Annex II – In depth review- Sustainable Dimensions Metrics

Dimensions	Indicators	Metrics	References	Problem	Result
Environmental	GHG Emission	Total emissions	[65]	Estimating the total emissions for solar power plants from various sources (removal of forests, soil life cycle.) can complicate the assessment of environmental impact in comparison to traditional power sources	Despite the challenges to estimate the total emissions, solar power plants' emissions are significantly lower than coal power plants.
		Carbon Intensity	[66] [73] [67] [68]	The problem is that carbon intensity doesn't fully account to the complex factors affecting carbon reduction such as different technologies and energy policy impacts.	Estimating carbon intensity helps ensure cumulative carbon emission doesn't exceed quotas
	Waste Generated	Waste Footprint Component	[71]	Biofuel production have increased impact on the environment which could affect water resources and challenge sustainability	The metrics highlight the need for sustainable resource management to support renewable energy transition goals.
	Water consumption	Water Footprint Component			
	Natural Resources	Natural resources depletion or Abiotic depletion	[72]	Evaluating natural resources depletion impact from wind and solar is underexplored	There is need to enhance the method that measure how renewable energy transition affect natural resources
	Land Use	Land Use Energy Intensity	[43]	Different and inconsistent metrics are used to measure the relationship between solar energy and land, making it difficult to compare and interpret results.	Standardized metrics can improve measuring the impact on land use.
		Absolute Area of land converted			
		Annual Land Transformation			
		Lifetime Land Transformation			
		Land-Use Efficiency			
		Energy Footprint	[69]	Traditional metrics such as energy footprint of measuring footprint	Integrated thinking is needed in assessing the impact of sustainable transition

				do not provide complete evaluation and usually cover one aspect of sustainability	on land use and local context.
		Land Occupation Metric	[70]	The use of land occupation metric is complex and difficult to yield accurate results to estimate future land requirements for renewable energy projects	Using land occupation metric allow comparing land needed between different renewable energy sources to support policymakers' decisions.
	Ecological Footprint	Carbon sequestration	[71]	The approach of using carbon sequestration is only limited to GHG emissions.	Reliance on only carbon sequestration underestimates the other environmental footprint and it doesn't account to the estimation of benefits when transitioning to renewable energy resources.

Dimensions	**Indicators**	**Metrics**	**References**	**Problem**	
Technical	Renewable Energy Share	Renewable Energy fraction	[74]	The nature of renewables such as solar and wind being unpredictable pauses a challenge to calculate the renewable energy fraction	Using renewable energy fraction can significantly increase clean energy production to meet energy needs and reduce emissions.
	System Generation	Residual Load Range	[75]	The issue with variable renewables such as wind and solar is how to provide constant supply of electricity.	The residual load range helps in understanding the operational flexibility required from conventional power plants to balance the grid to ensure power supply meets demand all time
		Surplus Energy	[76]	Systems that provide surplus of energy are considered inefficient leading to resource waste and higher cost.	Hybrid energy systems can generate balanced amount of surplus, can also be cost effective and environmentally friendly.
		Power system flexibility	[77]	Curtailment of renewables due to insufficient power system flexibility affects renewable	Improving system flexibility through integrated systems and modification to grid and reducing

			energy adopted Zangjiakoi, China	energy consumption can promote renewable energy
	Insufficient ramping resource expectation (IRRE)	[78]	Wind and Solar power systems have more variability, making it harder to plan and manage energy supply consistently.	IRRE metric helps measure the flexibility of a power system to handling variations and identify times when systems need
System Efficiency	Energy Efficiency	[79]	The authors discuss the challenges of the accuracy and comparability of different energy metrics as accounting methods as well as to support decision making.	Shifting from TPE to TFC can provide a better representation for policy targets, as renewable energy shares increases.
	Total Final Consumption (TFC)			
	Total Primary Energy (TPE)			
	Energy Intensity			
	LPSP Loss of power supply probability	[80]	Variability in renewable energy systems requires understanding the risk of not meeting energy demand.	LPSP metric assists in evaluating system designs in supplying power without interruption.
System Security	Full Load Hours of Generation	[81]	Full load hours of generation may not be accurate when measuring systems with high renewable energy sources	Using Full load hours of generation can lead to inaccurate assessment of generation as it doesn't account for the distributed nature of renewables
System performance	Net Energy ratio NER	[67]	There is lack of detailed information on energy footprints of large-scale solar systems.	The net energy ratio of large scale pv systems indicates that they produce more energy than they consume
Adequacy	Loss-of-Load Hours (LOLH)	[81]	Measuring the reliability for modern power systems may not be fully captured	It is not enough to rely on these metrics alone to measure system adequacy to meet demand.
	Loss of Load Expectancy	[81]		
	Loss of Load Probability	[81]		
	Loss of Load Events	[81]		
Reliability	Expected Unserved Energy (EUE)	[81]	May not account fully to the complexities and uncertainties in high level renewable energy sources.	Can lead to misleading conclusions if used with high renewable energy systems in
	Expected Energy Not Supplied	[81]		

		Energy Index of Unreliability (EIU)	[81]		terms of efficiency and reliability.
		Energy Index of Reliability (EIR)	[81]		
		System Minutes	[81]		
		Average Interruption Time (AIT)	[81]		
Dimensions	**Indicators**	**Metrics**	**References**	**Problem**	**Result**
Social	Equitable	Changes in Energy Expenditures	[12]	During transition, electricity prices can increase.	Increase in energy costs can affect, remote areas and areas with extreme climate.
	Secure	Energy Burden	[82]	Utility costs and energy costs are not well understood in housing affordability.	Low income house holds tend to have higher energy burden.
	Accessible	Energy Access	[12]	During transition, electricity prices can increase.	Increase in cost can cause household to disconnect from utility service especially among vulnerable communities.
	Acceptable	Community Acceptance	[83] [84]	Exclusion of communities in energy transition decision making can affect the pathway	Multiple factors affect community acceptance and communities can be included through various approaches to increase their participation.
	Health Impacts and Pollutant Exposure	Occupational Pollutant Concentration	[12]	Shifting from fossil fuel to renewables can pose different types of health risks	Exposure to hazardous material is a type of health risks associated to renewables.
		Proximity to Resource Extraction			
Dimensions	**Indicators**	**Metrics**	**References**	**Problem**	**Result**
Economic	Energy Affordabilit y	Levelized Cost of Energy (LCOE)	[85] [86]	LCOE does not account for variability and reliability of renewable energy sources which lead to incomplete assessment of true costs and benefits.	Using LCOE alone might overlook important factors such as integrational costs, leading to decisions that not fully support long term economic goals.
		Cost of Valued Energy (COVE)	[87]	Cove is challenging as it requires detailed	Despite its complexity, COVE provides accurate

			data that are complex to gather.	measure of the economic value of energy produced by renewable systems. It can support design decisions that can increase return on investment by focusing on producing higher value energy, not minimizing costs.
Resource Cost	Real Gross Domestic Product (RGDP)	[88]	If higher income earners will invest in renewable energy, may not be true especially in areas relying on fossil fuel due to lobby effect theory.	RGDP is limited as it supports the income hypothesis, indicating that as economy grows, there is more financial capability to invest in renewable energy sources.
Employment	Jobs created per installed capacity	[89]	The jobs created can be limited to specific time frame.	Despite the limitation, measuring the jobs created on a short period of time can assist in comparing the immediate job creation of different renewable energy projects that can boost employment.
Financial viability over time	EPBT Energy payback time	[67]	EPBT is a highly sensitive metric. Affected by efficiency of the technology as well as lifetime.	Despite these limitations, it can support in comparing different systems to estimate the return on investment select the better option.
	Energy Return on Energy Investment (EROI)	[90]	Fast transition to renewable might lower energy return and can affect current industrial societies.	EROI highlights the potential of increase demand and resources depletion in energy transition that can affect energy availability with poor management.
	Total net present cost	[91]	The metric factor variable costs that may change over long run.	NPC help compare the overall cost effectiveness over time, that help identify the most economical option for transition to renewable energy.

	Cost Effectiveness	Cost per Unit of Energy Saved	[92]	Cost per unit of energy saved may not capture the broader economic and social benefits of renewable and focused on the cost.	It can lead incomplete understanding of the economic impact and overlook potential increase in GDP and other market opportunities.
Dimensions	**Indicators**	**Metrics**	**References**	**Problem**	**Result**
Political and Institutional	Participation	Public Participation in Energy Planning	[41]	Public participation can be complex because it involves diverse factors like community engagement, awareness, and local support.	Can lead to inconsistent results when comparing public participation in different regions and countries.
	Policy support	Renewable Energy Policies	[41][93]	Renewable energy policies are influence by political context and can be difficult to measure progress in energy transition using only policies.	Despite limitations, effective renewable energy policies advance technology adoption, cost reduction, and support faster energy transition.
		Regulatory Certainty	[41] [94]	Regulatory uncertainties make it hard to measure energy transitions accurately because changing rules can lead to inconsistent data and unpredictable outcomes	Understanding regulatory uncertainties helps policymakers create stable regulations, supporting a smoother and more predictable energy transition
	Institutional Capacity	Institutional Capacity for Renewable Energy -	[41] [93]	There are many factors that affect regulatory frameworks, stakeholders' engagement, and administrative capacities.	Institutional capacity for renewable energy as a metric can lead to inconsistent comparison between different regions or context and can't capture the complexity that influence their capacity.