Fair and sustainable energy transition in Lao PDR

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Abstract*— The energy transition is a complex and challenging process, but it promises a more sustainable future. Its implementation involves not only technical issues but is also socially and politically challenging. The adoption of renewable energy sources and the reform of energy systems at a global level directly affect the well-being of populations, especially in regions with high levels of inequality and vulnerability. In this context, ensuring a fair energy transition is essential to prevent certain social groups from being excluded from its benefits or disproportionately bearing its costs. We can pave the way to a more equitable and sustainable world by addressing these challenges. This article presents a case study from the Lao PDR that analyses the intersection between the energy transition and social justice. It is necessary to analyse whether socio-environmental conflicts are related to energy projects, especially in rural communities and minorities. The analysis uses a methodological approach based on sustainability indicators, primarily the SDGs and human development metrics, to assess the impact of energy policies on the social, environmental and economic dimensions and try to understand how decisions in the energy sector can promote a fair and balanced transition between economic growth, environmental protection and social equity.

Index Terms—***Energy, Fair, Sustainability, Transition.***

I. INTRODUCTION

In recent years, energy transition has gained significant momentum globally, spurred by the need to combat climate change and reduce greenhouse gas emissions. This transition has been characterised by increased adoption of renewable energy sources and efforts to improve energy efficiency and reduce dependence on fossil fuels. However, this process has not been without challenges, especially regarding energy justice. While some countries and communities have managed to access cleaner and more affordable energy, others, particularly in developing regions, have been left behind, exacerbating existing inequalities in access to sustainable energy resources.

Energy justice has become a central issue in the debate on energy transition, as it seeks to ensure that the benefits of clean energy are equitably distributed and that the most vulnerable communities are not marginalised in the process. This implies not only ensuring universal access to energy but also considering the social and economic impacts of the transition, such as the loss of jobs in traditional sectors or the impact on local communities by renewable energy projects. To achieve a truly just transition, it is necessary to implement inclusive policies that prioritise community participation, the protection of human rights, and the reduction of socio-economic gaps in access to sustainable energy.

Based on the precept of the role of social justice as a decision-support tool for policymakers [1], any analysis referring to energy justice as part of social justice must apply its principles of justice to energy policy, energy production and systems, energy consumption, energy security, and climate change [2]. Jenkins et al. (2016) [2] consider that energy justice offers an opportunity to explore where injustices occur, develop new prevention and reparation processes, and recognise new sectors of society.

The Lao People's Democratic Republic (Lao PDR) is a pertinent case study to analyse the intersection between energy transition and social justice. As a developing nation with a strong focus on hydropower as a primary energy source, it faces challenges related to equitable access, environmental impacts, and economic sustainability. The proliferation of energy projects in the country has created both socio-environmental opportunities and conflicts, particularly in rural communities and among groups with less access to energy infrastructure.

Laos has historically relied on conventional energy sources to meet its growing demands as a landlocked country endowed with significant hydropower potential. 100% of Lao PDR's 7.7 million inhabitants have access to electricity [3], but a significant portion of the Lao population still relies on traditional biomass for cooking and heating, highlighting the socio-economic implications of energy policy transitions, particularly in rural areas [4]. Authors such as Keomeesay et al. (2025) [5] consider that, despite advances in policy formulation, the absence of integrated approaches that consider socio-economic conditions significantly undermines the effectiveness of these policies.

The study we present assesses energy development in Lao PDR, considering an analysis framework that includes political, economic, social, technological, environmental and cultural (PESTEC) aspects based on SDGs indicators and other indicators to provide elements for policy formulation that reduce gaps in access to energy for all social groups (especially minorities), improve energy efficiency and reduce environmental impact.

II. METHODOLOGY

Integrated SuWi Doughnut Approach

The Sustainability Window (SuWi) is a novel tool that can simultaneously assess the sustainability of development in its three dimensions (environmental, economic, and social). The method integrates social and environmental development analysis with economic development in a single quantitative

framework using joint metrics for analyses [6]- [7].

This method provides information on the minimum and maximum economic development necessary to maintain the path of social and environmental development towards more sustainable objectives or to maintain it at predefined sustainability levels [8] and furnishes a new perspective for analysing sustainability trends and the impacts of underlying sustainability policies [9]. Sustainability Window can be used to analyse development processes and sustainability transitions in different economies (see e.g. [10]). We use time series data for different indicators of environmental stress, social welfare, and economic output for the dynamic analysis. It is possible to utilise the SuWi analysis results to construct the Integrated SuWi Doughnut model.

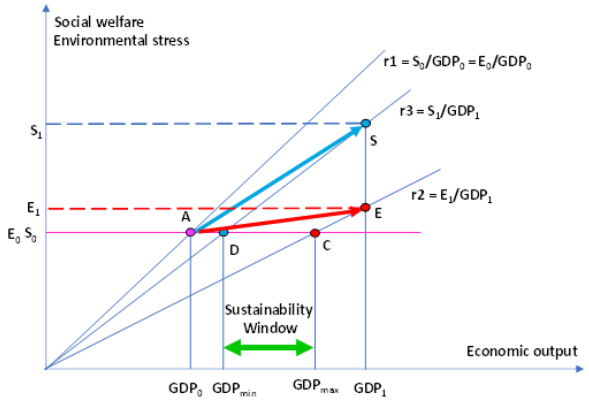


Figure 1. Definition of Sustainability Window [8].

Indexed time series of Social welfare, Environmental stress and Economic output have base year values S_0, E_0 and GDP_0 at point A. The values at the analysis year are S_1, E_1 and GDP_1. Environmental stress level at point E determines the environmental stress productivity line r2, which determines (ceteris paribus) the maximum GDP_{max} level at point C not to increase environmental stress. Social welfare level at point S determines the social welfare productivity line r3, which determines (ceteris paribus) the minimum GDP_{min} level at point D not to decrease social welfare. GDP_{min} and GDP_{max} define the Sustainability Window (SuWi).

The Integrated SuWi Doughnut Approach is based on the SuWi analysis and it takes into account social and planetary boundaries and allows us to visualise the environmentally safe and socially just space where humanity can thrive. The approach combines, contrary to the traditional Doughnut Economics, the economic dimension to the two other dimensions of sustainable development, ecological and social dimensions, in a coherent quantitative analytical framework using the same metrics in all dimensions.

SDG, SSI, HDI Indicators

In the Sustainable Development Reports [3], where compliance with the SDGs by most countries can be seen, Lao PDR appears 119th out of 166 countries. In addition to the SDG database [3], the Sustainable Society Index (SSI) [11] were the primary data source for the analysis. The SSI dataset integrates Human, Environmental, and Economic well-being indicators to form a more comprehensive view of development.

We used raw data from the SSI database and similar data from the SDG indicators. In addition, we have used [12] statistical data for GDP, [13] data for the Human Development Index, and [14] data on energy and CO_2 emissions.

III. RESULTS

Lao PDR Energetic systems

Lao PDR's primary energy comes primarily from coal, oil, hydropower, and other sources, including biomass and solar energy (see *Fig.2*). A large amount of electricity is produced for export. Lao PDR's energy supply is projected to double from 6.29 million tonnes of oil equivalent (Mtoe) in 2020 to 12.78 Mtoe in 2030 and triple by 2050 (18.57 Mtoe). [15]

Coal and oil combined are expected to decline to around 20% by 2050, and renewable energy sources such as hydro, solar PV, wind and biomass are expected to become the dominant energy sources by 2050. Other clean fuels, such as ammonia, should play an essential role in decarbonising the power sector through co-firing coal and ammonia [15].

Lao PDR exports electricity to neighbouring countries but is highly dependent on imports of other energy sources (100% import of finished products such as petrol, diesel and kerosene) for transport, commercial and residential consumption. This import will, in the future, put pressure on energy security. Demand growth is another challenge, along with energy security, in the face of unexpected supply disruptions [16].

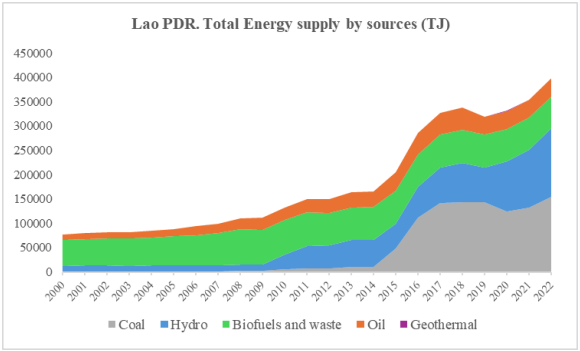


Figure 2. Lao PDR. Total energy supply by sources.[14]

Lao PDR has a broad policy orientation for the inclusive and sustainable development of its energy security. It has explored the entire energy system and developed a set of policy recommendations and suggestions to ensure that the transformation of the energy system can be financed, technology can be transferred, the cost of energy is affordable, and human resources and capacity can be developed along with the required technologies [15].

Among the policies proposed by the government to harness the considerable potential for energy savings is the implementation of energy management systems in energy service companies.

Alongside this, a national communication plan is being prepared to promote energy efficiency and energy conservation. Awareness of energy efficiency and conservation is crucial to reducing end-use energy and peak demand, resulting in lower growth in energy supply and installed capacity. Stakeholder engagement seminars and workshops are needed to deliver knowledge, and emphasis should also be placed on educating families and students

through fundamental energy conservation practices [16].

Socio-economic and cultural context

Lao PDR is organised into 17 provinces and one prefecture. Vientiane, the largest city, is central in driving economic growth, social progress and infrastructure development as the capital. Pakse, the capital of Champasak Province in the country's south, has a relatively advanced infrastructure compared to many other cities. Well-maintained roads, bridges and transportation networks facilitate connectivity within the city and with surrounding areas. In the north, Luang Prabang is a famous UNESCO World Heritage Site celebrated for its architecture, Buddhist temples, and landscapes. Savannakhet, located in the country's centre on the banks of the Mekong River, is the second largest city and the capital of Savannakhet Province, a historical and cultural destination for tourists. Several cities and areas (Vientiane, Pakse and Savannakhet) are strategically located and are important commercial hubs with diverse economic activities and connectivity to neighbouring countries [17].

In the north, the Boten Special Economic Zone (SEZ) is a major commercial hub facilitating cross-border trade between Lao PDR and China. The SEZ comprises commercial facilities, duty-free shops and logistics infrastructure, which attract businesses and traders from both countries. The Golden Triangle SEZ is located in Bokeo province, close to the borders with Thailand and Myanmar. This SEZ offers opportunities for cross-border trade, investment and tourism [15].

The economy of the Lao PDR has grown in recent years, moving from an agricultural economy to a more diversified one, although agriculture remains an important sector. Laos has abundant natural resources and seeks to expand its manufacturing and service sectors.

The economic structure can be described as follows (see *Fig. 3*):

1. Primary sector (agriculture, forestry and mining): This remains a key part of the Lao economy, contributing significantly to GDP, employment and exports.
   1.1. Agriculture is a cornerstone of the economy, with a large proportion of the population employed in this sector (see Fig. 4), especially in rural areas, and smallholder farmers rely on traditional farming methods. The government is working to modernise this sector through initiatives to improve productivity and expand market access.
   1.2. Forestry: Lao PDR has large rainforest areas, home to valuable hardwoods. However, deforestation and illegal logging have raised environmental concerns in recent years, and there are ongoing efforts to balance economic development with environmental sustainability.
   1.3. Mining: The mining sector is essential, considering global demand for natural resources has increased. Laos is rich in minerals, including gold, copper, tin and potash. The country has attracted foreign investment in its mining sector.
2. Secondary sector (manufacturing and industry): This sector is in the early stages of development; manufacturing and industrial activities are limited, focusing on natural resource processing rather than diversified industrial production. Some key industries include:

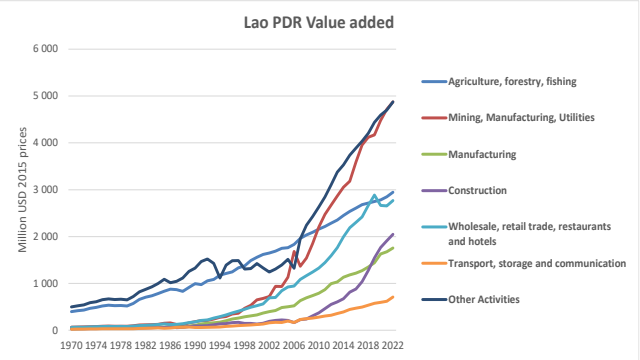
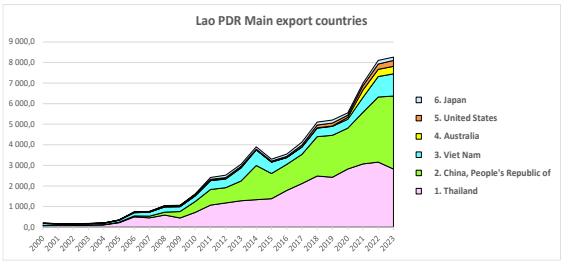


Figure 3: Lao PDR Value added [18]

   2.1. Construction: The construction industry has grown significantly, mainly driven by infrastructure development and foreign investment. The real estate sector has also boomed. Infrastructure development is focused on transport networks (roads, railways), power generation (hydroelectric plants) and urban development.
   2.2. Manufacturing: Laos has a relatively small but expanding manufacturing base. The sector includes food processing, textiles and clothing, electronics and household appliances.
   2.3. Energy and power generation: The energy sector, mainly hydroelectric power, is an important development area.
3. Tertiary sector (services): This sector is considered to be underdeveloped, although areas such as tourism, finance and retail trade are expanding.
   3.1. Tourism: Tourism has seen rapid growth in recent years. The country is known for its rich cultural heritage, beautiful landscapes and natural resources. Active efforts are being made to develop tourism infrastructure, including hotels, transportation and services. In addition to cultural tourism, the country also promotes ecotourism and adventure tourism.
   3.2. Retail and wholesale trade: This sector is growing, especially in urban areas. The growth of shopping malls, supermarkets and traditional markets drives the economy.
   3.3. Financial services: This is a small sector, although reforms have been introduced to increase access to banking services, credit and financial products. However, many rural areas still have limited access to formal banking, and microfinance institutions have grown to meet the needs of the unbanked population.
   3.4. Telecommunications: The telecommunications sector has seen rapid expansion in recent years, with increased access to mobile phones, the Internet and digital services. This sector is expected to grow as the country becomes more integrated into the global digital economy.
4. Foreign Trade and Investment: Lao PDR's economy is small and open, with an increasing focus on foreign trade and investment and expanding regional trade ties.

4.1. Exports: Lao PDR's exports are concentrated in minerals (gold, tin, potash), agricultural products (rice, coffee, cassava and wood products) and electricity.



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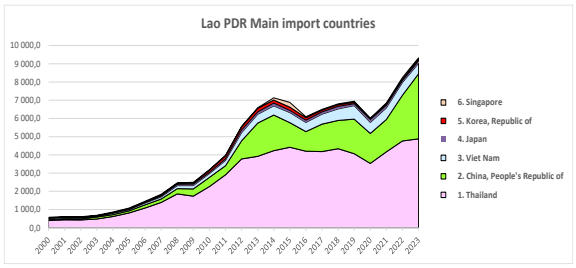


(b)

Figure 4: Lao PDR export (a) and import countries (b) [19]

5. Imports: Laos mainly imports petroleum, machinery, electronics, vehicles and consumer goods.
6. Foreign direct investment plays an important role in Lao PDR's economic growth. It has focused especially on the mining, energy and infrastructure sectors. Laos has also attracted investment in tourism, agriculture and manufacturing.
7. Labour Market and Employment: Lao PDR has a relatively young population, and employment is concentrated mainly in agriculture, with many people working in subsistence farming. However, the service and industrial sectors are growing, and the government is working to improve education and skills training to support a more diversified economy and shifting the workforce to more productive and better-paying sectors, including manufacturing, services, and infrastructure development.
8. Urbanisation is increasing, with more people moving to cities searching for work, particularly in construction, retail, and services. However, many urban areas still face challenges of unemployment and underemployment.

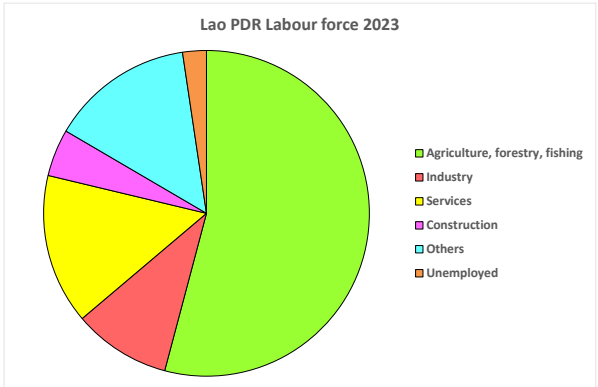


Figure 5: Lao PDR Labour force 2023. [19]

In this socio-economic context, Lao PDR faces several challenges in areas such as:

- Infrastructure, particularly in transport, electricity and communications. Investment in infrastructure is necessary to continue economic growth and facilitate trade.
- Environmental sustainability: the country's dependence on hydropower and forestry raises concerns about environmental degradation, mainly deforestation, water resources and biodiversity.
- Poverty and inequality: despite impressive growth in some sectors, poverty remains a significant problem, especially in rural areas. Inequality is also a concern, as the benefits of growth are not evenly distributed.

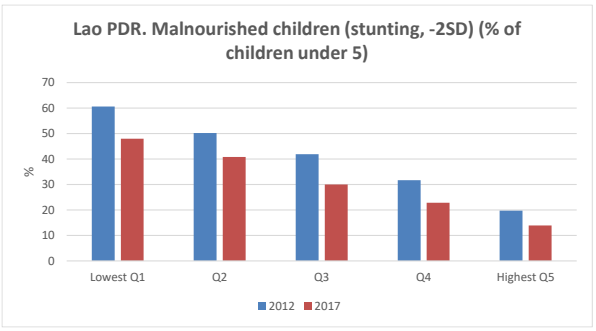
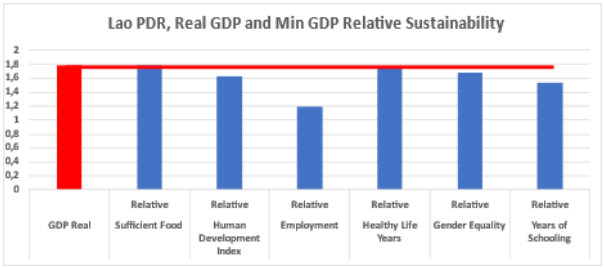


Figure 6. Lao Malnourished Children (2012,2017). [20]

Figure 6 is an example that illustrates the inequality between people with different income levels, directly affecting child malnutrition.



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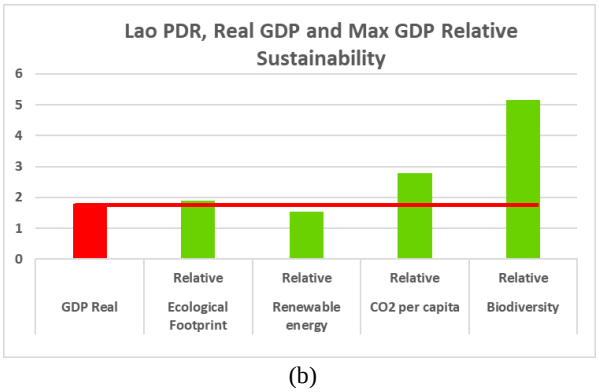

(b)

Figure 7. Lao PDR. Real GDP, Minimum GDP Relative Sustainability (a) and Maximum GDP Relative Sustainability (b). The bars in 6a define the minimum level of GDP to fulfil social sustainability, and in 6b, the bars above GDP real define positive environmental sustainability

Authors such as Pasanen et al. (2017) [21] have assessed the link between major environmental problems and poverty,

particularly in rural areas. They also concluded that the well-being of the poor in the Lao PDR could be significantly improved by closely integrating poverty alleviation and environmental strategies across all environmental dimensions examined.

For this reason, in addition to GDP as an economic indicator, several social and environmental indicators have been selected for analysis in this study (see *Table 1*). This allows us to analyse the main problem areas that require priority attention and specific policies in the energy transition process and on the path towards sustainable development.

We have constructed the Integrated SuWi Doughnut graph (Figures 8 and 9) to analyse the sustainability of Lao development in several dimensions. In the graph, the green area illustrates the sustainability area, which is limited by the maximum economic development defined by environmental criteria (illustrated with blue line) and minimum economic development defined by social criteria (illustrated with green line). The real GDP development is illustrated with red line. If the red line is all the way on the green area, it means that the development fulfils the sustainability criteria of both environmental and social development.

The simultaneous analysis in different dimensions provides possibilities for comprehensive analyses, where the interactions between different sectoral developments are revealed, and problematic areas can be detected.

Using the SuWi method, we can analyse both the relative and absolute sustainability of the development. Relative sustainability means that the development has been towards a more sustainable direction from the base year of analysis using the selected indicator. This could mean, for instance, a decrease in CO_2 emissions (environmental criterion) or an increase in Healthy Life Years (social criterion). Absolute sustainability means that the development fulfils a defined criterion. The criterion can be, for instance, that CO2 emissions are below 1.6 tons per capita or the Human Development Index is above 0.7.

The Integrated SuWi Doughnut clearly illustrates the problematic areas of development and can be utilised to communicate complex development problematique. Visualisation is crucial when policy planning includes actors from different areas and backgrounds to receive feedback from larger stakeholder groups.

Table 1: Indicators and targets used in the construction of the Integrated SuWi Doughnut model

Economic	**Social**			**Environmental**		
Indicator	Indicator	Acronym	Target	Indicator	Acronym	Target
GDP	*Sufficient food*	*Food*	*9.5*	*Renewable Energy*	*RenEne*	*30%*
	Human Development Index	*HDI*	*0.7*	*CO_2 Emission*	*CO_2*	*1.8 tons per capita*
	Employment	*Empl*	*7*	*Ecological footprint*	*Footprint*	*1.5*
	Healthy Life Years	*HLY*	*9*	*Biodiversity*	*Biodiv*	*7*
	Gender inequality	*Gender*	*0.4*			
	Expected years of Schooling	*Schooling*	*14*			

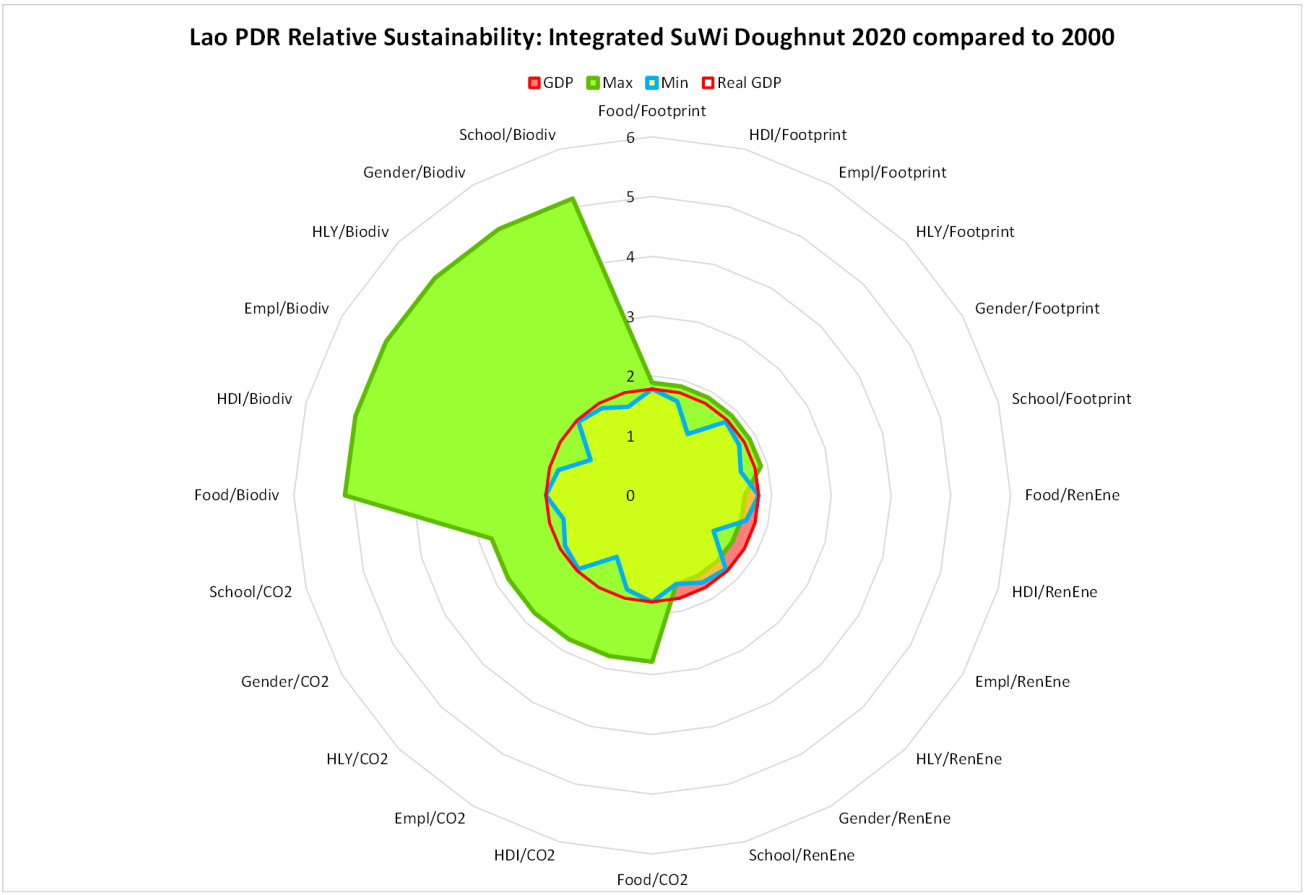

Figure 8. Integrated SuWi Doughnut. Lao PRD: Relative Sustainability 2020 compared to 2000.

Figure 8 shows that the maximum economic development is defined by environmental criteria and illustrated with a blue line, and the minimum economic development is defined by social criteria and illustrated with a green line. The real GDP development is illustrated with a red line. The green area illustrates the doughnut where development fulfils social and environmental sustainability criteria. The red area shows the problematic area, which, in this case, is related to the change in the amount of renewable energy (environmental criterion not fulfilled).

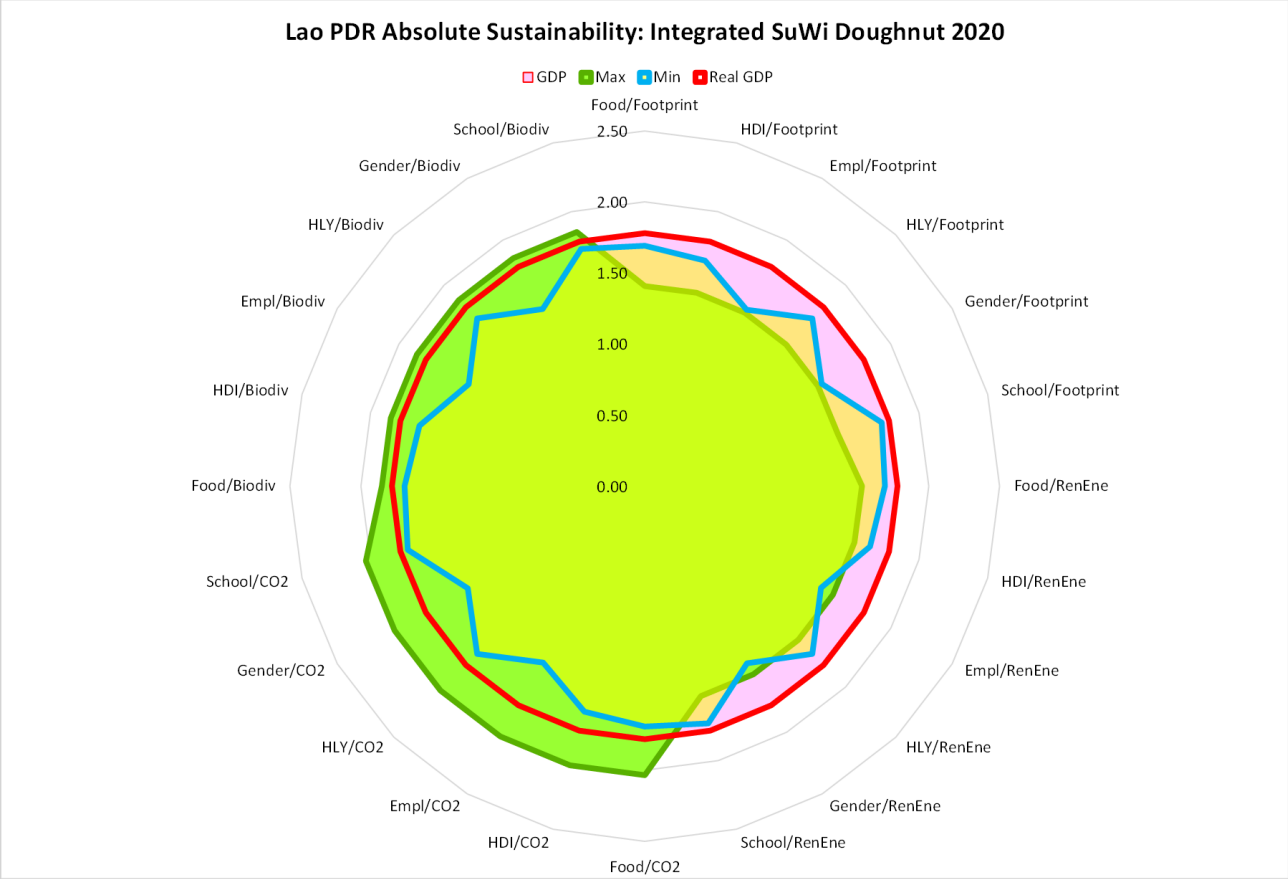

Figure 9. Integrated SuWi Doughnut 2020. Lao PRD: Absolute Sustainability.

Figure 9 shows that the maximum economic development is defined by environmental criteria and illustrated with a blue line, and the minimum economic development is defined by social criteria and illustrated with a green line. The real GDP development is illustrated with a red line. The green area illustrates the doughnut where development fulfils social and environmental sustainability criteria. The red area shows the problematic area, in this case, related to the share of renewable energy and ecological footprint (environmental criteria not fulfilled).

CONCLUSION

The energy transition in Lao PDR presents a unique case where the interplay between economic growth, environmental sustainability, and social equity must be carefully managed. While the country has made significant strides in expanding electricity access, the reliance on traditional biomass for cooking and heating underscores persistent socio-economic disparities. Addressing these inequalities requires policies prioritising energy justice, ensuring that all social groups benefit from clean and affordable energy solutions.

The application of Sustainability Window (SuWi) method and the Integrated SuWi Doughnut Approach has provided valuable insights into the sustainability of Lao PDR's energy development. By incorporating economic, social, and environmental dimensions into a single analytical framework, this approach highlights critical areas where progress is needed. The results indicate that while economic development has been robust, challenges remain in achieving an equitable distribution of energy resources and mitigating environmental impacts.

Policy recommendations should focus on diversifying energy sources, enhancing energy efficiency measures, and fostering community engagement in decision-making processes. Strengthening institutional frameworks, improving regional cooperation, and leveraging technological advancements will be essential in advancing a just and sustainable energy transition. Furthermore, targeted investments in renewable energy projects and energy education initiatives can empower marginalised communities, promoting a more inclusive and resilient energy landscape.

In conclusion, a holistic and integrated policy approach is necessary to balance the demands of economic development with environmental sustainability and social equity. The findings of this study underscore the importance of comprehensive and participatory strategies in ensuring that Lao PDR's energy transition is not only effective but also just for all segments of society.

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