways considered in the present situation. As a substitute for 100% oil economy, technology development and process based on the bio-waste can be developed. Based on the report of US energy information administration, 2010, has estimated that global total energy demand will increase 521903.3* 10^{15}J in 2007 to 778321.2*10^{15} J in 2035, and considering the current situation, renewable energy will contribute 13.5% in 2035 of the total energy consumed on 2035, (de Paula Protásio et al., 2013). Bioenergy contributed 69.5% of the global renewable source of energy in 2016 (IEA Renewables information 2018 overview). It is expected that the potential of global bio-mass resources would be approximately 100–600 EJ by 2050 (Slade et al., 2014), which would be equivalent to 15%–65% of primary energy demand by 2050 (IEA Energy technology perspectives, 2014). Using bio-waste to produce bio-energy as a sustainable energy source can replace fossil fuel burning, reduce GHG, and mitigate climate change. Worldwide, around 5300 million tons of dry bio-waste are produced yearly (Carrillo-Nieves et al., 2019). Using the full potential of such a massive amount of bio-waste can supplement the energy crisis shortly. Bio-energy production (commercial applications) from bio-waste in India has been presented in Table 7.

Table 7: Status of bio-energy generation in India and their sustainability assessment (Bio-waste valorizations)

Country	**Quantity of energy**	**Sustainability assessment**	**References**
India	Total biogas production 2.07 billion m3/year (potential of 29–48 billion m3/year)	Reduced GHG, mitigated environmental hazards, Supplements fossil fuel. Reduce social impact on the environment and climate change	Kapoor et al., 2020
India	278.71 Mt/year bio-mass is available for bio-energy generation in India, whilecrop residue and agricultural waste 45.8 Mm3/day is considered for estimated biogas potential for the crop residue and agricultural waste	Bioenergy potential as a percentage of total energy demand in 2013 ranged between 13.0 and 20.5% for agricultural biowastes	Kapoor et al., 2020
India	9490 MW 2017-2018, bio-energy makes up 2.8% of total energy installations in India at present.	Reduced GHG; mitigate environmental hazards, Supplements fossil fuel. Reduce social impact on the environment and climate change	Bisht and Thakur, 2019

With the development of technology at an advanced level and the interest of stakeholders and emerging circular economy principle, the bioenergy sector is growing gradually; a few recent examples for the development of process technology for bio-waste to bio-energy (valorization approach of bio-waste) has been presented in Figure 2and Figure 3 respectively.

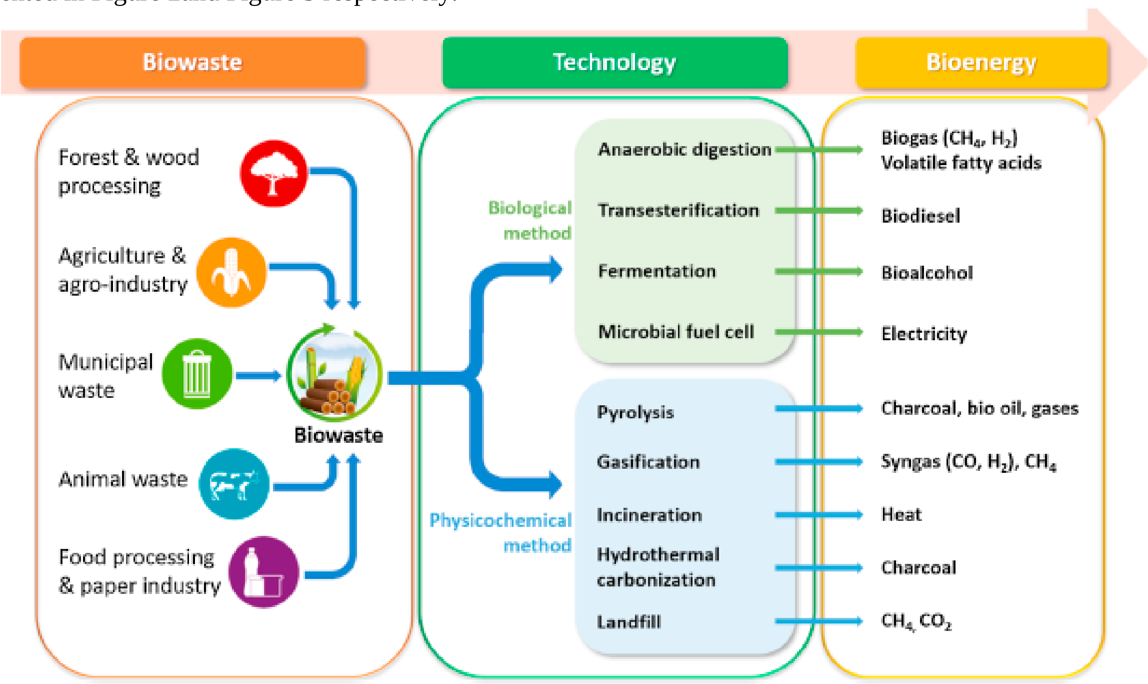

Figure 2: Schematic models for bioenergy production from different bio-wastes (Source: Bhatia et al., 2018)

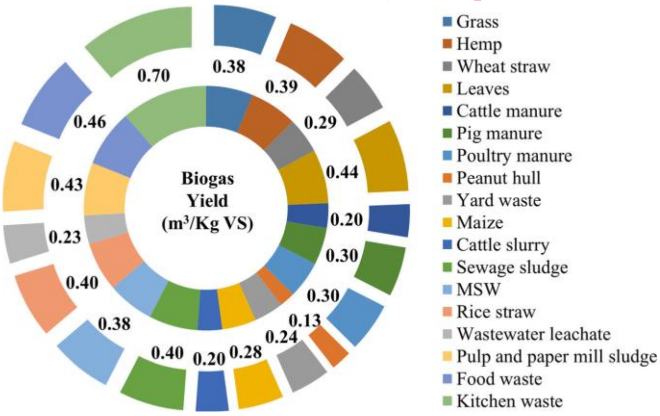

Figure 3: Differentbio-wastes and their biogas production potential (Source: Bhatia et al., 2020)

3. Main Policy Guidelines in the Present Context:

While designing specific policies to promote the recycling process, it is essential to have a fair understanding of all potential bottlenecks, needs, barriers, and inefficiencies that may exist in such processes and how such bottlenecks and other obstacles and inefficiencies can be overcome through public policy interventions. The utilization of bio-waste is an important economic sector in terms of employment, turnover, and investments. The policy pertaining to bio-waste utilization shall guide India to establish an appropriate legislative, administrative, and institutional framework for the valorisation of bio-waste. Table 8 presented the significant policy intervention relating to the seed sector by the Government of India (Source: ICAR, New Delhi)

Table 8: Significant policy intervention relating to seed sector by Government of India

- National Seeds Corporation (NSC), 1963
- Seeds Act, 1966
- Seed Rules, 1968
- National Seeds Programme (NSP), I, II, &III (1976-1995)
- Seeds (Control) Order, 1983
- New Seed Policy 1988
- New Industrial Policy 1991
- PPV &FR Act, 2001
- Seed Policy, 2002
- Revision of NPSD, 2011
- Sub Mission (NMEAT) on Seed, 2012
- Seeds (Control) Amendment Order, 2014 (enhanced license fee)
- Seed (Amendment) Rules, 2015 (all forms revised)

(Source: ICAR, New Delhi)

4. Zero Waste Concepts for the Industry through the Circular Economic Policy:

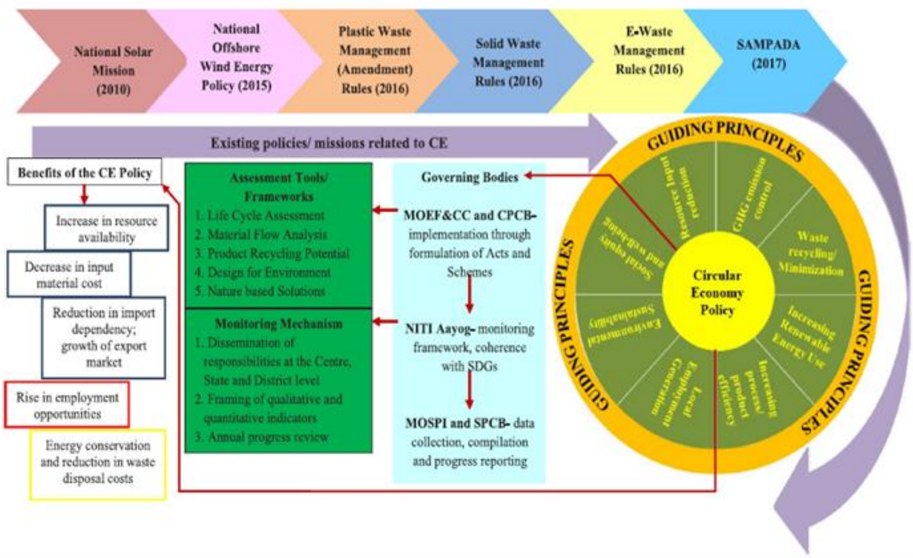

Figure 4: Proposed framework for a circular economy policy for India
(Source: Priyadarshini and Abhilash, 2020)

In India, the annual generation of bio-waste is around 486 million tons, the same can be converted into value-added products with fewer efforts and energy, utilizations of bio-waste can supplement replenish of virgin resources using for many essential and relevant applications, reduced energy consumption and GHG through circular economy (CE) route, favourable policy framework, and regulation can increase the utilization of bio-waste for productive applications. Government intervention on policy framing towards managing and valorization of the enormous amount of bio-waste would play a vital role in respect of transition of global economies towards closing the gap of circularity and making waste as a resource, fair policy and regulation can lead to process 100% bio-waste to a productive application such as, bio-energy, bio-fuel, and bio-chemicals and many more with the principle of circular economy (Priyadarshini and Abhilash, 2020). CE model in bio-waste utilization can increase available resource availability, minimize waste generation, and generate renewable energy sources. Priyadarshini and Abhilash, (2020) proposed a policy framework for managing waste through the circular economy principle in India presented in Figure 4.

While forming the policy, framework, and regulations for enhancing the utilization facilities of bio-waste, the following bottleneck needs to be addressed.

- Lack of initiative by Government and private agency for processing bio-waste to a valuable resource
- Lack of proper policy framework and amendments of existing policies/new approach to deal with bio-waste utilization.
- Policy needs to implement the compulsory use of bio-energy with subsidies rate wherever applicable.
- Increase the price for utilization of natural resources and reduce the cost for materials produced from bio-waste valorisation.
- Policy for imposing landfill tax, so that bio-waste shall not be dumped in open land instead of utilization.
- Policy for compulsory use of bio-waste residues through the proper process and protocol
- Bridging the gap between industry and Government officials
- Government should make policy regarding sustainability context in respect of bio-waste valorisation
- To realize that bio-waste is actually wealth and is a valuable resource.
- Policy formation for the circular economy business model instead of the traditional linear economy towards vaporization of bio-waste.
- Lack of a practical and attractive scheme for entrepreneurs who can open up startups to recycle bio-waste.
- Policy and Government intervention should be in the context like scheme of incentives, tax exemption, credit facilities, and flexible licensing system towards managing of bulk amount of bio-waste.
- Policy correlation within bio-waste utilization, sustainable development and mitigation of climate change

5. Recommendation to Improve the Policy Framework in the Present Context:

The future policy options available with the policymakers for managing bio-waste are to promote necessary schemes and facilities within the framework of policy and regulation by the Government of India with the alliance of Industry partners and stakeholders. The proper recommendation is essential to rebalance the policy and regulation towards bio-waste valorization to bring the reverse trend from linear to the circular economy and foster sustainable resource management. Few issues in the context of managing bio-waste causing barrier, and which needs to be addressed at the earliest to promote sustainable development through the managing huge quantity of bio-waste are as follows.

- Strengthen the policy in the context of environment governing land issues
- Strengthen and reform needs on existing policy so that private parties can join and develop process technology towards valorisation of bio-waste.
- Government should form a region-wise policy on bio-waste utilization, recycling, and bio-energy generation.
- Policy on bio-waste and feedstock price security
- Policy on adoption and utilization of bio-energy to reduce dependency on fossil fuel
- Fixation of the proper selling price of bio-waste
- Subsidy removal on utilization of non-renewable energy
- Promotion of bioenergy utilization
- Favorable policy and conditions for consumption of bioenergy in the domestic and industrial sector
- Reform market regulations and strengthen market functioning across states
- Reinforce existing policy initiatives already underway for the valorization of bio-waste
- Flexible licensing systems to promote bio-waste recycling and processing plant.
- Favorable environmental law in respect of bio-waste utilization
- Insurance scheme, Start-up facilities

- Financing facilities to set up a plant
- Emerging circular economic concept
- Policy to Introduce code and standard
- Policy to design LCA to reduce waste
- Policy for compulsory use of bio-waste as secondary products wherever applicable
- Policy for restricting the use of natural resources
- The particular policy required for penalties wherever applicable

Conclusion:

In India, the availability of a enormous quantity of bio-waste can be considered a potential feedstock for the generation of bio-based energy. In the context of recycling and reuse of bio-waste, there is a diverse scope and opportunities for industries, farmers groups, NGOs to come forward together and achieve the goal of mission "Zero-Waste." The sustainable use of bio-waste and bio-waste residues plays a vital role in resource optimization and energy security. In India, agriculture sectors generate a large amount of bio-waste residues, accumulating over long. The major part of the waste has remained unutilized, leading to environmental pollution, incurring substantial economic losses, and reducing sustainability. The full potential of bio-waste residues can be utilized through the circular bio-economy business model, which leads to producing many value-added products and generating renewable energy sources such as bio-energy, bio-fuel, and bio-gas. There is an urgent need for dedicated research to find out the hinders, barriers, knowledge gap, and policy deficiency towards utilization of the full potential of bio-waste, leading to accelerate the valorization of bio-waste residues and increase sustainable development. Government intervention in respect of proper policy formation towards managing a colossal quantity of bio-waste residues can accelerate the valorization process in many folds, thereby supplementing a portion of virgin resources, reducing the dependency on fossil fuel, meeting the energy demand, boosting up economic growth, increasing national GDP, open up entrepreneurial opportunities, create more employment opportunities, and improve overall sustainability.

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