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Ecosystem Service-Based Approaches in Agricultural Policy Making*

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ABSTRACT

The global surge in research and financial support towards understanding ecosystem services (ES) highlights their integral role in human well-being and agricultural sustainability. This approach aims for enhanced yields, resource efficiency, reduced environmental degradation, and improved landscape connectivity, integrating biophysical, cultural, and economic resources across landscapes. Despite recognizing ES values in policy decision-making, challenges persist due to issues related to value definition, valuation methodologies, and insufficient scientific studies. There are multifaceted dimensions of agroecosystem services, examining their influence and the hurdles in incorporating them into policy decisions. This keynote explores various global models of ecosystem service integration, showcasing their application in market-based policy instruments for fostering sustainable agricultural practices. Additionally, it addresses the need for comprehensive mapping of AES to inform policy formulation and highlights the growing attention towards the sustainability of production and environmental health in agricultural policy discussions.

Keywords: Ecosystem services, agricultural sustainability, resource efficiency, sustainable agricultural practices

JEL classification: Q01, Q56, Q57, Q58

I

INTRODUCTION

In the wake of global discussions on the vital role of ecosystem services in human well-being, there has been a remarkable surge in research efforts and financial support dedicated to exploring the multifaceted dimensions of Ecosystem Services (ES). Notably, the ecosystem services-based approach is gaining prominence in agricultural management and policymaking, offering a promising avenue for sustainable agricultural production (Gerowitt *et al.,* 2003a,b; Pagiola, 2008; Rasheed *et al*., 2021). This approach seeks to achieve better integration of biophysical, cultural, and economic resources across expansive landscapes, ultimately aiming for enhanced yields, resource efficiency, reduced environmental degradation, and improved landscape connectivity.

The transformative potential of this approach extends beyond agricultural productivity; it endeavours to optimise the delivery of ecosystem services to agricultural producers while ensuring the broader well-being of diverse life forms. For instance, integrating economic valuation into decision-making processes empowers policymakers to prioritize conservation efforts and advocate for sustainable development practices that safeguard both economic and ecological benefits. Compensating farmers for the ecosystem services they provide could emerge as an

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innovative strategy to simultaneously double farm incomes, alleviate rural-urban migration pressures, reduce strain on urban infrastructure, and incentivize sustainable agrarian practices in regions like India (Devi *et al.*, 2017)

Despite a quarter-century since the initial recognition of the importance of ecosystem services values, persistent challenges obstruct the seamless incorporation of these values into policy decision-making processes. Drawing insights from Pascual *et al.* (2023), these challenges encompass issues related to value definition, divergent valuation methodologies, doubts about method robustness, insufficient financial and technical resources, and a dearth of scientific studies. Economic dominance in policymaking, coupled with disconnects between valuation results and political jurisdictions, administrative levels, sectoral interests, or stakeholder perspectives, further complicates the situation. Power dynamics, especially evident in large investment projects, often prioritize instrumental values supporting broader development goals, side-lining the instrumental and relational values of local stakeholders. In contrast, Indigenous Peoples and Local Communities (IPLCs) frequently find their diverse perspectives on nature's values marginalized or overlooked in decision-making processes. Recognizing these challenges, Costanza *et al.* (2017) emphasized the importance of mapping all ecosystem services as a crucial step toward integrating them into policy formulation.

In the realm of agriculture, these challenges are magnified due to the inherent complexities of production systems, concerns about food security, historical approaches, livelihood aspects, social systems and related political views. Agricultural ecosystems exhibit vast heterogeneity in structure and function globally, with agricultural land use serving as a transitional stage in the human-impact continuum between wilderness and urban ecosystems (Swinton *et al.*, 2007). While agricultural lands have traditionally been managed to maximize provisioning services, the ecosystem services emanating from this sector are often inadequately acknowledged and poorly accommodated in management decisions.

Liu *et al*, 2022, based on a massive search of literature on ES, reports that most of the studies as focussing on valuation of urban ecosystems, forest ecosystems, wetland ecosystems and river ecosystems and the studies on Agro-Ecosystem Services (AES) as gaining attention since 2000, and it is slowly growing later on. Moreover, the publications on AES are globally unevenly distributed, the countries in southern hemisphere generally pay less attention to AES than that in northern hemisphere. AES are mostly studied in the European countries, especially the UK, Germany, France and Italy, followed by the USA.

As awareness of the close connection between environmental health, human welfare, and the sustainability of production and produce quality grows, the concept of ecosystem services is gradually capturing the attention of researchers, planners, and policymakers. Ecosystem services connected to agroecosystems are to be viewed both as inputs in agricultural production and as outputs of the agriculture sector, acting complementarily (Garbach *et al.*, 2014). Notably, while the global agriculture sector contributes 20 per cent to greenhouse gas emissions, it also holds significant potential for effectively mitigating the impacts of climate change through carbon sequestration. So, the Agro Ecosystems (AE) provide Ecosystem Services (ES) as well as Ecosystem Dis – Services (EDS). In that perspective, Agro Ecosystem Services (AES) are both the cause for ecosystem damages and remedy for the same (Figure 1). As the most prevalent form of land management globally, covering nearly 40 per cent of the Earth's terrestrial surface, the ecosystem services derived from agriculture take on heightened importance in the quest for a sustainable and resilient future. The conflicting challenges of achieving higher food production while ensuring ecological health and sustainability demands the integration of ecological services in the management decision making within the agricultural sector.

Figure 1. The Ecosystem Service Flow from Agriculture Sector

In this background, we delve into the intricacies of agroecosystem services, examining the extent of their influence, and the hurdles associated with seamlessly incorporating them into policy decisions. Additionally, the paper sheds light on various global models that successfully integrate ecosystem services, showcasing their application in crafting market-based policy instruments geared towards fostering sustainable agricultural production and the uninterrupted flow of ecosystem services.

II

AGRO ECOSYSTEM SERVICES (AES)

Agroecosystems, shaped by human intervention for cultivating crops, exhibit intricate dynamics with a reliance on both living (biotic) and non-living (abiotic) elements. Found in diverse climatic regions, these intricate systems encompass variables such as temperature, precipitation, and other factors that impact crop growth. This influence occurs through direct and indirect interactions with the soils, plant and animal life, including the growth-promoting microbiota, as highlighted by Yadav *et al*. in 2021. Agroecosystems provide essential services categorized into provisioning, regulating, cultural, and supporting services. Provisioning services encompass the supply of food, water, timber, fibre, and medicinal plants. Regulating services involve climate regulation, flood control, disease control, nutrient recycling, water quality regulation, and the maintenance of flora and fauna population dynamics, including agrobiodiversity. Cultural services manifest as recreational, aesthetic, and spiritual benefits, while supporting services contribute to soil formation, nutrient cycling, and photosynthesis. Although provisioning services in agroecosystems are recognized through market mechanisms, the remaining services often go overlooked in decision-making processes because they lack market tradability. A comprehensive breakdown of agroecosystem services and their indicators can be found in Table 1, modified based on Liu, 2022. However, the mapping of AES is often incomplete and of the 34 AES listed in Table 1, only 18 services were seen listed in the paper. This naturally impact the valuation approaches as well.

Amidst global discussions on the sustainability dimensions of economic development, there has been a heightened focus on the welfare implications of non-market services, as highlighted by scholars (Costanza *et al.,* 1997; Daily, 1997; MEA, 2005; Dale and Polasky, 2007; and Power, 2010). Traditionally, the approach to agricultural production operated on the premise that ecosystem services (ES) were inherent, free goods from nature. While early farming practices were not explicitly geared towards ecosystem conservation or the conceptualization of agricultural production as agroecosystems, they tended to be environmentally friendly. These practices unintentionally contributed to ecosystem health, creating a conducive environment for safe and sustainable agricultural production. Historical literature on farming underscores a reliance on natural inputs like livestock dung and urine, green leaf manure, and other organic matter forms, with ecosystem services not deliberately acknowledged as inputs. Emphasis was placed on factors such as monsoons, water, natural pest management, agrobiodiversity, and soil quality to establish an ideal ecosystem for crop production. In many developing economies, the primary objective was to maximise crop output to meet increasing food demand and alleviate poverty.

The publication of "Silent Spring" in 1962 sparked rising concerns about ecosystem health, prompting serious discussions on agricultural production practices and externalities, particularly the negative impacts. Consequently, there was increased attention on ES as an output, especially the negative aspects, from agriculture. Demand-side factors, including environmental quality and food safety, also played a pivotal role in this shift. Presently, there is a heightened awareness of the role of agroecosystems as providers of ecosystem services, especially when considering the sector's contribution to greenhouse gas emissions and its potential as a regulator in addressing climate change. Liu *et al.*, 2022 presents an exhaustive examination of contemporary research on Agroecosystem Services (AES), encompassing indicators, assessment methods, and future research directions. The paper chronicles the evolution of research in this domain, catalysed by initiatives such as the Economics of Ecosystems and Biodiversity (TEEB), the Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services (IPBES), and the global pursuit of Sustainable Development Goals (SDGs). Nonetheless, studies on ES from agroecosystems indicate variability over time, space, and subject matter, as noted by Vidaller and Dutoit (2021) and Liu *et al*. (2022).

TABLE 1. MAJOR ECOSYSTEM SERVICES FROM AGRO ECO SYSTEMS (AES)

AES (1)	Indicators (2)	Detailed explanations (3)
Provisioning services	Food Fodder and fibre Raw materials Medicine, Wood, by-products, Energy and fuel	Agroecosystems provide humans with a variety of goods. Grain, crops, domestic animals, and fisheries provide food. Cash crops such as cotton, hemp, ginseng, rape, and peanut provide industrial raw materials, medicinal materials, energy, and fuel.
	Groundwater recharge	Ecosystems contribute to groundwater recharge by allowing rainwater to infiltrate the soil and percolate downward.
Regulating services	Carbon Sequestration	Carbon sequestration in agroecosystems through crop photosynthesis and increasing soil organic matter.
	Local climate regulation	The transpiration of crops and other plant components and evaporation from farmland irrigation can effectively decrease the heat island effect.
	Waste decomposition	Soil microorganisms and invertebrates decompose dead tissues such as roots, stems and leaves of crops or other plants, and organic fertilizers.
	Soil Conservation	The covering of crops, herbaceous plants and shrubs, and the retention of stubble and straw after crop harvest can maintain soil by reducing erosion.
	Air purification	Trees or other plants play an important role in purifying air by removing pollutants from the atmosphere.
	Soil retention	Supporting soil retention ecosystem services is essential, utilizing natural processes and features to enhance the stability of the soil.
	Flood mitigation	Wetlands retain and control flood waters. Coastal ecosystems (e.g., wetlands, including salt marshes and mangroves) protect coastal communities from flooding.
	Erosion control	Vegetation cover and crop roots hold soil in place to prevent erosion.
	Mineralisation of plant nutrients	Ecosystems facilitate the mineralization of plant nutrients through the intricate interactions among soil microorganisms, plants, and other biotic components.
	Hydrological flow	Wetlands, floodplains, and vegetated areas help regulate hydrological flow by acting as buffers during periods of heavy rainfall.
	Gas regulation	The diverse functions and interactions within ecosystems contribute to the balance and stability of atmospheric gas concentrations.
	Regulating water quality	Wetlands also play an important role in regulating water quality and filtering water as it flows from inland areas to the sea.
Supporting Services	Soil structure and fertility	Soil pore structure, soil aggregation and organic matter are fundamental to crop nutrient acquisition and water retention.
	Nutrient cycling	The cycling of nutrition elements, such as nitrogen and phosphorus, between the soil, crops, and microorganisms is the basis. For maintaining soil fertility and productivity.
	Biological Control	The predators in agroecosystems, such as arthropod predators, insectivorous birds, bats, and microbial pathogens, act as natural enemies to agricultural pests.
	Pollination	The pollinators, such as bees and butterflies, help to fertilize crops by pollination and are key to maintaining a stable production for animal-pollinated crops.
	Weed control	The seed predators, like birds, crickets, ants and beetles, prevent weed seeds from entering the soil seed bank and reduce the potential weed infestation in the crops.
	Windbreaks	Trees and vegetation act as natural windbreaks, reducing the impact of wind erosion on soil.
	Shelterbelts effect	Shelterbelts serve as a vital ecosystem service by mitigating wind erosion.
	Biological nitrogen fixation	Ecosystem services by facilitating the conversion of atmospheric nitrogen (N2) into a form that plants can use
	Soil formation	Ecosystems contribute to soil formation through a combination of biological, physical, and chemical processes.
	Soil fertility protection	Ecosystems safeguard soil fertility through organic matter input, nutrient cycling, microbial activity, erosion prevention, water regulation, biodiversity support, symbiotic relationships and carbon sequestration.
	Agro-biodiversity	The diversity of plant and animal species in and around agricultural systems offers various services like pollination, pest control, soil nutrient cycling, and seed dispersal.

Source: Modified from Liu *et al.*, 2022)

In India, post-Independence era was emphasising on correcting the post-colonial policies, and concentrated on providing irrigation and implementing tenurial changes to enhance food production, emphasizing a direct connection between production and poverty reduction. In the quest to boost crop output, green revolution technologies gained popularity through various policy interventions, including input and marketing subsidies and tenurial policy adjustments. The widespread adoption of these technologies, fuelled by substantial fertilizer and food subsidies, often neglected the short-term and long-term negative impacts. Prioritization was given to food production targets over ecosystem health, with ecosystem services merely perceived as desirable inputs in agriculture rather than seriously considering their flow as an externality from agricultural production.

As awareness of the interconnectedness between environmental health, human well-being, and the sustainability of production and produce quality has grown, researchers, planners, and policymakers have gradually turned their attention to the concept in a holistic perspective and started focussing on undesirable service flows from agricultural production process. Numerous studies underscore this shift in perspective (Rola and Pingali, 1993; Pingali *et al*., 1994; Antle and Pingali, 1994; Crissman *et al.*, 1994; Zhang *et al.*, 2007; Devi, 2010; Bhattacharyya *et al.*, 2016; Lokesh, 2020). The flow of Ecosystem Services (ES) within agroecosystems is now being considered both as an input in agricultural production and as an output of the agriculture sector, as highlighted by Garbach *et al.*, 2014. This perspective acknowledges the complementary roles of agroecosystems as both ES providers and consumers. For instance, Marothia in 2022 furnished a detailed narrative of how wet land agriculture interactions in multiuse wetlands are to be addressed in view of its direct link with SDGs. He has furnished a detailed account of attributes, social structures of users, decision making arrangements, action situation and pattern of interactions and outcomes of these wetlands and proposes a policy agenda for sustaining the same. Concurrently, there has been policy emphasis on promoting eco-friendly methods of crop production and conservation approaches towards fragile agroecosystems. This involves a multifaceted approach incorporating legal, persuasive, educative, and market-based strategies. In many cases, for effective designing of policies it is important to assess the economic value of AES.

2.2 Economic Value of AES

The recognition of the importance of assigning economic value to ecosystem services (ES), previously undervalued or underappreciated, was brought to the forefront through a seminal paper by Costanza in 1997. This paper served as a catalyst for planners and researchers, delving into the significance of understanding the economic value of ecosystem services and its implications for policy development. The scope outlined in Costanza's work emphasized the need for designing policy instruments, communicating the importance of ecosystem services, and evaluating the extent of loss of ecosystems, among other practical considerations. This sparked increased research and policy interest in this domain, driving efforts to quantify and integrate the economic value of ecosystem services into decision-making processes. Despite the growing recognition of the importance of economic valuation, challenges abound, especially in quantification of the services and its impacts in the long run, methodologies for assessing the value of services, particularly those that are non-marketed. For instance, there has been inadequate information and limitations to establish the the health impacts of chemical pesticide exposure among human beings, animals and the ecosystem. It was a challenge to establish the cause effect relationship field level cases (Devi *et al.,* 2022). Sustainability perspectives further complicate valuation efforts.

Most of the earlier studies were focussing on specific ecosystems like forests, wetlands, mangroves and similar ecosystems with limited ones on agroecosystems (Marothia, 2001; Das and Cr´epin, 2013; Hema and Devi, 2015; Dang *et al.,* 2022;), in specific locations. The intricate and variable nature of agroecosystems, coupled with the dynamism of social systems, market forces, and other factors, pose obstacles to conducting comprehensive studies. Moreover, existing studies often narrow their focus to specific agroecosystem services, such as pollination (Breeze *et al.,* 2011; Mahendar *et al.*, 2022), agrobiodiversity (Hanley and Perrings, 2019) or AES without considering the negative impacts (Devi *et al*, 2017), leaving comprehensive estimates scarce (Drucker and Ramirez, 2020) (Table 2). This situation also stems from the incomplete mapping of AES.

Contingent Valuation Method (CVM), a frequently adopted approach for estimating the Total Economic Value, and a stated preference method, faces scepticism in scientific decision-making circles. This reluctance may stem from concerns about the subjectivity of stated preferences and the challenges in translating these preferences into meaningful policy action.

Some studies that considered net ecosystem service flows employing methodology that integrates the ES cascade framework within the cause-effect chain of life cycle impact assessment (LCIA) considered only carbon sequestration, water provisioning, air quality regulation, and water quality regulation functions (Liu *et al*, 2020). Furthermore, Lele 2023, while discussing the application of ecosystem service values in design, practice, and conceptualization of EIA , argues that there is a lopsided treatment of values of nature ,particularly that of relational values. This also holds true in the case of agroecosystem management perspectives.

In conclusion, while the acknowledgment of the economic value of ecosystem services has spurred research and policy interest, challenges persist in comprehensive mapping of AES, scientific evidences on cause effect /impact aspects at field level, the methodologies for valuation, particularly in the context of the dynamic and complex nature of agroecosystems. Addressing these challenges is crucial for formulating effective policies that balance economic considerations with the sustainable management of ecosystem services.

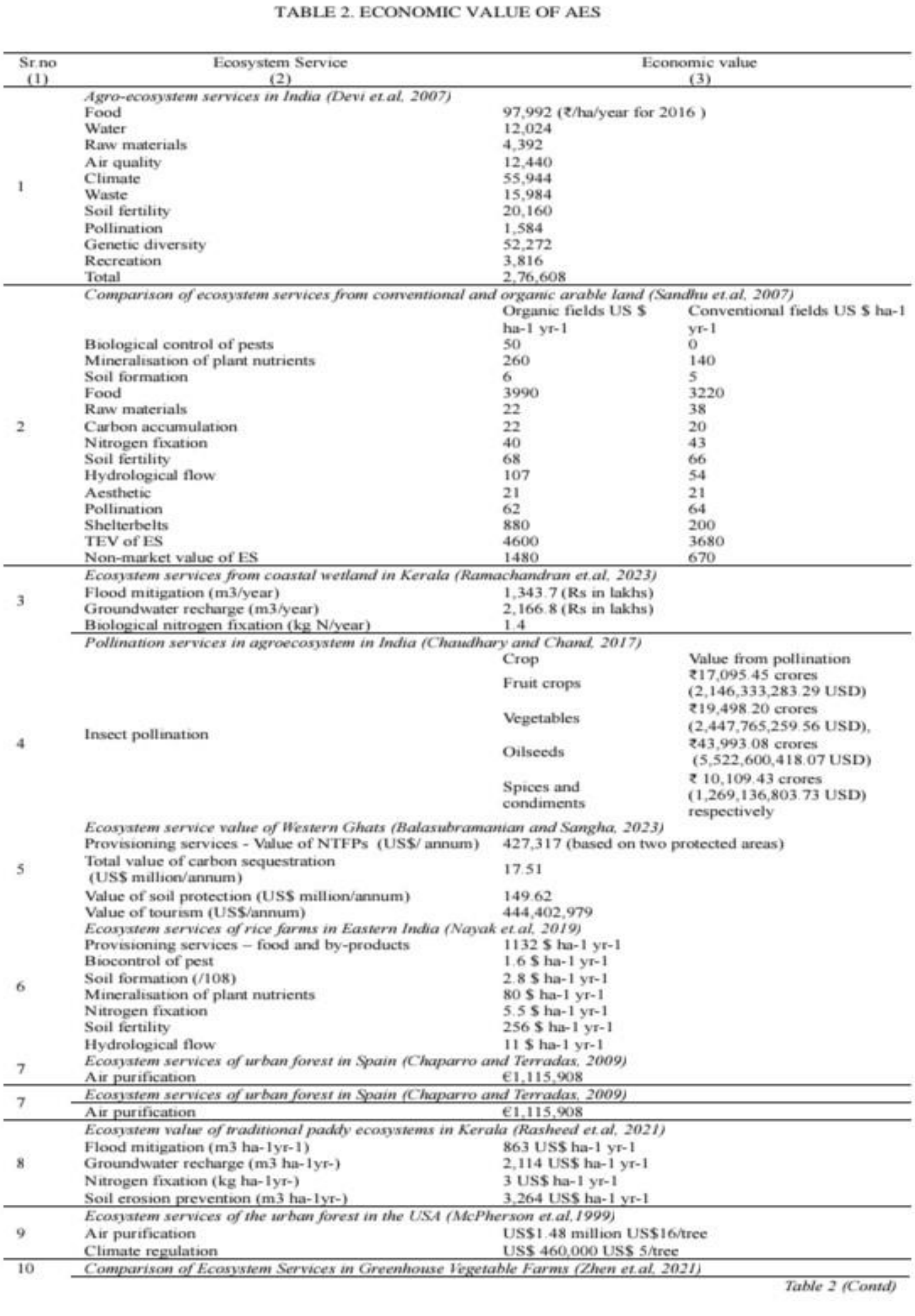

TABLE 2. ECONOMIC VALUE OF AES

Sr.no (1)	Ecosystem Service (2)	Economic value (3)	
1	*Agro-ecosystem services in India (Devi et.al, 2007)*		
	Food	97,992 (₹/ha/year for 2016)	
	Water	12,024	
	Raw materials	4,392	
	Air quality	12,440	
	Climate	55,944	
	Waste	15,984	
	Soil fertility	20,160	
	Pollination	1,584	
	Genetic diversity	52,272	
	Recreation	3,816	
	Total	2,76,608	
2	*Comparison of ecosystem services from conventional and organic arable land (Sandhu et.al, 2007)*		
		Organic fields US $ ha-1 yr-1	Conventional fields US $ ha-1 yr-1
	Biological control of pests	50	0
	Mineralisation of plant nutrients	260	140
	Soil formation	6	5
	Food	3990	3220
	Raw materials	22	38
	Carbon accumulation	22	20
	Nitrogen fixation	40	43
	Soil fertility	68	66
	Hydrological flow	107	54
	Aesthetic	21	21
	Pollination	62	64
	Shelterbelts	880	200
	TEV of ES	4600	3680
	Non-market value of ES	1480	670
3	*Ecosystem services from coastal wetland in Kerala (Ramachandran et.al, 2023)*		
	Flood mitigation (m3/year)	1,343.7 (Rs in lakhs)	
	Groundwater recharge (m3/year)	2,166.8 (Rs in lakhs)	
	Biological nitrogen fixation (kg N/year)	1.4	
4	*Pollination services in agroecosystem in India (Chaudhary and Chand, 2017)*		
		Crop	Value from pollination
	Insect pollination	Fruit crops	₹17,095.45 crores (2,146,333,283.29 USD)
		Vegetables	₹19,498.20 crores (2,447,765,259.56 USD),
		Oilseeds	₹43,993.08 crores (5,522,600,418.07 USD)
		Spices and condiments	₹ 10,109.43 crores (1,269,136,803.73 USD) respectively
5	*Ecosystem service value of Western Ghats (Balasubramanian and Sangha, 2023)*		
	Provisioning services - Value of NTFPs (US$/ annum)	427,317 (based on two protected areas)	
	Total value of carbon sequestration (US$ million/annum)	17.51	
	Value of soil protection (US$ million/annum)	149.62	
	Value of tourism (US$/annum)	444,402,979	
6	*Ecosystem services of rice farms in Eastern India (Nayak et.al, 2019)*		
	Provisioning services – food and by-products	1132 $ ha-1 yr-1	
	Biocontrol of pest	1.6 $ ha-1 yr-1	
	Soil formation (/108)	2.8 $ ha-1 yr-1	
	Mineralisation of plant nutrients	80 $ ha-1 yr-1	
	Nitrogen fixation	5.5 $ ha-1 yr-1	
	Soil fertility	256 $ ha-1 yr-1	
	Hydrological flow	11 $ ha-1 yr-1	
7	*Ecosystem services of urban forest in Spain (Chaparro and Terradas, 2009)*		
	Air purification	€1,115,908	
7	*Ecosystem services of urban forest in Spain (Chaparro and Terradas, 2009)*		
	Air purification	€1,115,908	
8	*Ecosystem value of traditional paddy ecosystems in Kerala (Rasheed et.al, 2021)*		
	Flood mitigation (m3 ha-1yr-1)	863 US$ ha-1 yr-1	
	Groundwater recharge (m3 ha-1yr-)	2,114 US$ ha-1 yr-1	
	Nitrogen fixation (kg ha-1yr-)	3 US$ ha-1 yr-1	
	Soil erosion prevention (m3 ha-1yr-)	3,264 US$ ha-1 yr-1	
9	*Ecosystem services of the urban forest in the USA (McPherson et.al,1999)*		
	Air purification	US$1.48 million US$16/tree	
	Climate regulation	US$ 460,000 US$ 5/tree	
10	*Comparison of Ecosystem Services in Greenhouse Vegetable Farms (Zhen et.al, 2021)*		

Table 2 (Contd)

TABLE 2 (CONCLD)

		Conventional	Organic	Community-supported agriculture
			(USD ha-1 yr-1)	
	Provisioning- Food production (×103)	43.4 ± 7.6	86.5 ± 11.9	115 ± 18.4
	Supporting- Nutrient cycling and retention (×103)	1.58 ± 0.23	1.84 ± 0.16	0.93 ± 0.19
	Cultural- Eco-tourism	304 ± 238	235 ± 220	6741 ± 3086
	Regulating- Gas regulation	505 ± 18	437 ± 13	397 ± 3
	Biological control	118 ± 267	755 ± 40	906 ± 58
	Climate regulation	72 ± 15	81 ± 6	80 ± 9
	Soil formation	72 ± 25	636 ± 223	66 ± 17
	Water regulation	25 ± 3	21 ± 3	28 ± 3
	Sum (×103)	46.1 ± 7.6	90.5 ± 11.8	124 ± 19.2
11	*Value of ecosystem services in diverse production systems in Denmark (Ghaley et.al. 2014)*			
		Conventional wheat	Combined food and energy production system	Beech forest
	Provisioning Food/straw/fodder/bioenergy/wood (1–5)	2343 (US$ ha_1 yr_1)	2428 (US$ ha_1 yr_1)	1276 (US$ ha_1 yr_1)
	Regulating- Water holding capacity	82	57	39
	Carbon sequestration	51	98	40
	Erosion prevention	53	–	177
	Shelterbelt effects	335	-	401
	Nitrogen fixation	9	-	-
	Pollination	24	-	-
	Pest control	4	-	-
	Supporting- Nitrogen mineralised	52	31	92
	Soil formation	14	15	8
	Cultural and Aesthetics	176	138	332
	Value of Total Ecosystem Services	3142	2767	2328
12	*Value of ecosystem services from tea plantations in China (Xue et.al. 2013)*			
	Carbon sequestration	392-yuan ha−1 year−1		
	Soil retention	72-yuan ha−1 year−1		
	Soil fertility protection	3,189-yuan ha−1 year−1		
	Water conservation	2,685-yuan ha−1 year−1		
13	*Value of ecosystem services from upland land use in Wales (Hardaker et.al. 2020)*			
	Total Ecosystem service benefits	1,472.25 (£ million year-1)		
14	*Ecosystem services from rice-wheat farming in China (Lv et.al. 2010)*			
	Carbon sequestration	2.30 × 10^9		
	Flood control	2.21 × 10^7		
15	*Total economic value of threatened livestock breeds in Italy (Zander et.al. 2013)*			
	TEV of a conservation programme for the Modicana breed	€90		
	Maremmana breed	€91		
16	*Net ecosystem services value of wetlands in China (Chen et.al. 2009)*			
	Beijing wetland (constructing year)	2,06,740 ($/ha/yr)		
	Beijing wetland (operating year)	2,06,740 ($/ha/yr)		
	Mean wetland	15,643 ($/ha/yr)		
	Sanyang wetland	702 ($/ha/yr)		
17	*Ecosystem services from integrated farming system in China (Yuan et.al. 2022)*			
	Honghe Hani Rice Terraces - Integrated rice–fish–duck farming ecosystem			
	General service value	510.09 million USD/hm2/year		
	Provisioning service value	270.90 million USD/hm2/year		
	regulation and maintenance service value	203.76 million USD/hm2/year		
	cultural service value	3.55 million USD/hm2/year		
18	*Valuation of ecosystem services provided by Mediterranean Mountain Agroecosystems (Bernues et.al. 2014)*			
	Landscape [non-extractive direct use]	10 € [WTP /person/ year]		
	Biodiversity [Non-use existence]	22.2		
	Forest fires [Indirect use]	64.4		
	Product Quality [Extractive direct use]	24.5		
	TEV	121.2		
19	*Ecosystem service value of riven Ken (core zone of Patna Tiger reserve) (Marothia,2001)*			
	Sand extraction from the leased mine	Rs.2500 crores per year		
	Sand extraction by individuals in villages	Rs.75 crores per year		
	Fish	Rs.2 to Rs.17 lakhs in different stretches (based on winter season survey only)		
	Ecotourism value of PTR '	Rs.7.69 crores (Travel Cost method)		
	Total Economic Value of PTR	Rs.369 crores per year		

Source: Compiled by Author).

III

AGROECOSYSTEM DIS-SERVICES

3.1 Ecosystem Dis- Services

Some ecosystem goods and services can have adverse effects on human well-being, and these detrimental consequences are commonly termed Ecosystem Dis-Services (EDS). Investing in the management or mitigation of these disservices may lead to more favourable outcomes for human well-being, sometimes requiring lower investments compared to managing ecosystem services alone, as indicated by Shackleton *et al.* 2016.

The concept of Ecosystem Dis-Services (EDS) was initially elaborated by Lyytimakki and Sipilä (2009), defining it as the "functions of ecosystems that are perceived as negative for human well-being." Adverse impacts on human well-being resulting from impaired ecosystem functioning are categorized as EDS (Barot *et al.*, 2017; Lyytimäki, 2014; Shackleton *et al.,* 2016; Campagne *et al.*, 2018). Drawing a distinction, carbon sequestration is considered an Ecosystem Service (ES), while carbon emission is an EDS. The net ecological benefits to economic activity depend on the balance between ES and EDS.

EDS can stem from natural phenomena, unintended consequences of human activities, deliberate modifications to ecosystems, or specific management practices. For example, health problems caused by pesticide spraying represent negative externalities associated with the management of agricultural ecosystems (direct effect of management). Conversely, the invasion of resistant weeds resulting from pesticide spraying represents an EDS induced by management practices (indirect effect of management) (Campagne *et al.*, 2018).

Whether an effect is classified as an Ecosystem Service (ES) or an Ecosystem Dis-Service (EDS) can be subject to variation based on the perspectives of individuals or societal groups, as well as the spatial and temporal context (Saunders and Luck, 2016; Shackleton *et al.*, 2016; Vaz *et al.*, 2017; Rasmussen *et al.*, 2017). In fact, the same ecological function or species can be perceived as providing both ecosystem services and disservices simultaneously, varying among different individuals or even within the same person (Lele *et al.*, 2013). For example, the presence of hedges may be positively viewed by some individuals as it provides privacy, while others may perceive it as a nuisance as it obstructs their view (Campagne *et al.*, 2018). This highlights the subjective and context-dependent nature of categorising effects as either services or disservices within the broader framework of ecosystem interactions.

The connection between ecosystem services and disservices is mainly defined by trade-offs and synergies. Both ecosystem services and disservices arise from the attributes and processes of ecosystems, exhibiting strong interdependence across various temporal, spatial, and socio-economic scales. Efforts to categorize ecosystem services and disservices into a single, universally applicable framework may encounter practical challenges (Vaz *et al.,* 2017; Saunders, 2020). For example, urban trees contribute to climate regulation through carbon sequestration, while simultaneously emitting volatile organic compounds (VOC) and solid particulate matter (PM), resulting in air pollution and adverse effects on human health (Roman *et al.,* 2021). Recognising this complexity, the latest version of the Common International Classification of Ecosystem Services (CICES) V5.1 explicitly includes eight categories of ecosystem disservices within its conceptual framework. This reflects a direct incorporation of these disservices alongside ecosystem services, acknowledging the nuanced and interconnected nature of ecological contributions (Diaz *et al.,* 2015; CICES, 2020)

3.2 Agro-Ecosystem Dis - Services (AEDS)

In addition to offering valuable services like food, fibre, soil conservation, and scenic landscapes, agroecosystems may also generate various negative services, largely contingent on the employed agricultural practices (Power, 2010). The outcome is highly dependent on the specific management practices and agricultural techniques in use. For instance, while fertiliser application can enhance soil nutrients, excessive fertilization may result in detrimental ecological effects such as water pollution, greenhouse gas emissions, or soil degradation (Zabala *et al.*, 2021).

The disservices emanating from agroecosystems exhibit variability based on the chosen management practices and agricultural techniques (Zhang *et al.,* 2007; Shah *et al.,* 2019). Earlier studies predominantly focused on assessing the impacts of these disservices on agricultural productivity, particularly during the initial years of the green revolution (Guo *et al.,* 2022; Zhang *et al.,* 2007). However, recent research has shifted its emphasis to evaluating the impacts of these Agroecosystem Dis-Services (AEDS) on ecosystem and human health. Table 3 provides a detailed breakdown of the major flows of AEDS.

High-input-dependent and resource-intensive agricultural systems have led to significant environmental challenges, including deforestation, water scarcity, soil degradation, and substantial greenhouse gas (GHG) emissions (FAO, 2017). Improper and unsustainable management practices can result in the generation of disservices, such as air pollution (emission of greenhouse gases like CO2, CH4, N2O), water pollution, and soil pollution (run-off of fertilisers and pesticides) (Shah *et al*., 2019; Shackleton *et al.,* 2016).For example, only a portion of the nitrogen applied in the form of N fertilisers is utilised by crops, leading to the release of unused nitrogen into the environment through processes like leaching, volatilisation, nitrification, and denitrification (Sutton *et al.,* 2017; Tilman *et al.,* 2002). Nitrogen pollution has emerged as a global threat to both environmental and human health (Kanter *et al.,* 2015; 2020). Part of the applied nitrogen fertiliser is lost as ammonia (NH3), nitrogen gases (N2 and NOx), contributing to environmental degradation. This has resulted in increased GHG emissions, particularly nitrous oxide, which has seen a significant rise in recent years (Nichols, 2022). In India, nitrogen fertilizer applications account for a substantial share of N_2O emissions, with a 49% share in 2005 compared to 40% in 1985 (Garg *et al*., 2012). The estimated N_2O emissions in 2019 were 57.18 Mt CO2e due to nitrogen fertilizer application and 57.19 Mt CO2e due to its manufacturing (Praveen, 2021). Ammonia, after oxidation to nitrate (NO3), also contributes to soil acidity, while other nitrogen oxides (NOx) are involved in the depletion of the stratospheric ozone layer. Part of the applied nitrogen fertilizer leaches down as nitrate, contaminating groundwater resources (Gulati and Banerjee, 2015). The Nitrogen budget of Indian agriculture indicates an increasing Nitrogen surplus and decreasing Nitrogen use efficiency over time.

TABLE 3. MAJOR AGRO ECO SYSTEM DIS-SERVICES

AEDS	Indicators	Detailed explanations
Provisioning disservices	Water resource consumption/ Groundwater depletion	Excess water consumption for agricultural irrigation, especially in arid and semi-arid areas, causes groundwater depletion.
	Agricultural waste	The waste produced in agricultural production, such as the plastic film and straw.
Regulating disservices	Water pollution	The excessive use of chemical fertilizers and pesticides causes groundwater water eutrophication and nitrate pollution.
	Soil pollution	The heavy metal pollution of farmland caused by sewage irrigation, pesticides, plastic film, sludge, and organic fertilizer
	Greenhouse gas emission	The greenhouse gas emissions from agricultural cultivation, breeding and agricultural machinery
	Soil erosion	Agricultural practices can cause soil erosion through excessive tillage, deforestation, removal of vegetation cover, and improper water management.
	Soil acidification	Agricultural practices can cause soil acidification by applying acidic fertilizers, excessive use of nitrogen-based fertilizers, and the repeated cultivation of certain crops.
Supporting disservices	Pest and disease	The yield reduction and economic loss caused by pests or diseases
	Weeds cover	Weeds and crops compete for water, nutrition, sunlight and pollination.
	Habitat loss	The disappear of non-crop habitats in agroecosystems, such as woodland, hedgerows, and flower belts
	Biodiversity loss	The abundance and diversity of agricultural species have declined due to habitat loss and the overuse of pesticides.
	Carbon flow	Engaging in intensive tillage and monoculture farming practices can increase carbon emissions.
	Pesticide residue	Pesticide residue can cause contamination of air, soil, water and food.
Cultural disservices	Extinction of Indigenous species	Loss of indigenous species can disrupt food webs and reduce ecosystem resilience. Customs and traditions linked with that species also disappear.
	Introduction of exotic species	Exotic species may outcompete native species for resources such as nutrients and water, displacing native flora and fauna.

(Source: Modified from Liu et. al, 2023).

Crop residue burning in fields contributes to air pollution (Bellarby *et al.,* 2008; Ravindra *et al.,* 2016). Additionally, the excessive use of pesticides and fertilisers serves as a significant non-point source of air and water pollution (Chen *et al.,* 2017). Approximately 60 per cent of greenhouse gas (GHG) emissions are of anthropogenic origin, with agriculture being the largest anthropogenic source, responsible for about one-quarter of these emissions. Agriculture contributes to GHG emissions through factors like livestock production, increased use of plant protection products, and fertilizers. Livestock, in particular, emit substantial amounts of methane during digestion, while fertilisers contribute to nitrous oxide emissions. Overall, agriculture accounts for 20 per cent of greenhouse gas emissions

Numerous studies underscore the Ecosystem Dis-Services (EDS) resulting from land use changes and green revolution technologies, including the negative impacts of chemical fertilisers, pesticides, irrigation, and mechanization (Gulati and Banerjee, 2015; Shukla *et al.*, 2022; Nichols, 2022; Devi *et al.*, 2022; Padhee and Whitbread, 2022; Bhattarai, 2021). The short-term and long-term ecological and human health consequences of chemical pesticides are well-documented globally, as discussed in the work by Devi (2022). The loss of agrobiodiversity emerges as a critical factor limiting risk management in production and sustainability, impeding scientific advancements in agriculture (Swinton *et al.*, 2007; Eliazer Nelson *et al.*, 2019; Bawa and Seidler, 2023).

3.2 Valuing EDS in Agroecosystems

Saunders *(*2020) conducted a comprehensive review, analysing 301 published papers, and identified 85 empirical studies that explicitly quantified or determined Ecosystem Dis-Services (EDS). The majority of these studies relied on researchers' subjective opinions or proxy data sources to quantify disservices, with only 15% of researchers collecting in-situ data on disservices resulting from ecological interactions.

Various methodologies were employed to quantify disservices. Some studies examined trade-offs and synergies between ecosystem services and disservices, utilizing correlation or relative scoring of services and disservices (Helfenstein and Kienast, 2014; Liu *et al.,* 2018; Milanović *et al.,* 2020). Others employed simple calculations, such as 'revenue minus cost' (Xue *et al.,* 2013; Wu *et al.,* 2015), to assess the balance between positive and negative impacts. These diverse approaches highlight the complexity and subjectivity involved in quantifying and understanding the nuances of Ecosystem Dis-Services.

Researchers have delved into the potential of valuating ecosystem services and disservices by constructing cascade models tailored to specific habitats (Alemu *et al.*, 2021). Blanco *et al.* (2021) applied this model in a joint assessment of Ecosystem Services (ES) and Ecosystem Dis-Services (EDS) in a Brazilian landscape, where reconciling agriculture and forest conservation poses a critical sustainability challenge. Their study focused on farmers' perceptions and management practices related to forests, revealing an overall positive valuation of forests by farmers. However, they identified both positive and negative interactions between forests and farms at different organizational levels. The constructed model shed light on a concerning pattern, indicating a vicious circle between crop expansion, a subsequent decrease in certain ES, and an increase in certain EDS. This dynamic could exacerbate tensions between agriculture and forest conservation in the future. The study highlights the intricate relationships between agricultural practices, forest conservation, and the associated ecosystem services and disservices, emphasizing the need for comprehensive and context-specific approaches to sustainable land management.

Systematic research on ecosystem disservices is still in development, with many studies focusing on the concept of disservices in specific environments or ecosystems. Guo *et al.* (2022), has compiled various indicators used in EDS research and classified them into different ecological contexts. Indicators used to study EDS in agriculture ecosystems are pest damage, habitat loss, biodiversity loss, nutrient runoff, pesticide poisoning of non-target species, competition for pollination and water from other ecosystems, decreasing water quality and/or quantity. These indicators provide a glimpse into the multifaceted nature of EDS in agricultural ecosystems, highlighting the diverse range of ecological impacts associated with agricultural practices. As systematic research in this field advances, a more comprehensive understanding of ecosystem disservices and their implications for sustainability will likely emerge.

The valuation methods commonly employed in the estimation of Ecosystem Services (ES) are also utilized to determine the value of Ecosystem Dis-Services (EDS), facilitating straightforward comparisons between them. For instance, Hardaker *et al. (*2020) estimated the economic value of tradeable ES and EDS from different agricultural and forestry landscapes using direct market-based methods. Their findings revealed that the highest levels of ES supply were derived from forestry land use, while EDS were more pronounced in agricultural land use. Zabala *et al.* (2021) employed the choice experiment method to estimate the integrated economic value of agroecosystem services (AES) and disservices (AEDS) in an irrigated situation. Their study found that the economic value of water supply for irrigation switched between AES and AEDS depending on its provision level. Devi, (2009) used the Cost of Illness method to estimate health costs due to pesticide exposure and the hedonic wage model (Devi *et al.*, 2012) to assess whether higher wages compensated for additional health cost.

Emergy analysis, rooted in thermodynamic principles, offers an eco-centric perspective by translating ecosystem inputs and outputs into solar emjoule (sej) units, using solar energy as the base (Ma *et al*., 2015; Rugani et al., 2013). Ma *et al*. (2015), applied this approach to assess inputs and outputs of agricultural ecosystems, focusing on resource consumption, ecosystem services, and ecosystem disservices. Shah *et al.* (2019) also developed an energy-based framework for the valuation of Agroecosystem Ecosystem Dis-Services (AEDS), introducing the "donor side" method as an alternative approach. Their comprehensive study across different agroecosystems revealed cotton cultivation as having the highest value of EDS

In summary, the methods for AEDS valuation are evolving, with new approaches like energy analysis and cascade models being employed for integrated valuation of both ES and EDS. This evolution aids in overcoming the limitations of studying and valuing ecosystem services alone, providing a more comprehensive understanding of the sustainability of agroecosystems.

Table 4 furnishes details of major AEDS and its value compiled from various studies.

TABLE 4. ECONOMIC VALUE OF AGRO ECOSYSTEM DIS-SERVICES

S.No (1)	Ecosystem Dis-Services (2)	Economic cost (3)			Location (4)
1	*Ecosystem disservices from pesticide use in Kuttanad (Devi, 2007, 2010)*				
	Welfare loss in the region from pesticide exposure	₹ 180 million			Kuttanad, Kerala
2	*Ecosystem disservices from coastal wetlands in Kerala (*Ramachandran *et al.,* 2023)				
	Net GHG emission (dis-service) (tonnes of CO2 equiv./year)	9.8 (Rs in lakhs)			Kerala, India
3	*Value of ecosystem disservices of rice farms in Eastern India (Nayak et.al., 2019)*				
	Carbon flow	0.5 $ ha-1 yr-1			India
	Soil erosion	-4 $ ha-1 yr-1			
	Net economic value	1473 $ ha-1 yr-1			
4	*Value of ecosystem disservices from traditional paddy ecosystems in Kerala (Rasheed et al., 2021)*				
	Greenhouse gas emission (kg ha-1yr-)	16 US$ ha-1 yr-1			Wayanad, Kerala
5	*Comparison of Ecosystem Disservices in Greenhouse Vegetable Farms in China (Zhen et.al, 2021)*				
		Conventional	Organic	Community-supported agriculture	Beijing China
			(USD ha-1 yr-1)		
	Life expectancy (×103)	24.1 ± 7.9	1.1± 0.13	0.63 ± 0.17	
	Normalized Extinction of species	2313 ± 856a	26 ± 3	14 ± 3	
	Severe morbidity	1518 ± 457	176 ± 30	117 ± 30	
	Nuisance	105 ± 18	128 ± 16	72 ± 19	
	Morbidity	210 ± 43	76 ± 10	46 ± 12	
	Crop growth capacity	11 ± 2	14 ± 2	8 ± 2	
	Soil acidification	3 ± 1	4 ± 1	2 ± 1	
	Wood growth capacity	-65 ±13	-84 ± 10	-48 ±13	
	Fish and meat production capacity	-86 ± 14	-91 ± 12	-46 ± 8	
	Sum (×103)	28.1 ± 9.3	1.32± 0.17	0.80 ± 0.22	
	Net ecosystem services Average (×103)	-25.4	2.7	8.4	
6	*Value of ecosystem disservices from tea plantations in China (Knapp et.al, 2019)*				
	CO2 emission	−39 yuan ha−1 year−1			China
	N2O emission	−137 yuan ha−1 year−1			
	Nonpoint source pollution	−108 yuan ha−1 year−1			
7	*Environmental cost of groundwater depletion (Knapp et.al, 2019)*				
	Groundwater depletion - estimated as mean WTP for irrigation water	$33.21/acre-foot			Arkansas (United States)
8	*Ecosystem disservices from rice-wheat farming in China (Lv et.al., 2010)*				
	GHG Emissions -Value of environmental externalities based on the average carbon tax rate (among Sweden, Norway, Finland and Denmark = 14.25 € / t CO2-eq.	−3.61 × 10^7 (US$ a−1)			Jiangsu (China)
	Non-point sources pollution	−4.59 × 10^6 (US$ a−1)			
9	*Value of ecosystem disservices from various wetlands in China (Chen et.al, 2009)*				
	Beijing wetland (constructing year)	4,12,504 ($/ha/yr) (NVES = -2,05,763)			China
	Beijing wetland (operating year)	14,120 ($/ha/yr) (NVES = 1,92,620)			
	Mean wetland	272 ($/ha/yr) (NVES = 15,372)			
	Sanyang wetland	2678 ($/ha/yr) (NVES = -1976)			
10	*Value of ecosystem disservices from upland land use in Wales (Hardaker et.al, 2020)*				
	Potable water quality reduction	£48.51 million year−1			Wales
	GHG emissions	£53.03 million year−1			
	Total Ecosystem dis-services cost from Uplands [Forestry and agriculture]	£101.54 million year−1			

(*Source*: Compiled by Author)

While ecosystem service frameworks have been instrumental in providing a thorough understanding of the positive contributions of ecosystems to human well-being, the significance of ecosystem disservices has not received equal attention. In recent years, there has been a noticeable increase in research focusing on ecosystem disservices, and some studies have successfully incorporated the assessment of ecosystem disservices alongside the evaluation of ecosystem services. However, studies that assess the Net Agroecosystem Services (AES), considering both AES and Agroecosystem Ecosystem Dis-Services (AEDS), are limited, especially under Indian conditions. For instance, Devi *et al.* (2017) attempted to assess AES using the benefit transfer method, primarily relying on TEEB studies, but their estimates did not account for AEDS.

Despite the growing recognition of ecosystem disservices, there remains a lack of proper integration between these two concepts. The need for a more comprehensive and integrated approach that considers both ecosystem services and disservices is apparent (Ma *et al.,* 2015; Herd-hoare and Shackleton, 2020; Guo *et al.,* 2020). Recognizing and quantifying the interplay between positive and negative ecological contributions is crucial to developing sustainable land management practices and policies that promote the overall well-being of ecosystems and human societies.

IV

ECOSYSTEM SERVICE-BASED APPROACHES IN AGRICULTURAL POLICY MAKING: MANAGEMENT OF ES AND EDS IN AGRO-ECOSYSTEMS

Agroecosystem services (AES) are shaped by the functions of agroecosystems and agricultural practices, encompassing both positive and negative impacts, scale effects, and trade-offs and synergies between AES and AEDS (Liu *et al.*, 2022). The acknowledgment of AES and AEDS is permeating various disciplines, emerging as pivotal considerations in stakeholder decision-making and policy formulation. Current policy approaches to agricultural management are to be increasingly oriented towards ensuring a balance between sufficient supply of ecosystem services while concurrently maximizing agricultural productivity (provisioning service).

Through the implementation of suitable management practices, there exists the potential to mitigate the adverse effects of agricultural production and enhance the capacity of agricultural ecosystems to provide a diverse array of ecosystem services, in addition to provisioning services (Herd-hoare and Shackleton, 2020; Guo *et al.*, 2020). Ensuring a net positive flow of desirable ecosystem services from agriculture necessitates thoughtful policy interventions. Beyond legal and persuasive strategies for managing ecosystem disservices, the significance of market-based policy mechanisms is growing, predominantly relying on the values attributed to AES.

Major approaches that integrate AES in policy decisions are:

4.1 Incentivising Eco-Friendly Practices

4.1.1 Subsidies in Agriculture

Agricultural subsidies have played a pivotal role in propelling the development of the farming sector in India, encompassing both investment and input subsidies. Subsidies constitute the costliest element of India's food and agricultural policy framework, providing support for high-yielding and hybrid seeds, energy, fertilizers, irrigation water, and price support mechanisms (Arora, 2013). These measures have led to notable shifts in cropping patterns and farming practices, contributing to increased production (Rasul, 2016). Unfortunately, the overreliance on subsidies has resulted in the excessive use of inputs, negatively impacting both ecosystems and human health. Notably, the efficiency of fertilizer use in Indian agriculture has declined over time, and a growing body of literature highlights the negative externalities associated with this trend. Consequences of overutilization include soil degradation, nutrient imbalances, environmental pollution, and groundwater depletion, significantly diminishing resource use efficiency (Arora, 2013). Consequently, many of these subsidies have taken on a perverse nature, and the escalating subsidy bills exert substantial pressure on limited resources (Planning Commission, 2001; Singh, 2012; Planning Commission, 2014; Sidhu *et al.*, 2020).

Although technological solutions exist, such as controlling excess inorganic fertilizer inputs, promoting organic fertilizer use, and improving water and fertilizer use efficiency, creating an environment conducive to widespread adoption requires appropriate policy instruments (Sun & Huang, 2012; Ma *et al.*, 2015; Fagodiya *et al.*, 2017; Shah *et al.*, 2019; Bawa and Seidler, 2023).The economic valuation of EDS from these technologies becomes crucial for re-evaluating decisions on the continuation or modification of the subsidy regime. For example, Keeler *et al.* (2016) estimated the social cost of nitrogen application, which must be weighed against social gains to inform decisions on subsidy support. The increasing focus of research on the externalities of input use in agriculture and alternative technologies underscores the importance of realistically estimating the values of Avoidable Environmental Dis-services (AEDS) and Alternative Environmental Services (AES). Accordingly, subsidies, taxes, or adjustments must be introduced, modified, or halted, especially concerning input taxes and subsidies related to chemical fertilizers, energy, and water.

4.1.2 Taxes

Carbon tax, a variant of a Pigouvian tax, is imposed on entrepreneurs engaged in activities with adverse side effects, such as climate change through the release of greenhouse gases (GHGs). Governments typically set a fixed price for carbon emissions in various sectors. This approach has been globally adopted, with each country following distinct norms for determining the value (tax) per unit of GHG emission or per ton of hydrocarbon fuel use. Finland was the pioneer, implementing a carbon tax in 1990, and other Nordic countries like Sweden and Norway followed suit in 1991. Norway, with a tax rate of $69.00 per ton of CO2 used in gasoline, boasts one of the world's most stringent carbon taxes. In Africa, South Africa, as an emerging economy, has taken steps against global warming by implementing a carbon tax system since June 2019. This tax targets carbon emissions from industrial, power, building, and transport processes. Currently, around 26 countries globally have adopted carbon tax.

Unlike some countries, India lacks explicit carbon pricing mechanisms such as a carbon tax. However, it employs various schemes and implicit taxation mechanisms, like Coal cess, Perform Achieve Trade schemes, and Renewable Energy Certificates. The Coal cess, introduced in 2010, is often considered equivalent to a carbon tax, aiming to finance and promote clean energy initiatives and fund research through the National Clean Environment and Energy Fund (NCEEF). Most of these schemes predominantly operate in the energy, fuel, and transport sectors (Ahmad and Mishra, 2019; Sarangi and Taghizadeh-Hesary, 2020). The proposed domestic carbon market in India is expected to become fully operational by 2026.

The European Union's Carbon Border Adjustment Mechanism (CBAM), introduced in December 2022 (also referred to as Carbon Border Tax), serves as a carbon leakage instrument designed to address the disparity in carbon prices paid by companies. This discrepancy arises between the domestic carbon price in the EU, established within the compliance market or Emission Trading Scheme, and the price paid by companies elsewhere for products imported into the EU. The EU contends that this mechanism serves as an incentive for trading partners to transition towards a decarbonized economy. However, it has been criticized for acting as a trade barrier for numerous countries, India included. Notably, sectors such as iron, steel, and chemical fertilizers in India are anticipated to be adversely affected (DTE, 2023; Goswami *et al*., 2023).

The Burp Tax initiative in New Zealand aims to address nitrous oxide emissions, from the livestock sector, by necessitating dairy farmers to reduce livestock numbers or transition to environmentally sustainable practices, also known as green farms. Nitrous oxide is a significant contributor to greenhouse gas emissions, particularly in the context of New Zealand, where the livestock sector accounts for nearly half of the total emissions. Under the Burp Tax proposal, farmers were required to pay taxes based on the quantity of cattle and feed they possessed. However, the implementation of this tax was deferred due to strong opposition from the farming community and concerns raised about potential threats to food security. The deferment reflects the challenges and complexities associated with balancing environmental sustainability goals with the economic interests of the agricultural sector. As the agricultural industry plays a crucial role in New Zealand's economy, any tax or regulation that directly impacts farmers can elicit significant resistance. Therefore, achieving a balance between environmental objectives and maintaining the viability of the agricultural sector remains a central challenge in the development and implementation of such policies (DTE, 2023).

The prospects of introducing tax on harmful chemicals (on pesticides based on the relative toxicity levels, ecologically harmful technologies) necessitates studies on the value of net AES flow as well as the demand elasticities of such technologies. Offering tax incentives for investments in sustainable agriculture encourages private businesses to contribute to the development and adoption of technologies and practices that safeguard agroecosystems. This includes, tax holidays for industries that produce green technologies, tax relaxations on agricultural income tax paid by corporates and commercial firms for effective management of AEDS.

4.2 Payment for Ecosystem Services (PES)

The term “Payment for Ecosystem Services" (PES) serves as an overarching descriptor for the comprehensive set of economic arrangements established to incentivize the conservation of ecosystem services. Specifically, PES refers to schemes where the users or beneficiaries of ecosystem services make payments to the stewards or providers of these services. In practical terms, PES often entails a series of payments to land or natural resource managers. These payments are made in exchange for a guaranteed supply of ecosystem services, or for management actions likely to enhance their provision, beyond what would occur without compensation. The beneficiaries, whether individuals, communities, businesses, or government representatives, are the entities making these payments (Fripp, 2014).

The primary goal of PES programmes is to provide incentives to land users for safeguarding crucial ecological or environmental services (Daily *et al.*, 2009). Agro-ecosystems, which supply valuable non-market ecosystem services are enjoyed by society at zero marginal cost fall beyond the agro-ecosystems' boundaries. Farmers, as the managers of these ecosystems, typically do not reap the benefits from these services, creating a potential lack of incentive to enhance their supply. Payment for Ecosystem Services (PES) is considered a market-based incentive mechanism to economically reward providers of non-market ecosystem services (Engel *et al.,* 2008; LaRocco and Deal, 2011). Rath *et al.* 2023 furnishes the history and concepts of PES programme in India.

A large number of PES schemes in developing countries are aimed at reducing soil loss and erosion. The silvo-pastoral PES schemes used in Colombia, Costa Rica, and Nicaragua, for example, were aimed at soil conservation by planting high densities of trees and shrubs in pastures, feeding livestock fodder rather than natural vegetation, and creating windscreens with shrubs and fast-growing trees (Pagiola *et al.,* 2007; Salzman *et al.,* 2018). Another type of PES scheme seeks to preserve landscape beauty, and some of these are also related to agriculture, especially when the landscape aesthetics involve 'rural amenities' (FAO, 2007). Some agricultural landscapes, on the other hand, can provide cultural services related to the pleasure that people gain from seeing, visiting, or simply knowing about the existence of these landscapes, in addition to provisioning services. Agritourism is one example, where traditional agricultural activities have imparted some distinct features to the landscape, which is valued for its historical value, attractive countryside, and distinct agricultural products. A PES scheme, for example, supported by the EU Common Agricultural Policy (CAP), rewards farmers for conserving a 6000-hectare area in Amfissa (Greece) where 150-year-old olive trees are grown (Vakrou, 2010).

In agriculture, PES can enhance biodiversity in different ways: by protecting patches of native habitats, by running agricultural activities which provides suitable ecological conditions for species' occurrence in the soil, water and air compartments, and by providing adequate connectivity for wildlife amongst natural habitats. Thus, biodiversity conservation implies a triple action, which includes conservation, monitoring and sound environmental management at the farm level, but also at the landscape level. The district of Bungo in Indonesia is an example of PES schemes for biodiversity that target specific management practises. Bungo is Indonesia's third most important rubber producing province, where traditional rubber agroforestry practises (in jungle rubber gardens) coexist with huge areas of rubber plantations. PES schemes appear to be promising in terms of incentivizing rubber production in traditional rubber jungles and rewarding farmers for their contributions to biodiversity conservation. Tyack *et al*., 2020 highlights the potential of PES in conserving the wild relatives of cultivated crop varieties. Table 5 lists some of the PES mechanisms in agriculture.

While some theoretical studies propose paying farmers for ecosystem services (e.g., FAO, 2007; TEEB, 2015), there is a scarcity of empirical studies exclusively addressing payment to farmers for non-market ecosystem services resulting from their current agricultural practices. Consequently, lessons must be drawn from individual case studies dealing with specific ecosystem services across various biomes, considering how PES schemes operate when farmers are required to alter their current agricultural or land-use practices.

Devi *et al.* (2017) in their pioneering attempt in India propose a PES program in the agriculture sector in India, conducting a detailed review of global experiences, their relative merits, and challenges. Using the benefit transfer method and applying estimated values of Ecosystem Services (ES) flow from agroecosystems (based on TEEB study), they estimate an average value of ES flow from agroecosystems as Rs 2,76,608 per hectare of crop land. But this fails to capture the AEDS. Lalit Kumar *et al.* (2019) further extends the concept in his paper, with estimates of ES value under different agroecosystems, size classes of farmers and operational design for implementation.

The scope of integrating the value assessment of net AES in the existing methodology and institutional mechanism for cost of cultivation studies under CACP is a viable approach which can be piloted at national level. The MSP decisions can be accordingly more inclusive with respect to environmental impacts of crop production. However, this approach is constrained by the limited coverage of crops under MSP programme, as per current status. The scope of Payment for Agroecosystem services to farmers can also be part of the direct income transfer mechanism under PM KISAN scheme, as proposed by Patel *et al.* (2022).

TABLE 5. PROJECTS ON PAYMENT FOR ECOSYSTEM SERVICES (PES) IN AGRICULTURE

SECTOR (1)	PROJECT (2)	Country (3)	SOURCE (4)
Forestry (sustainable land-use and forest-management techniques)	Pagos porserviciosambientales' (PSA), 'ecomar-kets' Costa Rica's Payments for Environmental Services (PES) program, known as Pago por Servicios Ambientales (PSA), operates as a market-based mechanism, incentivizing landowners to engage in land management activities that contribute to ecological benefits. These efforts encompass activities such as forest preservation, safeguarding watersheds, capturing carbon, and enhancing the aesthetic appeal of landscapes.	Costa Rica 1997	Rath, 2023
Watershed	Project started by the local Council for Administration of Water and Sewage Disposal, Honduras, for the benefit of coffee producers who lived upstream Payment of USD 0.06 per house-hold by the downstream farmers	Honduras Central America	Rath, 2023
Multiple ecosystem services	EU Environmental Liability Directive The EU's Environmental Liability Directive (ELD) since 2007 adheres to the 'polluter-pays' principle, ensuring responsibility for environmental harm. It aims to prevent and rehabilitate affected natural resources and ecosystem services, encouraging proactive actions and reinforcing additional EU environmental legislations	European Union	Primer, 2008
Multiple ecosystem services	Environmental impact/risk analyses required in various planning processes and/or permitting requirements	U.S. and other countries	Primer, 2008
Multiple ecosystem services, Watershed	Forest Law 7575 - Payments for Ecosystem Services program Costa Rica's Forestry Law 7575 of 1996 laid the groundwork for the nation's Payments for Ecosystem Services (PES) initiative by establishing the national fund for forest financing (FONAFIFO). Developed due to alarming deforestation rates, the PES program prioritized environmental services, emphasizing their significance over activities like timber production. The legislation mandated sustainable resource utilization and forbade alterations in forest land cover, while the program's regulations specified the valuation of ecosystem services.	Costa Rica	Primer, 2008
Watershed	Sloping Land Conversion Program China's Sloping Land Conversion Program (SLCP), established in 1999, stands as the globe's largest ecosystem restoration effort and payments for ecosystem services (PES) initiative. Designed to combat soil erosion and desertification, the SLCP is recognized alternatively as the Conversion of Cropland to Forest Program (CCFP) or "Grain for Green."	China	Primer, 2008
Watershed	Forest Ecosystem Compensation Fund In 2004, China instituted national funds dedicated to compensating forest ecological benefits. These funds support the plantation, nurturing, conservation, and management of public benefit forests at the national level, receiving financial backing from the central government's budgets (annual payment reaching 3-billion-yuan RMB).	China	Primer, 2008
Biodiversity	Wetland Banking (U.S. Clean Water Act) Wetland banking, devised as a compensatory mitigation approach, involves the restoration, creation, or enhancement of wetlands to counterbalance potential development impacts on other wetlands. This mechanism was created to align with the wetland preservation mandates outlined in the 1972 Clean Water Act (CWA).	U.S. A	Primer, 2008
Biodiversity	Conservation Banking (U.S. Endangered Species Act) Conservation banking, a market-based approach, aids in mitigating the detrimental effects on species protected under the United States Endangered Species Act (ESA).	U.S. A	Primer, 2008
Biodiversity	Offsets for Forest Regulation and National System of Conservation Units These offsets are geared towards preserving Brazil's forests and savannas. Landowners have the option to buy forest certificates from other properties, reducing their compliance expenses without necessarily restoring illegally deforested Legal Reserves, providing legal assurance to companies investing in forest conservation and restoration for carbon emission offsets.	Brazil	Primer, 2008

(CONTD.).

TABLE 5 (CONCLD.)

Biodiversity	Offsets for Forest Regulation and National System of Conservation Units These offsets are geared towards preserving Brazil's forests and savannas. Landowners have the option to buy forest certificates from other properties, reducing their compliance expenses without necessarily restoring illegally deforested Legal Reserves, providing legal assurance to companies investing in forest conservation and restoration for carbon emission offsets.	Brazil	Primer, 2008
Biodiversity	Federal Law for the Protection of Nature and Landscape Switzerland has a robust legal framework, including aimed at safeguarding the environment, cultural heritage, and natural resources. Article 78 of the Swiss Constitution delegates responsibility for protecting landscapes to the cantons, while federal initiatives, such as the revised Nature and Cultural Heritage Protection Act (NHG) in 2007 and the updated Swiss Landscape Concept in 2020, emphasize the identification and conservation of vital biotopes and landscapes at both federal and regional levels to ensure comprehensive protection measures.	Switzerland	Primer, 2008
Biodiversity	National Forestry Commission Fund to finance forest ecosystem services Mexico's National Forestry Commission (CONAFOR) operates a program compensating forest communities for preserving forests through fixed payments per hectare over five years. Landowners engage in sustainable practices, ensuring continued or enhanced ecosystem services. The program offers payments ranging from $10 to $40 per hectare annually, varying based on forest type and deforestation risk, intending to establish a sustained funding mechanism for conserving globally significant biodiversity in forest ecosystems.Top of Form	Mexico	Primer, 2008
Water markets Quality drinking water	Perrier Vittel's Payments for Water Quality Vittel pays each farm about $230 per hectare per year for seven years. The company spent an average of $155,000 per farm or a total of $3.8 million.	France	Scherr *et. al.*, 2004
Water markets Regularity of water flow for hydroelectricity generation	FONAFIFO and Hydroelectric Utilities Payments for Watershed Services Landowners who protect their forests receive $ 45/ ha/yr; those who sustainably manage their forests receive $70/ha/yr, and those who reforest their land receive $116/ha/yr.	Costa Rica	Scherr *et. al.*, 2004
Water markets Improvements of base flows and reduction of sedimentation in irrigation canals	Associations of Irrigators' Payments (Cauca River) Association members voluntarily pay a water use fee of $1.5-2/litre on top of an already existing water access fee of $0.5/litre.	Colombia	Scherr *et. al.*, 2004
Improved water quality	Nutrient Trading Trading of marketable nutrient reduction credits among industrial and agricultural polluting sources Incentive payments of $5 to $10 per acre	United States	Scherr *et. al.*, 2004
Carbon + biodiversity [Financial intermediary - Hancock New ForestsPty, Ltd.]	Hancock New Forests Pty, Ltd. Climate regulation (through carbon sequestration via carbon credits) + water regulation and recreation and nature-based tourism (salinity and biodiversity benefits).	Australia	FAO and Forest Trends, 2007
Biodiversity	Natural medicines and pharmaceuticals Pharmaceutical industry - AMRAD CUT	Australia	FAO and Forest Trends, 2007
Scenic beauty	The rafting company is dedicated to ensuring the preservation of forest cover along the rivers they navigate. Top of Form Tourism industry - Rio Tropicales	Latin America (Costa Rica)	FAO and Forest Trends, 2007

Source: Compiled by Author.

4.3 Environmental Markets

4.3.1 Carbon Markets

It is estimated that 110 billion tonnes of carbon have been released from the top layer of soil by agricultural activities over the past 12,000 years (Sanderman, 2017). Latest reports at CoP 28, the carbon emission from Indian farming as 13. 44 per cent. At the same time agriculture has a high potential for carbon sequestration in soils through adoption of practices like zero tillage and direct seedling, preservation of the carbon-rich organic matter layer of soil, crop rotation and sequencing, crop and tree cultivation associations, improved grassland management, and controlled grazing (FAO, 2007) Carbon farming/ Carbon neutral agriculture involves a wide range of agricultural practices with the primary goal of removing excess carbon from the atmosphere to reduce global warming.

Carbon markets offer a compelling avenue for incentivizing and rewarding agricultural practices that contribute to reducing greenhouse gas emissions, enhancing carbon sequestration in soils and vegetation, and promoting sustainable land management. In the context of the Indian agricultural sector, the application of carbon markets can be in the following aspects:

Eco-friendly agricultural practices: Practices like precision agriculture and efficient fertiliser use can be rewarded by carbon markets for reducing nitrous oxide emissions while maintaining or increasing crop yields. Organic farming and natural *farming are few methods in these lines*

Afforestation and Reforestation: Financial incentives from carbon markets can encourage landowners to plant trees on agricultural lands or convert degraded areas into forests, effectively sequestering significant amounts of carbon

Livestock management: Carbon markets can reward farmers for implementing improved livestock management practices, such as better feed management and methane capture technologies, to mitigate methane emissions from livestock production

Manure Management: Proper management of manure, including the use of technologies like anaerobic digesters, can reduce methane emissions and enhance nutrient management, with carbon markets providing financial incentives for their implementation

Climate Smart Agriculture and emission reduction approaches: comprehensive approach to agriculture prioritising carbon sequestration and emissions reduction can be financially supported by carbon markets, incentivising emission reduction goals on agricultural lands

Maintaining Agrobiodiversity: Carbon markets can consider co-benefits, such as improved biodiversity, enhanced water quality, and soil health, encouraging agricultural practices that offer holistic environmental benefits.

There are increasing number of facilitating agencies (mainly NGOs) that help the farmers to practice soil management practices that earn carbon credit and realise income through trading in carbon markets. In India one such firm alone is facilitating 100,000 farmers across 300,000-plus acres of farm land.

Government of India, Ministry of Environment, Forests and Climate Change have proposed the draft green credit Programme Implementation Rules 2023. This introduces a market-based mechanism, that seeks to incentivise individuals, industries, and others for environmentally positive activities. A green credit is a singular unit of credit specified for specific activity, which can be based on the technological coefficient. The activities include tree planting, water conservation and sustainable agriculture among the total eight specified sectors. The recent initiative by the Ministry of Power in India, through the Carbon Credit Market Scheme (July 2023), signifies a milestone in establishing the country's first domestic regulated carbon market. This step aims to boost the trading of carbon credits and underscores the importance of integrating market-based approaches to drive sustainable agricultural practices.

However, it is crucial to emphasise that successful implementation necessitates careful consideration of local conditions, agricultural practices, and potential challenges, along with well-designed policies and regulations to ensure effectiveness while considering the socioeconomic implications for farmers and rural communities. Robust measurement and monitoring systems encouraged by carbon markets are essential for accurately tracking emissions reductions and carbon sequestration

4.3.2 Water Quality Trading:

Implementing water quality trading systems allows farmers to buy and sell credits based on their impact on water quality. This encourages the adoption of practices that reduce nutrient runoff and improve water quality. NITI AYOG proposes the scope of water trading mechanism to promote reuse of treated waste water in India (NITI AYOG, 2023)

4.4 Green Bonds:

Green bonds are designated to fund projects that aim to deliver environmental benefits. These bonds attract socially responsible investors and channel funds into initiatives that enhance agroecosystem safety. Green bonds command a higher price than conventional bonds which vary across the type of projects. (Lau *et al.*, 2022). Governments can issue green bonds for agriculture sector to finance sustainable agriculture projects.

4.5 Eco Certification and Labelling:

Eco - certification in agriculture refers to a process by which agricultural products or practices are certified as meeting specific environmental and sustainability standards. This certification is typically granted by third-party organisations, known as certifying bodies, that assess and verify whether a farm or agricultural product complies with established eco-friendly criteria. The primary aim of eco-certification is to promote environmentally responsible and sustainable agricultural practices, ensuring that farmers adhere to certain standards that minimise negative impacts on ecosystems, biodiversity, and natural resource. These practices include organic farming, agroforestry, water conservation, and soil health management (Environmental Stewardship), biodiversity conservation, eco-friendly farm management practices, efficient resource use, social and ethical aspects (fair labour practices, worker welfare, and community engagement) and traceability and transparency. Upon a farm or product meets the criteria, it is granted a certification label. This label provides consumers with a recognisable symbol that indicates the product's adherence to specific eco-friendly standards. These products can gain access to premium markets, fostering a competitive advantage for sustainable agriculture.

Examples of well-known eco-certification programs in agriculture include USDA Organic, Rainforest Alliance, Fair Trade, and various country-specific organic certification schemes, and GAP (Good Agricultural Practices). These programs not only benefit the environment but also contribute to the marketability of certified products, appealing to consumers who prioritise sustainability and ethical considerations in their purchasing decision.

4.6 Research and Development Policy Support:

Investing in research to understand the local ecosystem dynamics and how they can be harnessed for sustainable agriculture is crucial. Policies should support collaborative efforts between scientists, farmers, and policymakers to develop context-specific solutions.

4.7 Education and Outreach

Creating awareness among farmers about the importance of ecosystem services and how certain agricultural practices can enhance these services is essential. Extension services should be geared towards disseminating knowledge about sustainable farming practices

V

CHALLENGES IN DESIGNING POLICY INSTRUMENTS FOR AGROECOSYSTEM MANAGEMENT

Designing policies for the management of agroecosystems faces numerous challenges due to the complex and interconnected nature of agricultural and social systems. Here are some key challenges:

1. The Diversity of agroecosystems:
   The agroecosystems vary significantly in terms of climate, soil types, crops, and farming practices. Crafting policy instruments that are applicable and effective across this diversity can be challenging.
2. The trade-offs and synergies in agroecosystems: Agroecosystems provide a wide range of ecosystem services, and these services are often interconnected. Policies targeting one aspect of agroecosystem management may have unintended consequences on other services. Balancing trade-offs and synergies among services is a complex task.
3. Dynamic nature of agriculture systems and uncertainties: Agricultural systems are influenced by numerous variables, including weather conditions, pest dynamics, and market fluctuations. Designing policies that can adapt to

uncertainties and changes in the agricultural landscape is a persistent challenge.

4. Time scale of externalities and farm decisions: Many day-to-day decisions in agriculture prioritise immediate financial returns, often at the expense of long-term sustainability. This approach undermines the fundamental structures and functions of ecosystems, leading to the degradation of environmental services. Balancing the immediate economic needs of farmers with the long-term sustainability goals of agroecosystem management is a constant challenge. Policies that encourage sustainable practices may face resistance if they are perceived to threaten short-term economic viability.
5. Assessment of ES: Aassessing the immediate effects of changes in land use, agricultural practices, or policy interventions on ecosystem services include monitoring changes in the short term as well as in the long term, in ecological, social, and human health dimensions. The long-term impacts involve factors such as climate change, cumulative impacts, and the resilience of ecosystems over extended period. Assessing such impacts pause great methodological challenges. For instance, it is difficult to establish the cause effect relationships between environmental quality decline and human and animal health impacts, at field level conditions. Apart from the non-marketed nature of ES that limits its valuation the complexities involved in the biosystem pauses great challenges in identification, quantification and valuation of AES and AEDS. This also applies in the case of assessing the impacts of new technologies at the special and temporal dimensions.
6. Fast depletion of environmental quality: Millennium Ecosystem Assessment revealed that over 60 per cent of studied environmental services are degrading faster than they can recover. This degradation poses a significant threat to the resilience and health of ecosystems and demand continuous monitoring efforts.
7. Research gaps: Despite the increasing recognition of the importance of ecosystem services, research in this field is still in its infancy. Many open questions remain, and there is a need for further investigation and understanding, especially on valuing agroecosystem services and dis services.
8. Cultural and Behavioural Factors: Farmers' behaviour and cultural practices play a crucial role in agroecosystem management. Designing policies that align with local knowledge, traditions, and the motivations of farmers is essential for successful implementation. Understanding and addressing these social aspects can be challenging.
9. Farm size and disparities: Disparities in access to resources, such as technology, finance, and information, among different farmers and regions, can affect the equitable implementation of policies. Ensuring that policy instruments do not exacerbate existing inequalities is a significant challenge.
10. Agricultural Markets and Dynamic Behaviour: Agricultural markets can be volatile, and policies need to be designed considering their potential impact on

market dynamics. Incentives or regulations that affect prices or market access can have profound effects on the behaviour of farmers and other actors in the supply chain

11. Multiple stakeholders and diverging interests and behaviour: Agroecosystem management involves a broad spectrum of issues, including land use, water management, biodiversity conservation, and climate resilience. Coordinating policies across different sectors and ensuring their alignment can be challenging due to the presence of multiple stakeholders with varying interest.
12. Monitoring challenges: Lack of accurate and timely data on agroecosystem conditions and management practices can hinder the design and implementation of effective policies. Developing robust monitoring systems to track the impact of policies is essential but can be resource-intensive.
13. Policy implementation and enforcement: Translating policies into on-the-ground actions and ensuring compliance can be challenging. The effectiveness of policy instruments relies on the capacity for implementation and enforcement, and this can be influenced by institutional capacity, governance structures, and regulatory framework.
14. Market based policy instruments are generally incremental in nature and may not be able to achieve the sustainability objectives to the fullest level. It also requires good governance and strong institutional mechanism. Further to it, the realistic estimation i.e., quantification and valuation of ES forms pivotal in the success and efficiency, in the absence of which the possibility of green washing is very high. Green washing involves making false or exaggerated claims on environmental gains without actually delivering the same.

Addressing these challenges requires a collaborative and adaptive approach involving stakeholders from various sectors, robust research and monitoring systems, good governance and continuous policy evaluation and adjustment mechanism. Successful agroecosystem management policies are those that take into account the complexity and dynamics of agricultural systems while fostering sustainable practices.

VI

CONCLUSION

The trajectory of research on Agricultural Ecosystem Services (AES) has undergone a significant evolution over time. Initially, the focus was on AES as inputs, highlighting factors such as soil fertility, water availability, and landscape characteristics. However, as investigations progressed, there was a shift in attention towards more conspicuous and vital services, such as pollination, carbon sequestration, and climate regulation. This change in focus marked a crucial moment where these prominent ecosystem services were acknowledged for their essential contributions to agricultural sustainability and climate change management (FAO, 2007).

In recent times, there has been a paradigm shift in research approaches. Contemporary studies now focus on ecosystem services as outputs. While emphasising their pivotal role as providers of provisioning services that support agricultural productivity, recognises their critical role in ensuring sustainability, climate change management and over all human welfare.

Amidst these revelations, the emergence of EDS from agriculture sector, such as chemical pesticide use, documented for its adverse effects on both ecological and human health, prompts a re-evaluation, necessitating a comprehensive assessment of net ES flow. The trade-off between the health impacts and financial benefits of crop production, as well as short term gains and long-term sustainability, highlights the critical need for policymakers to weigh the net flow of ecosystem services, potentially necessitating taxation on chemical pesticides while concurrently revaluating subsidy structures to incentivise and support the adoption of ecologically safer alternatives. This shift underscores the urgency to balance agricultural productivity with ecological sustainability, emphasizing the long-term health of ecosystems and safeguarding human well-being

The challenges in this sphere include comprehensive mapping of AES and AEDS, physical and biological science support for quantification of these impacts and identifying appropriate economic valuation methods that reflect the net ES flow from AES. For effective integration of the concept into practical application needs appropriate institutional mechanism, design of suitable policy instruments and efficient governance mechanism.

In conclusion, the integration of ecosystem service-based approaches into agricultural policy making is not just a choice but a necessity for the sustainable future of our planet. By acknowledging the invaluable services that ecosystems provide, we pave the way for a resilient and productive agricultural sector that meets the needs of the present without compromising the ability of future generations to meet their own needs. It is a collective responsibility that requires collaboration between governments, farmers, scientists, and the broader community.

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