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Rich Dad and Poor Dad: Biomass Circularity Science Empathizing Rubber Smallholders

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ABSTRACT

Analysis of rubber and rubberwood biomass management revealed an actualized twin-loop circularity arising from the multibillion-dollar export revenue downstream and upstream segments. Despite resembling a zero-waste and resource-efficient system, the revenue from natural rubber exports does not translate as the wealth of rubber smallholders, pressing them as the persistent 'poor dad' in the rubber value chain. This study dwells on how to empower smallholders through high-quality rubber production efficiency to compensate for the nose-diving rubber price. Analysis of the challenges facing the seemingly forced labor recognized operational costs as the main hindrance to productivity. Mapping the challenges through the biomass circularity lenses identified the strengths of the sector as clear opportunities to exploit the rubber and rubberwood commodities. Access to productive clones, a shift to machine-tapper and farm-integrated rubber and rubberwood processors are the immediately actionable solutions. Availing expandable rubber-related education programs for youths in smallholder families is critical to actualizing technology-driven, and high-productivity farming for the segment to build back better. Continuous learning is mandatory to innovate, engage in the value chain, and multiply the current twin-loop circularity for the succession of dignified smallholders in sustaining the rubber industry.

1. Introduction
1.1 Rubber: Global Players & Impacts

Global rubber consumption has witnessed a drop to 1.9% growth in 2022 [1] despite a steady 4.8% growth projection [2]. Despite the competition with fossil-based synthetic rubber, natural rubber has persisted in its critical role on the planet due to its high relevance to numerous sectors not limited to automotive, healthcare, military, construction, sports, and recreation. The magic carpet feels on cruising bumpy roads is the effect of the shock-absorbing capacity [3, 4] of rubber suspension. As an interfacial element, rubber's modifiable bonding property could promote vibration

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damping [5]. In tandem with vibration-damping effects, Gaunke and co-researchers proved the helpfulness of rubber flooring in promoting an uninterrupted recovery of bulls with leg and claw injuries [6]. Indeed, latex's superb sealing properties allow the safety and longevity of metal-glass interfacing joints. Its soundwave deflecting ability enables noise-proofing [7, 8] in the construction critical elements, which all combined, scores for latex's comforting and perfecting properties.

Southeast Asia is among the global players in the rubber industry despite *Hevea's* Amazonian origin. The growing demand had called for its synthetic counterpart to join hands in the rubber supply chain, particularly in the automotive industry and in applications requiring thermo-durability. Thailand, Indonesia, Vietnam, India, and Malaysia are the world's top rubber producers, supplying 14 million metric tonnes of natural rubber [1] to top-listed consumers amongst China, the US, India, Japan, South Korea, Brazil, Turkey, Europe, and Russia.

The prosperity of the global rubber smallholders is made sluggish by a string of bleak issues despite being the principal movers of the billion-dollar upstream (rubber growing) segment. The dwindling price has been ill-affecting approximately 6 million [9] rubber smallholders worldwide, prompting big names like Michelin and Continental to respond proactively. While the zero-waste downstream segment was designed, evaluated, and promoted by Michelin [10], responsible outsourcing of natural rubber is a paradigm shift introduced by Continental via digital trading aimed at achieving a traceable and transparent supply chain by 2030 [9].

1.2 Resource-efficient Serendipity for Prosperity

Delayed end-of-life, low-waste, and low-emission targets [11-15] is the pillar of resource-efficient or synonymously, circular management, exploitable to revive the rubber industry. Having a shared chronological root to the 20th century [11-15], circularity evolved into a circular economy, or "nature-powered" economy [17] to reduce waste and emissions through efficient natural resource use. As critically required as industrialization, emission reduction is achievable by tracking emissions and taking countermeasures as the world pursues industrialization. The growth of the global population and intensification of the demand for goods [18] and services increases the heat-trapping greenhouse gases (GHG) emissions [19], predominantly carbon dioxide (CO_2) ([20]. The hiking stratospheric CO_2 acidifies the planet, savaging marine biostructures and other inhabitants [21-24]. In addition to the already hiking CO_2, methane (CH_4), the GHG counterpart dissipating alongside biodegradation emerge as the multiple-times more corrosive than CO_2 [25, 26]. Perturbation in the natural ecosystem, uncontrolled evaporation [27,28] and ice-melting following global warming are factors to the recurring climate uncertainties manifested as drought, flood, and other environmental disasters, marking GHG an unceasing issue with a great deal of impact on agricultural [29] productivity - rubber without exception [30-32]. The circular bioeconomy (CBE) is strategized for humankind to further industrialization while ensuring a controlled level of emission by proper process design, controlled resource use, measured environmental pressure [13], and waste minimization analogous to the cradle-to-cradle life cycle [33]. The product's recyclability, dissipative, durability, and reparability are emphasized to achieve a maximum value allowing an extended functional life [13, 14].

Being the third largest consumer of energy in Southeast Asia [34], Malaysia positions itself with an obligation to actualize resource-efficient management or "circularity" [14], particularly in sustaining its economic growth [35] via multibillion-dollar export revenues from palm [36, 37] and rubber products [38-42] that are rapidly overtaking paddy [36, 43]. Routing the by-products as commodity feedstock of a subsequent process is a productive way of reducing waste and providing continued support for circularity. Given the critical requirement of scientific knowledge in the circular management of commodities, circularity is here specifically denoted "Biomass circularity science" or BCS to facilitate in determining the processing requirements and applications.

Captured by biomass circularity science is the multibillion-dollar export revenues value from rubber and rubberwood products. While rubber latex is the all-year primary harvest, felled rubberwood appears to generate a multibillion-dollar revenue from its unified utilization, giving an impression of a circular economy. Malaysia's USD1.1 billion natural rubber export [41, 42, 44, 45] has translated to a multi-billion downstream segment revenue but disconnected from the half-million natural rubber producers, making rubber smallholders the 'poor dad' in the industry. Concerns over the profit intractability [3, 40] plausibly associated with inefficient coordination of rubber production [44] remain ambiguous. The backstage smallholders contribute 95% of natural rubber export despite being challenged by the volatile, declining rubber prices, logistics, the lack of reasonably skilled process operators, and growers' old age [46]. No different is the fate plaguing Malaysia's rubber smallholders or farmers working on less than 10 hectares of estates and relying on rubber as the principal income, to the deplorable condition of the global upstream segment [30, 46-48]. Resolving the issue pertinent to the well-being of the smallholders is critical to advance the industry to its maximum efficiency while navigating times of economic turbulence in a proven low-risk and high-profit manner.

The study identified the commodities in the developed biomass circularity models and propose income diversification strategies to overcome the factors holding back rubber smallholders' productivity to the present day. In doing so, it answers two research questions (1) what are the strengths that can resolve the weaknesses and threats facing rubber smallholders, and (2) how scientific fronts of the resource-efficient circularity principles hereby denoted BCS (circular biomass sciences) can best be adapted to lift smallholders' burdens, diversify earnings, and enhance their productivity.

2. Materials and Methods

The adopted metathesis research acquired secondary data from a mix of literature and contextual analyses. By the scope of work, the study first analyzed the criteria of resource efficiency in a circular bioeconomy also known as circularity. Rubber and rubberwood nature, utilization, export revenue, and issues of the upstream segment were analyzed to understand the commodity routing. These are translated into a model and a framework to confirm the extent of circularity and to gauge the relative complexity of the processes, respectively. Analysis of the rich scholarly and mass media resources was performed to spot the global issues facing smallholders. Training resources related to commodity management were also analyzed for the possibility of adaptation to the needs.

2.1 Literature Analysis for Circularity Models and Framework Synthesis

The history, principles, and practices of circular bioeconomy, *Hevea brasiliensis* nature and utilization, and challenges facing rubber smallholders were analyzed by referencing policy documents, the mass media, and scholarly articles. The knowledge was translated into the circular bioeconomy model interchangeably referred to as the "Biomass Circularity Science", BCS, model. Analysis was performed to identify the leveraging possibility to improve the fate of smallholders, considering the trained industrial personnel and education sectors as potential transformation catalysts.

To abide by the circular management concept, the forms of residues regarded as commodities were identified by the general guide of the routing model in Figure 1.

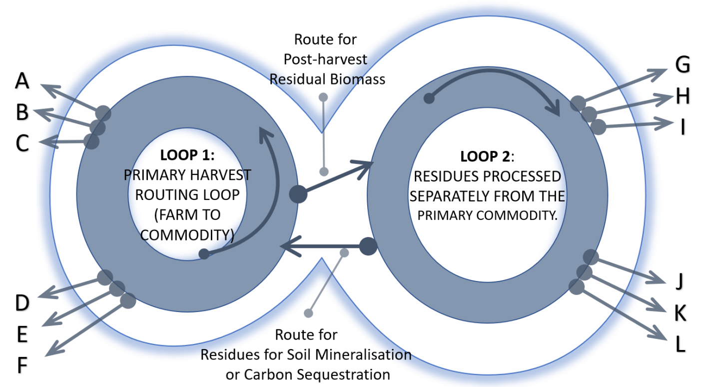

Fig. 1. The general resource routing based on the exploitable compositions that make residual biomass commodities (G to L)

Marked in Figure 1 as G to L, residues regarded as feedstocks are routed towards yielding a product, forming one feedstock-process-product (FPP) string. Thus, several FPP strings were displayable in a framework. A framework normally presents the process strings associated with the varying forms of one by-product identified from the lemniscate model in Figure 1. Specific to the by-products from rubber farming, only strings associated with the marketed by-product derivatives are shown on the FPP framework. Due to the industry's establishment, emphasis is placed on tracking industrial symbiosis (a by-product from a process becoming feedstock in another process), which is the heart of profit-making and responsible management in a circular bioeconomy.

2.2 Challenges Facing Smallholders: Weakness & Threat Identification

Besides the scientific literature, analysis of the plights of global rubber smallholders was also ascertained by statements reported in the mass media. The related issues are tabulated and appended to this article.

2.3 Knowledge Related to Biomass Resource Efficiency

Technical and vocational academic programs and contents proposed by two of the European Union projects identified as having high relevance to the implementation of resource-efficient management for rubber smallholders were analyzed and recommended for adaptation. Modules developed in the *Promoting Education, Training and Skills Across the Bioeconomy* (PETSAB) and the *Improving the Malaysian Higher Education Wood and Furniture Making* (MAKING4.0) project activities having link with the empowerment of the youths within the rubber smallholders' family were selected for adaptation to rubber and rubberwood upstream segments.

2.4 Smallholders in Focus

Being the backbone of the country's top three major commodities, the rubber growers and mini-plantation managers operating rubber estates of less than 10 hectares were the smallholders in focus. Analysis captured rubber smallholders' challenges from scholarly references verified in the most recent mass media. Progress is tracked and compared to the issues still plaguing Malaysian rubber smallholders were the focus due to the longstanding manifold influence of middlemen [41] on the fate of smallholders, beyond the farmgate price issue. The pains were mapped to a set of identified strengths and opportunities to move towards resource-efficient (circularity) principles.

3. Results and Discussion
3.1 Biomass Circularity Science Model

Analysis of commodity routing yields the model in Figure 2. It appears that the upstream and downstream rubber segments form a linking resource-efficient industry that not only capitalizes on latex from *Hevea brasiliensis* but also the rubberwood in its post-latex-producing years. Marking the export revenues [38-42] to the circularity model in Figure 2 reveals an approximately MYR10 billion revenue from rubberwood furniture making. The revenues, residues, and the associated applications were based on a huge body of literature including works by [19, 40, 48, 50-53].

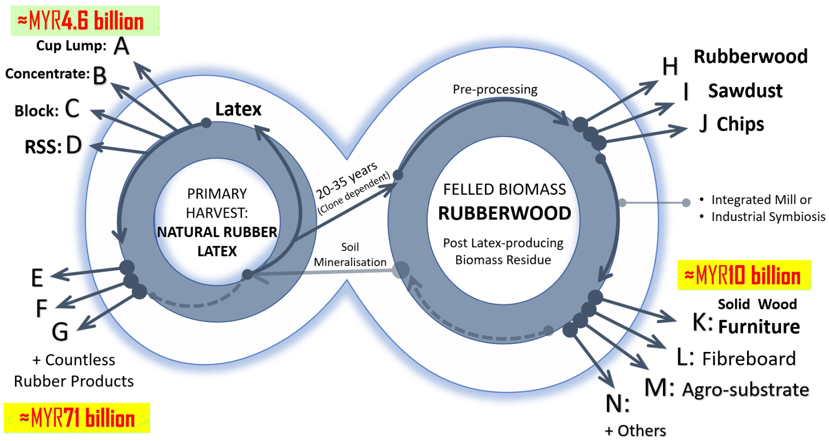

Fig. 2. Lemniscate management model resulting from the biomass circularity science twin-loop routing of the principal harvest and the by-product forming derivatives in the form of products (A-N) and commodity (A, B, C, D, H, I, J)

While the left loop shows the journey of the primary harvest, the right loop marks the by-products which used to be routed to the landfill, burnt, sold as firewood, and at a residual scale, used in furniture making since the 1980s and realized as an export revenue in Malaysia in the 1990s [54]. Together with sawn rubberwood, the rubberwood furniture industry export makes MYR10 billion resulting in a 74% gap relative to the natural rubber export.

The infinity pattern (also known as 'lazy eight' or lemniscate) of resource management in Figure 2 reroutes wastes to unlimited applications, making them commodities of specific product lines. Each arrow pointing outward is a possibility of industrial symbiosis, which is an integral part of the circular economy. The practice extends the by-product's functional life and prevents them from being routed to the landfill. Unlimited frameworks associated with A to N can be developed as illustrated in the proceeding section.

3.2 Circularity Science Empathising Poor Dads: Restraints and Drivers

A scientific glimpse of the circularity model in Figure 2 recognizes that approximately 450 000 [46] from about 150 000 to 200 000 nucleus families [32] smallholders were the responsible caretaker of the estate's rubber tree growth and productivity. The estates' gains depend on the tonnage rubber "yield price tag" deducted by the capital from the farm management, transportation, processing, and tappers' wages, on whom rubber yield depends. Rubber tapping involves a skilled debarking process, pursued throughout the rubber tree's latex-producing years. The activity is performed at the right time and the surface incision is 1.5 mm away from the critical growth-control region called the cambium. Skilled tapping ensures continuous latex production – in the complex [55] laticifer wiring system [56], and eliminates the costs of ensuing treatment from cellular damage that stops latex exudation and savior for the loss. Tapping the tree correctly triggers exudation and optimally flows the latex into the pool which is coagulated as a "cup lump" or gathered as liquid field latex.

The latex collected in cups and sold in the form of cup lumps, smoked rubber sheets (Ribbed Smoked Sheet, RSS), and concentrated rubber, was historically MYR5/kg (cup lump) and had dwindled to as low as MYR1.6/kg [46]. As of August 2022, the price rose to MYR2.6/kg and is projected to hike above MYR3.50/kg by the end of the year stimulated by an increase in the global export demand [57] and plausibly moved by Malaysia's rubber anti-corruption plan, GETAR 2021-2025 [58, 59]. Outside the radar of price control, more concerning is the 175% income gap between the latex farmgate export revenue and the manufacturing of latex-based products, signaling the timely need for rubber smallholders to engage in humble-scale rubber product making and marketing via a creative business model.

Given the high operational (wages, mobility, processing) and maintenance (fertilizer, remedial chemicals, and weed control) capital to actualize high rubber yield, the wages of rubber tappers fall prey to leverage the volatile non-competitive rubber prices. Worsened by the nose-diving rubber price and increasing cost of estate management, the deplorable living condition associated with rubber tappers demagnetizes the newer generation to continue rubber farming. The scenario attests to the predominance of senior citizens among smallholders and the 60% inactive plantation [60] in Malaysia and shrinking replanting activities in India [61].

As farmers switched to other more profitable cash crops [62], the production of natural rubber reduced, attenuating Malaysia's global contribution to the commodity. Today, Malaysia is only ranked the fifth most prominent global natural rubber contributor, having been overtaken by Thailand, Indonesia, Vietnam, and newcomer, Cote d'Ivoire [63]. To sustain the rubber upstream segment, the immediately actionable solutions related to understanding the commodity-bearing farm biomass were given a careful analysis.

3.3 Felled Rubberwood: Circularizing Commodity-loaded Biomass

The 20-30 tapping years reduced latex contents and partially removed the structure's surface bark and extractives, simplifying rubberwood conversion to high-price sliced lumber. Given the laborious nurturing process, felled rubberwood needs to be tagged at a reasonable price as payback to smallholders. Handing over free of charge is an injustice to the farmers and a valuation gauge is required for quality assessment to also break even the market-ready rubberwood costing MYR1300 per tonne [64]. Indirectly, the hardly-earning USD200/month smallholders who are seemingly the forced labor in the fragile upstream are also laboriously feeding meranti-compatible [65] raw materials to the furniture and rubber product manufacturing industry or the 'rich dad' while bearing the costs ensuing latex production. Indeed, The inequivalent biomass commodities propelled the rubber industry with dual monetary profit, marking the Thailand and Malaysia furniture industries [50, 66-68] as champions in implementing a circular biomass economy – Figure 3. Rubberwood export also embossed poor countries like Cambodia and Myanmar as furniture wood exporters, which is an excellent empowerment model.

Figure 3 recapitulates and extends the commodity routing possibilities. From the biomass science perspective, the rubberwood biomass and clean sawdust as a by-product generated from sawing of rubberwood are in their entirety useful feedstocks for furniture making. The heterogenous rubberwood sawdust residues are suited for rough applications not requiring extensive processing.

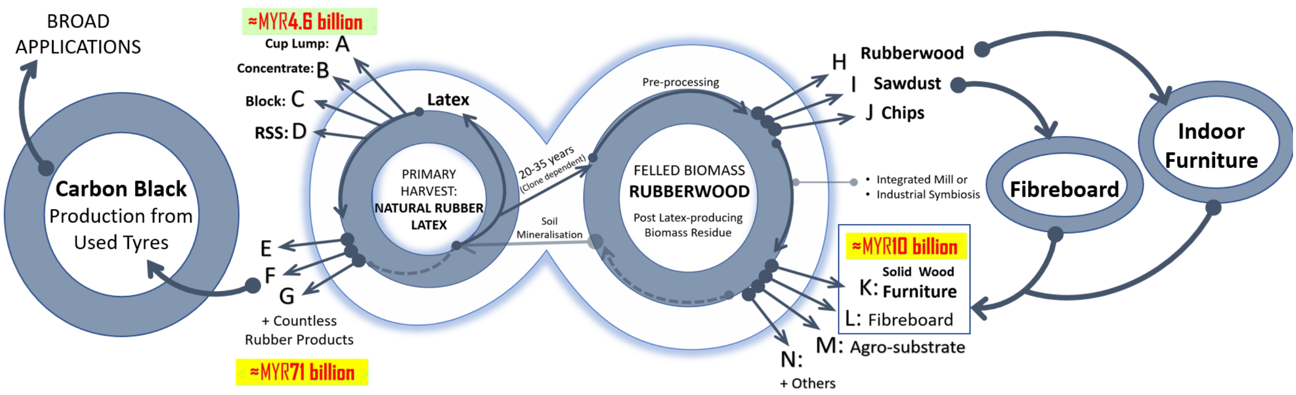

Fig. 3. Circularity in the rubber and rubberwood valorization as of 2022

In compliance with the Biomass Circularity Science (BCS) model in Figure 3, Figure 4 provides insights into other utilization choices and the pertaining processes to delineate large capital processes. The big picture of the feedstock-process-product (FPP) strings aids in visualizing the products developed from the felled rubberwood possibly capitalized by rubber smallholders and these are detailed in the next section from the BCS perspectives. At present, the billion-dollar revenue from furniture making is driven by the unified major downstream use of the felled rubberwood in the post-latex-producing years.

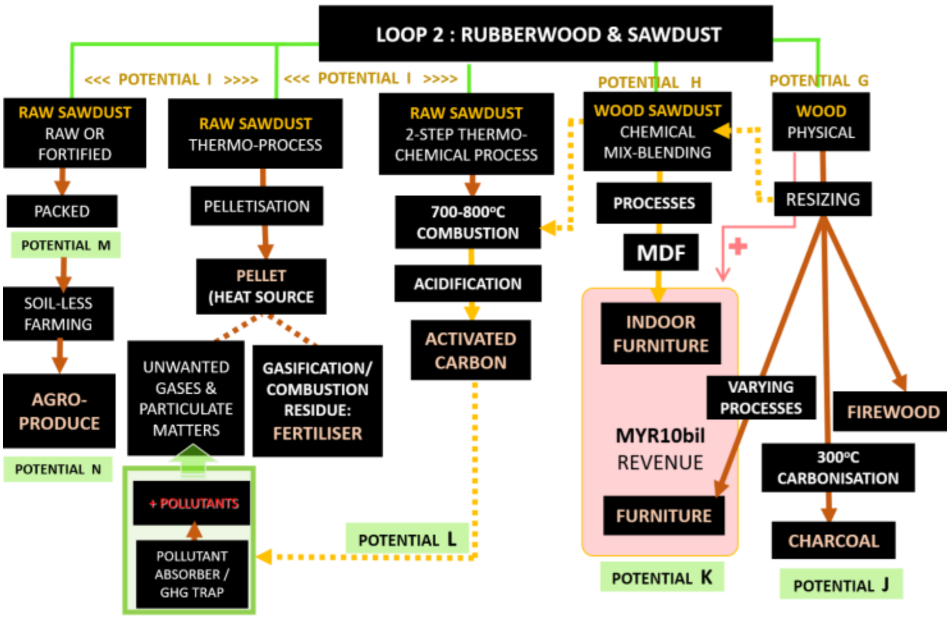

Fig. 4. Framework for the management of felled rubberwood as a commodity

Circularity strategies reserved for smallholders include low-risk, low-capital approaches towards higher latex yield and smallholders' higher earnings to proactively transform and propel the upstream segment, highlighting also the required skills. The proceeding section discusses the reserved lower capital, and low-risk circularity suited to smallholders acting as photons of small-medium enterprises

(SMEs), taking into account responsible management via pollution prevention from such known sources as agricultural and industrial manufacturing industries [69].

3.3.1 BCS sensing immediate income diversification

Analogous to woods' use since the Neanderthals, rubberwood's suitability as firewood [51, 54, 67] justifies its sawdust practical use as a biofuel resource [70], in line with [72] assessment of the ecologically sound use of wood waste for biofuel production (G, Figure 4). The potential use of rubberwood sawdust as a market standard activated carbon (Potential L, Figure 4) points the industry as self-resolving the GHG emission issue in the upstream segment arising from rubber processing [71] to generate Ribbed Smoked Sheet (RSS), concentrated rubber and block-rubber. More cost-realistic rubberwoods' remote use as a mushroom growth substrate [73] illuminated the possibility of functional food crop farming. The heterogenous rubberwood sawdust currently valued at MYR2 (USD0.5) per liter makes an excellent growth substrate for soil-less farming (I in Figure 3). Whether expanded by industrial symbiosis or integrated farming, mushroom production using the rubberwood sawdust illustrated in Figure 3 and Figure 4 is an economic way of diversifying smallholder expendable income from the immediate food market and feedstock for therapeutics extraction (Figure 5).

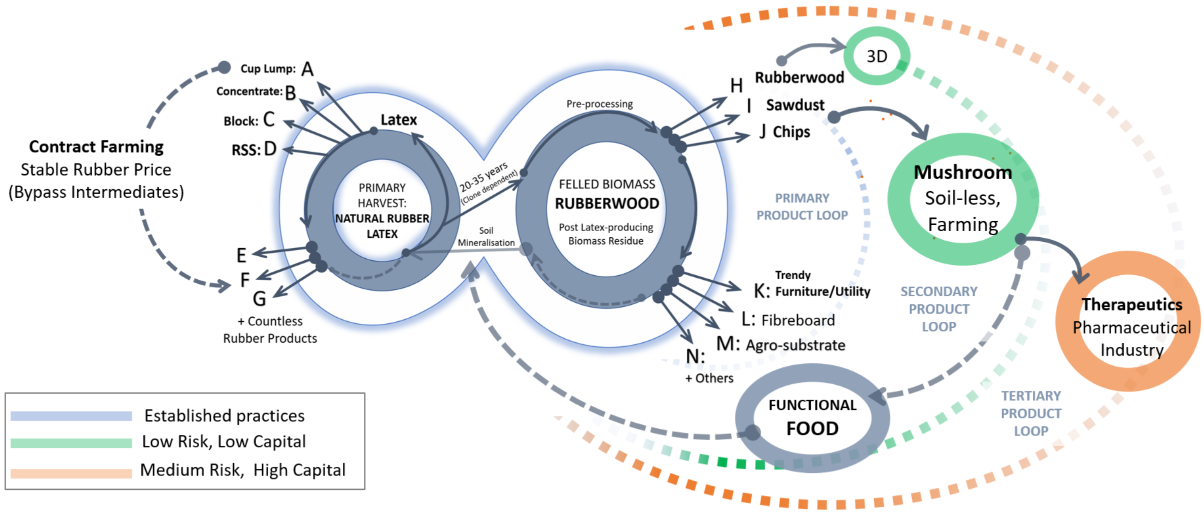

Fig. 5. Empowerment of the upstream segment by elimination of the middlemen in the natural rubber value chain. The direct purchase of rubber from farmers by passing intermediates was demonstrated as possible by the downstream sector

From a circularity perspective, the illustrated secondary and tertiary product loop for income diversification is a potential manifold gain for rubber smallholders regardless of realizing the expansion via industrial symbiosis or an integrated business model. Every liter of sawdust potentially returns MYR10 gross profit, plausibly MYR5 net gain per harvest which is the price of 3 kg of cup lump. Mastery of knowledge on the felled biomass, target revenue, business model, and marketing strategy would push the initiative forward. Marketed as seedling or growth substrates, physically or online [74], the strategies are sure earnings for the smallholders, given the established mushroom as a food item and rubberwood sawdust as an enabler of the soil-less growth substrate.

3.3.2 BCS – efficiency via doing Less for more latex

Natural rubber latex yield enhancement attained within the same or shorter working time is a form of efficiency achievable using available technology. Shifting to the use of machinery can reduce overhead costs associated with estate maintenance and labor. A speeded tapping activity ensuring higher throughput by reducing human energy (and long-term wrist injury) from exerting pressure on the living trunk is one of the millennial innovations [75-77] availed for the rubber sector. Deployment of a more efficient tapping process allows labor size reduction, which would, in turn, reduce labor costs. Expenses related to machine maintenance and fuel positively contrast the eliminated wages and medical bills of existing rubber tappers are the aim.

Hand-operated or automated portable sheeting machines are concepts worth considering. Roll press custom-made to 100 to 1200 kg/hour throughput could reduce dependency on factories and offer self-sufficiency with rubber pre-processing. Cost analysis is required to verify gain, loss, and breakeven points. Farm-integrated machinery for processing rubberwood at felling is also an avenue for increasing profits. Besides emission effects that will be deliberated elsewhere, rubber smallholders' readiness to exploit techie opportunities highlighted in the proceeding section.

3.3.3 BCS via trending technology and goods

Covid-19 has taught the need to reduce reliance on the foreign supply chain by integrator business model or localized outsourcing, possibly implemented in the rubber and rubberwood twin-loop circularity, particularly in product design. Through digital technology, designs emphasizing multi-functionality, flexible assembly, stackability, and portability are features that smallholders can offer using rubber and rubberwood as raw materials. 3D printing is one of the tools suited for custom design and in-time production by small to medium enterprises (SMEs). The *User-design* business model allowing users to choose color, material, and joints, for instance, is gaining popularity and setting the trend in industry 5.0. Purchase of rubber and rubberwood products via "bundle" is doable by pairing a rubber cushion with a wooden stool or a rubberwood tray and rubber anti-slip mat, for instance. The rubber used for safety and comfort would feature more value to design, analogous to the "*Add-ons"* business model. Besides digital design, digital marketing has proven to catalyze expandable revenue since the trying times of Covid-19. With appropriate training on digital marketing identified as one of the critical needs to boost agro-product markets [74] rubber smallholders too, could make the transformative move towards income from SME rubber and rubberwood trendy products.

3.3.4 BCS conquest by advancing with trading technology

Routing natural rubbers to farmgate dealers simplifies the marketing process but comes at a painful cost and digital trading is one of the means to troubleshoot the issue. While restructuring the value chain may resolve the issue locally, a concerted global price control analogous to the recently voiced instructions to the International Tripartite Rubber Council [78] is mandatory. Assuring results can be expected by engaging the downstream segment. In the present ambiguity, price is a complex, beyond-control parameter but sets the standard and direction for smallholders' productivity. Bypassing the dealers (intermediates) through contract farming (Figure 5) is envisioned as a fair deal for farmers to reap higher profits. Materializing this requires strategic governance and part-take in such rubber trading platforms as MyROL [79] and Singapore's HeveaConnect.

3.3.5 BCS catalyzing international engagement for sustainability

Setting Vietnamese as the model for transformative moves, rubber smallholders' readiness to engage in the Global Platform for Sustainable Natural Rubber (GPSNR) more actively is an avenue to exchange ideas on better, sustainable practices. Challenges with the disease vulnerability of clones and yield enhancement may be tackled in smart ways by exchanging ideas with smallholders from other regions. Productive clones could enhance latex yield from the existing 30% to 50% by genetic enhancement of polyisoprene biosynthesis [80]. Given the suitability of tapping at the fifth to the seventh year, nurturing rubber clones today is likely to reap an improved 50% yield starting between 2027 to 2029. With prior interventions (farm-integrated machinery), the optimized fertilization and weed control costs may be coverable. Such improvement in agronomics is critical for rubber tree productivity. The interventions, combined, target the theoretical yield of 7 000-12 000 kg/ha/yr latex [29, 80] from rubber clones. An enhanced yield is critical in compensating for the dwindling rubber price trap by such a beyond-control factor as stockpile release by a superpower. These diverse situations can be clearly understood by engagement in dialogues at the international platforms. The prerequisites for sustainable certification can also be negotiated to suit the local needs and challenges to align with the global goal.

3.4 Actualizing BCS Systematically

In essence, the strategies presented in section 3.3 implies the need for continuous, systematic learning in line with the evolving technologies. Capitalizing the Technical and Vocational Education and Training program (TVET) custom-made for a high-income high-skilled nation [81] is the stream projected to fulfill the hands-on training needs with less of the mainstream academic issues [82] to generate and impact the next generation of rubber estate leaders [83]. Expandable rubber-related TVET is envisioned for youths in smallholder families to start nurturing creative thinking skills related to rubber growing, rubber products, business models, and rubberwood as a commodity for creative earnings. Being hands-on in nature, rubber farms can be configured to serve as an experimentation ground to learn, develop problem-solving skills, and spawn innovations by needs, analogous to the tapping machine innovation by Kamil and team [75], Raghavendra [76], and Yang et al [77].

Communication and digital literacy are also fronts to catch up with. While digital trading has been proven to resolve transparency and traceability issues plaguing the rubber value chain, smallholders' mastery of international communication and digital literacy would facilitate engagement with the downstream players. Continental's initiative in the direct transaction of rubber commodities from smallholders [9] is analogous to the export-oriented contract farming [84] described by Meemken and Bellemare (2020). The move is a successful model for Continental's rubber deal with Indonesia [85] aimed at bypassing (Contract Farming, Figure 5) the seven intermediates identified as the root cause of complexity, poor traceability, and ambiguity in the natural rubber value chain. Future conquest of the value chain through the strategic empowerment of smallholder family members is expected to be the defense system for the upstream segment to eliminate the longstanding overreliance on middlemen [49] beyond rubber trading.

Technologies related to industry 4.0 and industry 5.0 is the phase of digitization for exposure to transform the currently 'poor dads' into dignified versatile smallholders. While implementation of resource efficiency towards Industry 4.0 requires continuous improvement [86] enculturation of circularity requires continuous learning [83]. Encompassed in the proposed expandable TVET is a higher institution similar to European Bioeconomy University. The long-term strategy can be initiated by first engaging the youths amongst the smallholder community experts to link and embark on projects tailored to the mutual needs of the region. Education, in this light, is the driver towards grooming creative thinkers and technology-savvy minds to comprehensively catch up with technology and innovate, as similarly posited by Kawano in 2019 [87]. Reliable education platforms are to serve well as a transformational strategy and provide a vivid roadmap to actualize sustainable and transformed rubber smallholders' future.

3.5 Capitalizing the Strengths

Biomass circularity sciences (BCS) lays the hugest opportunity for maximizing natural resources, human resources (particularly the champions of circularity), and systematic support resources (GPSNR and CIFOR, e.g.) to realize efficiency and justice for humankind and the ecosystem. The lower soil emission in the smallholding rubber farms in comparison to industrial plantations [88] is the reason to support rubber smallholders. As economic uncertainties continue to hit urban lives, migration to villages and villagers' choice to indulge in smallholder-farming is projected to hike. Empowerment of the smallholders creates resilience of the upstream segment to the rising demand for fossil-based synthetic rubber, which is recovering at a better rate [1]. Creative management of rubber and used rubber (e.g., conversion of tires to carbon black [89] in Figure 3) also promotes readiness to face the upcoming massive production of Dandelion rubber [90, 91]. The apparent expansion of residues utilization from the primary product loop to the tertiary orbit (Figure 5) in addition to contract farming are steps envisioned to diversify smallholders' earnings. The analysis implies that the developed BCS model lays the opportunities to exploit commodities and technology to troubleshoot arising issues and threats productively.

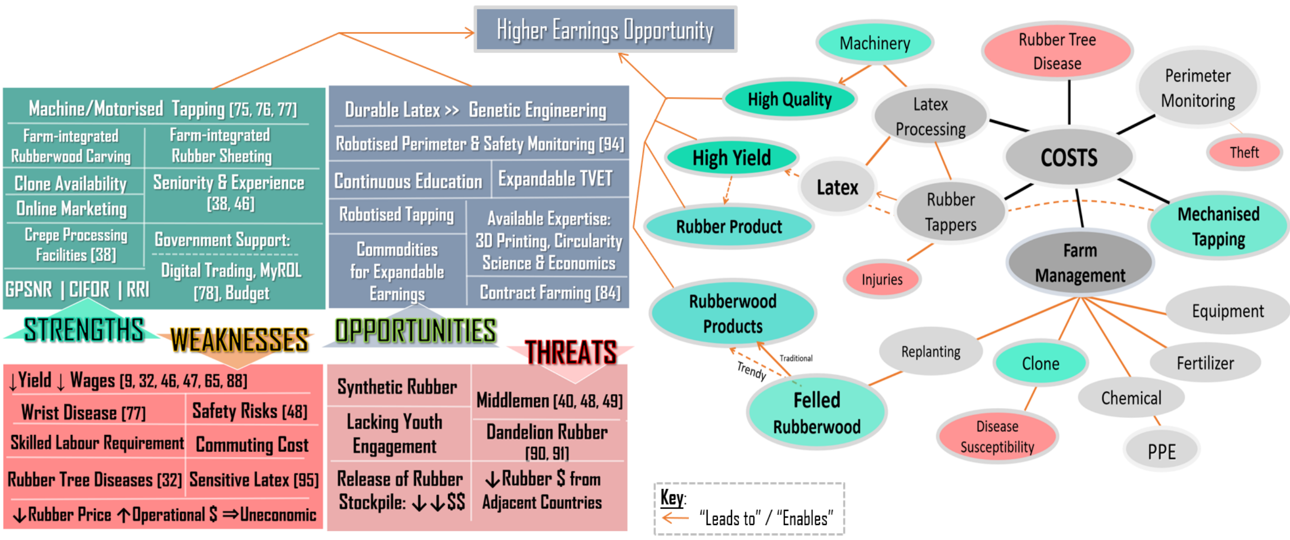

Fig. 6. Strengths, weaknesses, opportunities, and threats (SWOT) analysis of rubber upstream and downstream segments affecting rubber smallholders

4. Conclusions

The rubber industry's significant contribution to the national revenue and global goods manufacturing reasons for its sustainability during today's trying times. Despite the global economic turbulence, the declining rubber prices, and a string of unattended pain from maintenance and operational costs, smallholders continue contributing to 95% of rubber revenue. The challenged rubber smallholders who are currently the "poor dad" in the rubber supply chain can be immediately assisted by facilitating access to appropriate machinery and productive rubber clones for better rubber yield. Through the lenses of biomass circularity sciences, resources that smallholders could maximize for income diversification is expandable via industrial symbiosis or integrated farming. Improving the long-term livelihood through upskilling and continuous education on the adoption of resource-efficient circularity principles is essential for upstream rubber segment empowerment. Rubber smallholders' maximum participation in the trading and value chain is also a transformative solution. Acceleration of the desired transformation calls for smallholders' willingness to continuously learn and improve practices, to reap the fruit from the government's intervention, the opportunity for contract farming, and stakeholders' openness to work in synergy toward circularity and sustainable rubber industry.

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