Investigation of the status and the prospect of fuel pellet production and utilisation toward net zero emissions by 2050 in Vietnam

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Abstract:

The Vietnamese government has committed strongly to reducing greenhouse gas emissions to zero by 2050 at the United Nations Climate Change Conference in Glasgow (COP26). Vietnam possesses significant potential to develop renewable energy from wood biomass and agricultural residues. This study comprehensively evaluates the status and potential of fuel pellet production and utilisation in Vietnam. Factors affecting fuel pellet production were evaluated. Vietnam's total wood pellet output is approximately 5 million tonnes per year. Raw materials are mainly derived from residues of plantation forests (90%) and the wood processing industry (10%). Vietnam's wood pellet production potential could increase two to three times due to the extensive plantation forest resource of nearly 5 million hectares. Currently, Vietnam does not utilise any wood pellets or wood chips as fuel to produce electricity domestically. The Vietnamese government is strongly committed to achieving net-zero emissions by 2050 and has implemented numerous policies and mechanisms to encourage the development of renewable energy. Owing to the vast potential of biomass from both forestry and agricultural residues, the export of wood fuel, such as wood pellets and wood chips, is expected to continue increasing in the future due to rising global demand.

Keywords: biomass utilisation, net-zero emission, renewable energy, wood pellet.

Classification numbers: 5.1, 5.3

1. Introduction

Vietnam is regarded as a region with high potential for renewable energy sources, including wind, solar, and biomass [1]. The electricity industry has developed with an average annual growth rate of 10-12% in both production and consumption [2]. Vietnam is an active participant in agreements aimed at reducing greenhouse gas emissions as well as commitments related to energy, land, etc., with the ultimate goal of mitigating global warming [3]. At the COP26 Conference, Vietnam and nearly 150 countries committed to achieving net-zero emissions by 2050. The strong commitment of the Vietnamese government at COP26 has necessitated a significant shift in socio-economic development thinking within the country. The need for a green transition is stronger than ever, opening numerous opportunities for cooperation on low-emission growth, promoting circular economic development, and adapting to climate change. Various international organisations, development partners, and large corporations, particularly financial institutions and major players in renewable energy have committed to and signed cooperation agreements with Vietnam. T.K. Tran, et al. (2023) [4] explored how natural resource rents and depletion, along with economic growth, foreign direct investment (FDI), industrialisation, and population growth, impact methane emissions and commitments to COP26 in the Vietnamese context. T.H. Le (2022) [5] analysed the economic and environmental impacts of non-renewable and renewable energy consumption and CO_2 emissions in Vietnam using innovative multivariate wavelet analysis tools.

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Technologies have been researched and developed to convert biomass energy into forms that are practical for Vietnam's conditions [6-12]. Besides energy conversion technology, several studies have addressed the current situation and solutions for developing renewable energy sources in Vietnam. A.H. Truong, et al. (2022) [13] assessed the technology of blending 5% rice straw in two existing coal power plants in Vietnam, concluding that co-firing is cheaper than coal but not significant enough to motivate stakeholders. K. Handayani, et al. (2022) [14] indicated that in power sector pathways under the net-zero emissions scenario, ASEAN member states need to swiftly capitalise on their currently underutilised renewable energy potential to achieve net-zero emissions by 2050. D.L. Bui, et al. (2023) [15] calculated that for the 664,500 tonnes of pellet yields, the total amounts of carbon dioxide (CO_2) emitted during production and transportation are 7,680.6 and 28,627.0 tonnes, respectively. T.N. Do, et al. (2023) [16] recommended strategies to phase out unabated coal power by the 2040s, including (1) reforming regulations to facilitate investments in clean energy, electricity transmission, and energy storage; (2) continuing political prioritisation; and (3) building broad-based support from the community and enterprises. By applying the principles of a circular economy for sustainable development, the wood industry can contribute to Vietnam's commitment to carbon neutrality by reducing the total net carbon emission from +552,750 tonnes CO_{2eq} to -1,145,940 tonnes CO_{2eq} per year [17]. Early preparation of transmission systems for solar and wind electricity is needed to maximise the potential for expanding the use of these technologies [18]. However, most studies have not provided reliable data on the status, potential, and factors affecting the development of biomass energy sources in Vietnam.

Vietnam currently has more than 3 million hectares of commercial forests, annually providing 40 million m³ of wood for the manufacturing industry. In addition to domestic wood sources, Vietnam also imports 322 types of wood to meet domestic needs and for export to 104 countries. Residues from industrial wood are utilised and become a rich source of raw materials for stable biomass energy development. Moreover, rice straw, rice husk, sugarcane bagasse, and coffee husks are also inputs for available biomass energy in Vietnam. The combination of wood biomass resources from forests and plantations will undoubtedly play a crucial role in the development of energy alternatives [19].

The total amount of municipal solid waste (MSW) was 27 million metric tonnes in 2015 and is projected to reach 54 million metric tonnes by 2030. However, waste management and treatment in Vietnam are labour-intensive and inefficient. Vietnam consumed 65.5 million tonnes of coal in 2020, while a large amount of MSW was not utilised for energy production. Therefore, searching for alternative fuels that could replace fossil fuels and reduce gas emissions is an urgent need [6].

Vietnam has great potential to develop renewable energy from biomass resources. However, agricultural residues and other biomass are often unused or only used on a small scale. It is estimated that more than 40 million tonnes of rice straw are generated annually. However, this volume of straw has not been used effectively; on the contrary, it is one of the sources of serious air pollution due to the habit of burning in the rice fields. T.H. Le (2022) [5] produced rice straw pellets mixed with additives at a scale of 500 kg/day, opening the possibility of using pellets from agricultural residues as fuel. Other common sources of agricultural residues in Vietnam include approximately 8.6 million tonnes/year of rice husks, 3.5 million tonnes/year of sugarcane bagasse, and about 5 million tonnes/year from other sources. The total potential electricity generation capacity from this by-product source is over 1500 MW.

This study collected data from government statistical sources, timber and forest associations, and other reliable sources. The data were compiled and analysed to provide information on the status of raw materials for wood pellet production and biomass utilisation in Vietnam. The prospects for wood pellet production and biomass use were analysed comprehensively in the context of Vietnam's strong commitment to net-zero emissions by 2050. Factors affecting wood pellet production, such as raw material sources, forest land planning, sustainable certified forest development, and international and

domestic markets, were evaluated. Vietnam's biomass energy development policies were also discussed to assess the prospects for developing the wood pellet production industry and future use. For the first time, the study analyses the overall picture of all factors affecting the development of biomass energy pellets in Vietnam, from raw material types and sources to fuel pellet market development orientation, to Vietnam's policies with the goal of reducing net emissions to zero by 2050.

2. Subjects and methodology

Raw materials for producing fuel pellets primarily come from wood, agricultural residues, and municipal solid waste. Fig. 1 presents the scope of the study's assessment, which includes raw material sources, fuel pellet production, and market. Factors affecting raw material sources encompass geographical location, forest development policies, sources of agricultural residues, plantation forests, and the wood processing industry. Vietnam has forest resources that are unevenly distributed among regions. Moreover, in wood pellet production, the logistics costs of raw materials account for a significant proportion. Vietnam's wood processing industry utilises wood from domestically grown forests but mainly relies on imported wood sources. Residues from the wood processing industry provide raw materials for wood pellet production.

Fuel pellet production is considered in terms of technological aspects, policies, manufacturing enterprises, capacity, and geographical location. The fuel pellets currently produced and traded are mainly pellets from wood raw materials. There are some projects producing fuel pellets from agricultural residues such as rice husks, straw, or municipal solid waste, but the quantities are small. Therefore, the pellet production section mainly considers wood pellet production.

Factors affecting the fuel pellet consumption market include the international and domestic markets. Future market development trends are also discussed. Additionally, common factors affecting fuel pellets include policies on Vietnam's energy and electricity mix in the future with a vision to 2030 and 2050, and policies on developing Vietnam's wood processing industry. Vietnam's commitments at COP26 and the development of Vietnam's carbon credit market also influence the production and consumption of fuel pellets in the domestic market.
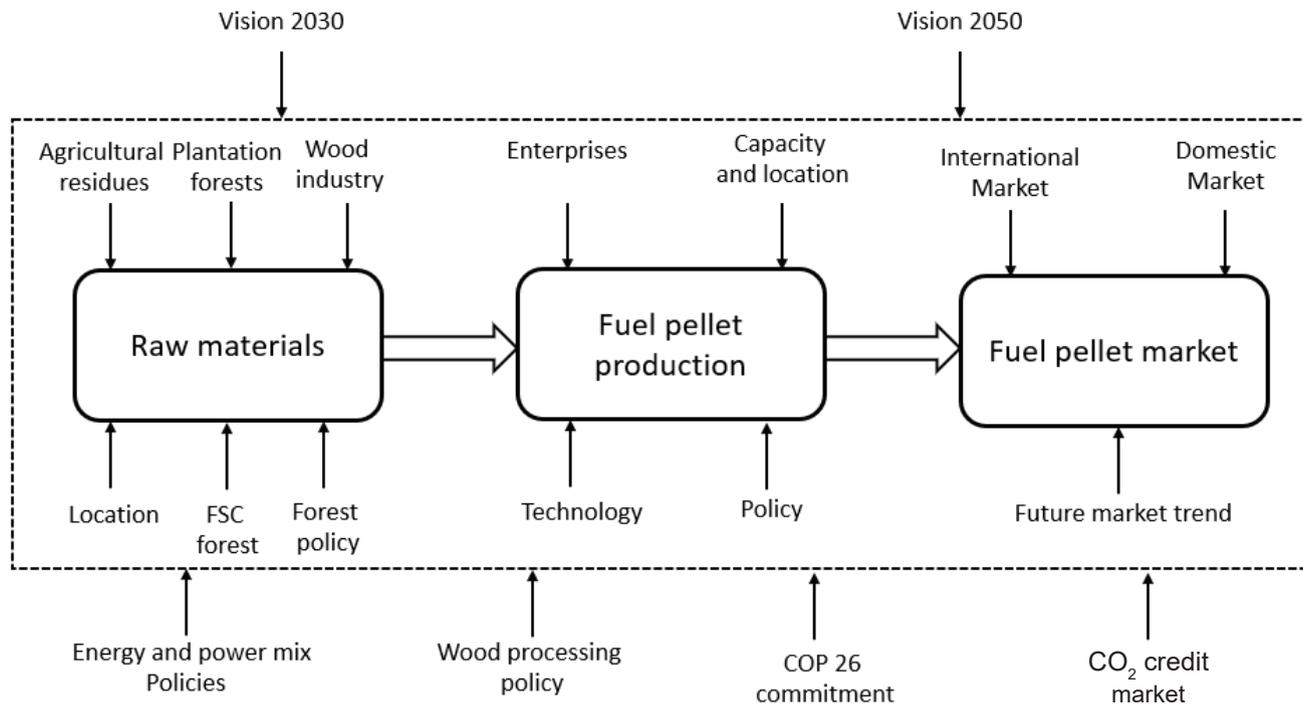
Fig. 1. Boundary of investigation of the status and the prospect of fuel pellet production and utilisation in Vietnam.

3. Results and discussion

3.1. Status of fuel pellet production in Vietnam

The status of fuel pellet production in Vietnam encompasses factors such as raw material sources, production volume and value, manufacturers, and markets.

3.1.1. Raw material

In Vietnam, wood pellets are typically made from waste wood such as sawdust, shavings, and tree branches. These materials are compressed under high pressure into pellet form. Some informants noted that small-scale producers often use any timber available locally, with a network of traders purchasing materials from villagers. However, some large-scale producers have their own plantations, typically of acacia or eucalyptus wood, some of which have Forest Stewardship Council (FSC) certification. Raw materials for wood pellets from domestically grown forest materials account for about 90% of the total supply of raw materials for wood pellet production. Raw materials from sawmills and wood processing factories account for less than 10% of the total source for the entire wood pellet industry (Fig. 2).

Official statistics from the Ministry of Agriculture and Rural Development indicated that Vietnam currently has nearly 14.7 million hectares of forest. According to function, this area is divided into protection forests (4.7 million hectares, 31.8% of the total area), special-use forests (2.2 million hectares, 14.8%), and production forests (7.8 million hectares, 53.4%). Production forests, which are the source of raw wood for the processing industry, are mainly located in the Northeast (2.42 million hectares), the North Central region (1.66 million hectares), and the Central Highlands (1.53 million hectares). According to origin, forests are classified into natural forests (10.3 million hectares) and plantation forests (4.4 million hectares). Fig. 3 shows the area of natural and plantation forests in different regions of Vietnam. Of the 4.4 million hectares of plantation forests, they are mainly located in the Northeast with 1.58 million hectares, the North Central region with 0.92 million hectares, and the Central Coast with 0.87 million hectares [21].
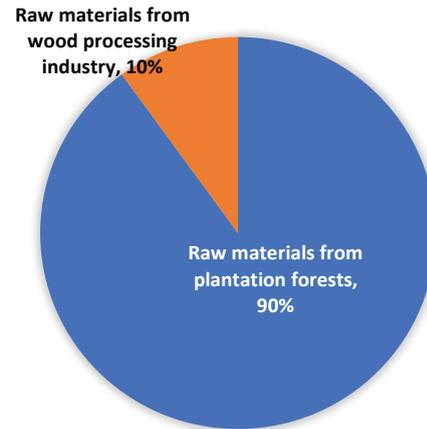

Fig. 2. Biomass feedstock for wood pellets production [20].
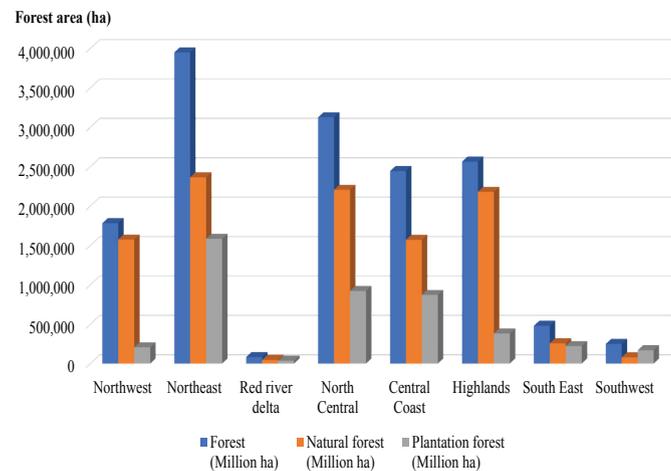

Fig. 3. Distribution of natural forests and plantation forests by region in Vietnam [21].

Table 1. Statistics of certified forest areas in Vietnam [21].

| Location | Number of certificates | Certified forest area by 2021 | | | Tree type |
		Total	*Natural forest*	*Plantation forest*	
Northwest	1	6,314	0	6,314	acacia
Northeast	23	85,549	5,178	80,371	acacia
North Central	21	79,046	30,889	48,157	acacia, natural forest, bamboo
South Central region	9	33,503	499	33,004	acacia
Highlands	7	24,718	486	24,232	acacia, rubber
Southeast	12	77,227	3,043	74,184	acacia, rubber
Southwest	1	752	0	752	acacia
Vietnam	74	307,109	40,095	267,014	

The government has been encouraging the development of plantation forests with sustainable forest management certificates (FSC, PEFC) because the demand for certified wood used as input materials for export products is high and increasing. Statistics from the General Department of Forestry indicated that by the end of August 2021, the total area of certified forests in Vietnam reached over 307,000 hectares, including 40,000 hectares of natural forests; the rest is plantation forests as shown in Table 1. The area of certified forests accounts for only 8.4% of the total plantation forest area of the country.

3.1.2. Wood pellet production volume and value

Most wood pellets produced in Vietnam are exported. There is no statistical data on the amount of wood pellets consumed domestically. Based on a survey of wood pellet factories, most of the pellets produced are sold to trading companies for export. Hence, the amount of wood pellets consumed domestically is very small. Additionally, thermal power plants in Vietnam all use coal, natural gas, or biomass such as sugarcane bagasse and rice husk. There are no power plants that use wood pellets or co-firewood pellets with coal to produce electricity. Therefore, in this study, data on exported wood pellets were used to represent data on domestically produced wood pellets.

Figure 4 shows the volume and value of wood pellets produced from 2013 to the end of 6 months, 2023. In 2013, the production of wood pellets was only 175 thousand tonnes, and the amount increased rapidly due to demand from Japan and Korea, especially after 2018, peaking in 2022 at nearly 5 million tonnes. In the first six months of 2023, the production of wood pellets was nearly 2.1 million tonnes. Although it is lower than in 2022, it is still at a high level. In 2022, the export value of wood pellets was nearly 800 million USD, nearly double that of 2021, although the output of wood pellets increased by 40%.
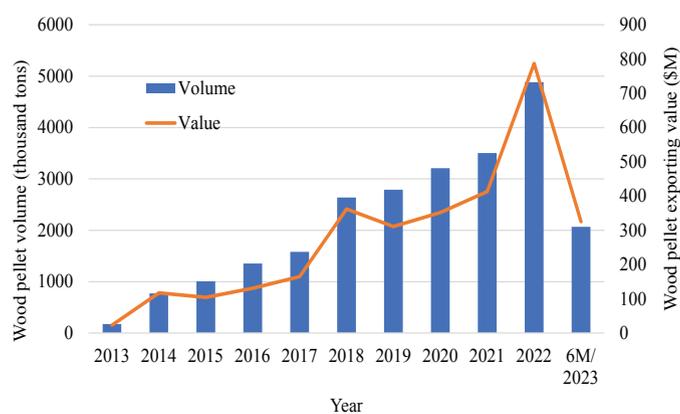

Fig. 4. Volume of pellets exported from Vietnam from 2019 to the end of 6 months in 2023 [22].

3.1.3. Wood pellet manufacturers

Currently, Vietnam has more than 100 enterprises directly involved in exporting wood pellets and over 300 large and small wood pellet manufacturers. However, wood pellet export is almost concentrated in a few large enterprises. Among the enterprises directly involved in exporting wood pellets today, there are only eight companies with an export volume of over 100,000 tonnes annually. The export volume of these eight enterprises accounts for nearly 67% of the total export volume of wood pellets in Vietnam. Among them, there are three enterprises with an export volume of over 400,000 tonnes, and particularly one enterprise with a very large export volume of wood pellets, nearly 714,000 tonnes, accounting for about 20% of the total export volume of wood pellets of Vietnam.

3.1.4. Wood pellet exporting markets

Korea and Japan are the two largest wood pellet import markets of Vietnam. The volume of wood pellets exported from Vietnam to these two countries accounts for over 95% of the total volume of wood pellets exported from Vietnam to all markets. The source of raw materials to produce pellets exported to Korea and Japan differs. Wood pellets exported to Korea are mainly made from the by-products of the wood processing industry such as sawdust, shavings, and wood chips. Enterprises exporting pellets to Korea are mainly located in the Southeast region, where furniture factories are concentrated. Pellets exported to Japan must be made from domestic
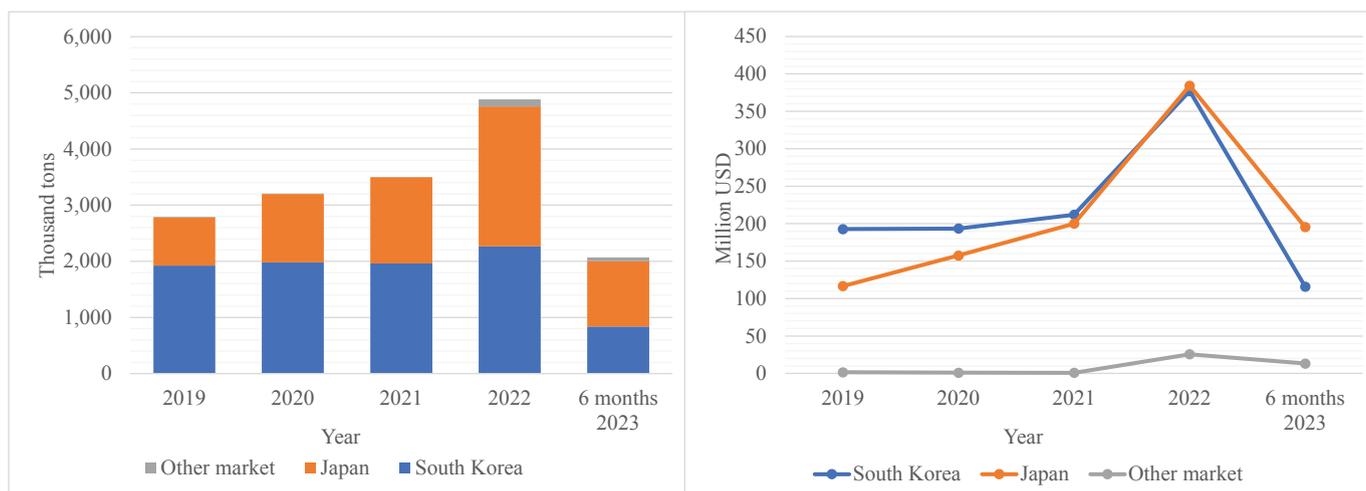
Fig. 5. Pellet export volume and volume by markets from 2019 to 6 months in 2023.

plantation timber with an FSC certificate. This material is only available where there are large regions of plantation forests, particularly from the Central region to the North of Vietnam.

Figure 5 shows the volume and value of pellets exported from Vietnam from 2019 to the end of 6 months in 2023, respectively. In 2022, exports increased sharply when the export volume reached nearly 4.9 million tonnes and the export value reached 0.79 billion USD.

3.2. Prospects of fuel pellet production

Prospects for developing fuel pellet production are considered, focusing on three aspects: raw material sources, markets, and related policies.

3.2.1. Raw materials sources

Potential of wood, agricultural, and municipal solid waste biomass: According to the Institute of Energy, Ministry of Industry and Trade, the total potential of wood biomass for energy is nearly 25 million tonnes/year, equivalent to 8.8 million tonnes of crude oil. The agricultural biomass energy potential, including straw, rice husk, sugarcane bagasse, and other agricultural products, is up to nearly 53.5 million tonnes/year, equivalent to 12.8 million tonnes of crude oil. The biomass energy in Vietnam includes wood biomass (25 million tonnes) from forest residues and the wood processing industry, MSW (27 million tonnes), and agricultural residues (53.5 million tonnes). Agricultural residues consist of

40 million tonnes of rice straw, 8.6 million tonnes of rice husks, 3.5 million tonnes of sugarcane bagasse, and others of 1.4 million tonnes.

Plantation forest: Vietnam has a total plantation forest area of 4.4 million hectares. Of which, households, forestry companies, and commune People's Committees manage 1.45 million hectares, 0.62 million hectares, and 1 million hectares, respectively. The remaining areas are plantation forests for protection and special use. Generally, forest lands of households and commune People's Committees are used inefficiently due to several difficulties such as lack of access to investment capital, science and technology, and management qualifications. Connecting with businesses can help minimise any restrictions, with the potential for large timber plantations in the future. Part protection and special-use forests are bare land and degraded forests. The government needs to put bare land areas and irreversibly degraded forests into developing plantation forests.

Vietnam's forestry development strategy for the period 2021-2030: Vietnam sets strategic goals for forest development and wood processing in the 2021-2030 period as follows: The growth rate of forestry production value is from 5.0 to 5.5%/year in the period 2021-2025 and remains stable until 2030. Export value of wooden furniture and non-wood forest products: reaching 18-20 billion USD by 2025; reaching 23-25 billion USD by 2030. Domestic wood exploitation output reaches

45 million m³/year by 2025, over 62 m³/year by 2030, basically meeting the demand for raw materials for wood and forest product processing. Improve the quality and efficiency of plantation forests and agroforestry systems; issue certificates of sustainable forest management for 0.5 million hectares in the period 2021-2025, reaching 1 million hectares in the period 2026-2030. Thus, compared to the status of Vietnam's forest product exploitation in 2020, by 2025 the output will double, and by 2030 the output will triple. Thus, the potential to provide raw materials for wood pellet production in Vietnam can increase 2-3 times in the period 2025-2030, equivalent to an increase in wood pellet output of 8-12 million tonnes.

Other popular biomass sources: The cinnamon area in Vietnam covers about 150,000 hectares, accounting for 17% of the global cinnamon area, located mainly in the provinces of Lao Cai and Yen Bai. Currently, Vietnam is the world's third-largest producer and exporter of cinnamon in terms of output, after Indonesia and China. The cinnamon branches and wood are estimated at 700,000 tonnes/year, of which cinnamon branches after separating essential oil are estimated at 400,000 tonnes/year and cinnamon wood at 300,000 tonnes/year. Currently, there are no large-scale factories processing this residue. This is a great potential source of biomass for wood pellet production.

Statistics from the Vietnam Rubber Association showed that Vietnam's rubber area in 2021 reached nearly 939,000 hectares, of which the area of smallholders' accounts for about half. In particular, the rubber industry is expected to contribute to Vietnam's wood industry by about 7-8 million m³ annually from the replantation of rubber tree area of over 25,000-30,000 hectares to provide large timber for about 20% of raw material needs.

The bamboo plantation area is 1,480,000 hectares, accounting for 10.5% of the total forest area of the country, of which pure forests have 240,925 hectares, mixed forests (wood and bamboo) of 1,152,864 hectares. Exploitation output is 40 million trees/year, equivalent to 0.92 million tonnes/year: In 2030, 57,000 hectares, exploitation output of 76 million trees/year equivalent to 1.75 million tonnes of bamboo/year. Bamboo wood

pellets have the highest quality among wood pellets due to their very low ash content. It is estimated that the number of by-products from the bamboo products processing industry will be about 200,000 tonnes in 2020 and increase to 350,000 tonnes in 2030.

3.2.2. Overseas and domestic markets

Exports are currently on the rise. The world's demand for pellets is projected to increase by about 250% over the next decade, reaching 36 million tonnes from 14 million tonnes in 2017. In recent years, demand has increased mainly in European countries, Japan, and Korea. However, Vietnam's pellet industry could expand the market when consumption demand in Vietnam begins to show signs of rapid growth as the government is making efforts to fulfill its commitments to reduce greenhouse gas emissions and use clean energy, including pellets to replace coal in energy production. The Power Masterplan VIII, which was approved by the government on 15 May 2023, prioritises the development of renewable energy sources, including biomass power to replace high-emission coal power. Therefore, the demand for wood pellets in the domestic market may expand very quickly in the future.

3.3. Status and prospects of biomass utilisation in Vietnam

3.3.1. Energy and power mix in Vietnam

Figure 6 describes Vietnam's energy mix in 2020 and 2021. Vietnam's main energy sources include coal, natural gas, hydroelectric, and renewable energy. The proportion of renewable energy increased significantly from 5 to 11%, mainly from wind and solar energy. Coal still accounts for the largest proportion of Vietnam's energy mix, about nearly 50%. Hydroelectric accounts for 31% of Vietnam's energy structure, the rest is natural gas. In the period from 2011 to 2021, the energy consumption rate increased by an average of 7.2% per year, among the highest in the world.

The lower heating value of some fuels such as coal is 17-25 MJ/kg, natural gas 42-55 MJ/kg, biomass 12-16 MJ/kg, and MSW 7-9 MJ/kg. The amount of coal and
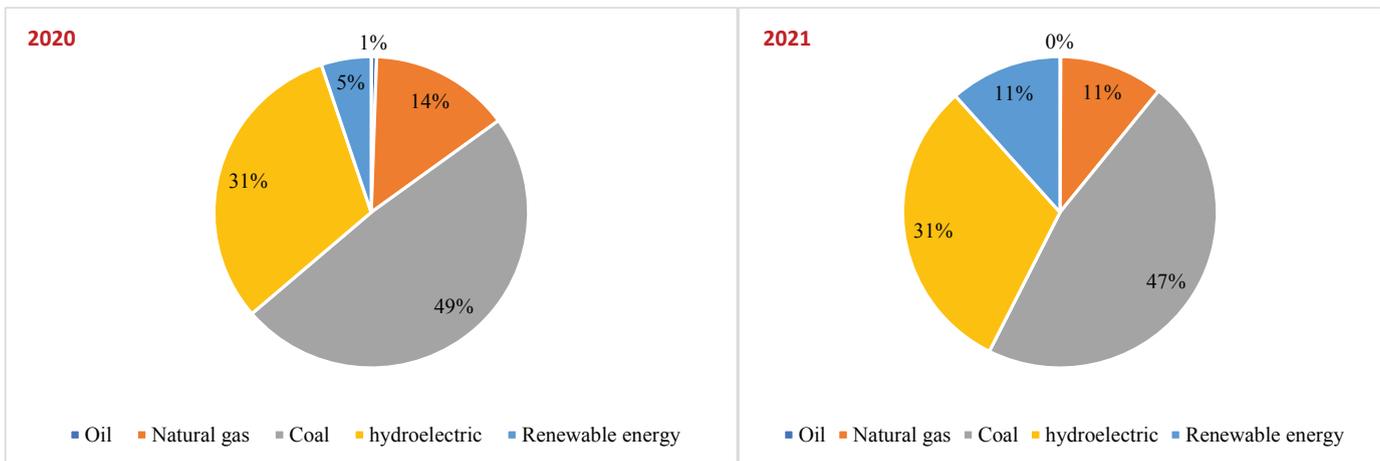
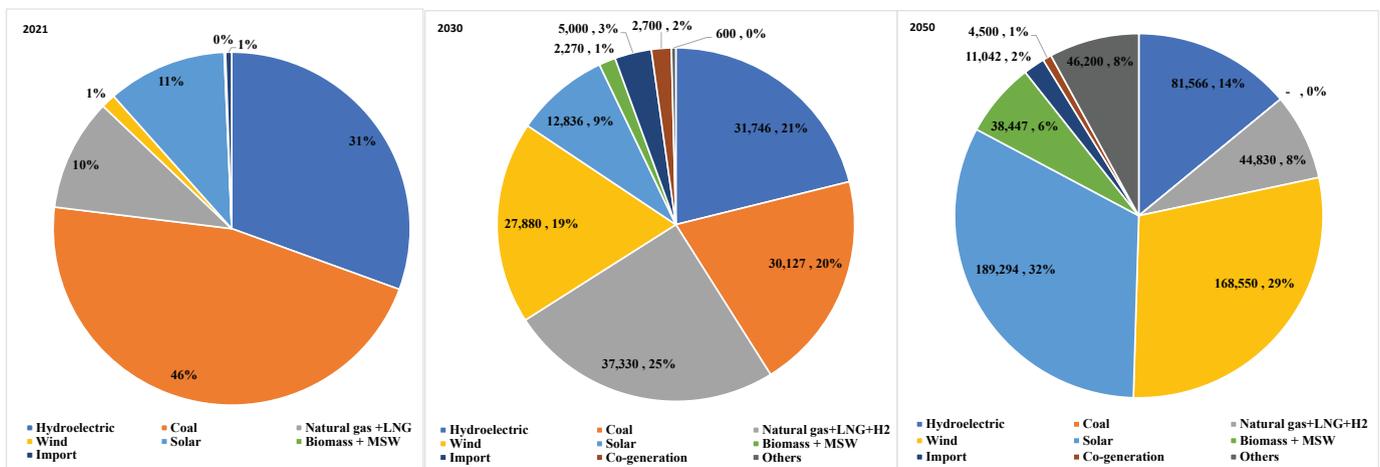**Fig. 6. Vietnam's energy mix in 2020 and 2021** [23].

Fig. 7. Vietnam's power mix in 2021 and vision to 2030 and 2050 [24].

natural gas that could be replaced by biomass can be roughly estimated based on calorific value. At the current energy mix in Vietnam, agricultural residues, woody biomass, and MSW can replace more than 25 million tonnes of coal (12 million tonnes of natural gas); 12.5 million tonnes of coal (6 million tonnes of natural gas), 9 million tonnes of coal (4 million tonnes of natural gas), respectively.

In the period 2021-2050, the growth rate of energy demand is about 6.5-7.5% per year. The total final energy demand is 107 million tonnes of oil equivalent in 2030 and will reach 165-184 million tonnes of oil equivalent by 2050. The total primary energy supply will be 155 million tonnes of oil equivalent in 2030 and 294-311 million tonnes of oil equivalent by 2050.

By the end of December 2021, the electricity output from renewable energy was expected to reach 110 billion kWh, accounting for nearly 43% of the electricity generation output of Vietnam's power system, of which 31% is hydropower and 12% is wind, solar, and biomass power (Fig. 7) [24].

The ratio of coal power will decrease from 46% in 2021 to 20% in 2030 and to zero by 2050. The proportion of other renewable energy will increase from 8.5 to 32.4% (wind power) and from 8.5 to 32.4% (solar power). Hydroelectric will increase output from 31,746 to 81,566 MW, but the proportion in the electricity mix will decrease from 21.1 to 14%. By 2050, the total biomass potential is over 120 million tonnes, and MSW is about 60 million tonnes, equivalent to 40 million tonnes and 10 million tonnes of oil equivalent, respectively. Wood biomass and

agricultural residues can replace 60 million tonnes of coal, and MSW can replace 20 million tonnes of coal. In the power production mix, the total power generation capacity from biomass and waste will be about 38,500 MW. By 2050, Vietnam will no longer produce electricity from coal, but will still produce electricity from natural gas. However, to evaluate the CO_2 emissions of biomass pellet products, lifecycle analyses are necessary under Vietnamese conditions. The carbon footprint of wood pellets ranges from 30 to 106 kg CO_2/MWh depending on the type of wood used to produce the pellets, its source, and the drying method. The carbon footprint of coal is about 850 kg CO_2/MWh. The CO_2 emission reduction from using wood pellets can be from 88-96% compared to coal.

3.3.2. Biomass power plants

Vietnam has issued a number of decisions related to biomass power development such as Decision No. 24/2014/QD-TTg supporting the development of biomass power projects in Vietnam, Decision No. 51/VBHN-BCT on the mechanism to support the development of biomass power projects, and Decision No. 500/QD-TTg of the Prime Minister approving the National Electricity Development Plan for the period 2021-2030, with a vision to 2050 (Power Plan VIII). According to Decision No. 500/QD-TTg, Vietnam will develop between 1,230 and 2,270 MW of biomass power sources and electricity from waste by 2030. It is expected that the proportion of electricity produced from these power sources will reach about 1.5%. It will develop about 38,447 MW, accounting for about 6.6% of total electricity production by 2050 as shown in Fig. 7.

Figure 8 lists Vietnam's biomass and municipal solid waste power plants and their respective capacities. Some factories are in operation, while others are under construction. Biomass and municipal solid waste power plants have small capacities ranging from just a few MW to the largest of nearly 100 MW. The main reason for small capacity is that factories are built only to take advantage of available raw materials around them without mobilising large biomass sources such as wood pellets and wood chips.
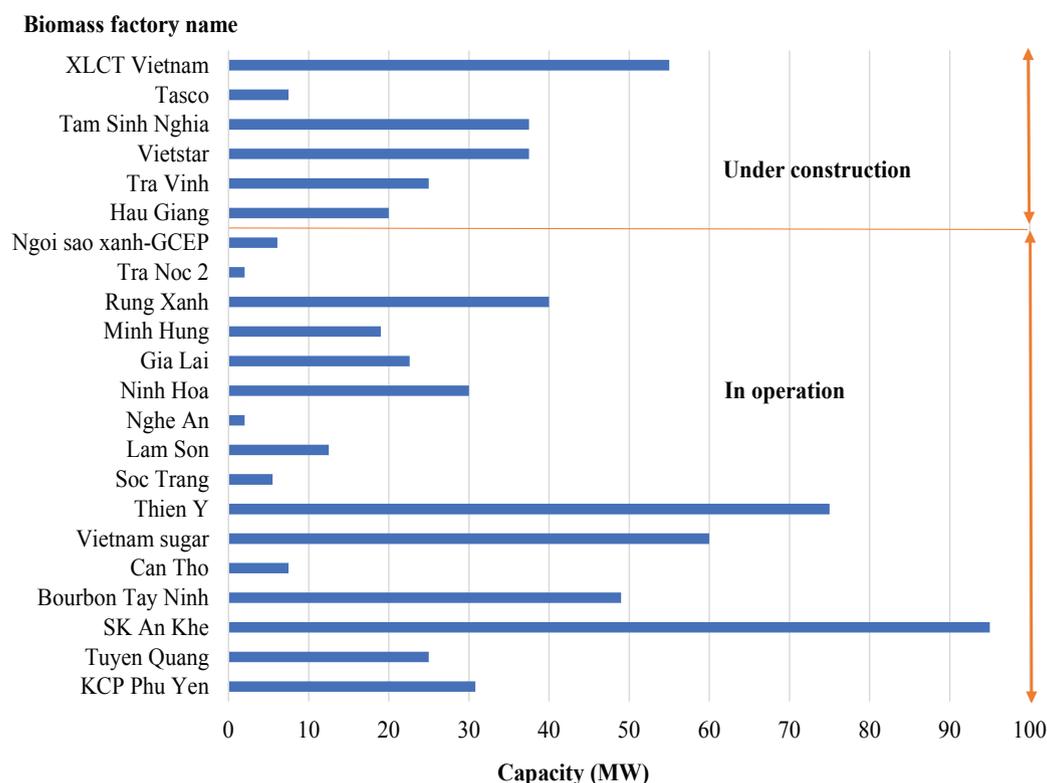

Fig. 8. List of biomass factories in operation and construction in Vietnam.

3.3.3. Action towards a net zero emissions commitment by 2050 of Vietnam

Vietnam has taken concrete policy actions to gradually realise a net zero emissions commitment by 2050, including: (1) National Steering Committee to implement Vietnam's commitments at COP26; (2) Project on tasks and solutions to implement the results of the COP26 Conference (Decision No. 888/QD-TTg dated 25 July 2022); (3) National Strategy on Climate Change for the period up to 2050 (Decision No. 896/QD-TTg dated 26 July 2022); (4) Action plan to reduce methane emissions until 2030 (Decision No. 942/QD-TTg dated 5 August 2022).

For the implementation of emission reduction activities nationwide to meet commitments at the COP26 Conference, on 7 January 2022, the government issued Decree No. 06/2022/ND-CP regulating the mitigation of greenhouse gas emissions and protection of the ozone layer. Accordingly, the greenhouse gas emission mitigation target approved by the Prime Minister in the Nationally Determined Contribution (NDC) includes the greenhouse gas emission mitigation target for the energy sectors, agriculture, land use and forestry, waste management, and industrial processes in accordance with the country's socio-economic development conditions and international commitments to which Vietnam is a member.

Vietnam's updated NDC has set targets for reducing greenhouse gas emissions by 2030 for sectors contributing to achieving net zero emissions by 2050. On 18 January 2022, the Prime Minister issued a list of fields and establishments emitting greenhouse gases that must conduct greenhouse gas inventories (Decision No. 01/2022/QD-TTg) with nearly 2,000 facilities with annual greenhouse gas emissions of 3,000 tonnes of CO_2 equivalent or more. Sectors and establishments that emit greenhouse gases are responsible for reporting emission levels, formulating, and implementing emission reduction plans to achieve the national goal of reducing greenhouse gas emissions.

Based on the decisions issued by the Prime Minister, ministries and sectors have developed and issued sectoral action plans to implement commitments at COP26 with very specific targets for each field. The Ministry of Industry and Trade has researched and developed a programme to reduce the use of fossil energy in the energy industry, integrating it into the process of developing Power Plan VIII and the National Energy Development Strategy. The Ministry of Agriculture and Rural Development has developed a plan to implement the Glasgow Declaration on forests and land use and submit it to the Prime Minister for approval; reviewing forest carbon credit exchange projects and implementing initiatives in the agricultural sector that participated in the COP26 Conference. The Ministry of Transport has developed and submitted for promulgation an Action Programme on green energy conversion and reduction of carbon and methane emissions in the transport sector; develop mechanisms, policies, and roadmaps for developing electric vehicles (E-mobility) for the national and city levels. The Ministry of Natural Resources and Environment has developed and published a report on offshore wind and wave energy potential in Vietnamese waters to serve the development of renewable energy, especially offshore wind power projects.

In the updated NDC for 2022, Vietnam increased its unconditional emission reduction contribution to 2030 from 9% (NDC 2020) to 15.8%; and conditional contribution from 27 to 43.5% (compared to the business-as-usual scenario (BAU)). NDC has specific emission reduction targets for each sector, specifically 37 remedies in the energy sector, 14 remedies in the agriculture sector, 7 remedies in the forestry and land use sector, 5 remedies in the industrial processes sector, and 11 remedies in the waste management sector.

4. Conclusions

Currently, Vietnam's total wood pellet output is about 5 million tonnes/year. Raw materials are mainly from forest residues and residues of the wood processing industry. Vietnam's wood pellet production potential can increase 2 to 3 times due to the huge plantation forest resource of nearly 5 million hectares. Vietnam's plantation forest area

can be increased by taking advantage of land areas that are being used ineffectively or fallow. The area of forests with FSC certification is still small at about 200,000 hectares, however, the area of forests with FSC certification will increase in the future, thus providing a source of quality raw materials for wood pellet production. Wood pellet production also faces strong competition with wood chip production due to higher production costs but lower value. Vietnam currently does not use many wood pellets or wood chips as fuel to produce electricity domestically. Currently, the demand for domestic wood pellets for co-firing to generate electricity is not high, but in the future, it will compete with wood pellet exports due to the strong commitment of the Vietnamese government to net zero emissions by 2050.

Vietnam is a country with huge biomass potential from forestry and agricultural residues. By 2050, biomass energy and MSW could account for up to 16% of Vietnam's total energy mix. However, the application of bioenergy has many limitations in terms of technology, conversion efficiency, and economic competitiveness compared to fossil energy sources. Therefore, many policy mechanisms are needed to encourage the development of energy sources from biomass and household waste. Furthermore, the biomass pellet production process also emits greenhouse gases. Therefore, life cycle analysis is needed to predict the percentage of biomass energy that can replace fossil fuels.

Currently, Vietnam's biomass electricity mainly utilises sugarcane bagasse, rice husks, and municipal solid waste. There are no biomass power plants from wood pellets or wood chips in Vietnam. The proportion of biomass electricity in Vietnam in the future will increase but not significantly compared to other renewable energy sources. The Vietnamese government is strongly committed to reducing net-zero emissions by 2050 and has many policies and mechanisms to encourage the development of renewable energy. However, due to the huge potential of biomass from both forestry and agricultural residues, the export of wood fuel such as wood pellets and wood chips will continue to increase in the future as world demand is still growing.

COMPETING INTERESTS

The author declares that there is no conflict of interest regarding the publication of this article.

REFERENCES

[1] A.T. Hoang, A. Pandey, E. Lichtfouse, et al. (2023), "Green hydrogen economy: Prospects and policies in Vietnam", *Int. J. Hydrogen Energy*, **48(80)**, pp.31049-31062, DOI: 10.1016/j.ijhydene.2023.05.306.

[2] T.H. Le, P. Han, H.C. Le, et al. (2023), "Electricity market development in Vietnam: Historical trends and future outlooks", *Utilities Policy*, **81**, DOI: 10.1016/j.jup.2023.101510.

[3] H.T. Nguyen, S.V. Nguyen, V.H. Dau, et al. (2022), "The nexus between greenhouse gases, economic growth, energy and trade openness in Vietnam", *Environmental Technology & Innovation*, **28**, DOI: 10.1016/j.eti.2022.102912.

[4] T.K. Tran, C.Y. Lin, Y.T. Tu, et al. (2023), "Nexus between natural resource depletion and rent and COP26 commitments: Empirical evidence from Vietnam", *Resources Policy*, **85**, DOI: 10.1016/j.resourpol.2023.104024.

[5] T.H. Le (2022), "Connectedness between nonrenewable and renewable energy consumption, economic growth and CO_2 emission in Vietnam: New evidence from a wavelet analysis", *Renew. Energ.*, **195**, pp.442-454, DOI: 10.1016/j.renene.2022.05.083.

[6] T.X. Do, T.T.N. Phan, T.V.D. Son (2021), "Process modeling and economic assessment of converting municipal solid waste into solid fuel via hydrothermal processing: A case study in Vietnam", *J. Mater. Cycles Waste Manage*, **23**, pp.2318-2335, DOI: 10.1007/s10163-021-01286-5.

[7] T.X. Do, Y.I. Lim, H. Do, et al. (2018), "Techno-economic analysis of fry-drying and torrefaction plant for bio-solid fuel production", *Renew. Energ.*, **119**, pp.45-53, DOI: 10.1016/j.renene.2017.11.085.

[8] T.X. Do, Y.I. Lim, H. Cho, et al. (2017), "Process modeling and energy consumption of fry-drying and torrefaction of organic solid waste", *Drying Technol.*, **35**, pp.754-765, DOI: 10.1080/07373937.2016.1211674.

[9] T.X. Do, Y.I. Lim (2016), "Techno-economic comparison of three energy conversion pathways from empty fruit bunches", _Renew. Energ._, **90**, pp.307-318, DOI: 10.1016/j.renene.2016.01.030.

[10] T.X. Do, Y.I. Lim, S. Jang, et al. (2015), "Hierarchical economic potential approach for techno-economic evaluation of bioethanol production from palm empty fruit bunches", _Bioresour. Technol._, **189**, pp.224-235, DOI: 10.1016/j.biortech.2015.04.020.

[11] T.X. Do, Y.I. Lim, H. Yeo, et al. (2014a), "Techno-economic analysis of power plant via circulating fluidized-bed gasification from woodchips", _Energy_, **70**, pp.547-560, DOI: 10.1016/j.energy.2014.04.048.

[12] T.X. Do, Y.I. Lim, H. Yeo (2014b), "Techno-economic analysis of biooil production process from palm empty fruit bunches", _Energ. Convers. Manage._, **80**, pp.525-534, DOI: 10.1016/j.enconman.2014.01.024.

[13] A.H. Truong, M.H. Duong, H.A. Tran (2022), "Economics of co-firing rice straw in coal power plants in Vietnam", _Renew. Sust. Energ. Rev._, **154**, DOI: 10.1016/j.rser.2021.111742.

[14] K. Handayani, P. Anugrah, F. Goembira, et al. (2022), "Moving beyond the NDCs: ASEAN pathways to a net-zero emissions power sector in 2050", _Appl. Energy_, **311**, DOI: 10.1016/j.apenergy.2022.118580.

[15] D.L. Bui, L.T. Le, T.M.N. Vu, et al. (2023), "Economic and environmental analysis of biomass pellet supply chain using simulation-based approach", _Asia Pacific Management Review_, **28(4)**, pp.470-486, DOI: 10.1016/j.apmrv.2023.02.002.

[16] T.N. Do, P.J. Burke (2023), "Phasing out coal power in a developing country context: Insights from Vietnam", _Energy Policy_, **176**, DOI: 10.1016/j.enpol.2023.113512.

[17] T.T.H. Do, T.B.T. Ly, N.T. Hoang, et al. (2023), "A new integrated circular economy index and a combined method for optimization of wood production chain considering carbon neutrality", _Chemosphere_, **311**, DOI: 10.1016/j.chemosphere.2022.137029.

[18] T.N. Do, P.J. Burke, H.N. Nguyen, et al. (2021), "Vietnam's solar and wind power success: Policy implications for the other ASEAN countries", _Energy for Sustainable Development_, **65**, pp.1-11, DOI: 10.1016/j.esd.2021.09.002.

[19] B.M. Yudego, J. Arevalo, O.D. Yáñez, et al. (2017), "Wood biomass potentials for energy in northern Europe: Forest or plantations?", _Biomass and Bioenerg._, **106**, pp.95-103, DOI: 10.1016/j.biombioe.2017.08.021.

[20] T.C. Cao, X.P. To, K.A. Luong (2022), "Vietnam's pellet production and export: Current status and some policy aspects", https://goviet.org.vn/upload/aceweb/content/Vien%20nen%20Xuat%20khau%20cua%20Viet%20Nam_Thuc%20trang%20va%20mot%20so%20khia%20canh%20chinh%20sach.pdf, accessed 20 August 2023 (in Vietnamese).

[21] Vietnam Ministry of Agriculture and Rural Development (2020), _Vietnam Forestry Development Strategy Period 2021-2030, Vision Toward 2050_ (in Vietnamese).

[22] T.C. Cao, X.P. To, L.H. Tran (2023), _Wood Pellet Production and Export of Vietnam: Current Dynamics and Market Trend_s, https://goviet.org.vn/upload/aceweb/content/Wood%20pellet%20production%20and%20export%20of%20Vietnam%20T7-2023_EN.pdf, accessed 20 August 2023.

[23] Vietnam Energy Association (2023), "Vietnam renewable energy in 2022: Events, achievements and identifying challenges", https://nangluongvietnam.vn/nang-luong-tai-tao-viet-nam-nam-2022-cac-su-kien-thanh-tuu-va-nhan-dien-thach-thuc-30046.html, accessed 20 August 2023 (in Vietnamese).

[24] Vietnam Government (2023), _Vietnam's Electricity Planning VIII_, https://xaydungchinhsach.chinhphu.vn/toan-van-quy-hoach-phat-trien-dien-luc-quoc-gia-119230516163315244.htm, accessed 20 August 2023 (in Vietnamese).